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Designing a lifting and lowering device to the storage market

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Abstract

The aim of this thesis is to design a lifting and lowering device for the storage market. The design is based on a patent, held by Dropracks, which is a collaborator in the thesis. Dropracks is a company developing a lowerable roof rack for cars. This rack is protected by their patent of a lifting and lowering device. This patent gives Dropracks an immaterial protection in all industry sectors, and has other potential areas of use. The Dropracks team has expressed a wish for this thesis to contain the design of the lowering and lifting device for the storage market.

The design methodology of the thesis is based on the book Engineering Design Thinking by Nigel Cross [1]. The first part of the thesis covers an introduction to the market, an illustrated explanation of the mechanical principles of the Dropracks patent, as well as design variations adapted to the storage market. There has been developed a set of specifications and requirements for these design variations. It is concluded to design lifting and lowering device to tall shelves and closets. Finally, the product design phase is conducted, including the prototyping process and simulations. Based on the simulations and prototyping process, material assessments are made. The final product is a lifting and lowering system for tall shelves and closets, designed and animated with CAD.

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Introduction

Dropracks is a company developing a lowerable roof rack for cars. This rack is protected by their patent for a lowering and lifting device. This patent gives Dropracks an immaterial protection in all industry sectors, and has other potential areas of use. The objective of the thesis is to use the patent framework to design a lowering and lifting device to fit a product segment in the market. Dropracks' current lifting and lowering mechanism is an aluminum and steel system, developed with rooftop racks in mind. There will be performed a re-design from the ground up to ensure that the solution has an optimal design for the product function.

Glossary

LLD (Lifting And Lowering Device):	A lifting and lowering device based on Dropracks' patent
Loading plane:	The plane of the device which the load is placed upon. Cited as bracket 2 in the patent illustrations. (Figure 3-6).
Wiggling	Sideways movements caused by lack of stiffness in the system.

1. Literature Study

1.1. Market

Dropracks A/S has concluded that there is a demand for their patented mechanism in the storage market. Access solutions for hard to reach places are an important aid in the everyday life of wheelchair users and people with limited reach. This may include elders, short people, and people with other physical limitations.

Figure 1 - A wheelchair user with a pull-down shelf [2]

There is already a market for pull-down shelf solutions, and several market actors offer products that provide access to high shelves and cabinets. The marketing of these products takes aim on not only handicapped people, but also fully functional people. Having a pull-down shelf means that one can easily reach the goods that are placed on tall closets or in the back of the shelf, without removing goods that are in front. To properly assess the market competition, an understanding of the Dropracks patent function is necessary.

1.2. The Dropracks patent

The Dropracks Lifting and Lowering Device (hereby referred to as LLD) is developed with rooftop racks in mind (Figure 2). The current LLD solution is a rack that improves access to a ski box, bike rack or other top mounted transport utilities. It has a framed aluminum and steel construction, which is mounted on the existing roof rack of the car. The patent allows for certain structural variations with regards to geometry and dynamic behavior.

Figure 2- The Dropracks Lifting and Lowering Device mounted to the roof of a car [3].

1.3. Motion study

Figure 4 to Figure 6 illustrate step by step the key motions which makes the LLD lower and lift the load that is applied. The Figures illustrate one of many possible configurations of the LLD patent. These Figures are simplified. Figure 3 provides a more detailed overview. These Figures are composed of brackets (1,2), bars (3,4), braces (5,6) and pivoting joints (7,8,9,10,11,12).

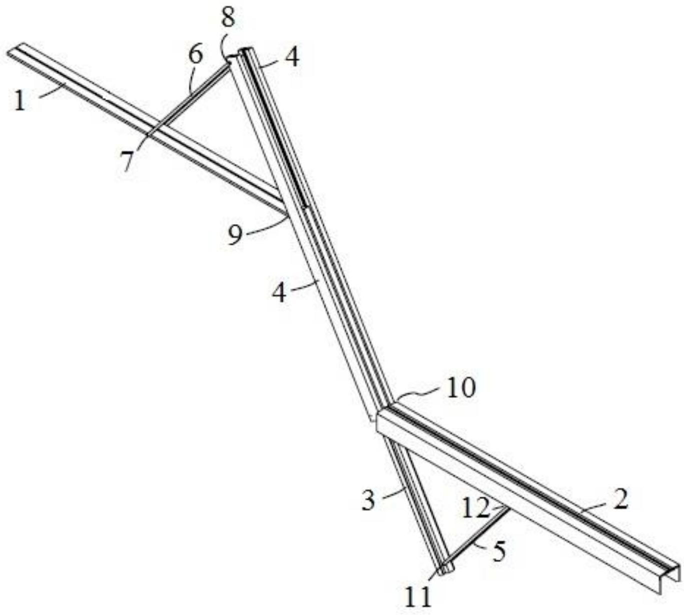

Figure 3 - Detailed view of the components of the Dropracks LLD [3].

Compressed state

This is how the system may look when it is compressed and at rest. Bracket 2, which is on top will be carrying the items to be stored.

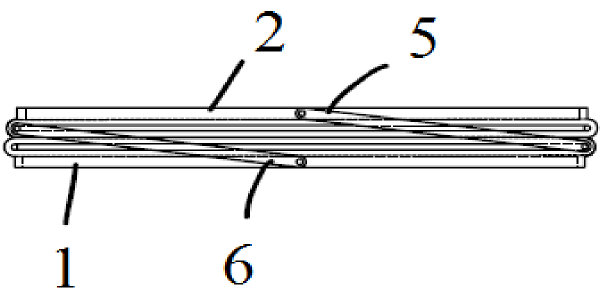

Figure 4 - Conceptual view of the Dropracks LLD in its compressed state [3].

Horizontal sliding motion

When grabbing bracket 2 and pulling it outwards, bar 3 and brace 5 will follow. Bar 3 will glide on top of, or inside bar 4 (Figure 3), depending on the design configuration of the patent. These will glide in a horizontal motion until they are stopped by notches 9 and 10, which stop in bar 3 and 4 respectively.

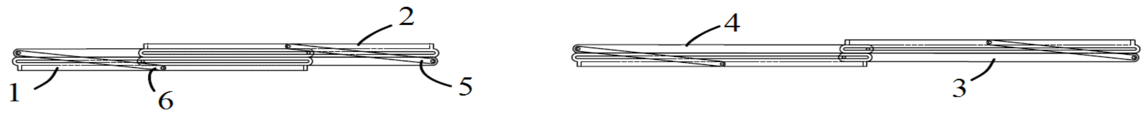

Figure 5 – A visualization of the sliding motion of the LLD [3].

Lowering motion

To lower the LLD, apply gentle pressure to the area between joint 10 and joint 12 on bar 2 (Figure 3). Bar 3 and bar 4 will glide in a collinear motion, while bracket 2 is lowered. The braces, 5 and 6 help guide bracket 2, such that it remains in the horizontal plane. (Figure 6).

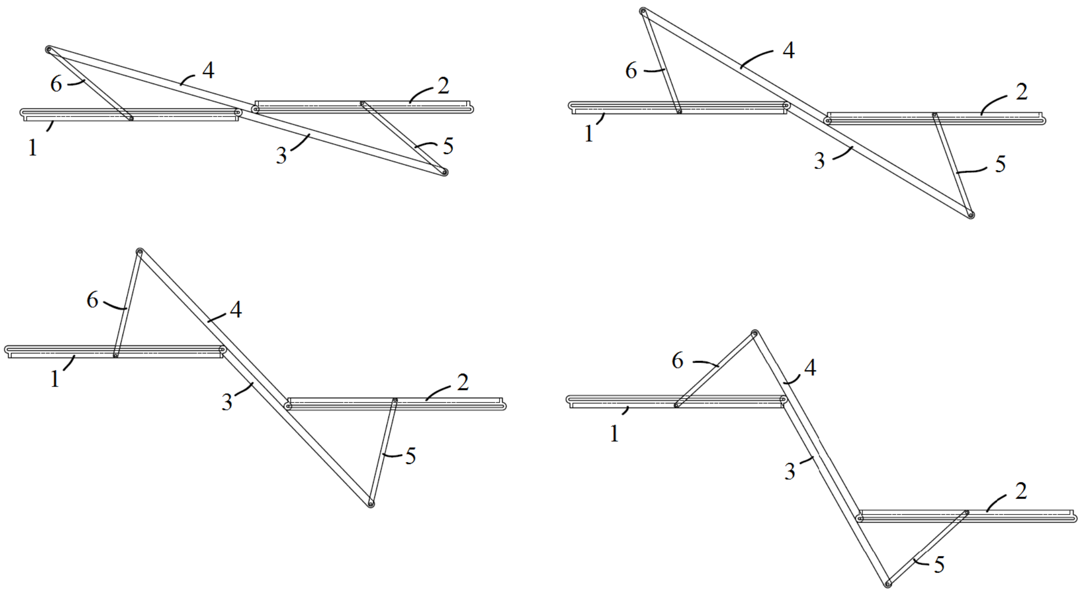

Figure 6 – A visualization of the lowering motion of the LLD [3].

The lifting motion of the LLD will be the reverse of the lowering motion. The lifting force must also here be located between the area between joint 10 and joint 12 on bracket 2 (Figure 3) After lifting it all the way up, it may be slid back into the compressed state (Figure 4). To get a more in-depth understanding of the motions, please study the interactive CAD models and animations attached to this thesis.

1.4. Geometry for optimal reach

To utilize the full potential of the patent, the construction of which the LLD is mounted on needs to be deep. In this context, *deep* means the length from the back wall to the face of the storage structure, as seen in Figure 7. Figure 8 illustrates how the change of shelf depth influences the reach of the extended system. As one can see from this figure, the potential reach of the system is linearly increasing with the depth of the shelf.

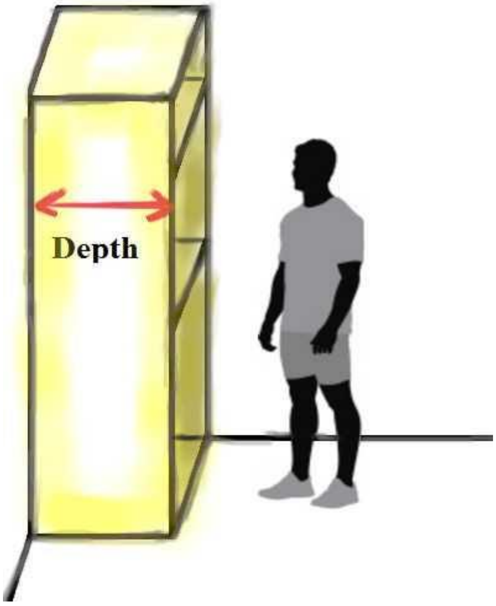

Figure 7 - The depth of the shelf is the driving factor of the reach of the LLD [4].

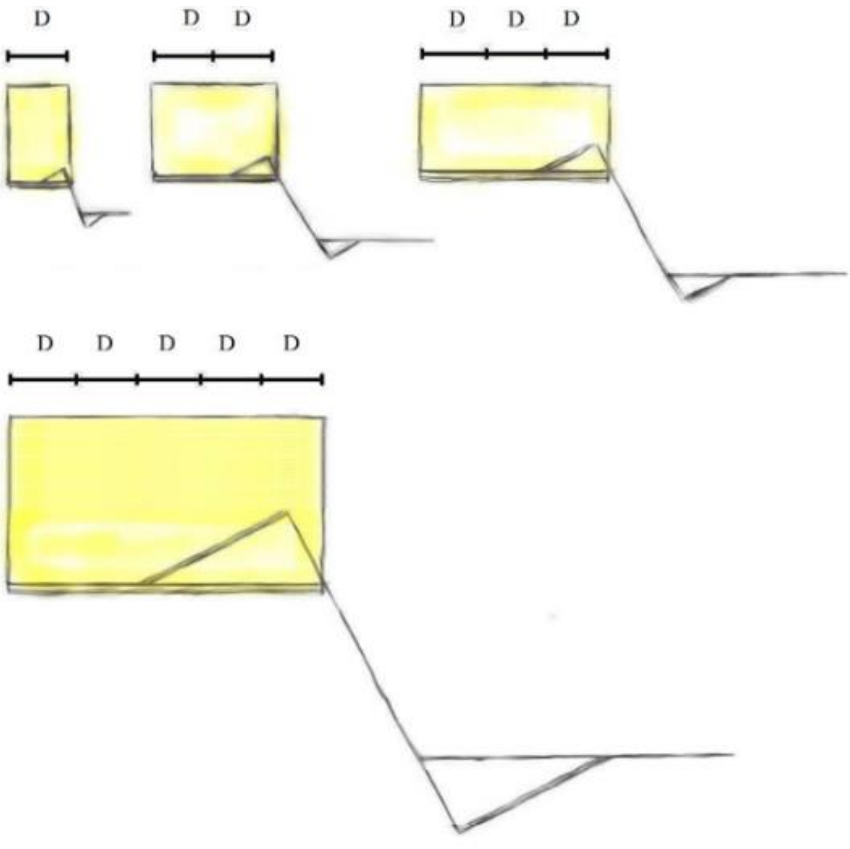

Figure 8 - Correlation between shelf depth and reach of the LLD [4].

1.5. Assisted lifting function

For heavy lifting, an assisted lifting solution may be needed. The Dropracks team is working on optimizing an assisted lifting function, such that the user does not have to lift the entire load. A car roof rack has certain restrictions when it comes to an assistive lifting system. It cannot conflict with the packability of the rack, which becomes compact and low-profile when the system is at rest on top of the roof. Figure 9 shows a lifting solution with an electric motor which is connected to a gear that moves on a track (red color). This solution may typically be installed in a closet, and the track is fixed to the closet wall. Figure 10 shows a wire solution where bar 2 is pulled upwards by an electric motor. Possible assisted lifting solutions will need to be tailored to the specific LLD product.

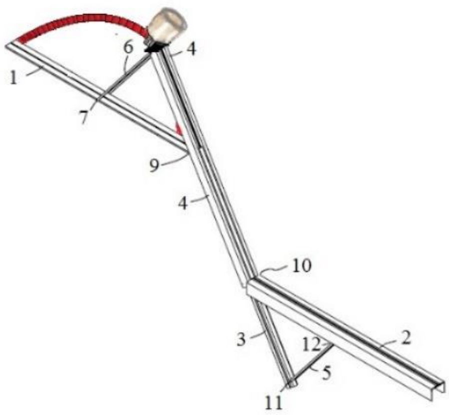

Figure 9 - Assisted lifting concept with an electric motor fastened to bar 4. [3], [4].

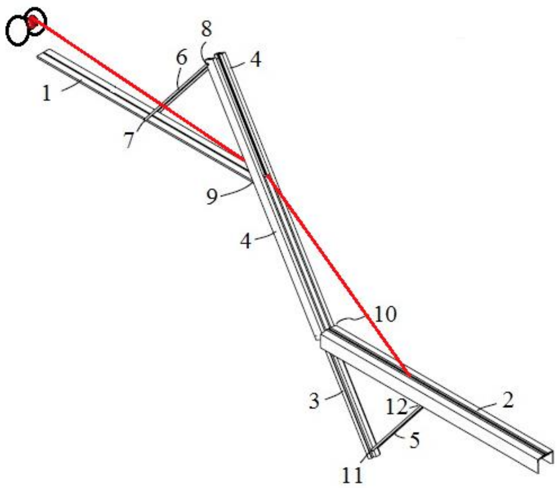

Figure 10 - Assisted lifting concept with a wire pulling bar 2 upwards [3], [4].

1.6. Competition design variations

Conventional pull-down shelves

There exist numerous designs of pull-down shelf systems on the market, most of which share the same mechanical concept. Two braces (a and b in Figure 11) are the lowering and lifting arms. These arms may be placed as one pair on each side of the device (Figure 12), or as a single pair of arms in the middle (Figure 13). There is a mounting bracket (d in Figure 11) where the construction is fastened to the inside of the closet. The third element is the frame (c), where the storage compartment is placed. Due to the geometry, where the arms are always parallel, of the same length and have similar distances between pivot points, the storage compartment will always be in the same plane as the base of the closet, shown with red lines in Figure 11.

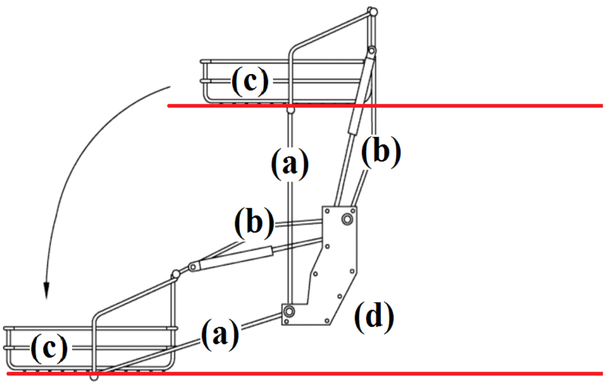

Figure 11 - Illustration of the pull-down shelf concept [4], [5].

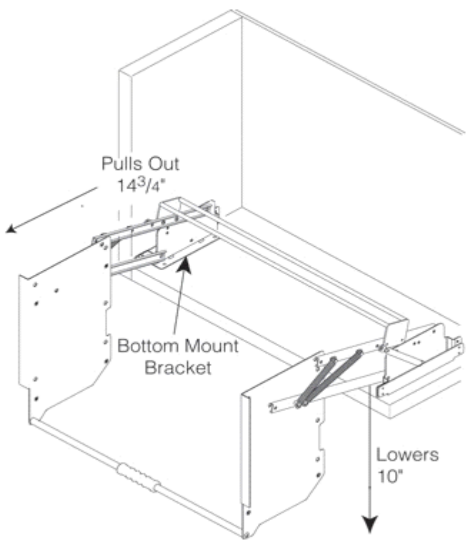

Figure 12 – A pull-down shelf design with parallel braces and springs for assisted lifting [6].

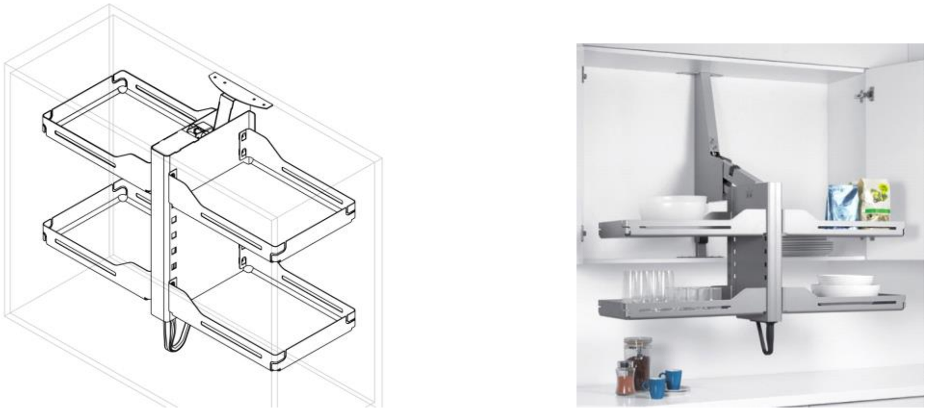

Figure 13 - Peka Systems' two story concept with lowering mechanism in the center. [7].

Figure 14 - Further design varitions. [6],[8],[9] ,[10] ,[11] .

1.7. Case study of a conventional pull-down shelf system

This pull-down shelf is designed to fit inside a kitchen closet. In this example, the height of the pull-down shelf system is fitted to the height of the closet. When pulled all the way down, the vertical distance traveled will then be close to the height of the closet (Figure 15). In addition, there is a horizontal movement of about two thirds of the height of the closet. The different pull-down shelf designs all share the same mechanical principle, and are not protected by a patent. Most of these solutions provide lifting assistance in the form of a spring or a gas cylinder. Also, some of these solutions have cylinders that provide dampening when the shelf is lowered. As shown in Figure 15 the height H of the closet makes it possible to install taller shelf racks, which increases the reach of the system.

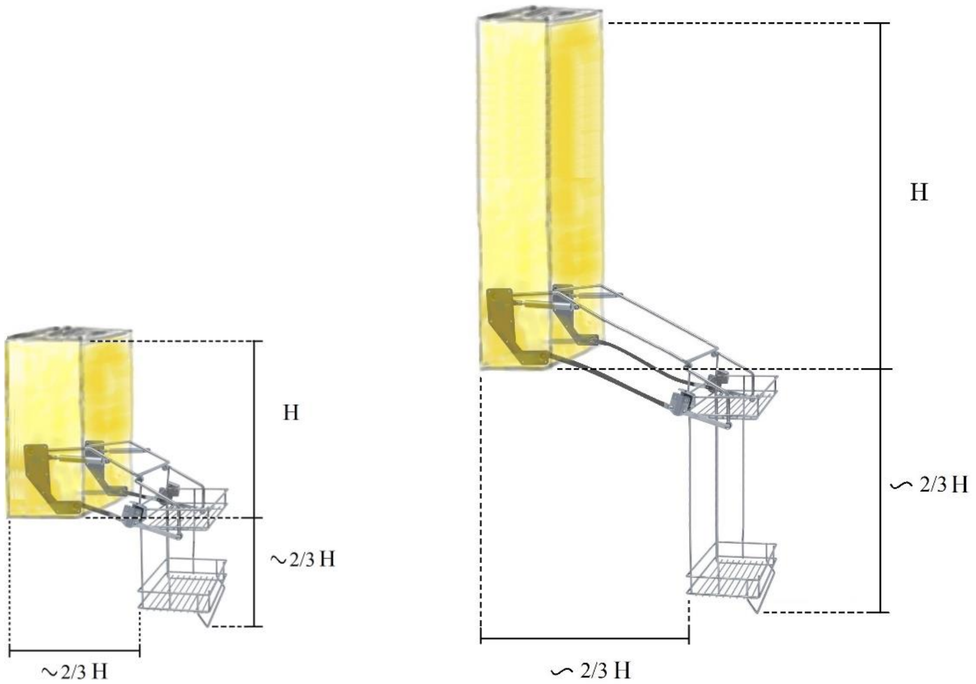

Figure 15 - Reach of a traditional LLD mechanism compared to the height of a closet. [4], [5].

1.8. Comparison between the Dropracks LLD and a conventional pull-down shelf system

From Figure 15 we see that the driving geometric factor for the extended reach of this lowerable shelf is the height H. From Figure 8 we recall that the reach of the Dropracks system is linearly increasing with the depth D of the storage structure. From this it can be concluded that the Dropracks LLD is not suited for closets that are tall and have limited depth. The conventional pull-down shelf solutions are also of a less complicated design than the Dropracks LLD. For deep shelves, the Dropracks LLD patent is well suited, while the conventional pull-down shelf would be unfit.

1.9. Warehouse use

To effectively utilize the space available, warehouses generally store goods in tall racks. When transporting goods up and down from these high shelves, a forklift is the preferred choice. However, a forklift needs a lot of space for turning. Also, it needs maintenance and fueling or charging. Dropracks A/S has looked into the idea of the shelf moving the goods up and down, instead of the forklift doing it. In that case, only a simple pallet jack would be required to do move the goods to the LLD. A pallet jack requires very little space to move around. If the forklift can be replaced by a pallet jack, the gates between the storage racks could be as narrow as 1m. One possible market for this is offshore rigs, which have offshore spare part warehouses with very limited space. Additionally, all warehouses with little or no options for warehouse volume expansion would benefit from a compact system with easy access.

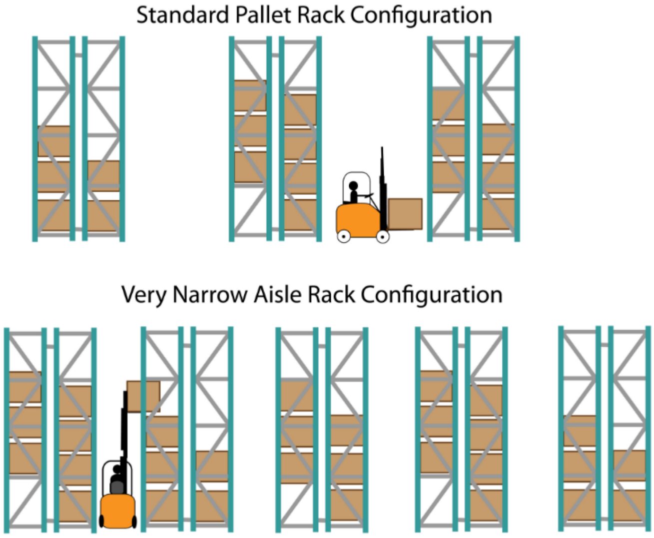

Figure 16 - Aisle rack configurations [12].

The main challenge of using the Dropracks LLD patent is that it requires a certain shelf depth to reach far enough down. This means that the depth of the shelf must be at least equal to the distance from the shelf to the floor, depending on the geometrical factors of the LLD. By altering the lengths of braces 6 and 5, seen in Figure 3, the vertical reach of the LLD is increased, (Figure 17). The horizontal gap G decreases with longer vertical reach. However, with increased shelf height, the depth of the shelf must be at least the same as the height. Storage racks that have more depth than height are not common, as it is more difficult to load and unload from deep shelves. From this it can be concluded that tall warehouse storage racks will not benefit from being equipped with the Dropracks LLD.

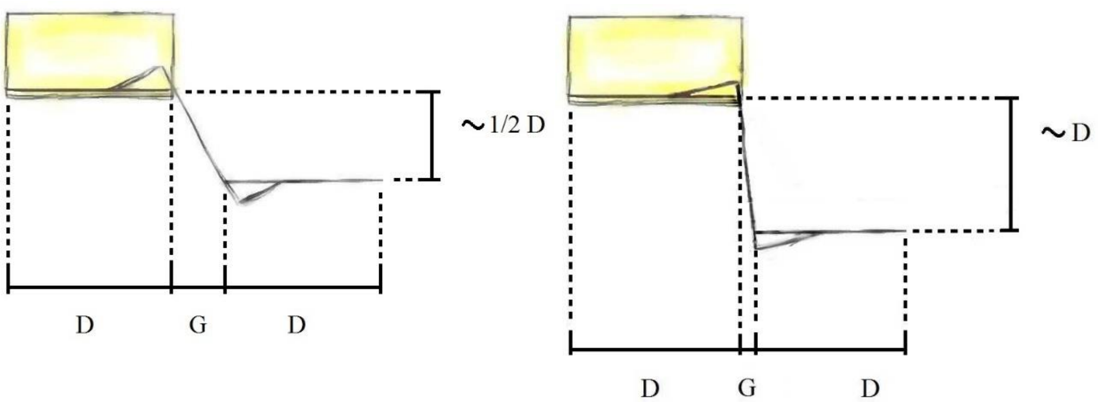

Figure 17 - Changing potential reach of the LLD by altering the lengths of the braces [4].

2. Product variations and their specifications and requirements

2.1. Lowerable shelf solution

This solution is especially suited for deep closets, i.e. the top of wardrobe closets, as the vertical reach of the system is dependent on the depth of the closet. It is typically hard to reach into shelves which are tall and deep. The life expectancy of the device should at least be the renovation interval for the given room. i.e. a bedroom may have a renovation interval of around 20 years. The design must be carried out such that the closet does not tip over if there is too much weight on the LLD. For simplicity one may assume that all closets are fixed to the wall.

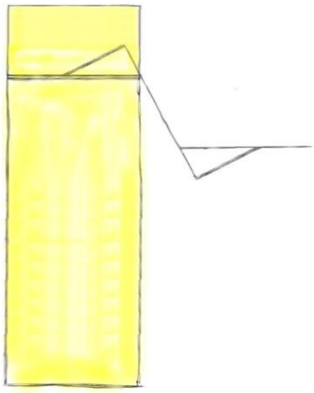

Figure 18 - Lowerable shelf [4].

Lowered to the floor

If the LLD is intended to reach all the way down to the floor, the pivot joint between bar 3 and brace 5 will touch the ground first, making it impossible for the loading plane to be lowered further. The patent is however flexible in terms of altering the geometry. If brace 5 is moved, and the hinge between bar 4 and bar 2 is repositioned, bar 2 will still travel in a vertical position (Figure 18). Now, the loading plane can rest on the floor, without the pivot joint between bar 4 and brace 5 preventing it from doing so.

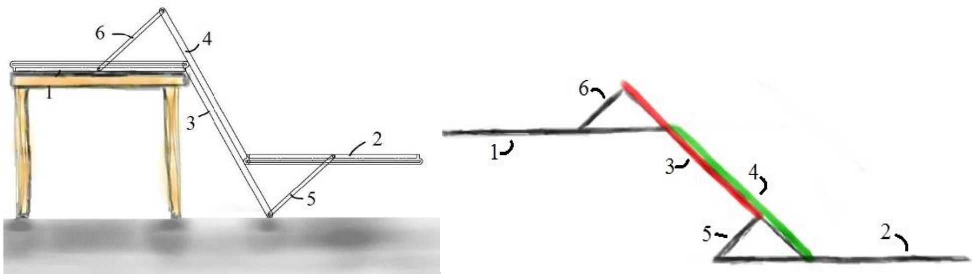

Figure 19 - Changing the geometry to be able to reach the floor [3], [4].

2. 2. Pop-up coat hanger rod

The Dropracks LLD patent can be modified to a pop-up coat hanger rod for closets, which is locked in the upper position. This solution fills a hole in the market. With a pop-up coat hanger rod, the user can store coats and shirts on lower parts of the closets, saving space. If the user has back problems, or prefer to handle the coat hangers (point 13 in Figure 19) in standing position, this solution would be ideal. Wheelchair users would also benefit from this solution, as coat hangers are normally stored at a height of around 160 cm. The closet shelf on which the hanger is supposed to me mounted, must be fixed to the rest of the closet to avoid tipping.

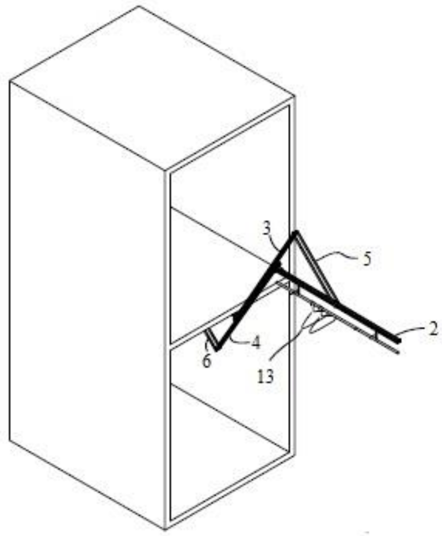

Figure 20 - The LLD utilized as a pop-up coat hanger rod [3].

This system must be rigid, and able to withstand forces in all directions. Most of the force will be forcing bar 2 downwards. The rack should be able to handle at least 15 kg of clothes distributed along bar 2. Preferably it should be able to handle as much as 30 kg, such that in can take rough treatment from kids and adults. When operating the device, sideways movements should be reduced to the minimum. To avoid wiggling, joints and sliding surfaces must be sturdy, and not subject to plastic deformation.

2. 3. Retractable nightstand

The Dropracks LLD patent may be modified to a pop-up rack for a nightstand, which is locked in the upper position. This solution is especially relevant for the hospital bed market, where the nightstands are frequently an obstruction and moved around when the patient is treated. This is a reported problem by medical students at St. Olavs University Hospital in Trondheim [13]. The nightstand can be slid away in seconds, and if the bed is moved out in the hospital corridor due to limited space, the nightstand follows. This solution is also applicable to private households, and may be of interest for larger companies like IKEA. Apart from being compressible, another upside is that it is easier to wash the floor when the nightstand has no legs.

Figure 21 - Retractable nightstand [4].

The nightstand should be able to support a force of 20 kg evenly distributed on the top plate. Preferably it should be able to handle 40 kg to withstand rough treatment in a hectic hospital environment. It should also be possible to operate the nightstand with one hand. To avoid wiggling, joints and sliding surfaces must be sturdy, and not subject to plastic deformation.

2. 4. Considering product alternatives

2.4.1. Market research.

In April 2017, a survey was conducted at IKEA Leangen. The target group was employees in the storage department and the bed department. These employees are very familiar with the products they sell, and handle hundreds of customers every day. A series of pictures was shown to the employees (Appendix B), and the function and purpose of the concepts was explained. A total number of 6 employees were questioned.

Pop-up coat hanger: IKEA already has a few access solutions for coat hangers, however they all glide in a horizontal motion. The four sellers on the storage department did not agree if a pop-up coat hanger would be attractive enough for their customers. It was agreed that this concept may be useful for bedrooms or walk-in closets with very limited space.

Pop-up nightstand: The two sellers in the bed department agreed that customers have very little focus on the nightstands when purchasing a bed. They tend to purchase the nightstand at a later time, and chose whatever nightstand that fits their bedroom. The pop-up nightstand requires a gap between the floor and the bottom of the bed for the braces (6 in Figure 3) to complete their path of motion.

Lowerable shelf: IKEA has no system for lowering high shelves from wardrobe closets. The sellers that were questioned agreed that a solution like the one presented to them was highly likely to be purchased by their customers.

2.4.2. Choice of solution

The survey at IKEA Leangen concluded that there was a unanimous approval of the lowerable shelf solution. In agreement with the Dropracks team, this feature will be further investigated in this thesis.

3. Design, methods and calculations

– Designing a lowerable shelf for use in households

3.1. Clarifying objectives

Objectives tree

The objectives are sorted in a hierarchical tree in the following categories, and can be found in Appendix C.

- Easy to operate
- Safe to operate
- Attractive
- Robust

3.2. Establishing functions

Overall function: Moving a shelf in horizontal and vertical directions.

The system is composed by the following sub-systems.

The mounting brackets

These brackets are mounted to the closet. They have two functions.

1. Mounting features for fastening to the closet
2. Grooves, or other features that makes the rest of the system able to glide horizontally outwards before the lowering motion (Figure 6) begins.

The shelf brackets.

These are similar to the mounting brackets, but are installed on the loading plane. They have the following functions:

3. Mounting features for fastening to the shelf
4. Pivoting features for fastening to the braces (Point 12 in fig3)
5. Grooves, or other features that makes the rest of the system able to glide horizontally outwards before acting as a pivot point in the lowering motion (Point 10 in Figure 3).

The sliding rails

The sliding rails handle shear forces when the LLD is at rest in the extended position. They must also handle shear forces in the lifting and lowering motion. They have the following functions:

6. Pivoting features (notches) in the sliding rails glide inside the grooves of the brackets (Point 9 and 10 in Figure 3)
7. Pivoting features for fastening to the braces (Point 8 and 11 in Figure 3)
8. Sliding in and out while subject to transverse forces.

The braces

The braces have pivotal joints on both ends, which means that they are subject mostly to axial forces, depending on the design configuration. They have the following functions:

9. They serve as the link between the sliding rails and the brackets
10. Pivoting Features for fastening to the brackets
11. Pivoting Features for fastening to the sliding rails

The diagram in Figure 22 shows which of the functions are active during the motions and positions of the LLD.

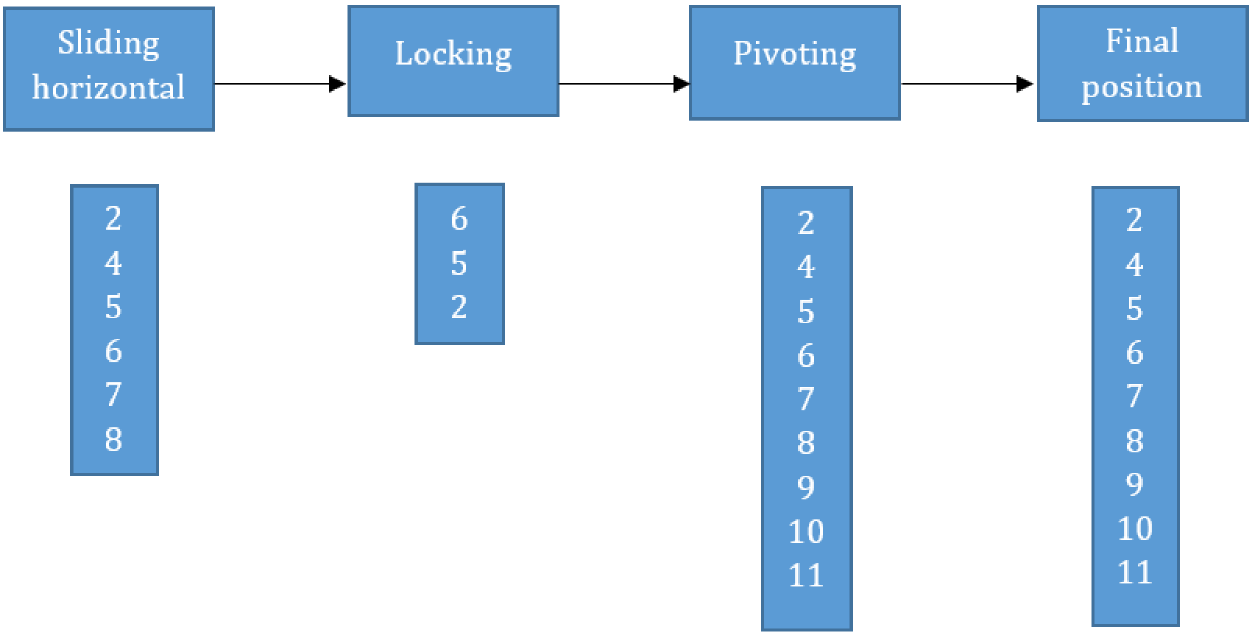

Figure 22 - Correlation between the LLD motions and the defined functions.

3.3 Setting requirements

Requirements	**Household shelf solution**
Weight	Maximum 5 kg, due to the risk of the closet tipping over. A heavier rack requires a heavier closet, or the closet must be bolted to the wall or floor. The lifting motion is made easier if the components are lighter.

Stiffness	Must be stiff enough to avoid wiggling (sideways movements), vibrations and plastic deformation. A maximum of 20 mm defection is allowed when applying a force of 10N sideways to the system. No plastic deformation is allowed.
Service lifetime	15-25 years of weekly use, or 5000 cycles of use. It should be able to be re-installed in new closets when refurbishing.
Assisted lifting	Not needed, as there will not be too heavy loads. Typical loading in wardrobe shelves is less than 10 kg.
Ease of use	It should be possible to lower the system with one hand. Lifting should be done with two hands.
Load force	Should support 200 N distributed on the loading plane without suffering from plastic deformation
Ease of installation	Depends of the product is distributed pre-installed in a closet, or if it comes as a mountable solution. It should be able to be moved and re-installed
Adjustable reach	This would be desirable if adjustable reach is possible to implement in the design. Desirable reach of flexibility is 20 cm
No sharp edges	Yes
Maintenance free	Yes
Minimal friction in the system	Joints, sliding surfaces and rolling surfaces must have minimal friction.
Price	Affordable for anyone. A price survey has not been made, but one may assume that the purchase price should be below NOK 350.
Able to compete with existing solutions	There are no solutions on the market which utilizes the depth of a storage unit like the Dropracks LLD patent.
Noise level	Must be silent in use. Maximum acceptable noise is 55 dB, the sound level of two people having a conversation.
Dampening function	May have a dampening function when lowered

Table 1 - Design requirement for household shelf solution

3.4 Determining characteristics

There has been developed a QFD which defines the relative importance of the customer requirements. Additionally, the matrix identifies the relationships between engineering characteristics and customer requirements. From the QFD it is clear that the cost of production affect most of the customer requirements. Also, stiffness and the force required to move the shelf up and down are significantly affected by customer requirements.

Engineering characteristics

Customer Requirements

Lowerable shelf for households. The numbering refers to the magnitude of dependency between customer requirements and engineering characteristics. The degree of dependence is weighted from 1 to 10		**Importance (1-10)**	Steps to attach	Time to attach	Weight of l parts	Force to move up and down	Universal fit	Stiffness (horizontal)	Low cost production
Functional performance	Easy to lift and lower the shelf	**10**			4	8		7	2
	Easy to attach	**2**	9	4	3		7		1
	Not wobble	**7**				6		10	3
	Not lock	**6**				4		8	2
	Not bend	**9**				3		7	2
	Lightweight	**7**	6	3	9	2		7	3
	Long reach	**5**				4		6	1
	Long service life	**10**			3				4
General constraints	Must fit most closets	**10**	4	3			10		
	Silent in use	**3**				1		2	1
	Safe	**10**			3	3			1
	Intuitive operation	**8**				2			4
	Low cost	**10**						8	10
Appea r-ance	Appealing design	**7**						3	5
	Appealing surface finish	**7**							5

Figure 23 - Determining characteristics.

3.5 Generating alternatives

Before assessing components and features, a visual introduction to the terms used in this thesis is needed. Featured here is the final CAD model of the system with the most used terms.

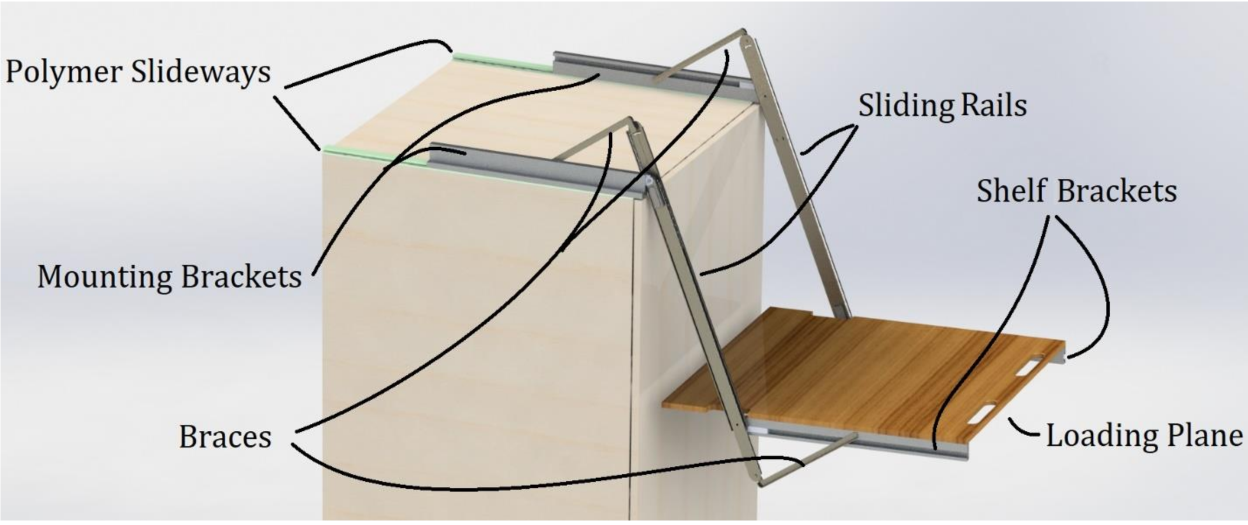

Figure 24 - Description of the most commonly used terms in this thesis. [4].

The process of designing features which consist of human-to-system interaction is often iterative. This chapter discusses the initial alternatives for solutions to challenges regarding the LLD. This is a system that is relatively easy to construct. The alternatives that qualify as the most promising will be tested and compared to each other during the process of prototyping, thus the *Evaluating alternatives* methodology suggested by Cross [1] is here ignored.

3.5.1. Interaction between bar 3 and 4

Bar 3 and 4 in Figure 3 slide relative to each other. Dropracks has developed large scale prototypes for the automobile industry. To ensure a collinear motion between the two bars, they design their bars in a telescopic configuration, where there is one inner and one outer bar.

I Telescopic pipe configuration

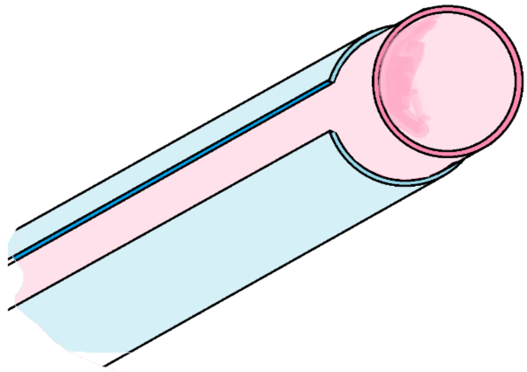

Figure 25 - Telescopic pipe configuration [4].

This configuration ensures that the interaction between bar 3 and 4 is collinear. This solution ensures stability in x, y and z directions. However, this configuration is fairly space demanding, and the pipes need to be reinforced in the interaction points with the rest of the system. There may also a be a degree of friction between two pipes like the ones illustrated.

II Telescopic extruded aluminum profiles

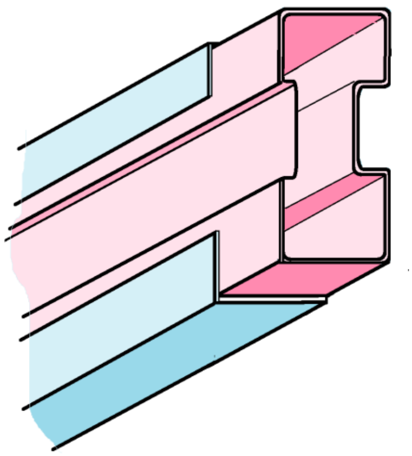

Figure 26 - Telescopic extruded aluminum profiles [4].

Dropracks' initial prototypes are equipped with this feature, often combined with internal roller bearings for less friction. It ensures stability in all directions, and can support large forces, depending on geometry and wall thickness. This solution is also fairly space consuming. Using telescopic extruded aluminum profiles requires either purchasing pre-fabricated profiles, or that the aluminum profiles are made to order. Since this design process involves prototyping, this feature will be rejected for further investigations.

III Sliding rails

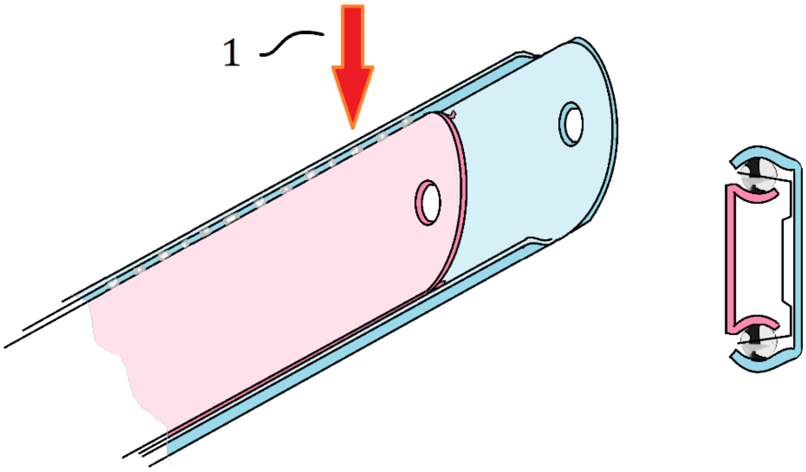

Figure 27 - Sliding rail [4].

Sliding rails has been the initial and biased thought for this area of application. There is minimal generation of friction, as a bracket with bearing balls is placed between the inner and outer cover of the rail. The bearings may also be greased to ensure a smooth and silent motion. The design of standard house appliance sliding rails support large forces in the direction of the arrow (point 1 in Figure 27). The rails also demand very little space, as they have a low profile. In agreement with the Dropracks team, this feature will be further investigated through prototyping.

3.5.2. Features to prevent a collapse of the loading plane

To prevent a collapse of the loading plane in the lifting and lowering motion, a feature is required to prevent the pivoting pins (9 and 10 in Figure 3) from sliding in the tracks of the brackets (1 and 2 in Figure 3).

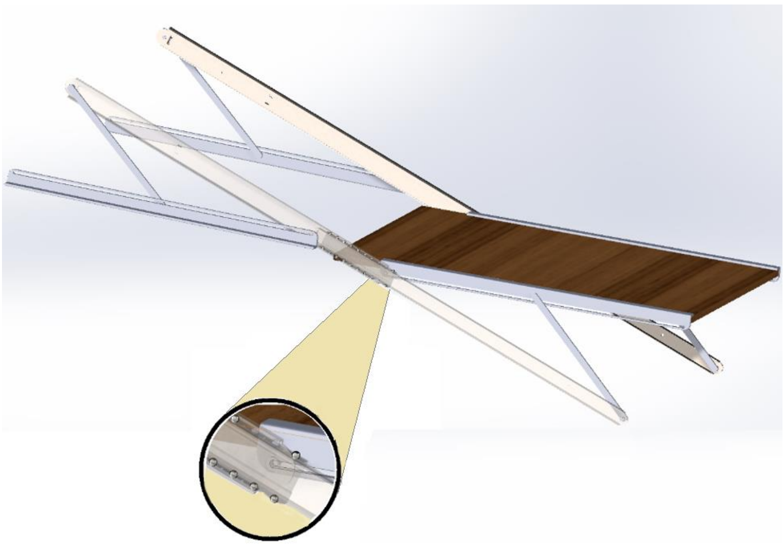

Figure 28 - Collapse mechanism. Sliding pin and groove [4].

If there are no mechanisms to stop the pivoting pins 9 and 10 in the grooves of the brackets (1,2) in the lifting and lowering motion, the functional design of the device will be compromised. As seen in Figure 29, a downward force on top of the loading plane will in the position illustrated result in the plane sliding inwards and tilting to the plane of the sliding rails. There should be a feature in these points that prevents internal sliding during the lifting and lowering motion.

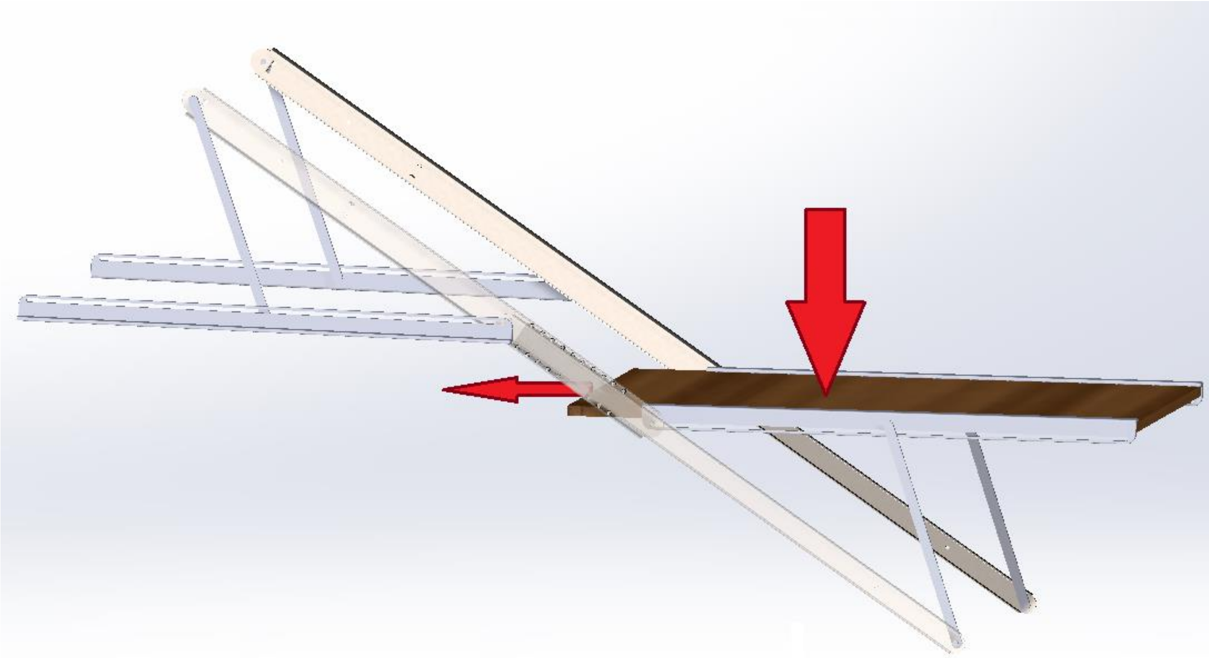

Figure 29 - Collapse mechanism. Forces and direction of collapse [4].

I Manual motion stopper

A spring loaded manual lever may work as a feature to prevent that pins 9 and 10 slide in the grooves of bracket 1 and 2. Figure 30 illustrates a lever solution in point 10. The design of the lever must allow the sliding pins (9, 10) to slide past the lever feature before the lever “snaps” in place, locking the pins in place. To release the sliding pins, the lever is tilted, and the pins are free to travel along the groove.

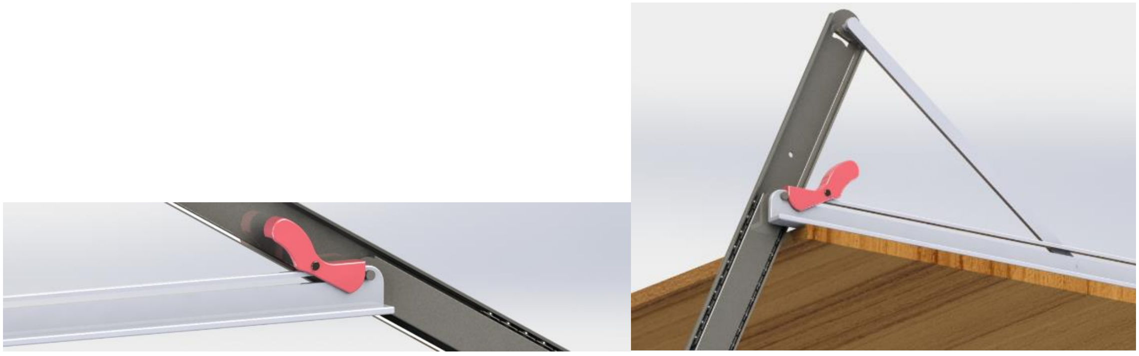

Figure 30 - Manual lever solution to prevent structural collapse [4].

II Rotation Guide

To solve the collapse problem, a mechanism hereby referred to as a rotation guide may be used. The rotation guide, illustrated in Figure 31 only allows rotation in the end positions. This Figure illustrates bracket 1 and bar 4 (sliding rail). When the sliding rails reach the same orientation as the mounting brackets (i.e. horizontal), the geometry of the rotation guides allows the system to slide horizontally to the compressed state.

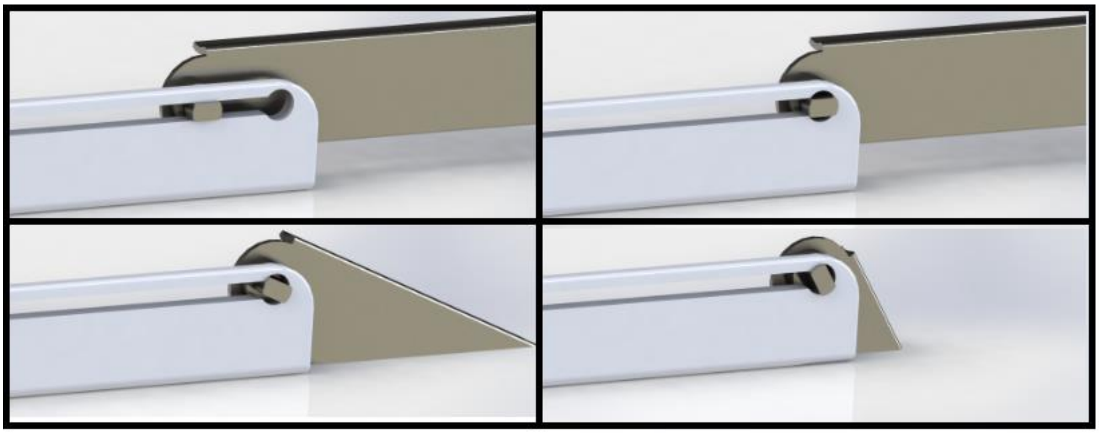

Figure 31 - Rotation guide solution to prevent structural collapse [4].

The main mechanical challenge of the rotation guide is that the pin (1) in Figure 32 must be firmly placed in the slot (2) before any rotation takes place. If the pin is not centered in the slot like illustrated in Figure 31, plastic deformation in the slot may compromise the function of the system. Due to the probability of plastic deformation, this feature does not qualify for the prototyping process of this thesis.

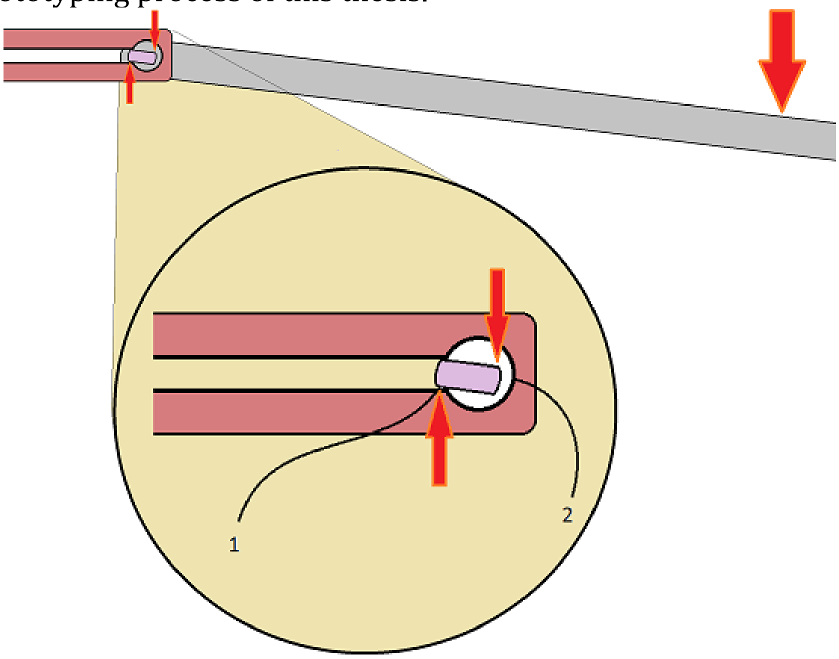

Figure 32 - Unwanted forces leading to possible plastic deformations in the rotation guide [4].

III Internal pivoting feature

Another alternative is to construct a pivoting feature that slides inside a slot of an extruded aluminum rail (Figure 33). This solution has less probability of failure, as the aluminum rail helps guide the pivoting feature. The downsides of this design compared to the rotation guide is that the friction contact surface is larger, and that the small hinges in each of the internal pivoting features will experience the largest forces in the system. This feature may be installed on both the mounting brackets and the shelf brackets. Stopping features (Point 1 in Figure 46) are required to ensure that the entire internal pivoting feature does not slide out of the extruded rail.

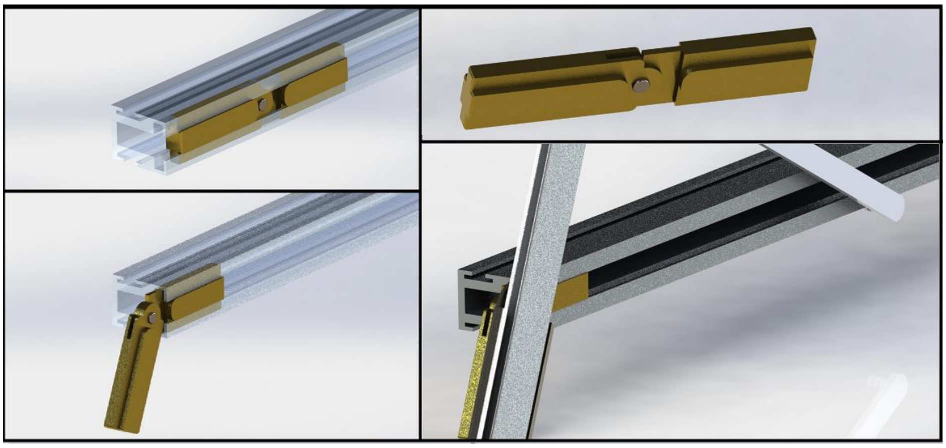

Figure 33 - Internal pivoting feature [4].

3.5.3. Installation

I On top of shelf or on top of closet

During the prototyping process, it was found that the use of sliding rails proved a challenge when executing the linear compressing and expanding motions in Figure 5. Due to the geometry of the sliding rail, the horizontal sliding motion must happen in two steps. (Figure 35) The reason for this is that the sliding rail cannot expand to twice its length. There must be an overlap of the inner and outer frame of the rail. This overlap is the same length as the bracket that holds the bearing balls in place inside the sliding rail (Figure 34 and 36).

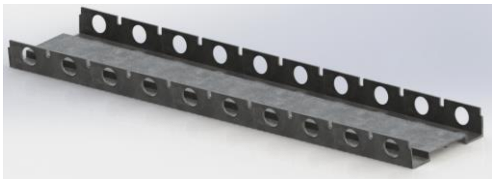

Figure 34 - The ball bearing bracket [4].

For the system to be able to pivot, joint 9 (Figure 3) must be located past the edge of the shelf it is mounted on. This means that in order to compress the system completely on top of the shelf, there must be a sliding motion between the mounting surface and the mounting bracket. This is more thoroughly visualized in the attached animations and video recordings.

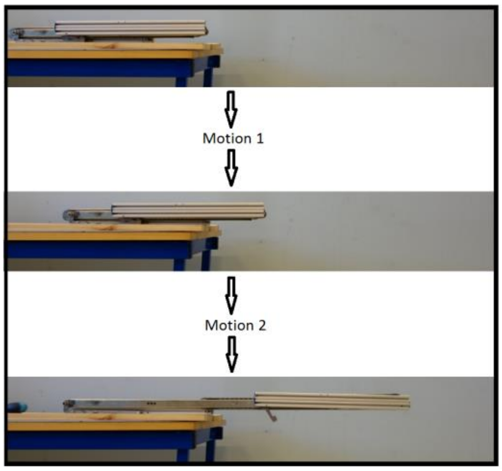

Figure 35 - The horizontal movement is composed of two motions [4].

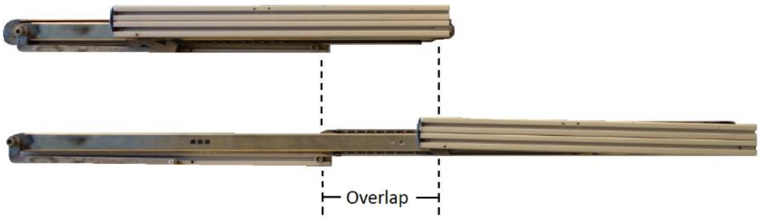

Figure 36 - The overlap due to the ball bearing bracket [4].

II Inside walls

When the system is mounted on the inside of a closet, only one motion is required for the compressing and expanding stages. This solution is elegant and less complicated, however the braces (6 in Figure 3) require space over the mounting brackets in order to travel without obstruction through their path of motion.

Figure 37 - The LLD mounted on the inside of a closet [4].

3.5.4. Sliding function for horizontal motion 1

This issue first arrived in the process of prototyping. The generated alternatives below have not been constructed through prototyping, but they are relevant for future work. In the first horizontal motion (Figure 35), only vertical forces affect the system. These forces are evenly distributed throughout the motion.

I Sliding rails

Conventional sliding rails (Figure 27) may be used to ensure a low friction motion. The main challenge with this configuration is that the rails are not designed to lay flat on a horizontal surface and support forces working in the vertical direction. There are however many sliding rail models with different configurations available on the market. One solution, illustrated in Figure 38 can withstand forces in both the horizontal and vertical direction.

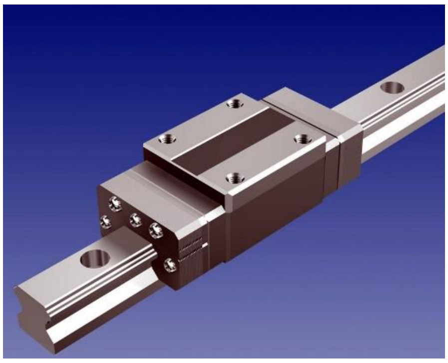

Figure 38 - Linear rail bearings which withstand forces in all directions [14].

Figure 39 - Movement 1 by utilizing a sliding rail [4].

II Slideway of self-lubricating polymer

Self-lubricating polymers are known for their excellent wear resistance and low friction. They are often used in bearings, fittings and slide elements. The polymer compound is filled with solid lubricants, which are released when the polymer is abraded [15].

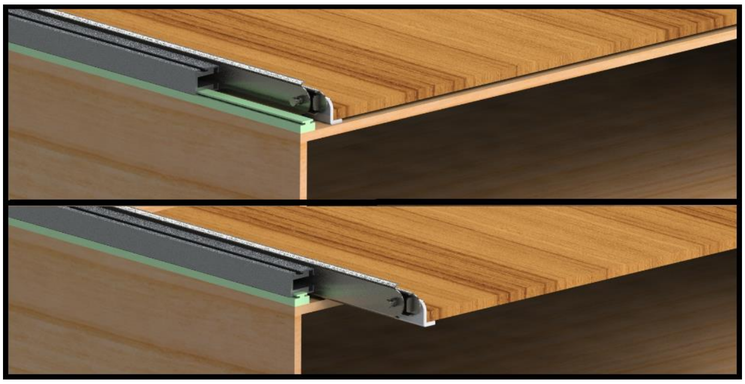

Figure 40 - Movement 1 by utilizing a polymer slideway [4].

3.5.5. Decision table

The following features were decided to be investigated to in the prototyping process.

Interaction between bar 3 and 4	**Pivoting feature**	**Installation**	**Sliding motion 1 feature**
Telescopic pipe configuration	Manual motion stopper	On top of shelf/on top of closet	Conventional sliding rails
Telescopic extruded aluminum profile	Rotation guide	Inside closet	Slideway of self-lubricating polymer
Sliding rail	Internal pivoting feature		

Table 2 - Decision table

Alternatives that **qualify** for prototyping process	
Rejected alternatives	
Alternatives that appeared in the prototyping process, which **should be further investigated**	

Table 3 - Color descriptions for Decision table.

3. 6. Loads

Excessive loads

If the force working downwards on the loading plane is too large, several structures may fail. According to simulations (Chapter 3.9.3.), the largest forces in the LLD appear in the region of point 9 in Figure 3. It is likely that this will be the place where structural failure first occurs.

User inflicted loads

User interactions with furniture and mechanic home appliances can be both gentle and reckless. People have different degrees of coordination and strength. This results in most furniture and home appliances being robust and often dimensioned for forces a lot larger than expected. If we consider the system to be mounted on top of a 2,2-meter-tall closet, the reach of the person handling the system must be at least 2,2 meters. This excludes most children from being potential users. Children may lack the understanding of complex systems like this, and may use excessive force when the system does not function properly.

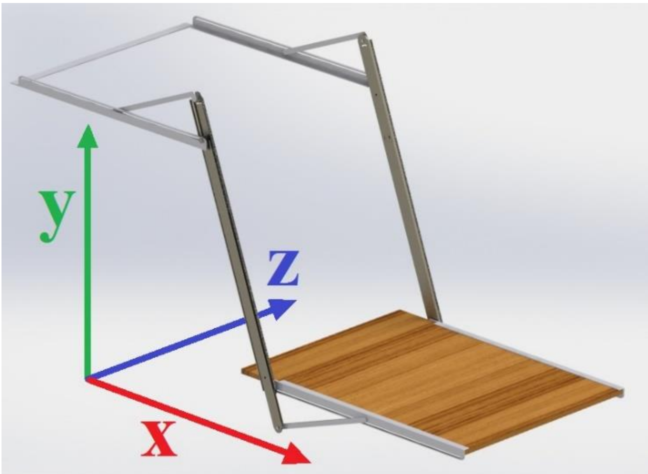

Figure 41 - The LLD in a coordinate system for future references [4].

Special consideration with respect to the sliding rail

Initial worries that the sliding rail would be the weakest link of the system meant that the design had to be adapted to the strengths and weaknesses of the rail. The strengths of using a sliding rail are its low profile and its ability to withstand large forces working in the x-y plane. (Figure 41) In the z direction however, large forces will lead to bending or dismounting. The sliding rail which is used in this thesis is designed to only support loads in the y direction. Its ability to support loads in the z direction has been investigated by simulations and a practical experiment (Chapter 3.9.1.), (Appendix G).

Torsion forces

To avoid forces in the z direction in the system, some measures has been taken. It is however impossible to make all forces in the system act linearly, as the elements are stacked side by side in the z direction. There will be torsion forces working in the system. Through the work with mock-up prototypes, a lot was learned about the directions and magnitude of the torsion forces in the system. It was uncovered that most of the torsional twisting occurred in the braces. In Figure 2, it can be observed that in Dropracks' prototypes, the braces come in pairs, one on each side of the brackets. This eliminates the torsion in their design.

3.6.1. Safety

When lowered, the loading plane of the system will rest on the side of the closet's center of gravity. This will cause the closet to tilt if the force acting down on the loading plane is large enough. This is especially relevant if there is no dampening feature in the system. A falling load will inflict large forces onto the system if it stops without damping. The vertical reach of the system will be around 0,4 m. If there is a load of 20 kg ≈200N on the loading plane, the following is the potential energy of the system:

$$P = mgh = 20 * 9{,}81 * 0{,}4 = 78{,}48\,J$$

This is equal to the kinetic energy at impact. When the impact takes place, the velocity of the loading plane is the following:

$$v = \sqrt{2gh} = \sqrt{2 * 9{,}81 * 0{,}4} = 2{,}8\,m/s$$

To calculate the impact force, the impact damping distance must be defined. We first assume there is no damping feature, and that the natural elastic suspension of the system is d= 50mm at the point of impact. the following formula gives the impact force.

$$F_{No\ dampening} = \frac{\frac{1}{2}mv^2}{d} = \frac{\frac{1}{2}*10*2{,}8^2}{0{,}05m} = 1568\text{ N}$$

If there is installed a feature that provides damping through the whole lowering motion of 0,4 m, the impact force at the end would be the following:

$$F_{Full\ dampening} = \frac{\frac{1}{2}mv^2}{d} = \frac{\frac{1}{2}*10*2{,}8^2}{0{,}4m} = 196\text{N}$$

As the calculations show, a non-damped system will be fatal to the structure, and possibly the user, if it falls the whole distance of 0,4 m. Friction and air resistance will influence the real-life forces, but not significantly. The weight of the shelf brackets and the shelf itself will also contribute to the downward force. There is concluded that a dampening feature is necessary for the structural integrity of the system. Unwanted loads from intentional and unintentional use suggest that the material choice must be made with a safety factor of 2 based on the results from the stress simulations of the system. The need for a damper was not realized until after the prototyping process was complete. It is defined as future work.

3.7. Prototyping and Proof of concept
– The iterative process of technical design

To uncover the weaknesses and design flaws of the initial CAD model, a series of design concepts have been constructed in the metal lab of UIT Narvik. The background for these trials has been to examine the user friendliness and the degree of friction in the different concepts. To properly design a product of this complexity, 4 full size mock-up prototypes have been constructed. Other advantages of making mock-up prototypes are that unforeseen structural problems and obstacles can be found. Additionally, assembly methodology and welding strategies can be fine-tuned for a possible final prototype.

The objective of the prototyping process has been to

- Compare solutions for preventing collapse in the lifting and lowering phase
- Compare sliding solutions internally in the mounting brackets
- Uncover mounting solutions
- Optimize pivoting solutions

To ensure quick and easy changing of parts in the prototypes, measures were made to make the parts flexible and interchangeable. Features to ensure quick adjustments between concepts included the following:

- Use of threaded bolts and nuts instead of smooth fittings for pivoting joints and sliding pins
- As few weldments as possible
- Adjustable brace holder (Figure 42)

Figure 42 - Adjustable brace holder [4].

The adjustable brace holder made it possible to experiment with brace lengths without drilling new holes in the brackets. The flat structure on the bottom of the brace holder slid in the slots of the aluminum profiles, and the feature was fastened by screwing down the knob on top (Figure 46).

3.7.1. Execution of the prototypes
The mock-up prototypes were constructed from aluminum and construction steel. The prototypes were mostly made from scrap parts found in the metal lab of UIT Narvik.

To save time and materials, only one side of the framed system was designed. The LLD consists of two equal systems that are mirrored along the middle of the loading plane. Figures of prototype III and IV show the right half of the system. When the whole LLD is completely assembled, there is a shelf resting between the two parallel systems. This provides a substantial rigidity to the system.

3.7.2. Prototype I

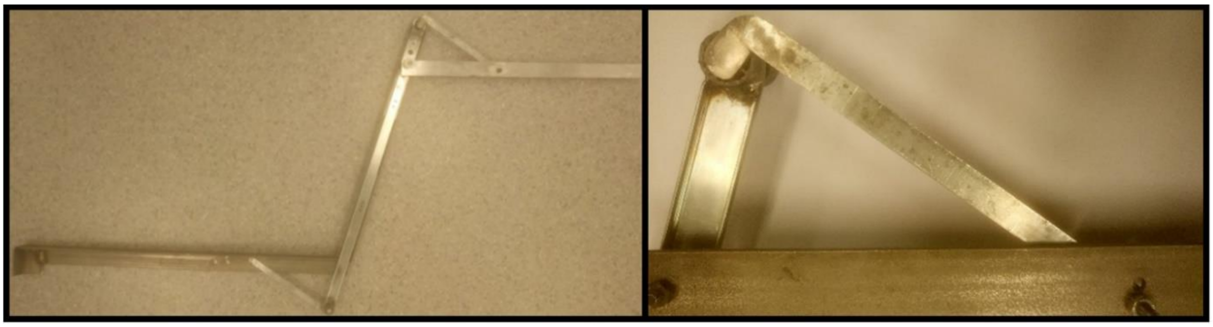

Figure 43. - Prototype I. Only lowering motion [4].

The goal of the first mock-up prototype was to obtain a proof of concept of the lifting and lowering motion. This prototype had no tracks for sliding, instead, holes were drilled in location 7, 9, 10 and 12 in Figure 3. This ensured a snag-free lifting motion. The system got from the bottom to the top position and back without problems. The main cause of deflection in the z axis was loose joints.

3.7.3. Prototype II

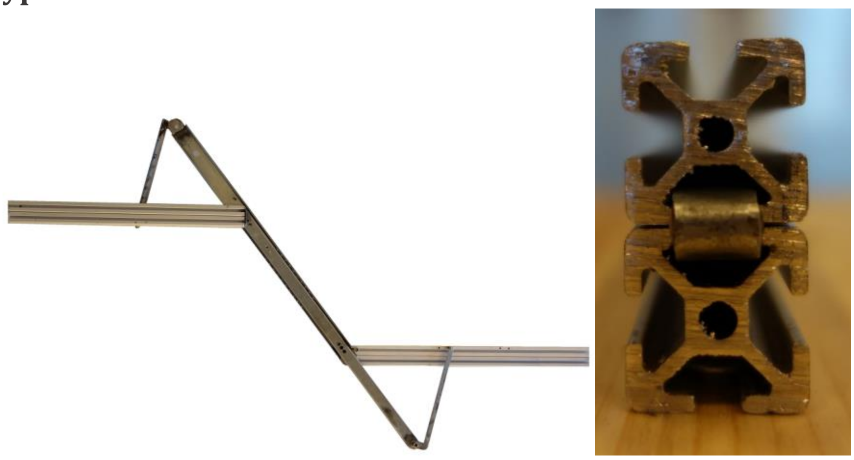

Figure 44 - Prototype II. Both lowering and horizontal sliding motions [4].

The goal of the second prototype was to obtain proof of concept of the horizontal sliding motion combined with the lifting and lowering motion. The sliding rail was equipped with a flat steel knob (1 in Figure 45), that slid inside profiled grooves in extruded aluminum bars. There was a significant amount of friction in the sliding motion. By repeating the sliding process numerous times while doing small adjustments of the knobs and the orientation of the aluminum bars, some of the friction was eliminated. Most of the friction is assumed to be a result of disproportions between the contact surfaces combined with the unfortunate steel against aluminum friction coefficient (0,47) [16]. Additionally, forceful use of the system may result in the steel knob cutting into the softer aluminum, resulting in less glide. Use of this prototype reinforced the theory that a locking mechanism is needed, as the loading plane kept collapsing when lifted up, as illustrated in Figure 29.

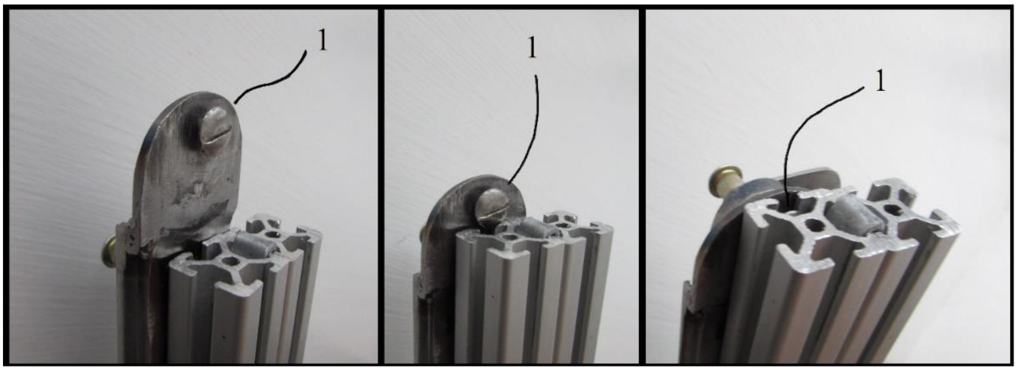

Figure 45- Wide flat head screws served as sliding pins 9 and 10 [4].

3.7.4. Prototype III

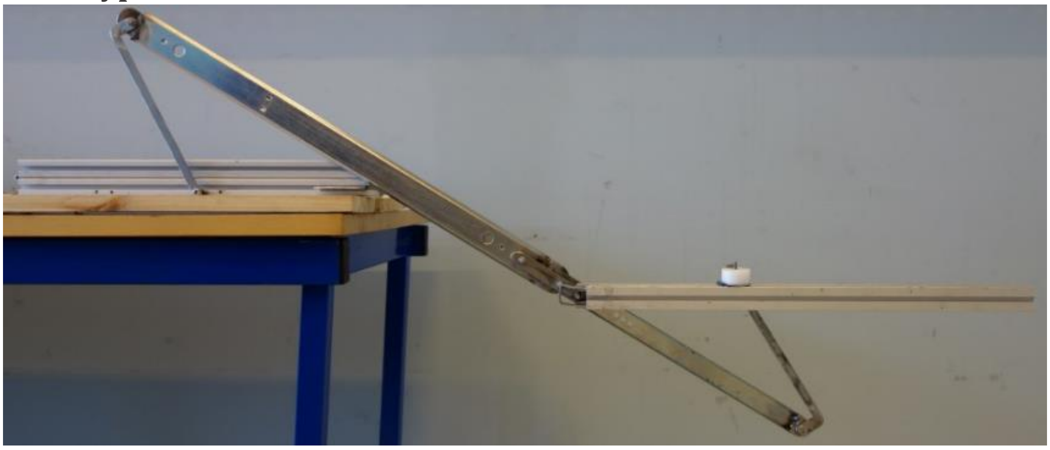

Figure 46 - Prototype III. Internal pivoting feature [4].

The goal of the third mock-up prototype iteration was to install an automatic feature for locking the joints in location 9 and 10 (Figure 3) to prevent a collapse. Initially, the rotation guide (Figure 31) was intended, but the concept was discarded because of the high requirements for user precision needed to make the system work. Also, plastic deformations may take place (Figure 32). The choice to disqualify this solution was especially relevant in the case of rapid prototyping. Accurate milling and lathing, and low tolerances would be important to ensure low levels of friction and smooth operation. The chosen solution was the internal pivoting feature. A suitable extruded aluminum bar was found in UITs stock of materials. A hinged sliding element (Figure 48) was constructed to fit inside the slot of the aluminum bar. A stopping feature was constructed at the end of the aluminum profile. This feature interacted with the screw in the hinged joint (Point 1, Figure 47).

Figure 47 - Prototype III. Interaction between hinged slide element and aluminum profile [4].

Figure 48 - Details of the hinged slide element [4].

3.7.5. Prototype IV

Figure 49 - Prototype IV. Magnified view of the motion stopper [4]..

The fourth iteration of the mock-up prototype has a similar build as the second prototype. The major improvements were enforced braces (Figure 50), a manual rotation stopper on the upper mounting bracket (Figure 49) and a manual rotation stopper in the lower mounting bracket (Figure 51). The friction was reduced by inreasing accuracy when making the parts.

Figure 50 - Prototype IV. Details of the final iteration of the brace design [4].

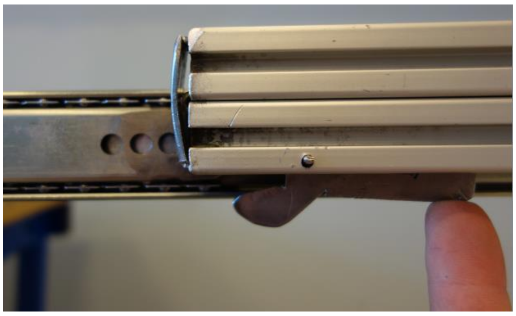

Figure 51 - Prototype IV. Manual motion stopper [4].

3.7.6. Results from the prototyping process

The background for the prototyping process was to investigate if the planned design would work as intended and to compare solutions discussed in chapter 3.5.

The mock-up prototype process revealed flaws in the planned design. Originally, the braces were not angled, but straight bars (point 3 in Figure 52). When trying to compress the system (Horizontal sliding motion 2, Figure 35), there was in the design a conflict between the braces and the sliding pin (Red area in Figure 52) when the pin moved along the track of the bracket. Point 1 in Figure 52 shows positions before the sliding rail is compressed. Point 2 shows how the brace is designed to avoid contact with the pin.

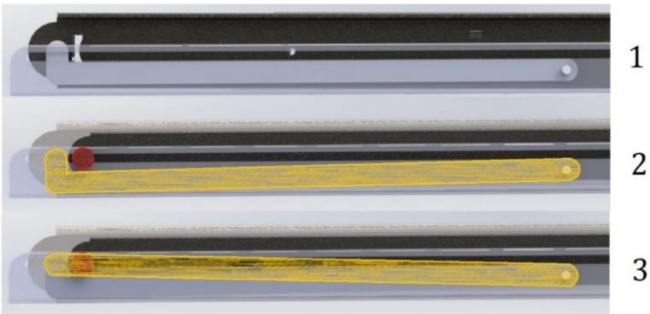

Figure 52 - Interaction between sliding pins and the braces [4].

This problem may have been avoided, had the initial CAD model been investigated more thoroughly. Another unexpected finding was that the horizontal sliding movement had to be composed of two separate movements if the LLD was to be mounted on top of a closet. As illustrated in Figure 36, the sliding rail must have a certain overlap to keep its structural integrity. If the overlap is too small, the sliding rail loses its ability to withstand forces perpendicular to its longitudinal direction. In prototype 2, 3 and 4, horizontal sliding motion 1 (Figure 35) was conducted simply by letting the extruded aluminum bars slide on a row of wide flat head screws, as shown in Figure 53.

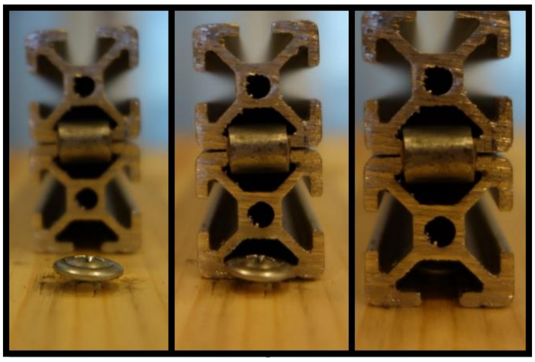

Figure 53 - Motion 1 mock-up sliding solution [4].

3.8. The final CAD model

Choice of alternatives

The final CAD model is composed by the most promising features that were investigated during the prototyping process.

- The mounting brackets and shelf brackets will be made from extruded aluminum (Appendix L)
- To ensure that there is no sliding of pins in point 9 and 10 (Figure 3) in the lowering motion, the internal pivoting feature is chosen. This is because it works automatically, and does not require the user to initiate the horizontal sliding motion by operating a lever. Also relatively low levels of friction was observed in the prototyping process.
- The slideway of self-lubricating polymer is chosen as the solution for the CAD model, as it is a low-cost alternative with high probability of success. However, this has not been tested through prototyping.
- The braces are angled, with reinforcements (Figure50)

The result is a high precision system, where the assembled components have a low profile. For a 600 mm wide closet, the top shelf will be 500 mm wide. The vertical reach is up to 420 mm. Adjustable reach is possible to obtain, by installing a feature that stops the lowering motion at a certain place. This is described in *Future Work.* The remaining assessments made with respect to dimensions and shapes of the aluminum rails and other components in the CAD model will not be discussed further. The number of components and the complexity of the system deserves attention, and further work is required as a continuation of this thesis. The following chapter is a visual representation of the CAD model.

3.8.1. Documentation

This is a still picture representation of the final solution. In the attached files, more detailed descriptions are provided:

- Interactive CAD assembly where the lifting and lowering motion can be carried out using the mouse pointer.
- 2D drawings of the components.
- Animations of the lifting and lowering motions
- Animations of horizontal sliding motion 1 and 2
- Video recordings of prototype III and IV in action.

Figure 54 - Final CAD model [4].

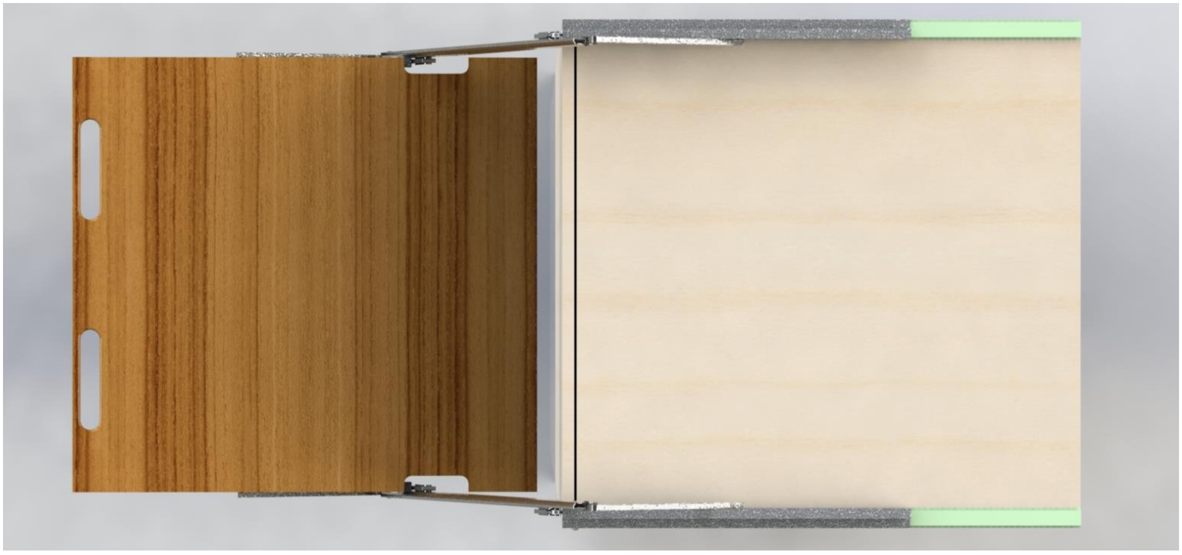

Figure 55 - View from above. [4].

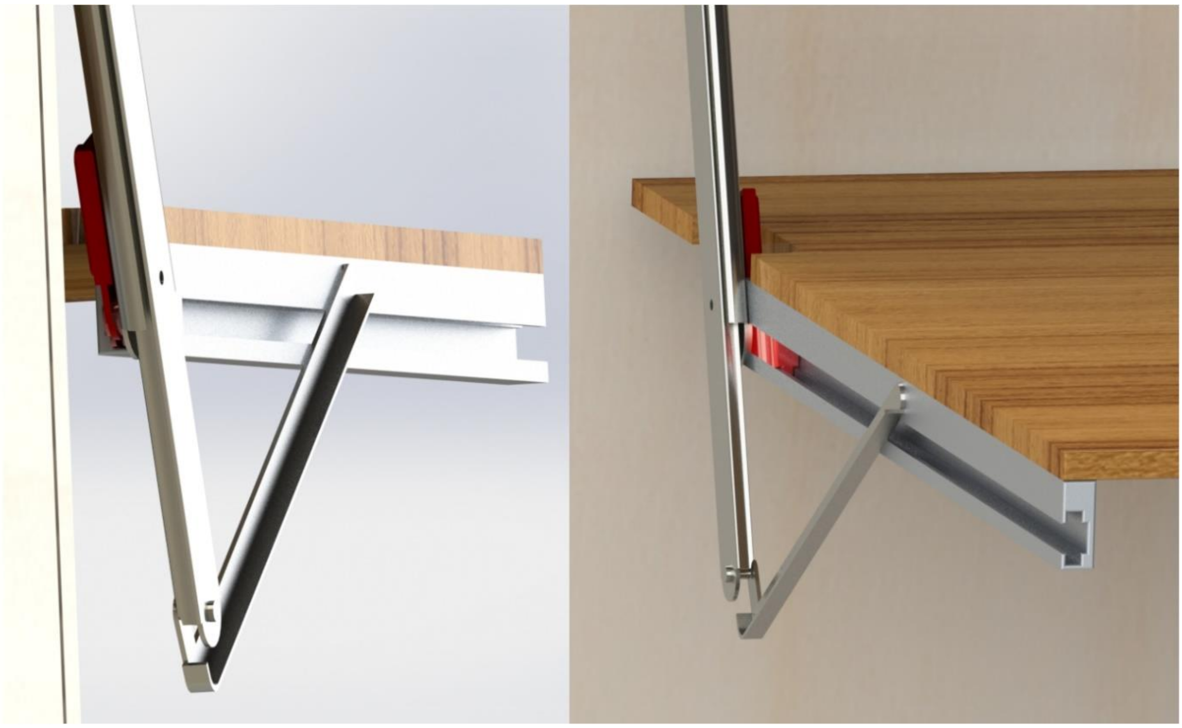

Figure 56 - Details of the internal pivoting feature. [4].

Figure 57 - Mounting inside closet. [4].

3.9. Simulations

For the virtual prototyping, a system with all the moving parts was drawn in SolidWorks, and compiled in an assembly. Trying to simulate the entire model in FEM software was not feasible, as there were too many contact surfaces, especially in the bearing balls of the sliding rail. Three simplified CAD models were made especially for the simulation process. Using the sliding rail and a measure tape, the distance between all points in the sliding rail was measured. When compressed, the ball bearings become centered in the sliding rails. The ball bearings are marked with red color in Figure 58.

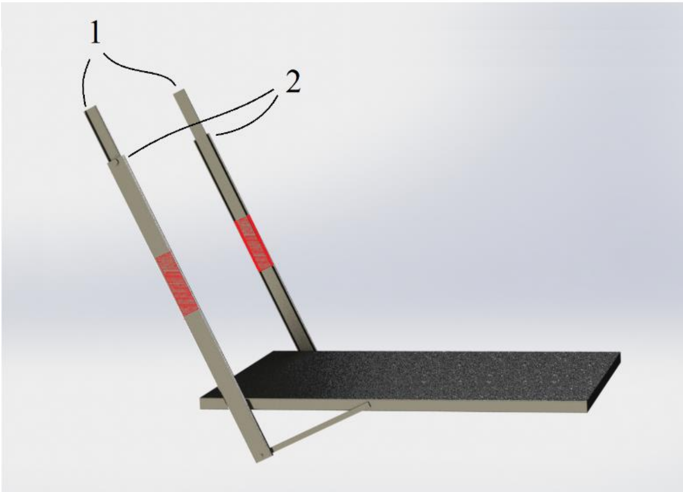

Figure 58 - Rigid simulation model for simulation 4. Ball bearing brackets marked in red color [4].

For simulation purposes the ball bearing brackets were replaced with solid structures, joining the inner and outer parts of the sliding rails. The simulation CAD models can be found in the attached file folder. Due to the initial orientation of the simplified CAD model, the simulation results are presented “laying down”, as shown in Figure 60. Sideways forces in real-life will be projected as vertical forces in the simulations. Detailed descriptions and assumptions in the simulations are added in Appendix G, H and I.

Simulation results

Results from 4 simulations are added in the thesis. Simulations cover both isolated parts of the system and the complete system integrity. The detailed figures and procedure can be found in Appendix H and I. The following chapter describes briefly the applied forces and their directions in the simulations. For each simulation, the resulting stress, and displacement are discussed.

3.9. 1. Simulation 1

Simulation 1 features the sliding rail as an isolated part. A vertical force of -29,42N (≈3 kg) is applied. The background for this simulation is to uncover the differences in the simulated deflection and the real-life deflection of the sliding rail. The simulation model has a fixed area along the back side of the rail cover, and the outermost edge of the inner sliding rail cover is subject to the force (Figure 59)(Appendix I).

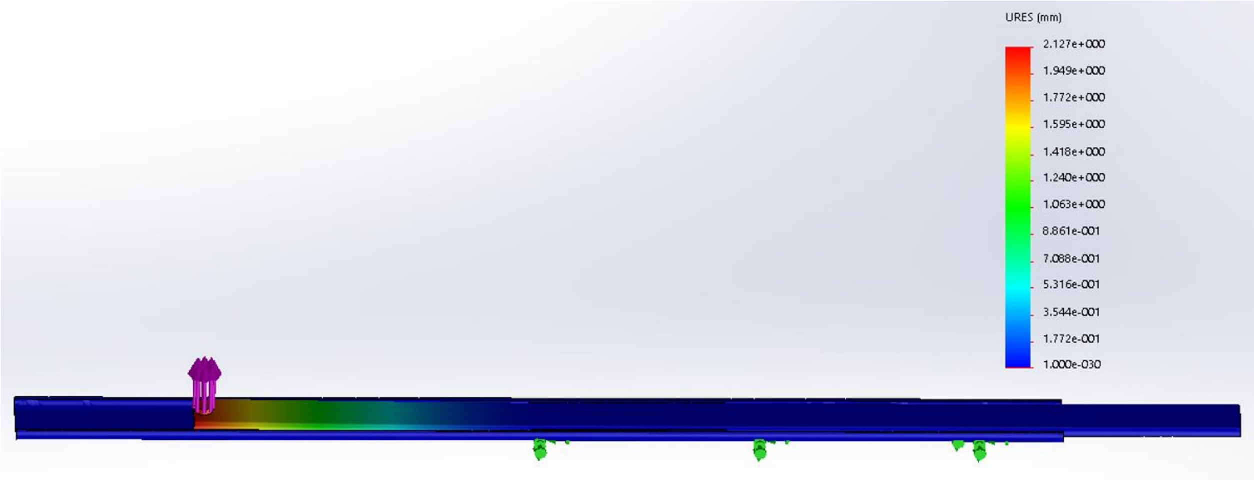

Figure 59 - Simulation of single sliding rail. 10N [4].

- ***Results:*** A maximum deflection of 2,127mm.

Evaluation: The simulated deflection was lower than expected. The ball bearing in the real-life sliding rail has a certain degree of play. There was conducted an experiment before the simulation was carried out. This experiment used a 3 kg weight and a pulley, connected with a string to the sliding rail, which was fastened to a wooden plate. Documentation of the project can be found in Appendix G. The experiment showed a deflection of 4,3 mm, which is about twice as much as the simulation shows.

$$Deviation: 4{,}3\ mm - 2{,}127\ mm = 2{,}173\ mm$$

The reason for this is believed to be two things:

1. Play between the rail covers, the bearing ball bracket and the bearing balls.
2. Some degree of elastic deformation in the walls of the rail covers, as a result of the bearing balls jamming against the walls.
3. Wrong material properties in the simulation. *Steel Alloy* was chosen.

The gap between simulated deflections and real-life deflections is believed to be present also at higher forces. However, the real-life deflection is believed to be far from twice as large as the simulated results when larger forces are applied. The experiment is classified as partly inconclusive, as more testing is required to fully understand the deviations between measured and simulated deflections.

3.9. 2. Simulation 2 and 3

The background for these simulations is the design requirement for stiffness (Chapter 3.3.)

Stiffness	Must be stiff enough to avoid wiggling (sideways movements), vibrations and plastic deformation. A maximum of 20 mm defection is allowed when applying a force of 10N sideways to the system. No plastic deflection is allowed.

Simulation 2 features an evenly distributed force of 10N on the edge of the loading plane in the z direction (Left side, Figure 60). The braces have been left out of the simulation because they have a negligible sideways stiffening effect. Simulation 3 (Right side, Figure 60) features the same setup, but the force of 10N is located at the outermost end of the loading plane.

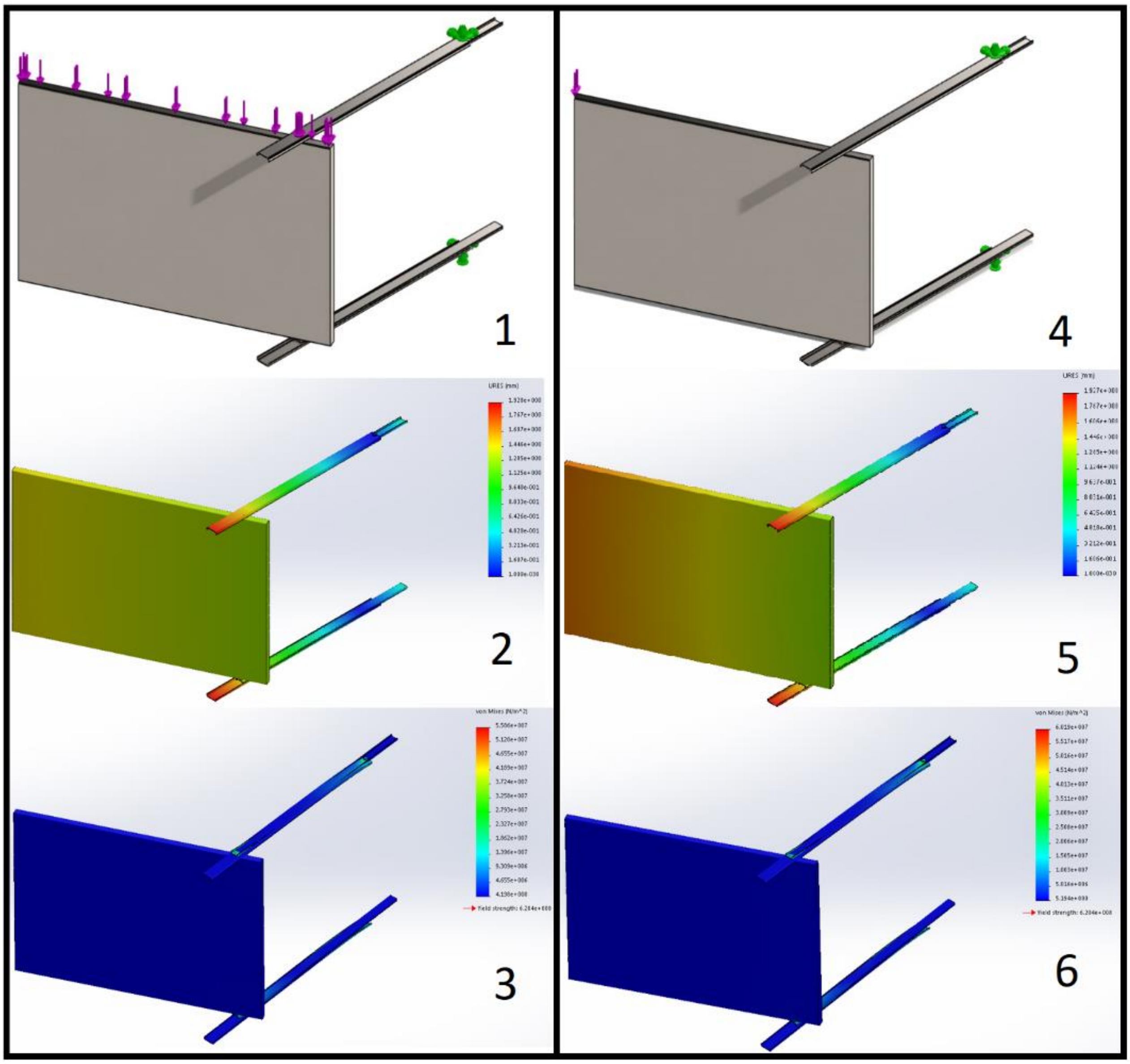

Figure 60 – Simulation of 10 N sideways force. Left: Evenly distributed. Right: point load [4].

- ***Results:***
  - Simulation 2
    - Maximum deflection: 1,92794 mm
    - Maximum stress: 55,856 MPa
  - Simulation 3
    - Maximum deflection: 1,92737 mm
    - Maximum stress: 60,1894 MPa

Evaluation: The simulation shows almost identical maximum deflection in the two simulations, despite different load points. Simulation 3 shows a larger degree of deflection on the edge of the loading plane (Frame 5 of Figure 60). The simulations reveal that the point of maximum deflection is the same in the two Figures (Node 11361)(Appendix I). The deflection of ≈1,93 mm is well within the design requirements. The maximum stress in the simulations is well within the tensile strength of the material (Figure 62). There is a larger stress in simulation 3 than simulation 2. This may be due to the larger degree of rotation in the system, when the point of applied force is at the tip of the loading plane.

3.9. 3. Simulation 4

The background for this simulation is the design requirement of Load Force:

Load Force	Should support 200 N distributed on the loading plane without suffering from plastic deformation.

Simulation 4 features an evenly distributed force of 200N, downwards on the loading plane. Included in the simulation is also the lower braces (5 in Figure 3). The braces on the top (6 in Figure 3) are removed, and the intersection point between these braces and the sliding rails have been replaced with geometric fixtures in the simulation (frame 1, Figure 61). The pivoting point (9 in Figure 3) is defined as a hinged fixture, which allows rotation in the point.

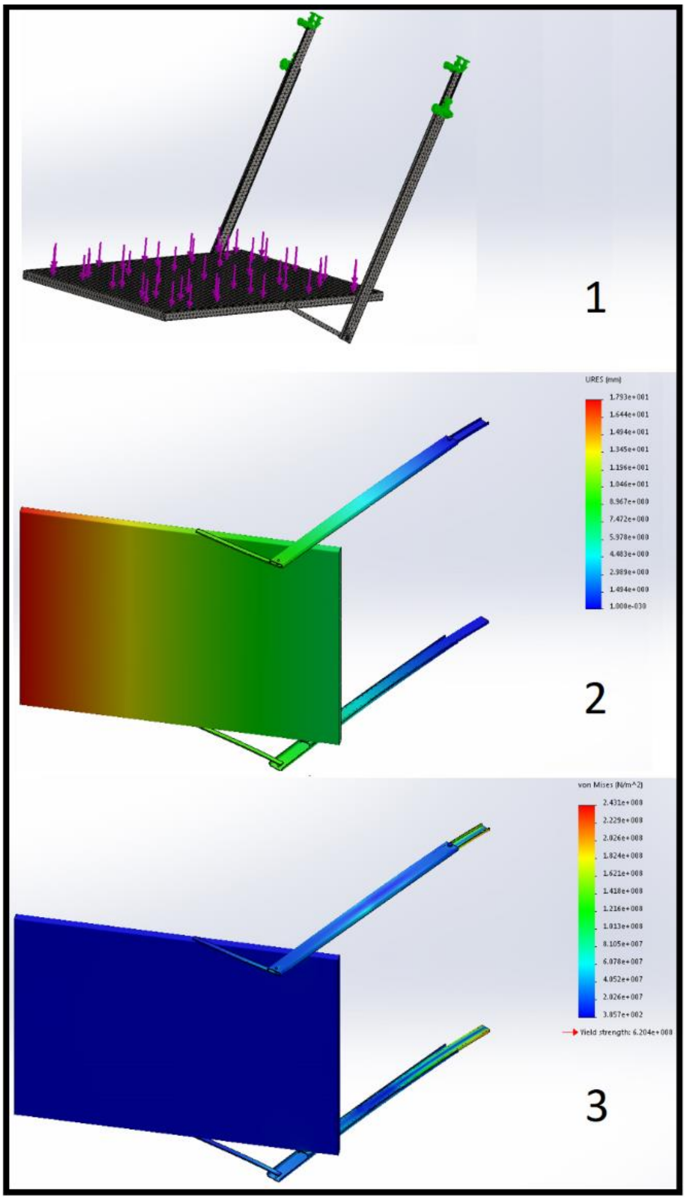

Figure 61 - Simulation 4. Evenly distributed downward force of 200 N [4].

- ***Results:***
  - Maximum deflection: 17,9339 mm
  - Maximum stress: 243,139 MPA

Evaluation: The maximum deflection of ≈18mm occurs on the far end of the loading plane. This is because the loading plane gets tilted forwards (frame 2, Figure 61). The maximum stress occurs in the inner cover of the sliding rails on the top of the system (frame 3, Figure 61) This is the stress value that determines for the material choice of the components.

3.9. 4. Replicating simulations

As the type of steel alloy on the purchased sliding rails were not specified from the vendor, the material was set to be *steel alloy* in the simulations. In SolidWorks, *steel alloy* has the following properties:

Property	Value	Units
Elastic Modulus	2.1e+011	N/m^2
Poisson's Ratio	0.28	N/A
Shear Modulus	7.9e+010	N/m^2
Mass Density	7700	kg/m^3
Tensile Strength	723825600	N/m^2
Compressive Strength		N/m^2
Yield Strength	620422000	N/m^2
Thermal Expansion Coefficient	1.3e-005	/K

Figure 62 - Mechanical properties of "Steel alloy" in SolidWorks

Due to the complex nature of the system, there were significant difficulties with both modelling and CAD file import in ANSYS Product Launcher and ANSYS Work Bench. It was decided to execute the numerical simulations with SolidWorks FEM simulation tool. Modelling in ANSYS gives the user the possibility to generate a log file that can replicate the geometry. This feature is not included in SolidWorks. To replicate the executed simulations, see Appendix H and I.

3.10. Evaluation of the structural integrity of the system

Features that reduces stiffness in the prototypes

Sources of slack and play in the prototype include varying tension in the different joints and a significant difference in diameter between some holes and bolts. Also, the use of threaded bolts causes more play in the joints. Each of the brackets are constructed by joining two extruded aluminum bars on top of each other (Figure 44). This joining is not very strong, and some sideways dislocation between the upper and lower bar has been observed.

Features that improves stiffness in the prototypes

In joint 9, at the transition between the sliding rail and the mounting bracket, two flat areas are in contact (Orange shaded area in Figure 63). When forces are applied in the z direction, these overlapping surfaces create a highly rigid pivotal connection in the x-y plane (Figure 41). Enlarging this contact area, whilst utilizing a low tolerance internal pin (red color in Figure 63), will improve stiffness significantly.

Figure 63 - Large surface contact between the flat sliding rail and the mounting bracket improves stiffness. [4].

Mass

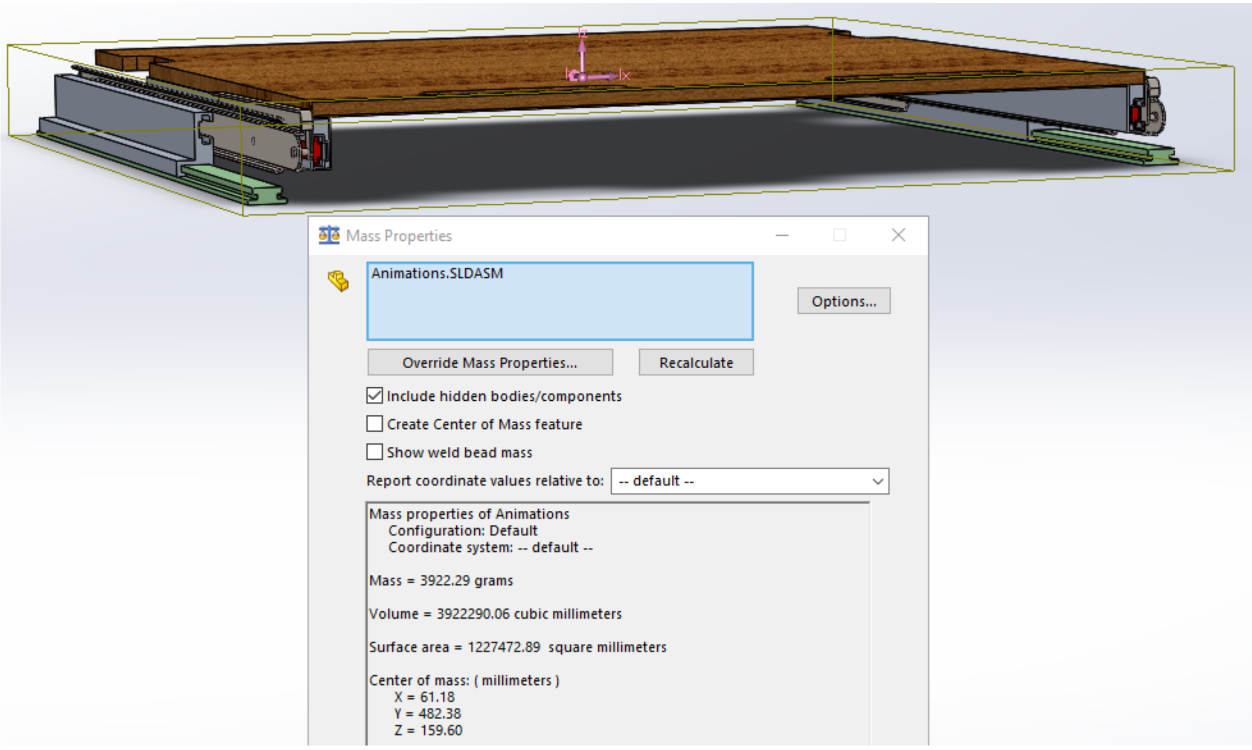

Figure 64 - Mass of the system

The complete system with a wooden shelf weighs 3922 grams. Assessments should be made on how the geometry can be changed to save weight. The shelf plate may also be made by a lightweight material. This is within the design requirement of a maximum mass of 5 kg.

Considerations on deviations between simulations and measurements.

The deflection experiment (Appendix G) showed a considerable deviation between simulations and measurements. It is believed that similar experiments on an entire system will result in deviations from simulations. It is also assumed that the shelf plate which is mounted in between two parallel systems will provide a significant stiffening effect. If the system is installed inside a closet, the inner walls of the closet will be an effective boundary of movement in the z direction.

3.11. Materials and manufacturing

The lifting systems is reliant on low tolerances and accurate movements. Any plastic deformation could be fatal to the operation of the system. If the system is deformed, more force may be required to use it, which may result on even bigger deformations. Softer materials like plastics and wood would not have the sufficient yield strength for the intended use.

Material for the sliding rails and braces

Both the sliding rails and braces experienced stress. The sliding rails are constructed from a steel alloy. The simulation of a 200N load evenly distributed on the loading plane revealed a maximum stress of ≈243 MPa in the sliding rails. It is desirable to apply a safety factor of 2 to ensure that the product can handle tough use over its lifetime. With the simulations as the foundation for material selection and a safety factor of 2 (Chapter 3.6.1.), it is decided that the material must have a yield strength of at least 486 MPa (Appendix J).

Using CES Edupack [18], the universe of construction materials has been narrowed down to a small number of possible materials. Three charts have been used to make the selection:

- Yield Strength VS Fatigue Strength (Appendix J)
- Hardness VS Tensile Strength (Appendix J)
- Price VS Density (Appendix J)

Yield Strength The system will be subject to at least 243 MPa of stress with the current design requirements. Insufficient yield strength may cause the system to suffer a considerate loss of function through plastic deformation. With a safety factor of 2, the yield strength criterion is set to 486 MPA.

Fatigue Strength The system must handle weekly use over a period of 15-25 years, or 5000 cycles of use. It is important that the material keeps its structural integrity for its intended lifetime of use.

Hardness For structural stiffness, material hardness is a valid measurement. One goal of the design is to avoid wiggling and vibrations in use.

Tensile Strength This is especially important when considering materials that might be brittle. On more ductile materials, the tensile strength is less important.

Price This is a product designed for the private market. The price of the material is a driving factor of product development.

Density It is desired to have a relatively lightweight construction. This can either happen by use thinner geometry with strong, dense materials, or enforced geometry with lighter materials.

Conclusion

Low alloy steel satisfies all criteria, and an overall assessment of the charts generated by CES Edupack suggest that the current rail is sufficiently strong. It is a low-cost option with excellent material properties for the area of application. The yield strength of the simulated steel alloy is 620,422 MPa (Figure 62). This is also well within the design requirements; thus, it can be concluded that the current sliding rail is sufficient for the further development of the product. The braces should also keep their structural integrity by utilizing low alloy steel as the construction material.

Material for the mounting brackets and shelf brackets

Throughout the process of this thesis, there has been a clear bias to use extruded aluminum to construct the mounting brackets and shelf brackets. The most plausible alternative to using aluminum rails is to use extruded steel rails. Extruded steel is however more expensive with respect to tooling and the extrusion process. Also, the components will be significantly lighter if they are made of aluminum. The material choice for the mounting and shelf brackets will continue to be aluminum.

Ease of manufacturing

Even if some materials apparently are more fit for the final product than others, production and manufacturing costs greatly influence the material choice. The components of this product are based on widely available materials. There are numerous suppliers for sliding rails in a large variation of configurations. Extruded aluminum rails can be mass produced at a low cost. These factors ensure a competing market of component suppliers, which results in lower purchasing costs. The braces may be cut out from metal sheets using waterjet cutters or other machinery, before the enforcing edge is welded in place. The material and production method of the internal pivoting feature remains to be investigated. An alternative is a steel core, with a self-lubricating polymer casted or pressure molded around.

Surface treatments

For aesthetic and corrosion inhibition reasons, the system components may be varnished or otherways surface treated. Challenges may occur when the system is subject to friction between components. The paintwork may scratch or flake off. The inner ball bearing tracks of the sliding rails should have a thin film of oil or grease to ensure a smooth and silent motion.

4. Attachments

There is a zipped folder attached to the thesis. It contains the following:

Animations

There are attached 6 animations on the folder "*Animations and video recordings".*

- The lifting motion.
- The lowering motion.
- Linear motion 1
- Linear motion 2
- Animated exploded view
- Animated assembling.

CAD models

There are 18 files in the folder "*Interactive CAD assembly".*

- The interactive assembly where one can carry out the lifting and lowering motion by using the mouse pointer.
- A CAD assembly that shows the system mounted inside a closet
- A STEP file of the final CAD assembly
- The remaining 15 files are parts that compose the assemblies. These do not need to be investigated.

Simulation models

The folder "*Simulation models*" contain the three simulation models needed to replicate the simulations.

5. Results and Discussion

After assessing the market, three application alternatives were generated. Lowerable shelf, retractable nightstand and pop-up coat hanger. After consolidating with Dropracks and salesmen – and women at IKEA it was decided that the lowerable shelf should move on to the design process. Alternatives for functions and components were tested through prototyping.

The orientation of the assembly was different from Dropracks' earlier models, as they had utilized telescopic bars and double braces in all positions. Key features in the final design are sliding rails, extruded aluminum rails, enforced braces and internal pivoting features.

The requirement of 200 N loading force is meant as safety guideline. Normally, less than 10 kg is loaded into wardrobe shelves. Simulations were performed. In order to simulate the sliding rails, the bearings had to be replaced with solid structures in the simulation model. This made the simulation model more rigid. An experiment was conducted to compare measured and simulated deflection. A deviation of 2,173 mm was calculated. This result suggests that simulations 1, 2 and 3 has produced results that are deviant to corresponding real-life measurements. In simulation 4, the forces are applied in the vertical direction, evenly distributed onto the loading plane. The simulations show a maximum stress of 243 MPa. By utilizing a stress factor of 2, the yield strength criterion is set to 486 MPA. The original material of the sliding rails combined with an overall assessment of the charts generated from CED Edupack, suggest that the current rail design is sufficiently strong.

In the CAD assembly, which is customized to a 600 x 600 mm closet, the system has a vertical reach of up to 420 mm when fully lowered.

5.1. Future work

Joinings of the components: In this thesis, the focus has been on the fundamental mechanics of the LLD system. There have been few considerations around joinings and attaching points. Threaded bolts, which are used in the prototypes is likely not sturdy enough for a lifetime of use. The placements of weldments, mounting features and threaded holes is an important next step in the design process.

Dampening Feature If the user slips the shelf during the lifting or lowering motion, the loading plane may fall rapidly to its bottom position. If this happens many times, or there is a heavy load on the loading plane, plastic deformations and functional failure is likely to happen. A feature to dampen the downwards pivoting motion is necessary. A dampening feature may include the use of springs, pneumatic dampeners or hydraulic rotation dampers.

Lifetime cycle simulations One of the design requirements is that the system shall endure a minimum of 15-25 years of weekly use, or 5000 cycles of use. This design requirement has still not been verified. This may be simulated with a software like ANSYS.

Motion stoppers The need for motion stoppers was not registered during the initial work, and proved to be a problem in the prototyping process. In the CAD assembly, all motions have been limited, by applying distance mates. Without these mates in the assembly, the components would slip out of each other. The prototypes feature several mock-up motion stoppers. There were made no conclusions to which motion stopping features to carry forward with. Motion stopping features are required in three instances:

1. Backwards motion stopper in the back of the polymer slideways (Chapter 3.5.4.)
2. Forwards motion stopper in the front of the polymer slideways (Chapter 3.5.4)
3. Motion stoppers for the internal pivoting features, on both sides of all braces (Point 1, Figure 47).

Further investigations are required to define the geometry and eventual dampening features in the motion stoppers.

Aesthetical design This was an initial goal of this thesis. As the thesis converged in the direction of concept proofing, the aesthetical design process was neglected. To be able to compete in the market, the product needs to be pleasing to the eye.

Shelf design The shelf in the CAD model is flat. For a safer use of the product, the shelf could be replaced with a tray.

Proofing of Simulation 1 Simulation 1 showed a result gap of almost 100% compared to the measurements made in the experiment. This needs to be further investigated.

Material for the internal pivoting feature A material has not been dedicated to the internal pivoting feature. To choose a material, further simulations and prototypes must be carried out. The material must be strong and have a low friction coefficient against aluminum. A resilient, but low-friction surface treatment or coating may be a viable solution.

Adjustable reach By installing a feature that stops the lowering motion at a given point, the reach is made adjustable. This must be further investigated.

Environmental impact A product can obtain numerous certifications for clean and environment friendly materials, production, assembly and packaging. These certifications may give the product an improved market position.

Self-lubricating polymers More knowledge is needed on the physical properties of self-lubricating polymers. The next step will be to define a selection of polymers that fit the application.

Looking into the market of hospital beds This alternative was not properly assessed in the decision phase, and may be promising.

Focusing on the objectives The generated objectives (Appendix C) has generally not been met in this thesis. They must be in focus in further development and prototyping.

Sliding rail orientation In simulation 4, the highest levels of stress were in the top section of the sliding rails. In the model, the thinnest part of the sliding rail (The inner cover) was in this position. If the rail was turned around, the outer cover, which is wider and possibly stronger would be subject to the largest forces.

6. Conclusion

The thesis project has taken the Dropracks patent for a Lifting and Lowering Device, and developed a concept for lowerable shelves in the private market. The lowerable shelf solution is intended to be mounted on top of, or inside tall, deep closets. There are still considerations to be taken regarding optimization of assembly, production, simulations and aesthetical design, but the concept still fulfils the general purpose of the thesis. For full functionality, it is recommended that the product undergoes further development, especially through prototyping. The next natural step in the process will be to investigate a damping feature. Initially, the goal of the thesis was to construct a perfectly working prototype with a loading plane. When the prototyping process started, the focus shifted from making a complete product to concept proofing. The design requirement that the system shall endure a minimum of 15-25 years of weekly use, or 5000 cycles of use has not been investigated. The reminding design requirements have been met. The final prototype can be studied through an interactive CAD assembly, where the pivoting feature can be experienced.

7. References

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Appendix A – Engineering design requirements for literature study applications

- Design requirements for the household shelf solution are not included.

Pop-up coat hanger rod engineering design requirements

Requirements	Pop-up coat hanger rod
Weight	Less than 10 kg
Stiffness	Must be stiff enough to avoid wiggling (sideways movements), vibrations and plastic deformation. This is important both in terms of service life, ease of use and quality feel.
Service lifetime	20 years of daily use. It should be able to be re-installed in new closets when refurbishing.
Assisted lifting	Yes. A spring-loaded solution or a linear actuator may be applied.
Locking mechanism	Yes. The rack should be locked in the upper position to avoid sagging when applying weight to the system
Ease of use	Should be able to be operated with one hand.
Load force	At least 15 kg of clothes. Larger and more sturdy models may be designed to hold equipment and gear of up to 30 kg
Ease of installation	Should be able to be installed by a single person. Dismounting and re-mounting should also be easy.
Adjustable reach	If possible, this would be optimal. This way the system may be customized to one user.
No sharp edges	Yes. The user will be operating the system with bare hands.
Maintenance free	Yes
Minimal friction in the system	Yes. Joints, sliding surfaces and rolling surfaces must have minimal friction.
Price	Affordable for anyone. A price survey has not been made, but one may assume that the purchase price should be below NOK 350.
Able to compete with existing solutions	There are no solutions which lifts and lowers a coat hanger rod like this on the market.
Noise level	Must be silent in use. Maximum acceptable noise is 55 dB, the sound level of two people having a conversation.
Dampening function	Might be necessary. It depends on the force of the assisted lifting solution.

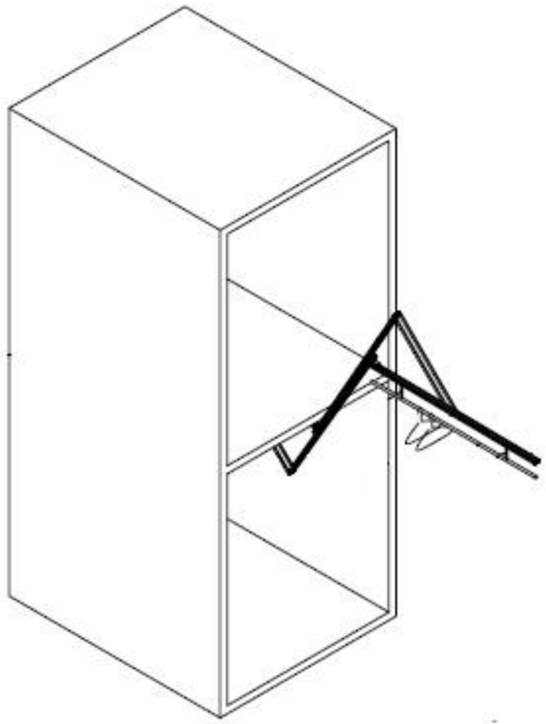
Design	Must be appealing to the buyer. Both the lines of the structure, color and surface finish should have both a modern and timeless look.
Universal fit	If sold separately, it should fit most closets. Mass produced closet solutions with this mechanism inside may not need a universal fit.

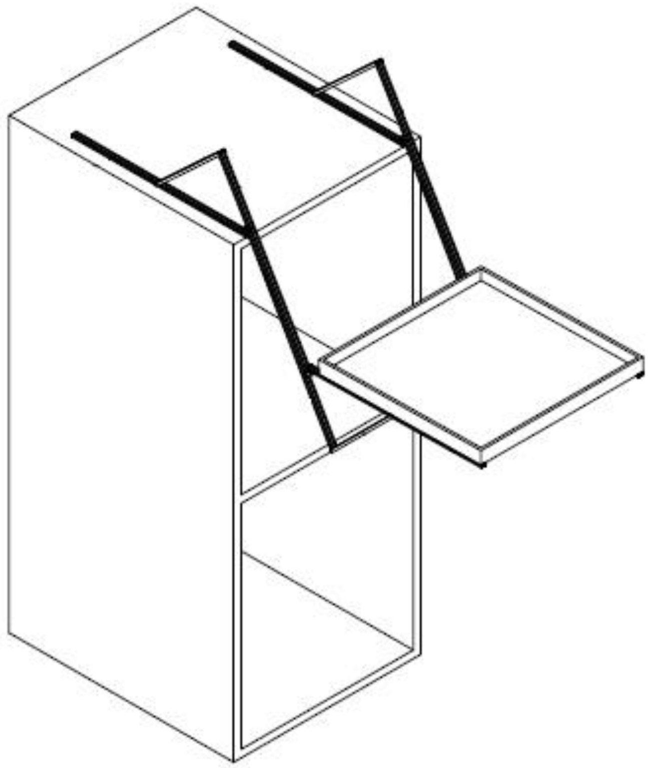
Retractable nightstand engineering design requirements

Requirements	Private market	Healthcare market
Weight	Up to 6 kg	Up to 6 kg
Stiffness	Must be stiff enough to avoid wiggling (sideways movements), vibrations and plastic deformation. This is important both in terms of service life, ease of use and quality feel.	Must be stiff enough to avoid wiggling (sideways movements), vibrations and plastic deformation. This is important both in terms of service life, ease of use and quality feel.
Service lifetime	About 15 years. The same as a bed	About 15 years. The same as a bed
Assisted lifting	Not needed	Not needed
Ease of use	Should be possible to be operated with one hand	Should be possible to be operated with one hand
Load force	A minimum of 200 N	A minimum of 440 N, as it must handle a hectic and rough environment
Ease of installation	Must be easy to install if it is bought separately.	Would be a built-in feature of a mass-produced hospital bed.
Adjustable reach	Reach should be adjusted to the bed	No need for adjustments, as the system is constructed specially for a bed model.
No sharp edges	Yes. The user will be operating the system with bare hands.	Yes. The user will be operating the system with bare hands.
Maintenance free	Yes	Yes
Minimal friction in the system	Yes. Joints, sliding surfaces and rolling surfaces must have minimal friction.	Yes. Joints, sliding surfaces and rolling surfaces must have minimal friction.

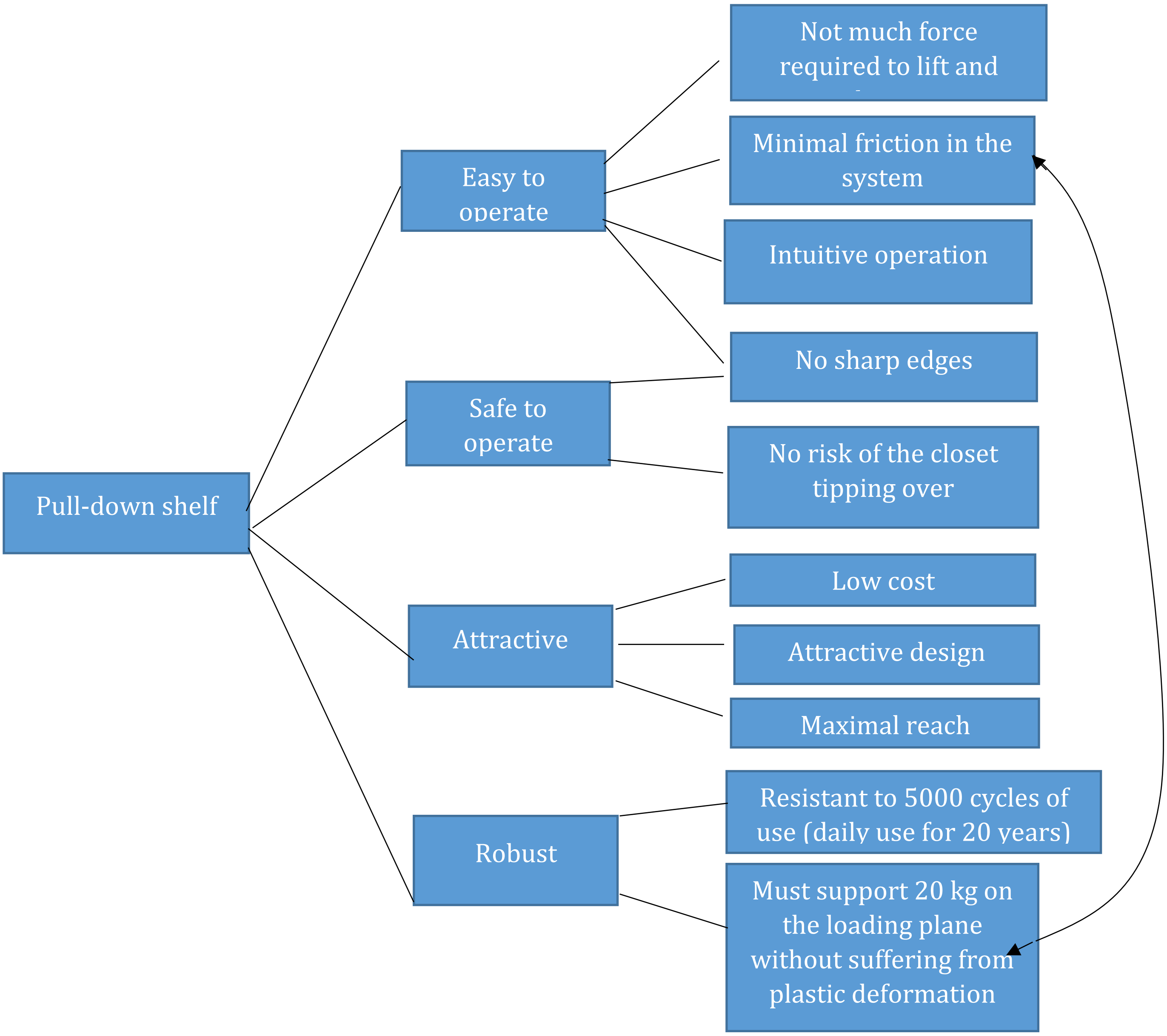
Price	A price survey has not been made, but one may assume that the purchase price should be below NOK 600 for a unit with a tabletop if purchased separately. It may also be fabricated as a part of a mass-produced bed, and assembled externally. In that case, the price can be lowered according to the size of the order. Perhaps NOK 300 per unit	It may be fabricated as a part of a mass-produced hospital or nurse home bed. In that case, the price can be lowered according to the size of the order. Perhaps NOK 300 per unit
Able to compete with existing solutions	There are no nightstand solutions that retract under the bed today.	There are no nightstand solutions that retract under the bed today.
Noise level	Must be silent in use. Maximum acceptable noise is 55 dB, the sound level of two people having a conversation.	Must be silent in use. Maximum acceptable noise is 55 dB, the sound level of two people having a conversation.
Dampening function	No need for a dampening function	No need for a dampening function
Design	Must be appealing to the buyer. Both the lines of the structure, color and surface finish should have both a modern and timeless look. If designed for a specific bed, the design may be changed	Both the lines of the structure, color and surface finish must fit the type of bed.
Universal fit	It must be equipped to fit a wide range of beds. The main requirement is that the bed is elevated from the floor, such that the retractable nightstand fits underneath.	The product must be tailored to a specific bed type, as healthcare beds have different structural functions. This includes changing the positioning of the mattress from flat to sitting, or elevating the head or foot section of the bed.

Appendix B Questionaire for employees at IKEA



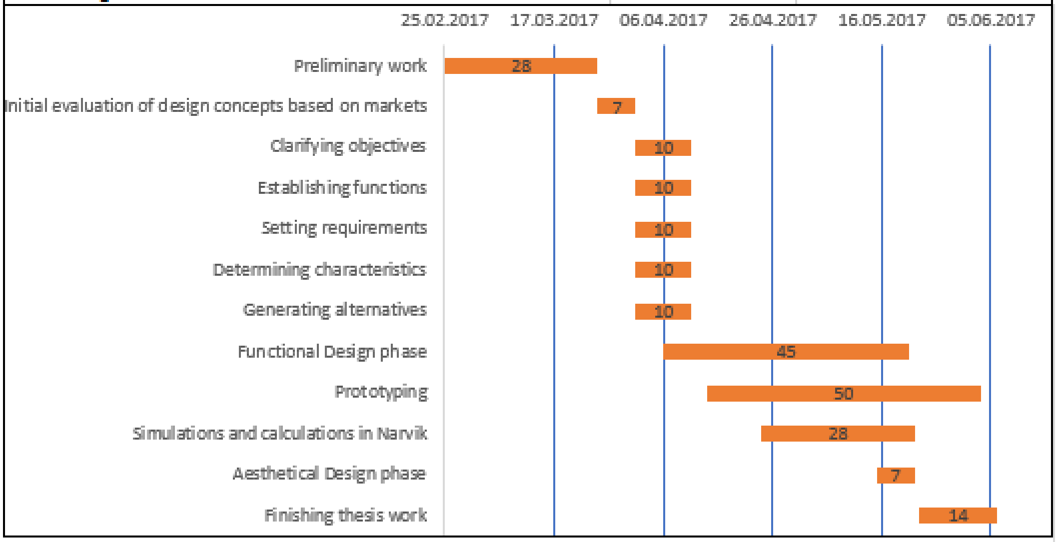


Appendix C Objectives Tree

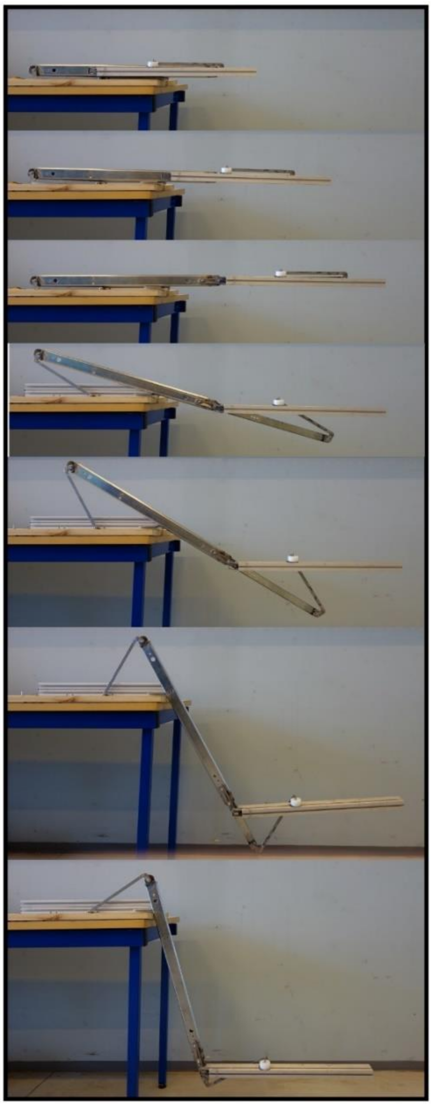


Appendix D Progress plan

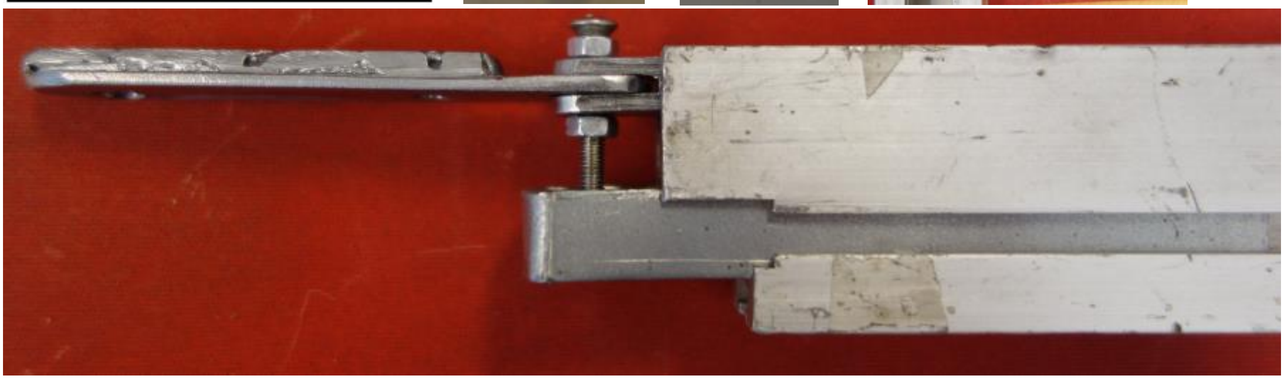
Description	Start Date	Duration (days)
Preliminary work	25.02.2017	28
Initial evaluation of design concepts based on markets	25.03.2017	7
Clarifying objectives	01.04.2017	10
Establishing functions	01.04.2017	10
Setting requirements	01.04.2017	10
Determining characteristics	01.04.2017	10
Generating alternatives	01.04.2017	10
Functional Design phase	06.04.2017	45
Prototyping	14.04.2017	50
Simulations and calculations in Narvik	24.04.2017	28
Aesthetical Design phase	15.05.2017	7
Finishing thesis work	23.05.2017	14



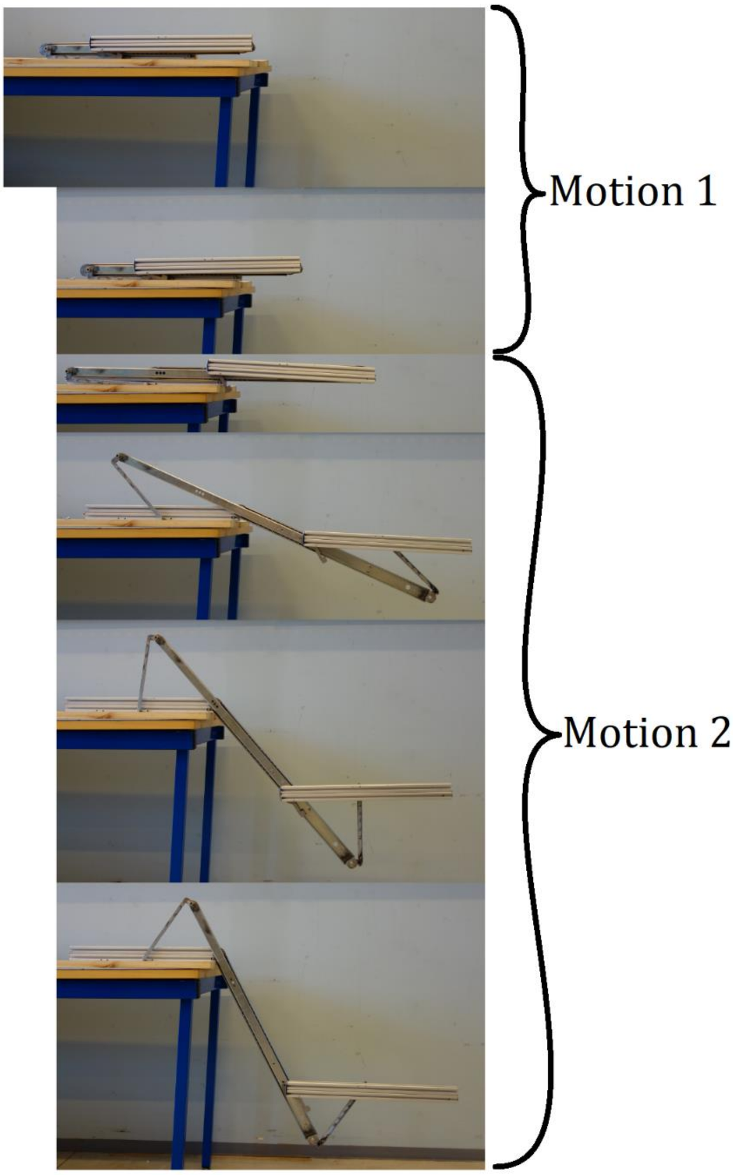
Appendix E Prototype III







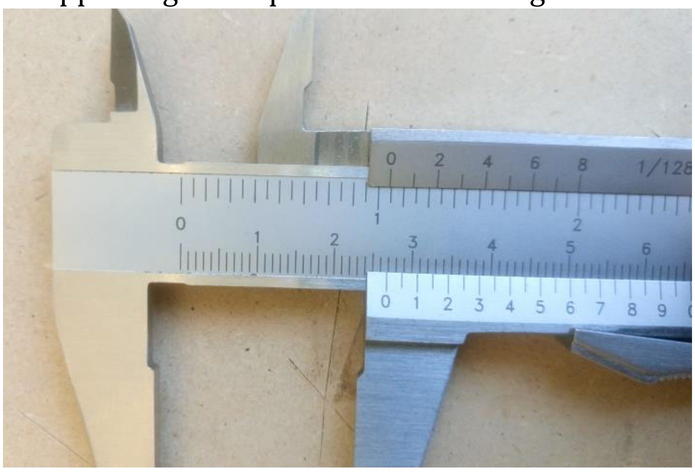
Appendix F Prototype IV



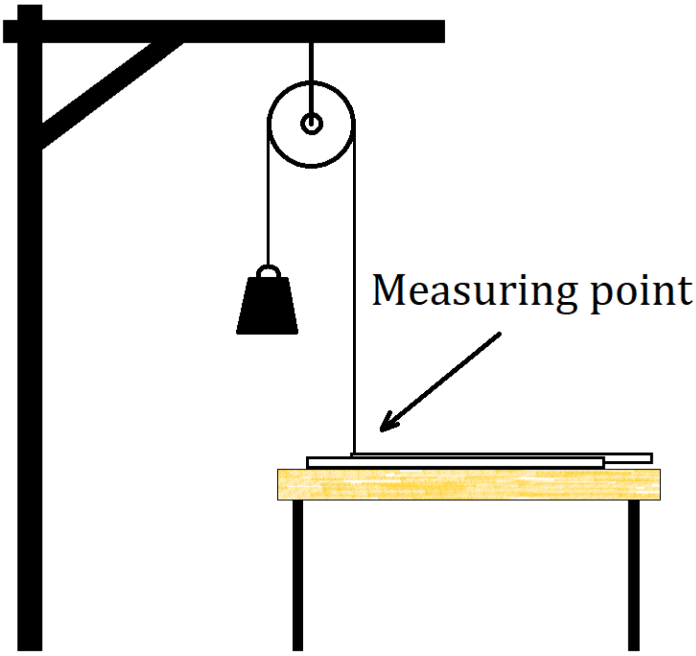
Appendix G Deflection Experiment

1. Using scrap metal and a container, a weight of 3 kg was measured:

2. Initial thickness of the supporting wood plate and the sliding rail was 26,8 mm

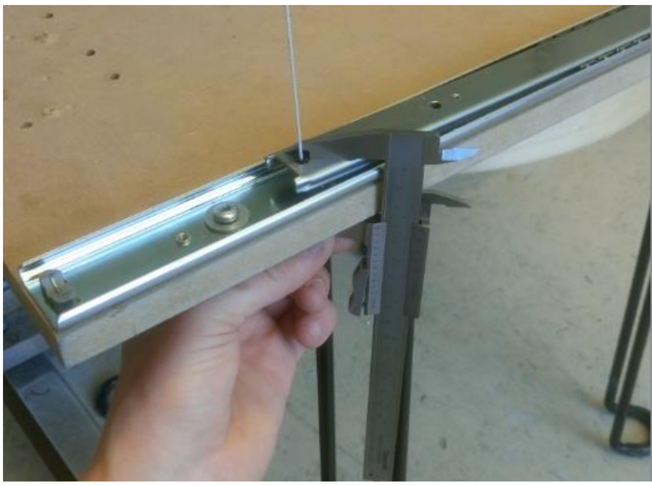



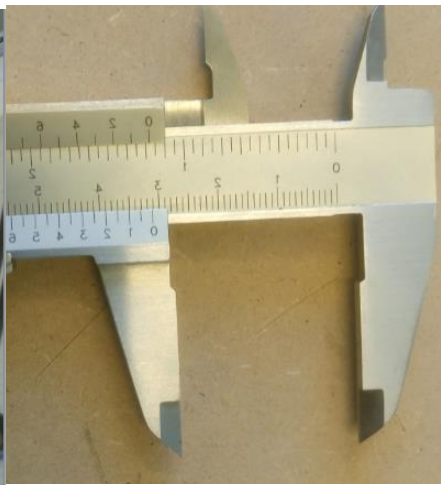
3. A test rig was set up. A string and pulley was used to transfer the force. The sliding rail was fixed to the wood plate with wood screws.



4. When the load was applied, the thickness of the supporting wood plate and the sliding rail was measured again. New thickness was measured to 31,1mm.

$$\textit{Deflection: } 31{,}1\ mm - 26{,}8\ mm = 4{,}3\ mm$$

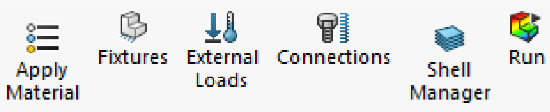




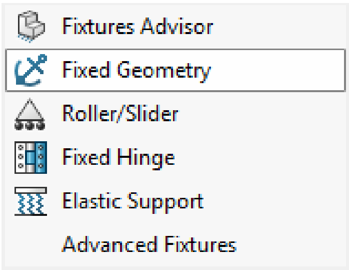
Appendix H Simulation guide

To replicate the executed simulations, the following steps must be performed.

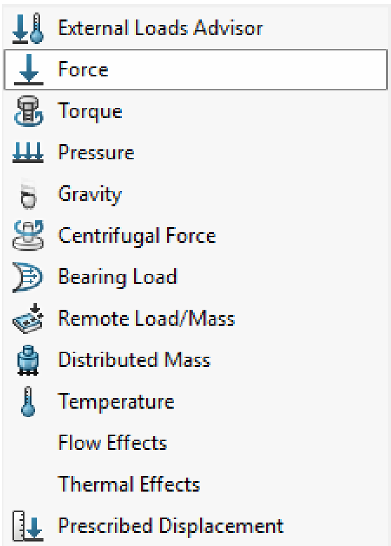
- Open the file [NAVN] in SolidWorks 2016
- Choose *New Study in the* task bar. Select *Static.* The following bar appears.



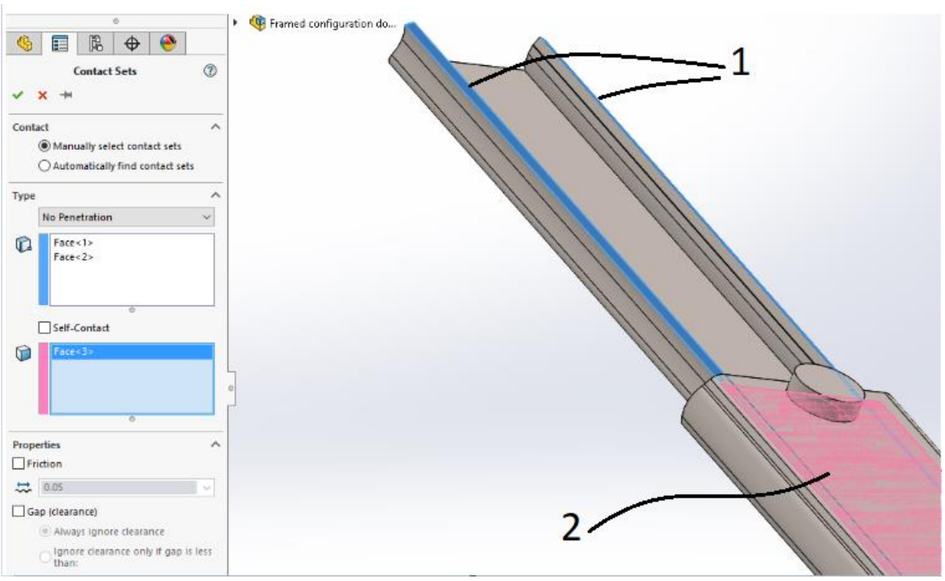
- Follow the steps described below:
  - Apply Material. The material for all simulations is set to be *Steel alloy.*
  - Apply the fixtures, as explained in the simulation reports below. In the simulations, both *Fixed Geometry* and *Fixed Hinge* has been used .



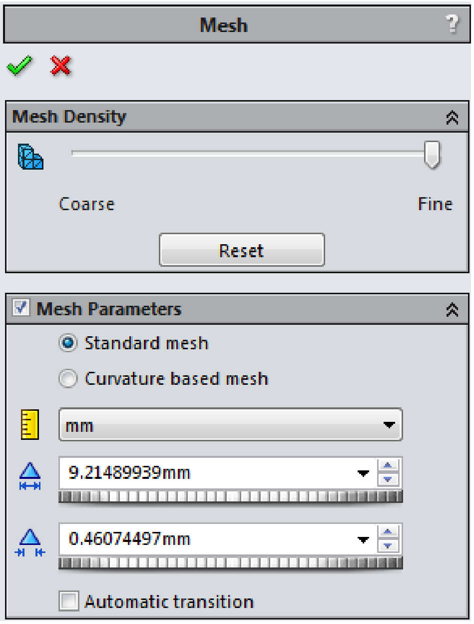
  - Apply the forces, as explained in the simulation reports below. To create a uniform distributed load, select a surface. For a point load, select a point or an edge.



  - Define Contact Sets. In simulation 1,2 and 3, contact sets need to be defined for the simulations to be valid. The reason for this is that the forces act in the z direction in these simulations. The sliding rail is constructed to carry larger forces applied on the in the xy plane. When simulation forces are applied in the z plane, the members of the sliding rail merge into one another. To avoid this in the simulation, contact sets must be defined. As illustrated below, the blue lines marked with number 1 refer to the first contact surface. The pink area is the inner surface of the sliding rail cover, which is the second contact surface. Together these surfaces define a contact set, which allows no penetration. This sequence is also repeated on the sliding rails on simulation 2 and 3. Further descriptions and assumptions are described in the simulation reports below.

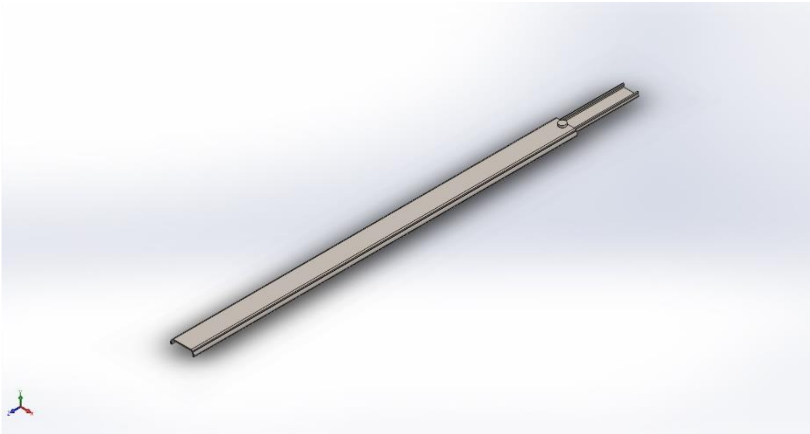


- Mesh the geometry. The SolidWorks FEM Analysis tool does allow specific mesh sizes. One can also choose a pre-defined mesh size interval. All simulations were conducted with the finest pre-defined mesh size interval for maximum accuracy, as illustrated below.



  - Solve the simulation set by pressing the *run* button.
- These steps must be carried out whilst applying the forces, fixtures and contact sets on the locations described in the simulation reports below.

Appendix I Simulation Reports generated by SolidWorks

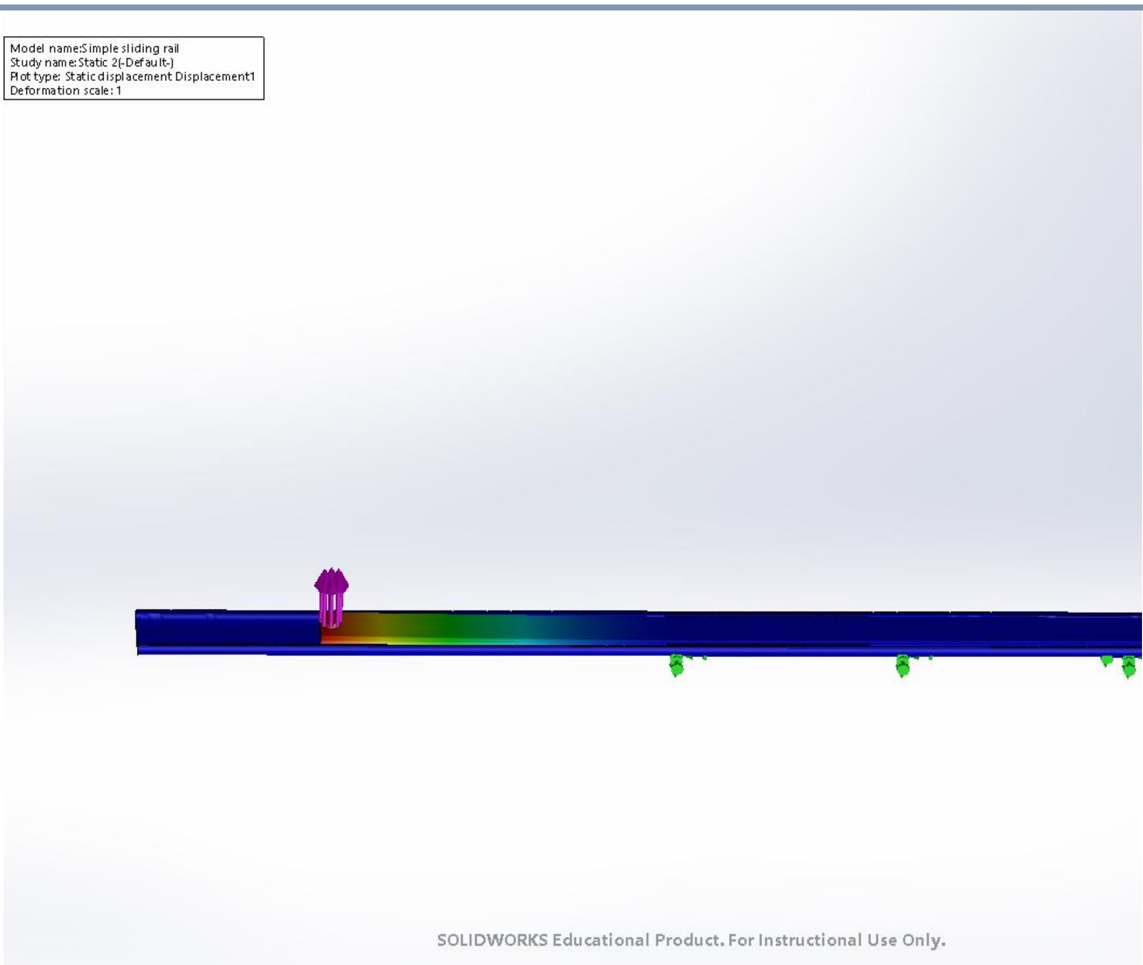


Simulation of Simple sliding rail

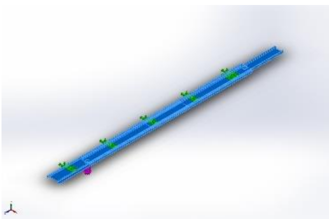
Date: lørdag 3. juni 2017
Designer: Solidworks
Study name: Static 2
Analysis type: Static

Description
The background for the first simulation is to compare the simulated and the real life deflection of the sliding rail under a certain load. A load of 29,42N is applied as a point load to the end of the inner cover of the sliding rail. The ball bearing bracket is situated in the center of the geometry. The sliding rail outer and inner surfaces cannot penetrate each other due to defined contact sets in the simulation. The sliding rail cover is fixed .

Assumptions
Only the top pivoting joint of the sliding rail cover is fixed. The fastening points for braces are assumed to have little or no effect in stiffening the rail when forces are applied in the current direction.



Model name: Simple sliding rail
Current Configuration: Default

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude7 	Solid Body	Mass:0.533886 kg Volume:6.93358e-005 m^3 Density:7700 kg/m^3 Weight:5.23208 N	\\sambaad.stud.ntnu o\olavgje\.profil\stu datasal\Desktop\Soli works simulering\Simple sliding rail .SLDPRT Jun 03 12:48:52 2017

Study Properties

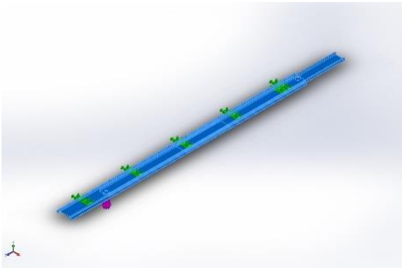
Study name	Static 2
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On

Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\sambaad.stud.ntnu.no\olavgje\.profil\stud\datasal\Desktop\Solidworks simulering)

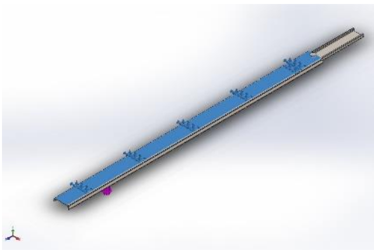
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

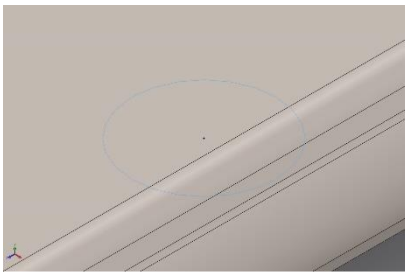
Model Reference	Properties	Components
	Name: **Alloy Steel** Model type: **Linear Elastic Isotropic** Default failure criterion: **Max von Mises Stress** Yield strength: **6.20422e+008 N/m^2** Tensile strength: **7.23826e+008 N/m^2** Elastic modulus: **2.1e+011 N/m^2** Poisson's ratio: **0.28** Mass density: **7700 kg/m^3** Shear modulus: **7.9e+010 N/m^2** Thermal expansion coefficient: **1.3e-005 /Kelvin**	**SolidBody 1(Boss-Extrude7)(Simple sliding rail)**
Curve Data:N/A		

Loads and Fixtures

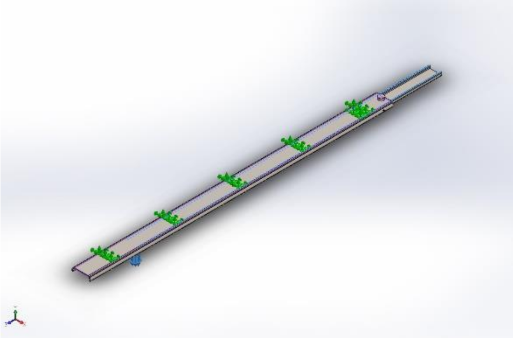
Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** **1 face(s)** **Type:** **Fixed Geometry**

Resultant Forces

Components	**X**	**Y**	**Z**	**Resultant**
Reaction force(N)	**3.67234e-006**	**29.42**	**-5.91582e-007**	**29.42**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details
Force-1		**Entities:** **1 face(s)** **Type:** **Apply normal force** **Value:** **-29.42 N**

Contact Information

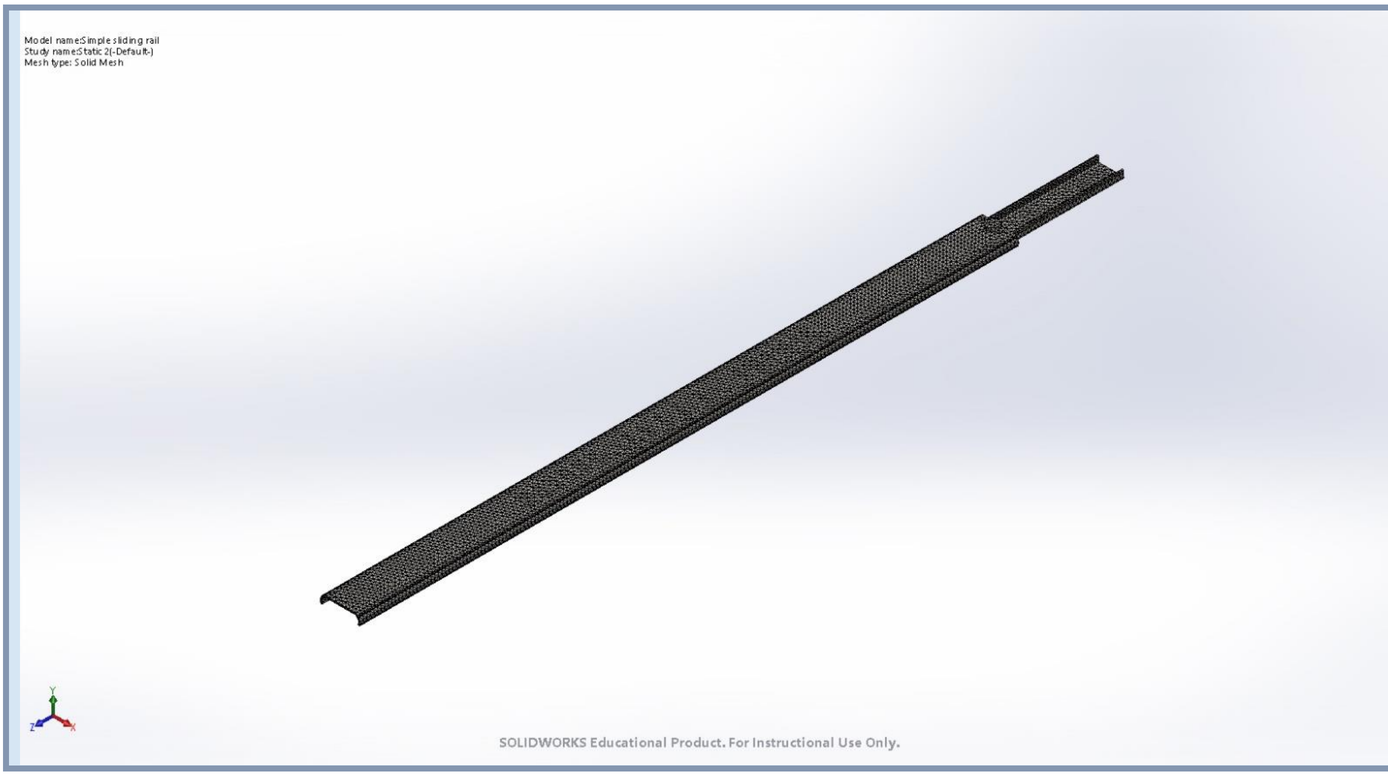
Contact	Contact Image	Contact Properties
Contact Set-1		**Type:** No Penetration contact pair **Entites:** 2 edge(s), 1 face(s) **Advanced:** Node to surface

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	3.05878 mm
Tolerance	0.152939 mm
Mesh Quality Plot	High

Mesh information - Details

Total Nodes	84944
Total Elements	42780
Maximum Aspect Ratio	13.071
% of elements with Aspect Ratio < 3	76
% of elements with Aspect Ratio > 10	0.0234
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:13
Computer name:	NTNU03827



Resultant Forces

Reaction forces

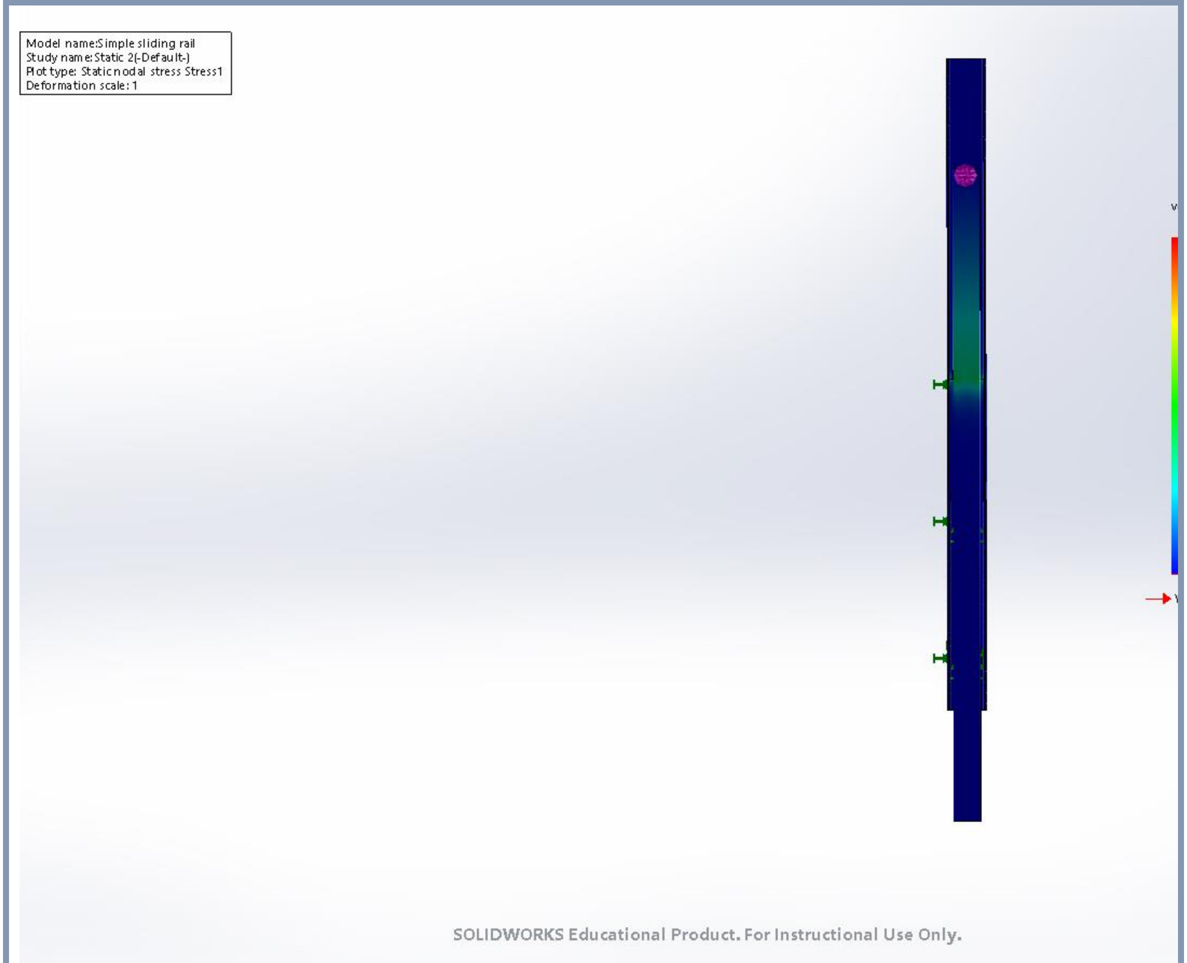
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	3.67234e-006	29.42	-5.91582e-007	29.42

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

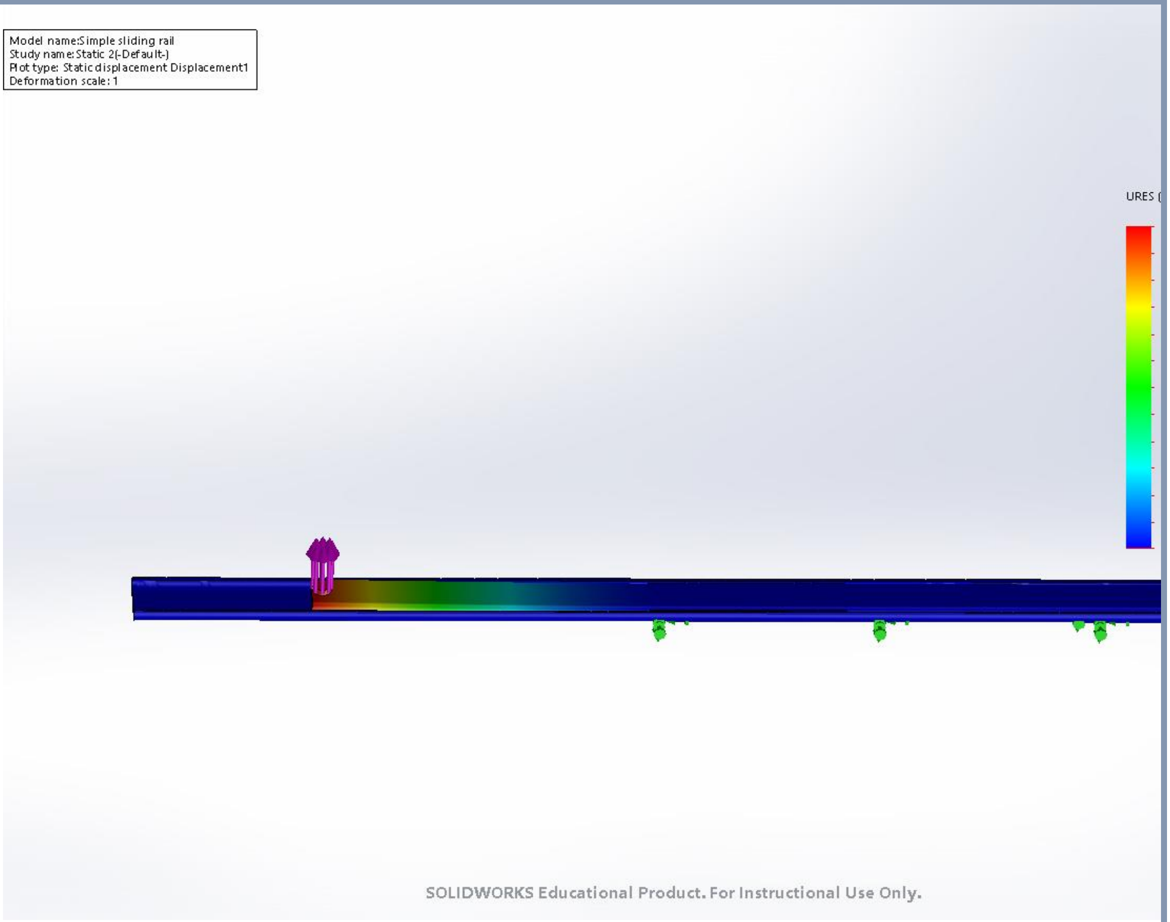
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.272e-008N/m^2 Node: 14444	1.740e+008N/m^2 Node: 21568



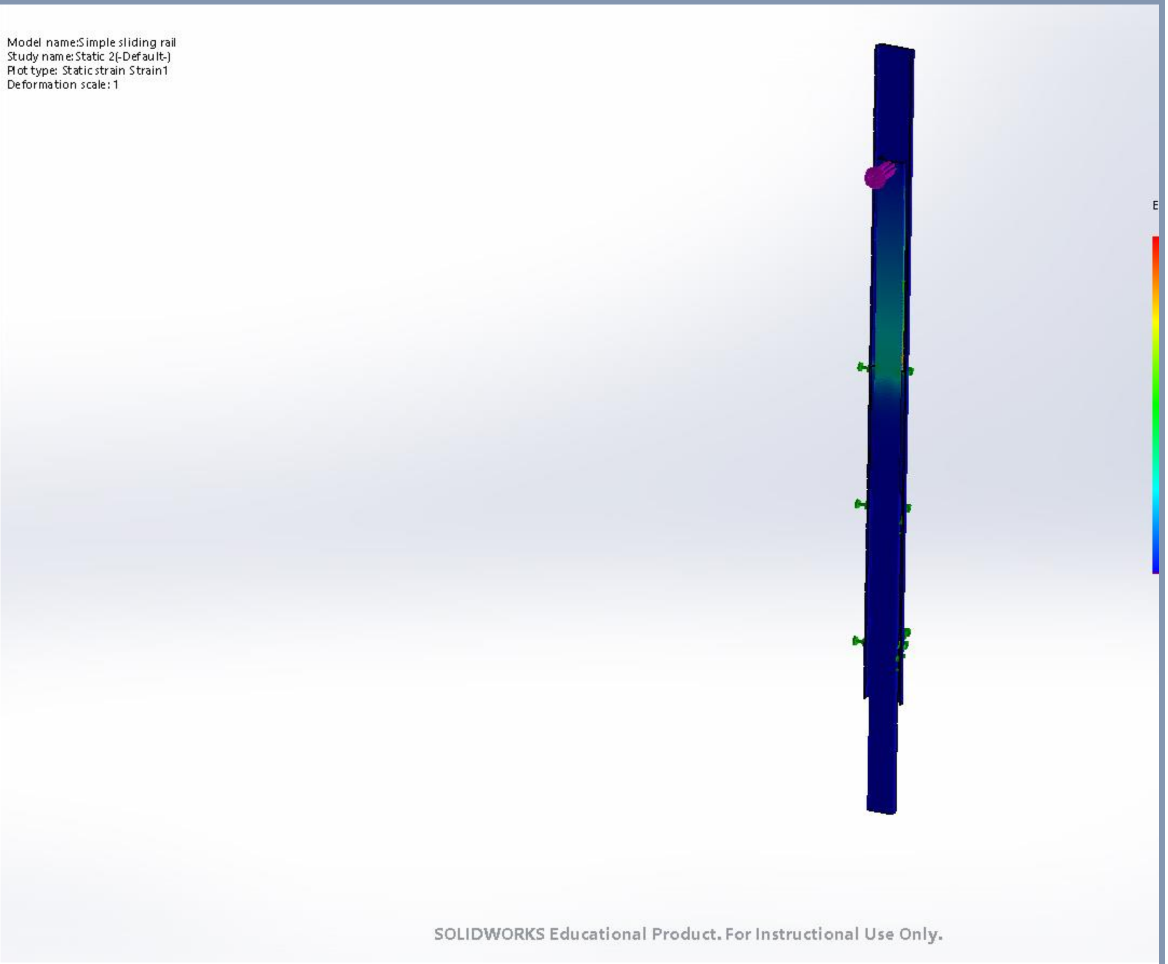
Simple sliding rail -Static 2-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+000mm Node: 31	2.127e+000mm Node: 19093

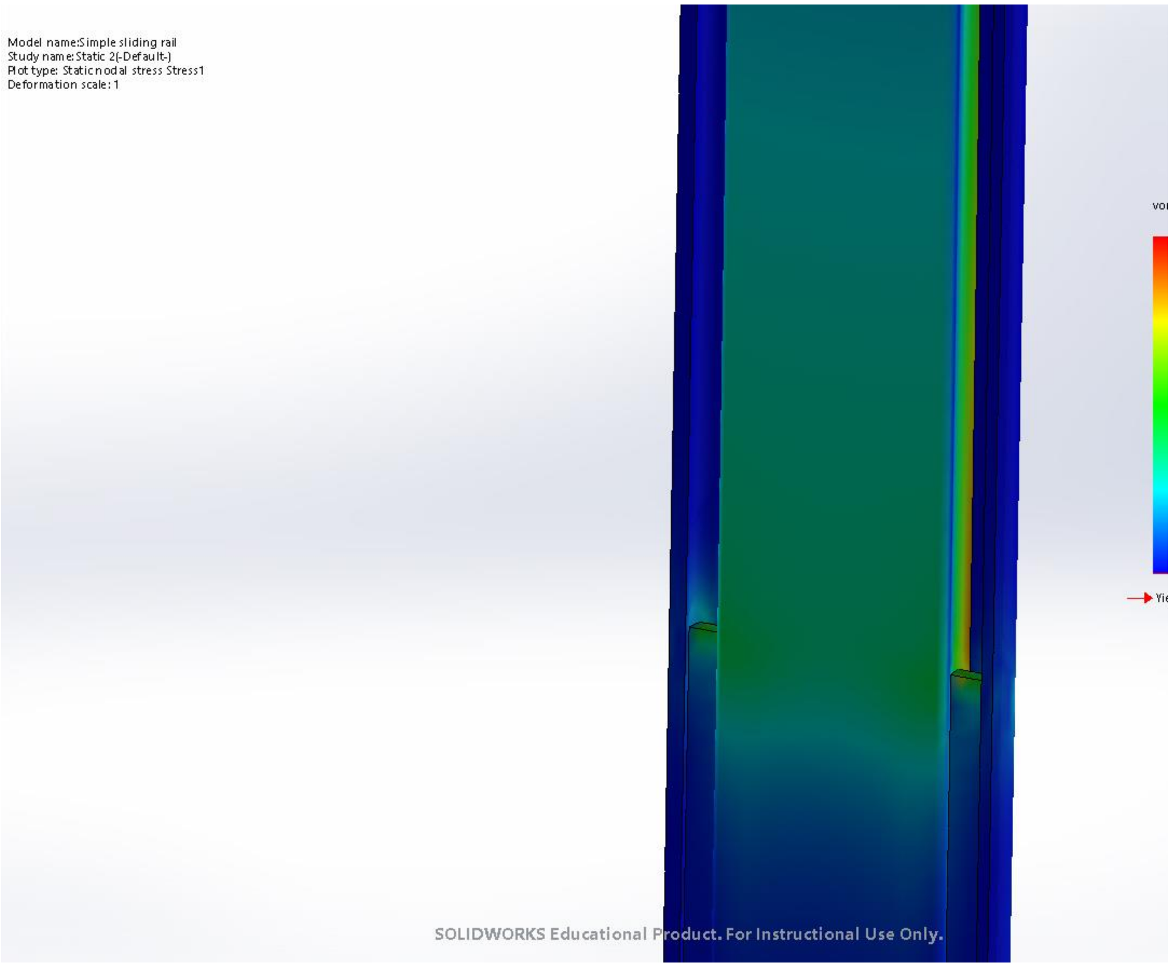


Simple sliding rail -Static 2-Displacement-Displacement1

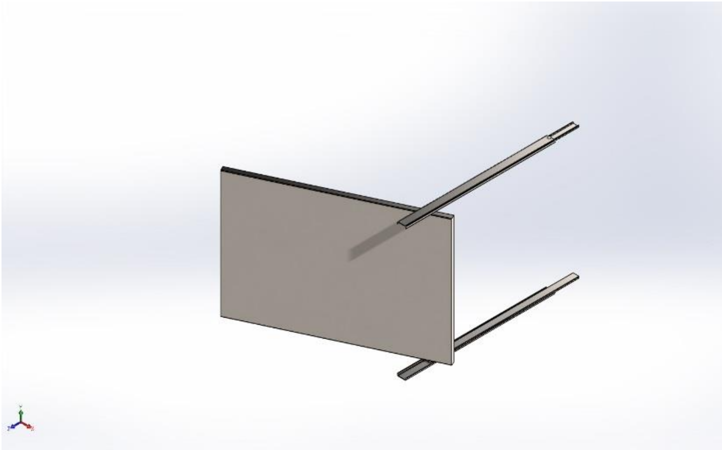
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	2.352e-020 Element: 11350	6.403e-004 Element: 37681



Simple sliding rail -Static 2-Strain-Strain1



Detailed image of stress. The most stress occur in the central area between the sliding rail covers.



Sideways force of 10 N. Evenly distributed. Framed construction.

Date: 14. mai 2017
Designer: Solidworks

Study name: Static 2

Analysis type: Static

Description

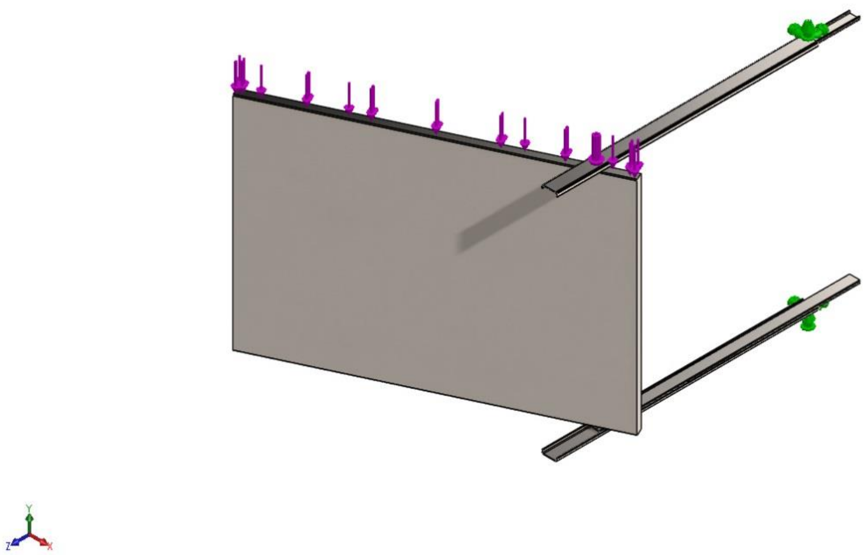
The background for this simulation is the design requirement of a maximum deflection of 40mm when a force of 10N is applied in the z direction. This configuration simulates the user being reckless and inflicting a moderate sideways force to the system. Another reason for sideways force is that the user unintentionally bumps into the system.

To minimize complexity, the brackets have been eliminated, and the geometry is fixed at the top pivot points. (green arrows) A horizontal load of 10N is applied as a uniform load to the right hand face of the loading plane

Assumptions

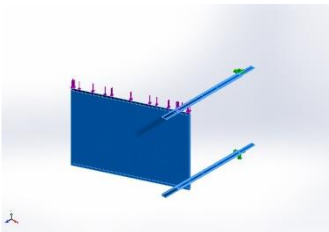
The loading plane on the bottom is fastened directly to the pivoting bolts. All joints that normally pivot are made rigid, as the forces applied appear in the plane that is perpendicular to the pivoting plane. The loading plane can be considered infinitively stiff compared to the stiffness of the sliding rails. The material of the entire model is set to steel alloy. All braces are excluded from the model because these are assumed to have a negligible stiffening function when forces are applied in the current direction.

Model Information



Model name: Framed construction

Current Configuration: Default

Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Fillet1 	**Solid Body**	**Mass:48.0231 kg** **Volume:0.00623677 m^3** **Density:7700 kg/m^3** **Weight:470.627 N**	**\\homer.uit.no\eho062 esktop\MASTER\CAD\S dworks simulering\Framed construction.SLDPRT** **May 14 11:59:01 2017**

Study Properties

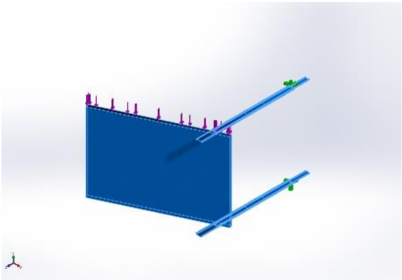
Study name	Static 2
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\homer.uit.no\eho062\Desktop\MASTER\CAD\Solidworks simulering)

Units

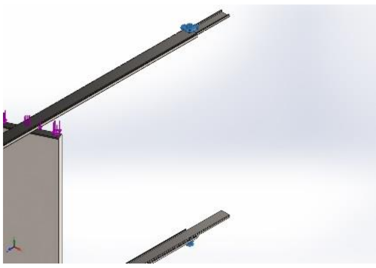
Unit system:	SI (MKS)

Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

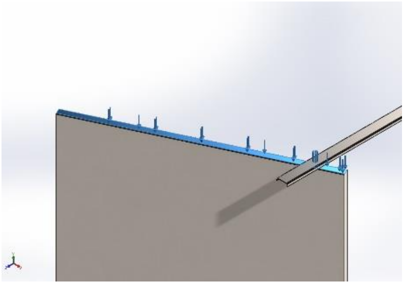
Model Reference	Properties		Components
	**Name:**	**Alloy Steel**	**SolidBody 1**
	Model type:	**Linear Elastic Isotropic**	
	Default failure criterion:	**Max von Mises Stress**	
	Yield strength:	**6.20422e+008 N/m^2**	
	Tensile strength:	**7.23826e+008 N/m^2**	
	Elastic modulus:	**2.1e+011 N/m^2**	
	Poisson's ratio:	**0.28**	
	Mass density:	**7700 kg/m^3**	
	Shear modulus:	**7.9e+010 N/m^2**	
	Thermal expansion coefficient:	**1.3e-005 /Kelvin**	
Curve Data:N/A			

Loads and Fixtures

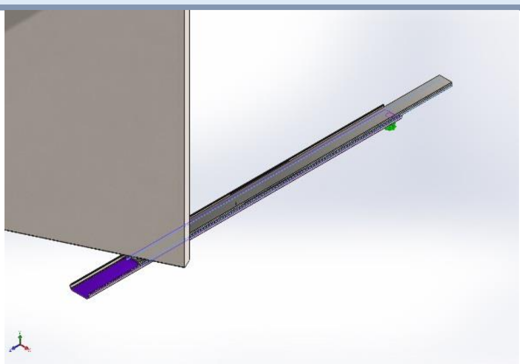
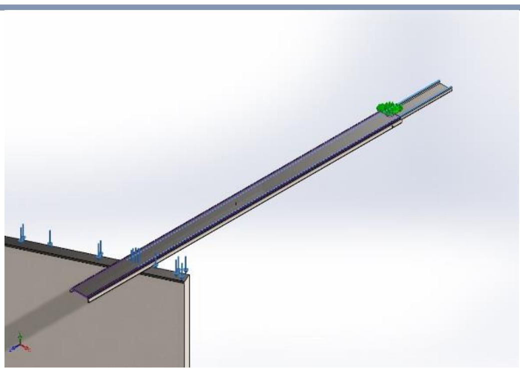
Fixture name	Fixture Image	Fixture Details	
Fixed-3		**Entities:**	**2 face(s)**
		Type:	**Fixed Geometry**

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-1.90735e-006	9.99897	-3.57628e-006	9.99897
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 10 N

Contact Information

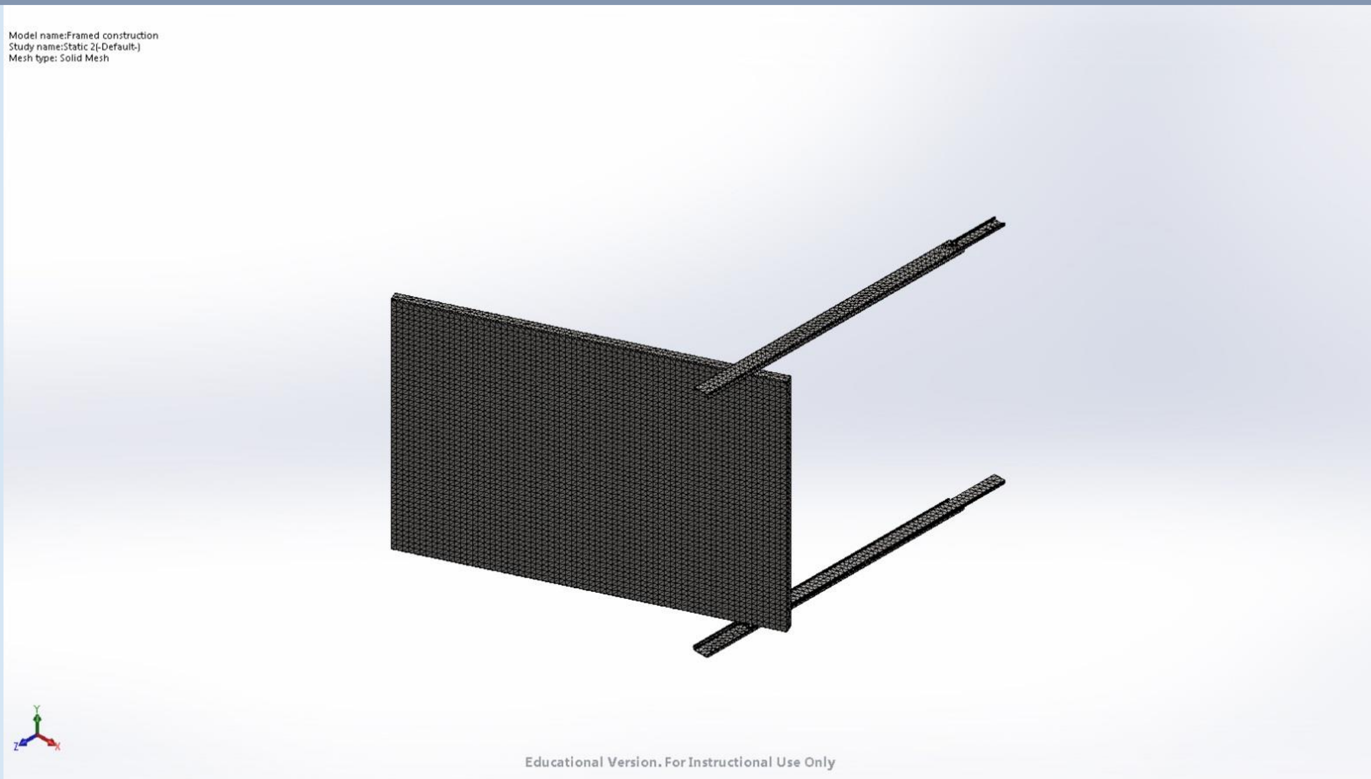
Contact	Contact Image	Contact Properties
Contact Set-1		**Type:** No Penetration contact pair **Entites:** 2 edge(s), 1 face(s) **Advanced:** Node to surface
Contact Set-2		**Type:** No Penetration contact pair **Entites:** 2 edge(s), 1 face(s) **Advanced:** Node to surface

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	0 mm
Minimum element size	0 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	123247
Total Elements	72741
Maximum Aspect Ratio	102.03
% of elements with Aspect Ratio < 3	77
% of elements with Aspect Ratio > 10	2.94
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:19
Computer name:	NAR-E1570-07



Resultant Forces

Reaction forces

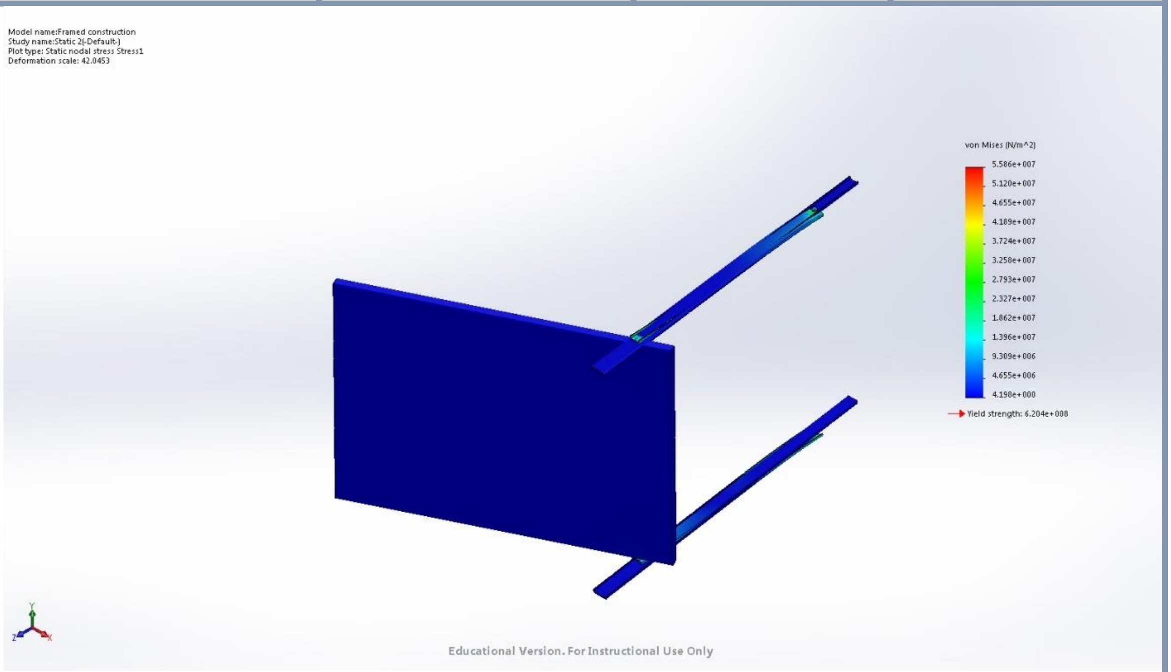
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-1.90735e-006	9.99897	-3.57628e-006	9.99897

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

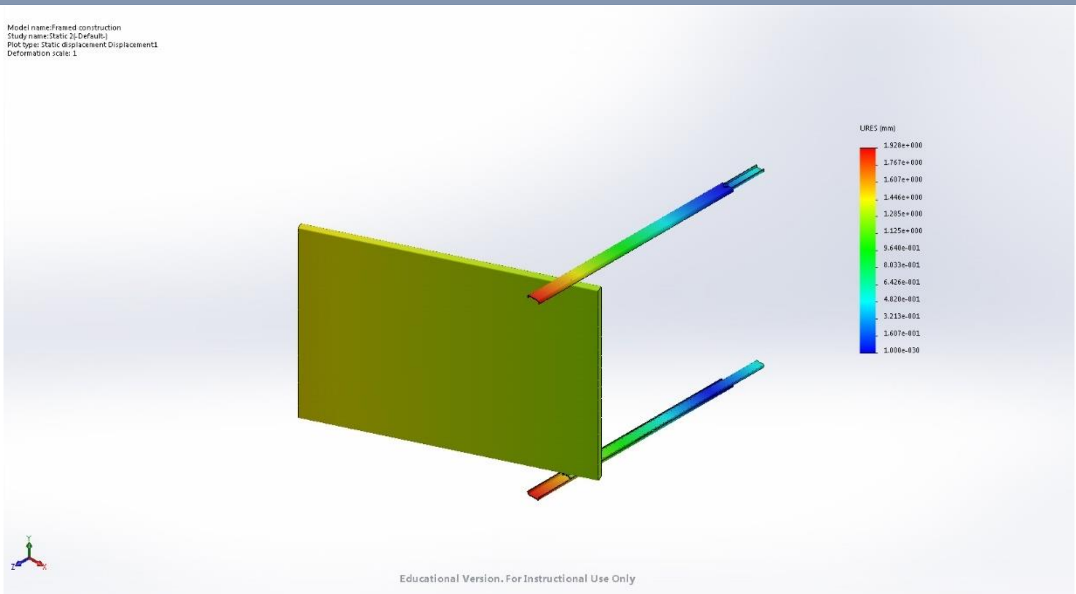
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	4.19825 N/m^2 Node: 108294	5.5856e+007 N/m^2 Node: 115317



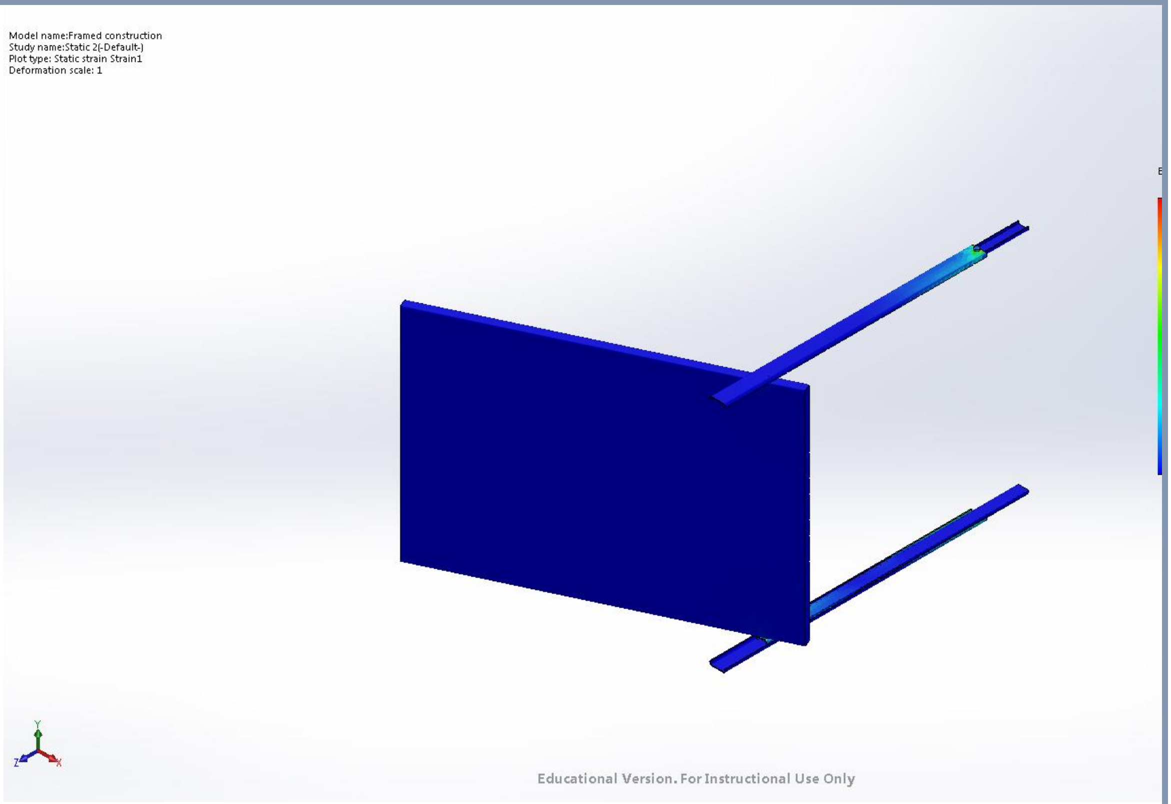
Framed construction-Static 2-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1	1.92794 mm Node: 11361



Framed construction-Static 2-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.00964e-011 Element: 44419	0.000167036 Element: 28639



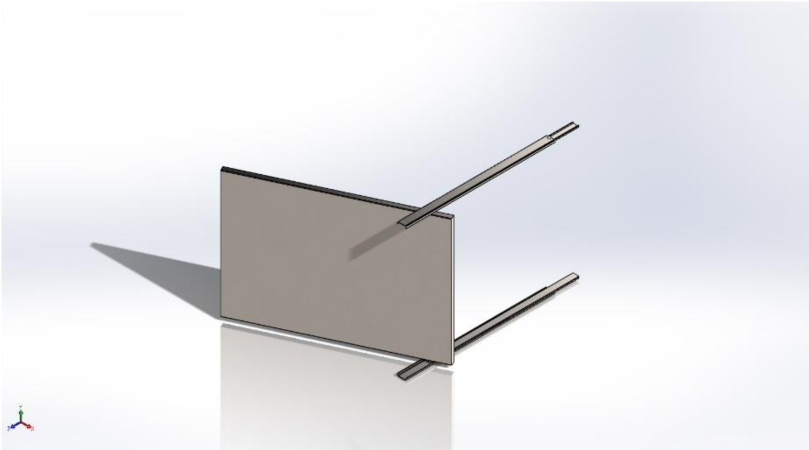
Framed construction-Static 2-Strain-Strain1

Sideways force of 10 N Point Load. Framed construction.

Date: 13. mai 2017
Designer: Solidworks

Study name: 10N Point Load

Analysis type: Static



Description

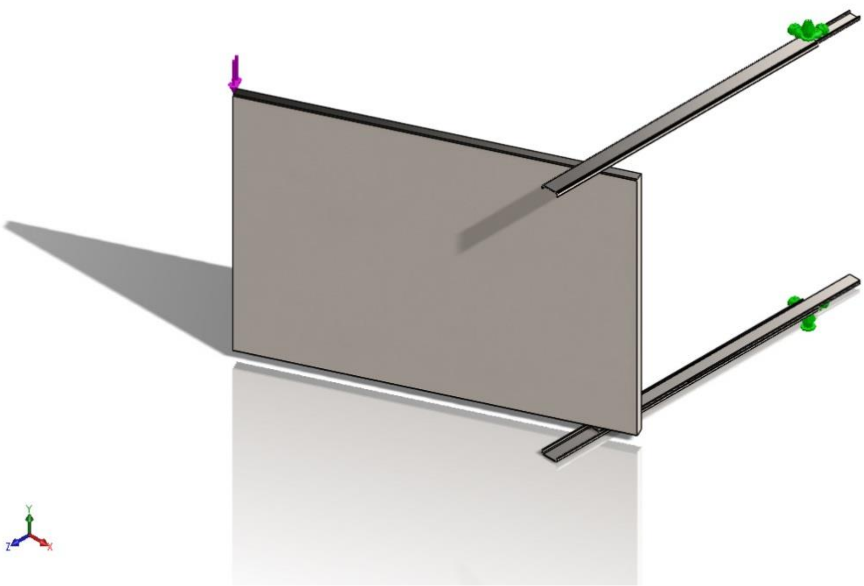
The background for this simulation is the design requirement of a maximum deflection of 40mm when a force of 10N is applied in the z direction. This configuration simulates the user being reckless and inflicting a moderate sideways force to the outermost part of the loading plane. Another reason for sideways force is that the user unintentionally bumps into the loading plane.

To minimize complexity, the brackets have been eliminated, and the geometry is fixed at the top pivot points. (green arrows) A horizontal load of 10N is applied as a uniform load to the right hand face of the loading plane

Assumptions

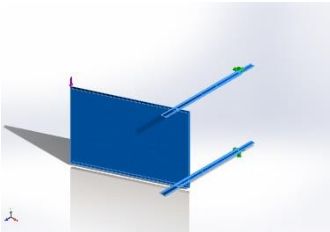
The loading plane on the bottom is fastened directly to the pivoting bolts. All joints that normally pivot are made rigid, as the forces applied appear in the plane that is perpendicular to the pivoting plane. The loading plane can be considered infinitively stiff compared to the stiffness of the sliding rails. The material of the entire model is set to steel alloy. All braces are excluded from the model because these are assumed to have a negligible stiffening function when forces are applied in the current direction.

Model Information



Model name: **Framed configuration, Force applied at the tip of loading plane**

Current Configuration: Default

Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Fillet1 	**Solid Body**	**Mass:48.0231 kg** **Volume:0.00623677 m^3** **Density:7700 kg/m^3** **Weight:470.627 N**	**\\homer.uit.no\eho06 esktop\MASTER\CAD\ dworks simulering\Simulering rammekonfigurasjon Belasning ytterst.SLDP** **May 13 13:46:23 2017**

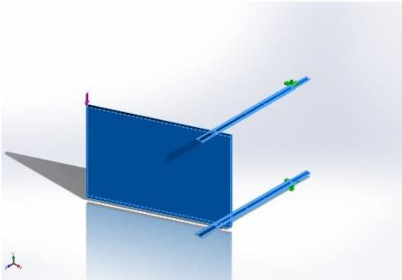
Study Properties

Study name	Static 2
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\homer.uit.no\eho062\Desktop\MASTER\CAD)

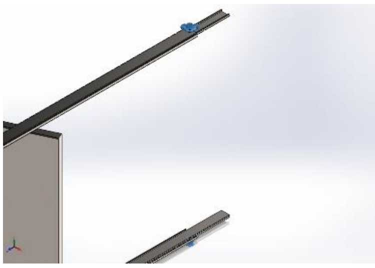
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

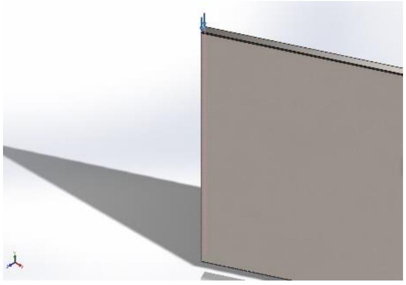
Model Reference	Properties		Components
	Name:	Alloy Steel	SolidBody 1(Fillet1)(Simulering rammekonfigurasjon)
	Model type:	Linear Elastic Isotropic	
	Default failure criterion:	Max von Mises Stress	
	Yield strength:	6.20422e+008 N/m^2	
	Tensile strength:	7.23826e+008 N/m^2	
	Elastic modulus:	2.1e+011 N/m^2	
	Poisson's ratio:	0.28	
	Mass density:	7700 kg/m^3	
	Shear modulus:	7.9e+010 N/m^2	
	Thermal expansion coefficient:	1.3e-005 /Kelvin	
Curve Data:N/A			

Loads and Fixtures

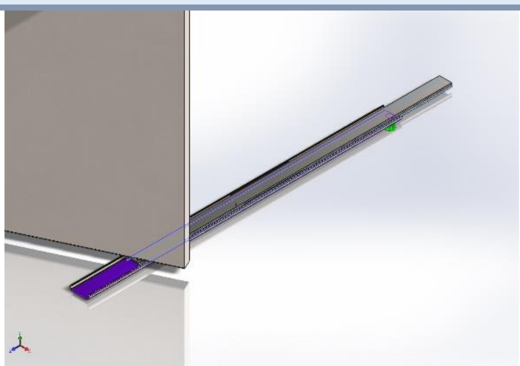
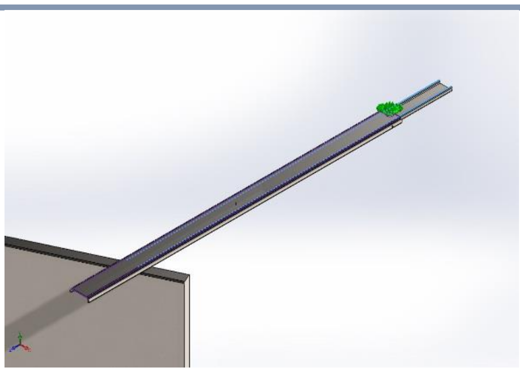
Fixture name	Fixture Image	Fixture Details	
Fixed-3		Entities:	2 face(s)
		Type:	Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-3.24249e-005	10	-1.38283e-005	10
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details	
Force-1		**Entities:**	**1 edge(s)**
		Reference:	**Edge< 1 >**
		Type:	**Apply force**
		Values:	**---, ---, -10 N**

Contact Information

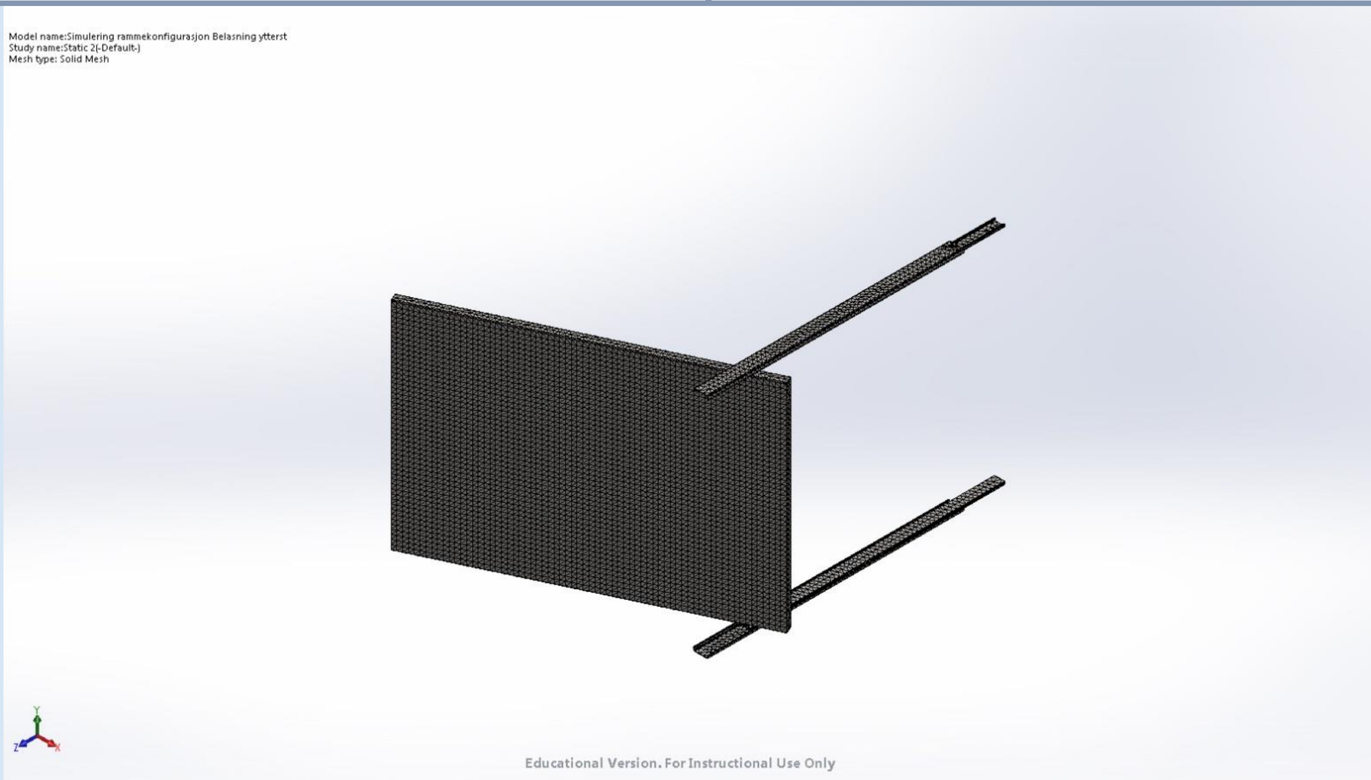
Contact	Contact Image	Contact Properties	
Contact Set-1		**Type:**	**No Penetration contact pair**
		Entites:	**2 edge(s), 1 face(s)**
		Advanced:	**Node to surface**
Contact Set-2		**Type:**	**No Penetration contact pair**
		Entites:	**2 edge(s), 1 face(s)**
		Advanced:	**Node to surface**

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	0 mm
Minimum element size	0 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	123247
Total Elements	72741
Maximum Aspect Ratio	102.03
% of elements with Aspect Ratio < 3	77
% of elements with Aspect Ratio > 10	2.94
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:19
Computer name:	NAR-E1570-07



Resultant Forces

Reaction forces

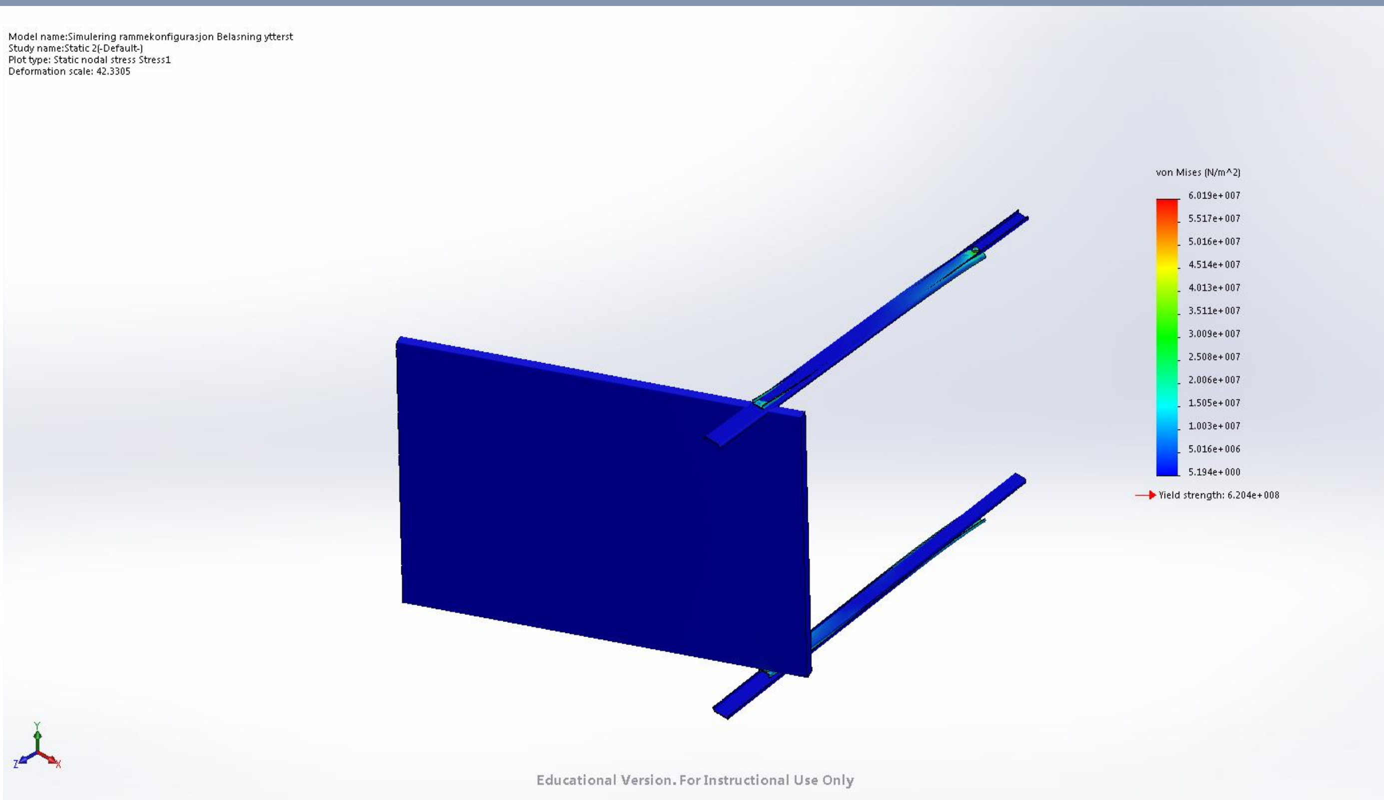
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-3.24249e-005	10	-1.38283e-005	10

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

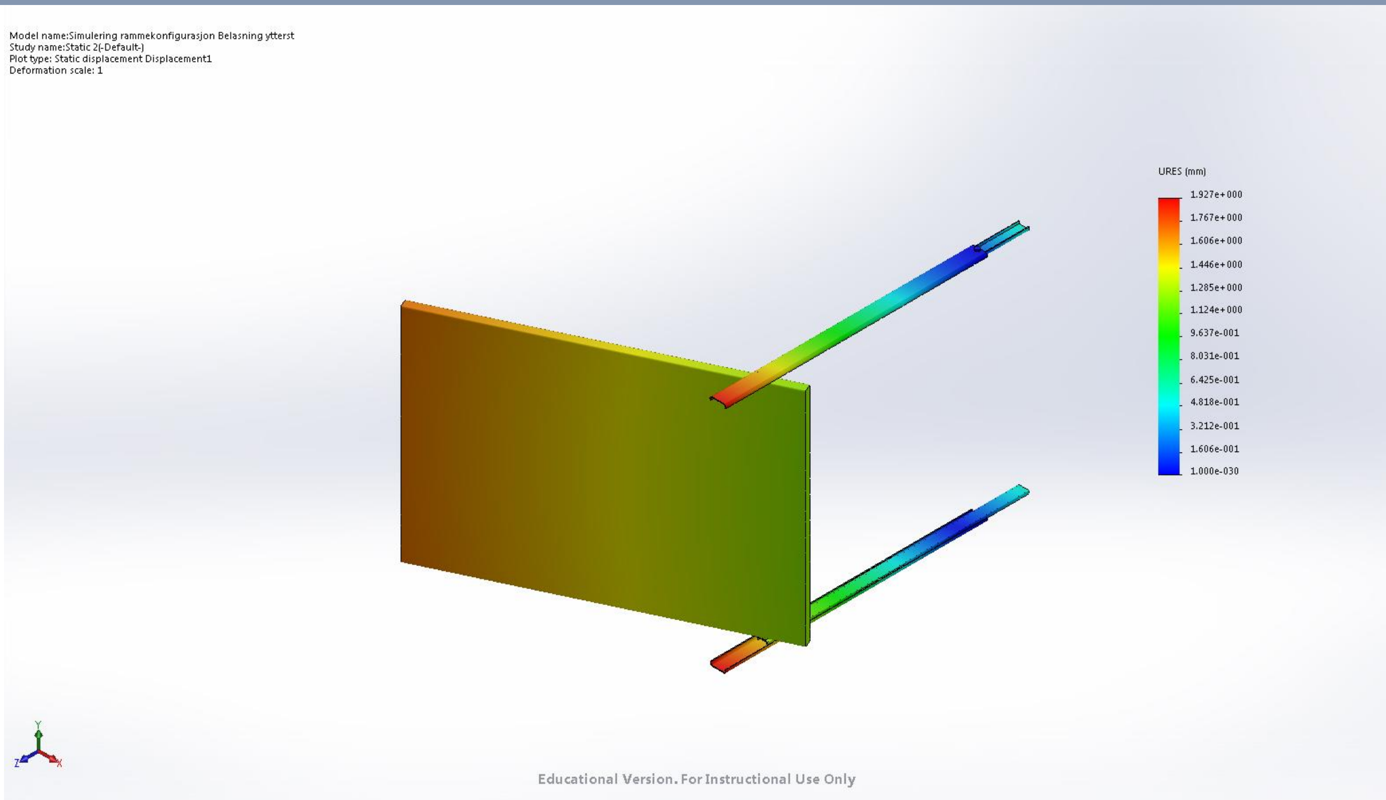
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	5.19443 N/m^2 Node: 47096	6.01894e+007 N/m^2 Node: 123210



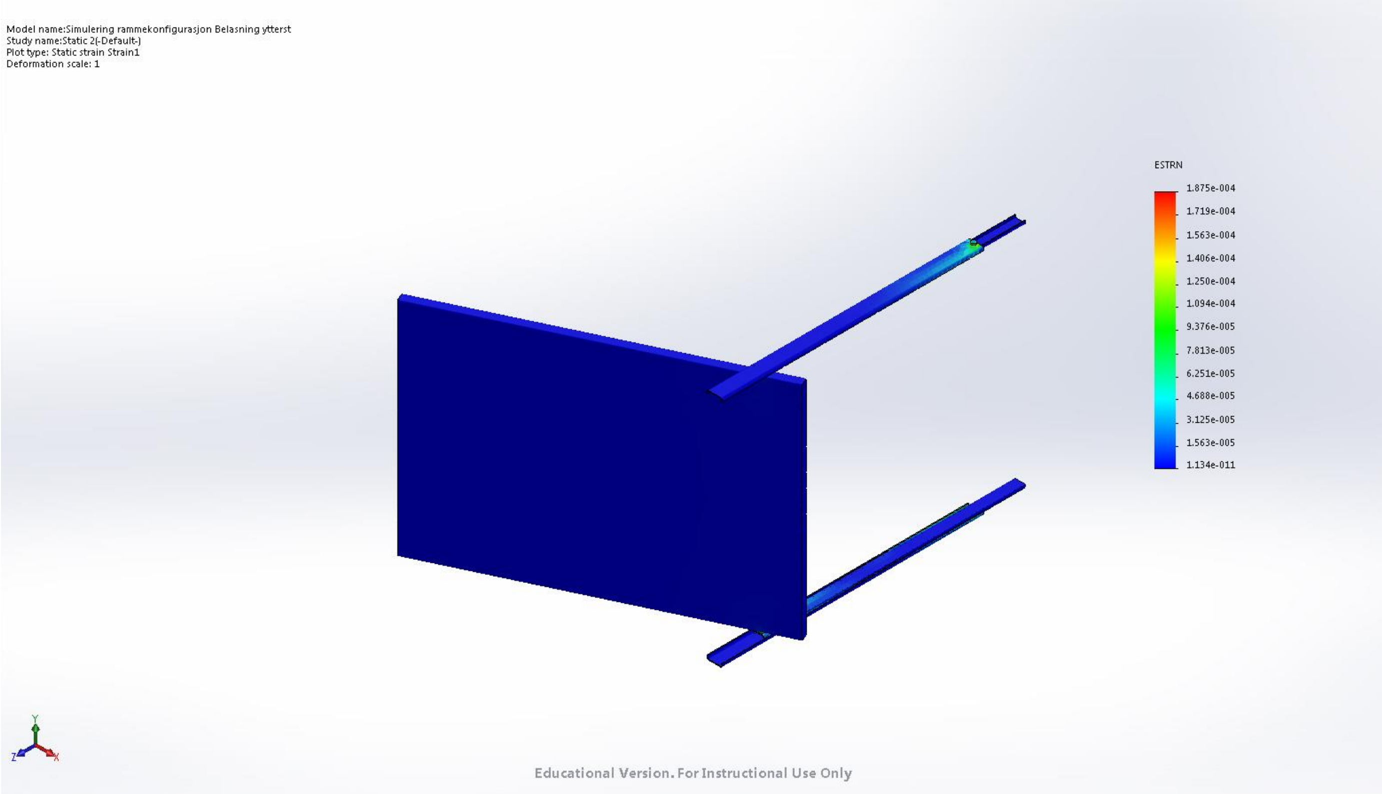
Simulering rammekonfigurasjon Belasning ytterst-Static 2-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1	1.92737 mm Node: 11361



Simulering rammekonfigurasjon Belasning ytterst-Static 2-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.13403e-011 Element: 39887	0.000187515 Element: 32954



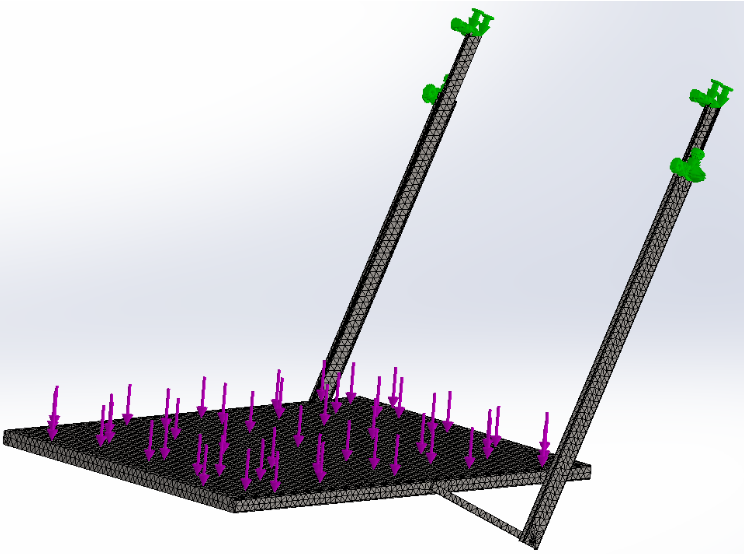
Simulering rammekonfigurasjon Belasning ytterst-Static 2-Strain-Strain1

Simulation of Framed configuration 200 N downward force

Date: 14. mai 2017
Designer: Solidworks

Study name: Downward force 1

Analysis type: Static



Description

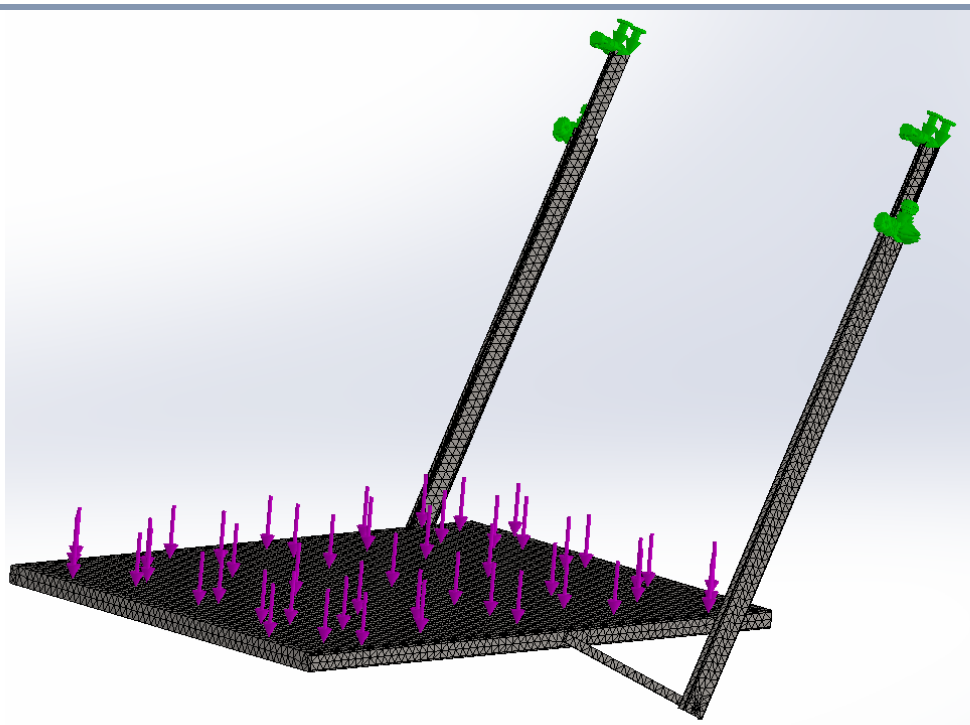
The background for this simulation is the design requirement of load support. The system must handle 200N distributed on the loading plane. The load on a shelf is rarely this heavy. However, a certain safety factor must be made in order to ensure that unforeseen loads do not compromise the system.

To minimize complexity, the top brackets have been eliminated, and the geometry is hinged at the top pivot points. The point where the sliding rail is normally connected to the top braces has been replaced with a *fixed geometry* fixture.

Assumptions

The loading plane on the bottom is fastened directly to the pivoting bolts. All joints that normally pivot are made rigid, exept for the hinged fixture in point 9 (Figure 3 in the report). The loading plane can be considered infinitively stiff compared to the stiffness of the sliding rails. The material of the entire model is set to steel alloy.

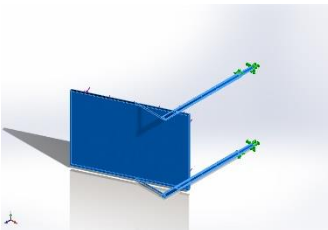
Model Information



Model name: Framed configuration downward force

Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude13 	**Solid Body**	**Mass:48.1183 kg** **Volume:0.00624913 m^3** **Density:7700 kg/m^3** **Weight:471.559 N**	**\\homer.uit.no\eho062 esktop\MASTER\CAD\S dworks simulering\Framed configuration downwar force.SLDPRT** **May 14 17:46:35 2017**

Study Properties

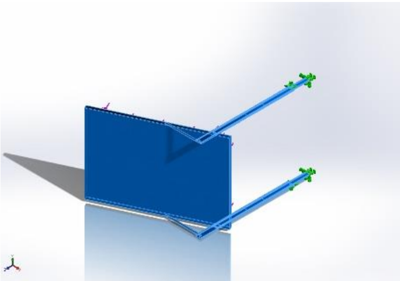
Study name	Downward force 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On

Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	FFEPlus
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (\\homer.uit.no\eho062\Desktop\MASTER\CAD\Solidworks simulering)

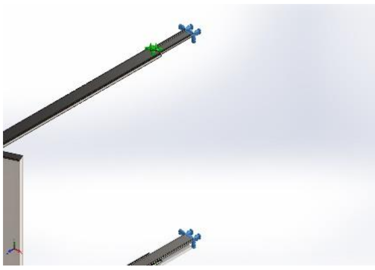
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

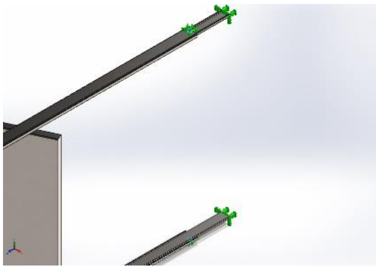
Model Reference	Properties		Components
	**Name:** **Model type:** **Default failure criterion:** **Yield strength:** **Tensile strength:** **Elastic modulus:** **Poisson's ratio:** **Mass density:** **Shear modulus:** **Thermal expansion coefficient:**	**Alloy Steel** **Linear Elastic Isotropic** **Max von Mises Stress** **6.20422e+008 N/m^2** **7.23826e+008 N/m^2** **2.1e+011 N/m^2** **0.28** **7700 kg/m^3** **7.9e+010 N/m^2** **1.3e-005 /Kelvin**	**SolidBody 1(Boss-Extrude13)(Framed configuration downward force)**
Curve Data:N/A			

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details	
Fixed-1		**Entities:** **Type:**	**2 face(s)** **Fixed Geometry**

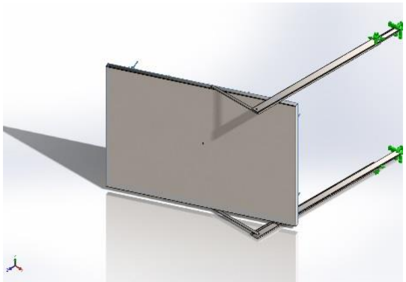
Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-253.135	-0.288443	-140.623	289.572
Reaction Moment(N.m)	0	0	0	0

Fixed Hinge-1		**Entities:** **Type:**	**2 face(s)** **Fixed Hinge**

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	168.457	-0.0215144	-40.4449	173.244
Reaction Moment(N.m)	0	0	0	0

Load name	Load Image	Load Details	
Force-1		**Entities:** **Type:** **Value:**	**1 face(s)** **Apply normal force** **200 N**

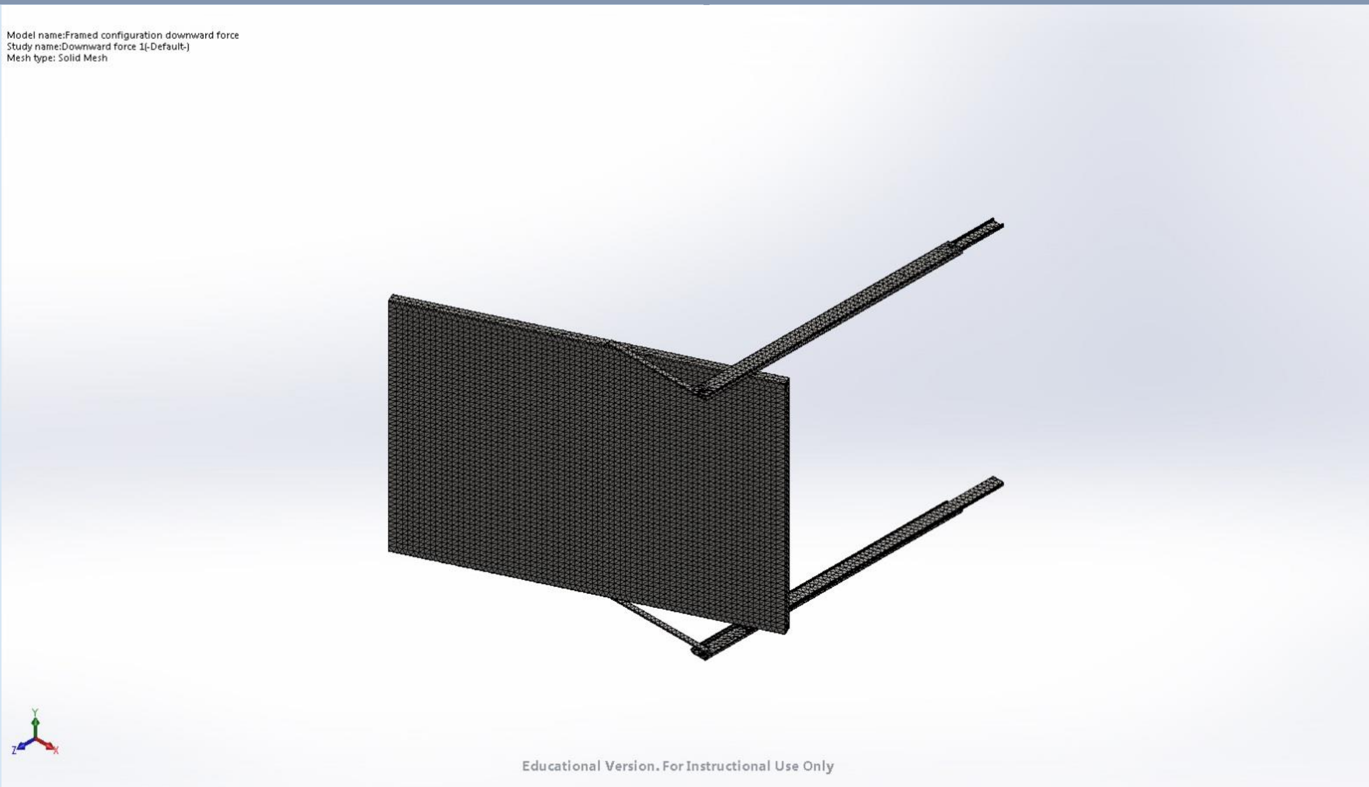
Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature based mesh
Jacobian points	4 Points
Maximum element size	0 mm
Minimum element size	0 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	150677
Total Elements	91286
Maximum Aspect Ratio	102.03

% of elements with Aspect Ratio < 3	70.1
% of elements with Aspect Ratio > 10	8.17
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:26
Computer name:	NAR-E1570-07



Resultant Forces

Reaction forces

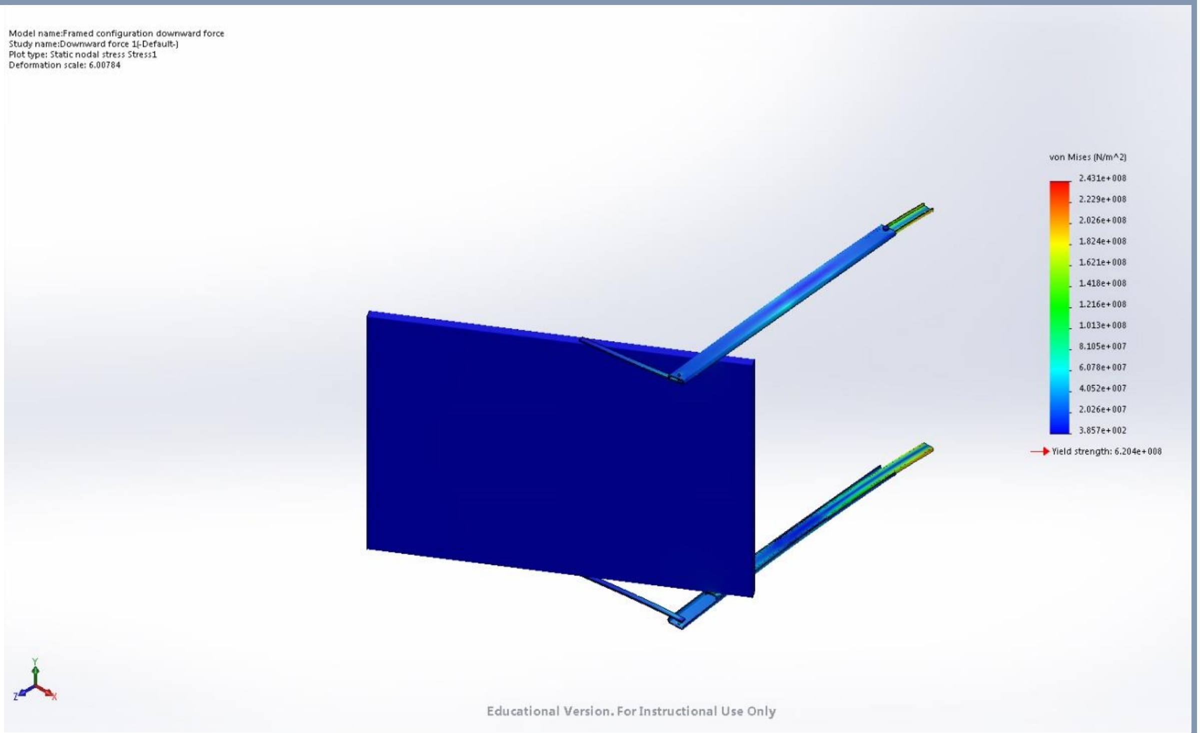
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-84.6775	-0.309966	-181.068	199.89

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

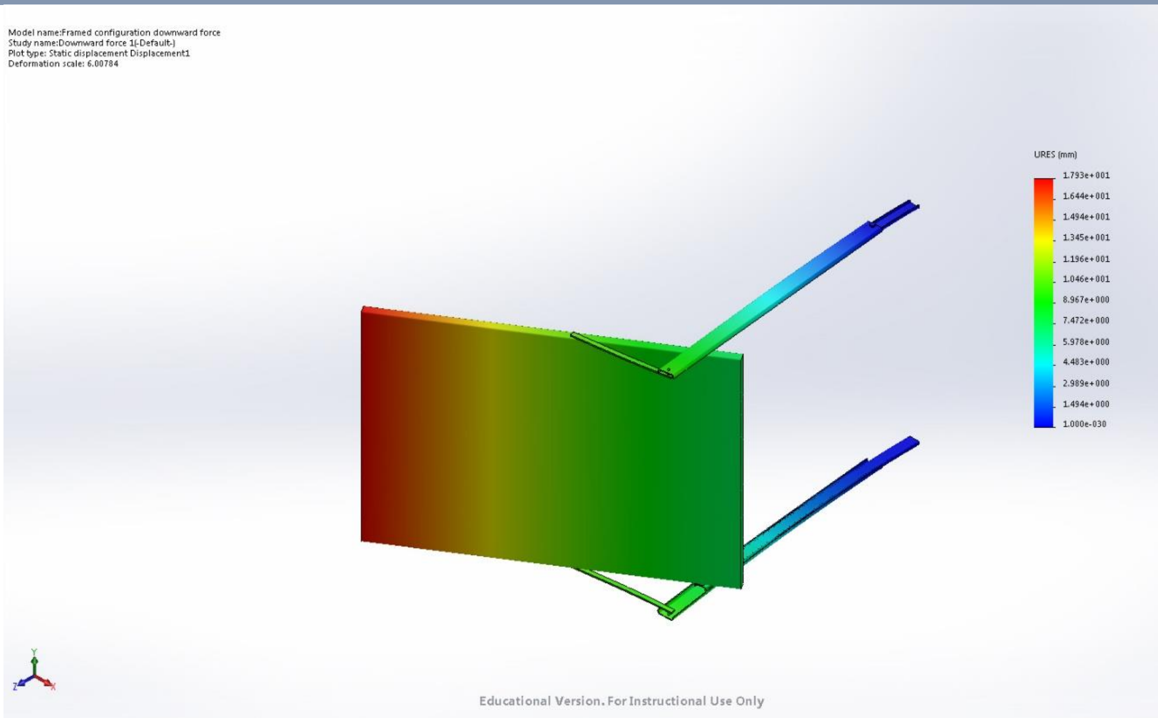
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	385.721 N/m^2 Node: 127845	2.43139e+008 N/m^2 Node: 2161



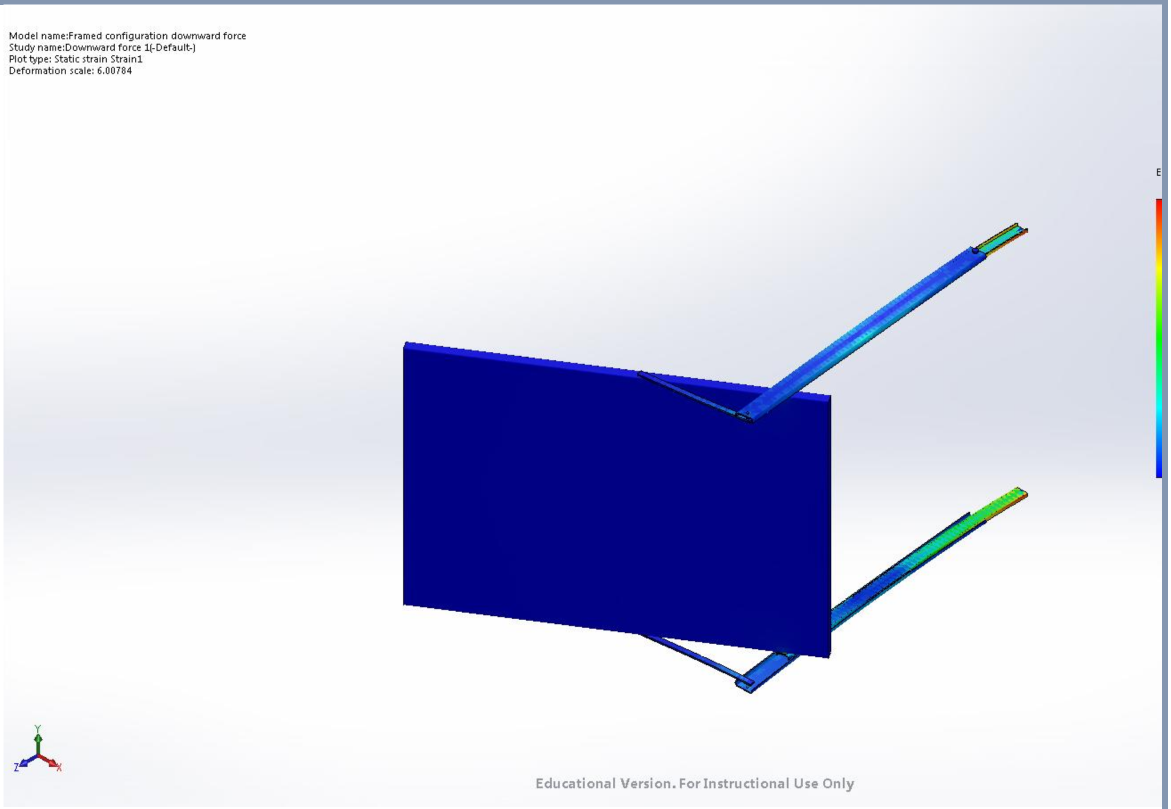
Framed configuration downward force-Downward force 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 2162	17.9339 mm Node: 367



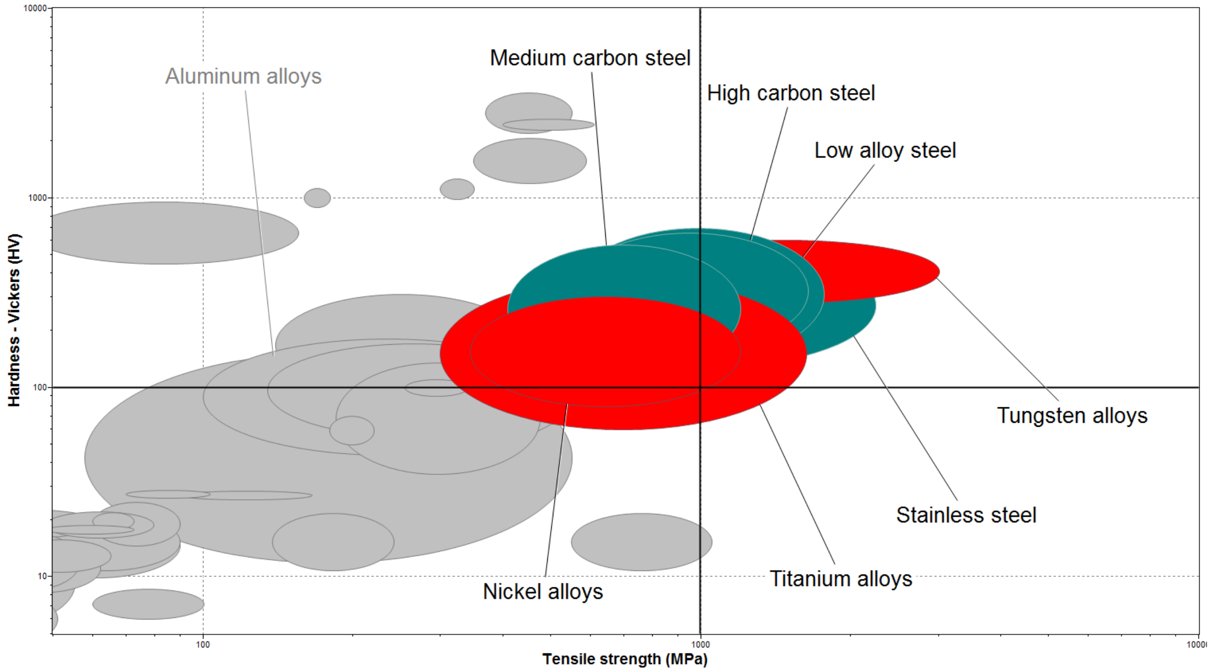
Framed configuration downward force-Downward force 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.73135e-009 Element: 36980	0.000848143 Element: 89732

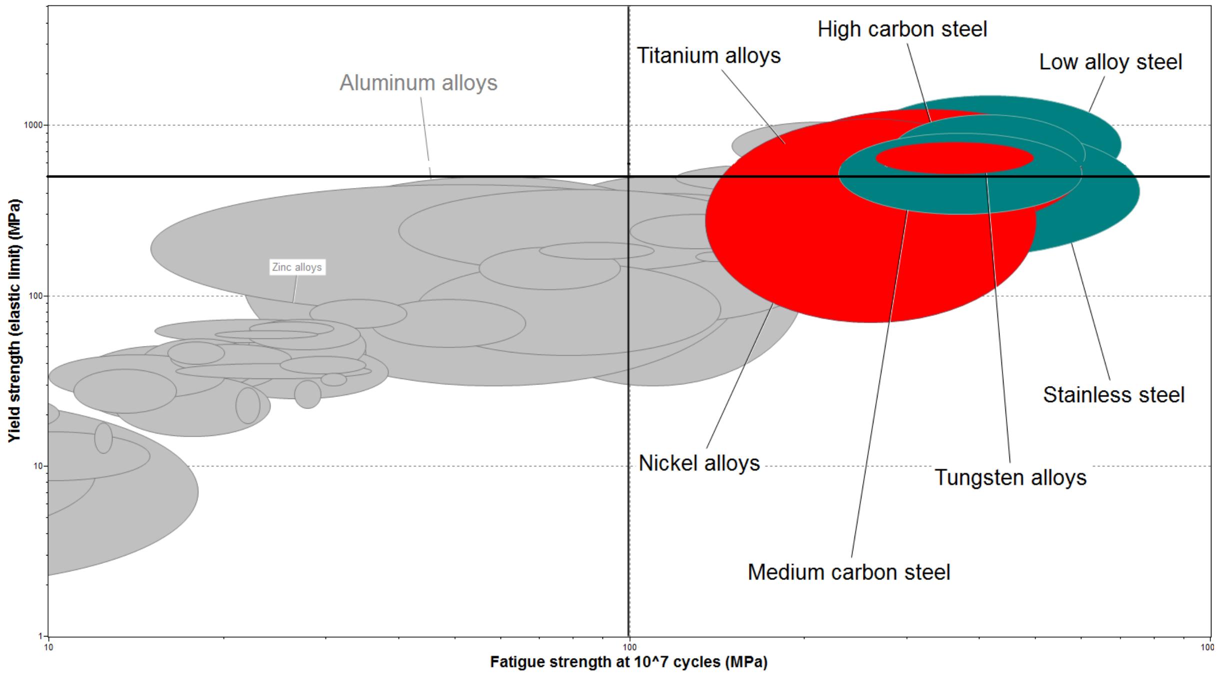


Framed configuration downward force-Downward force 1-Strain-Strain1

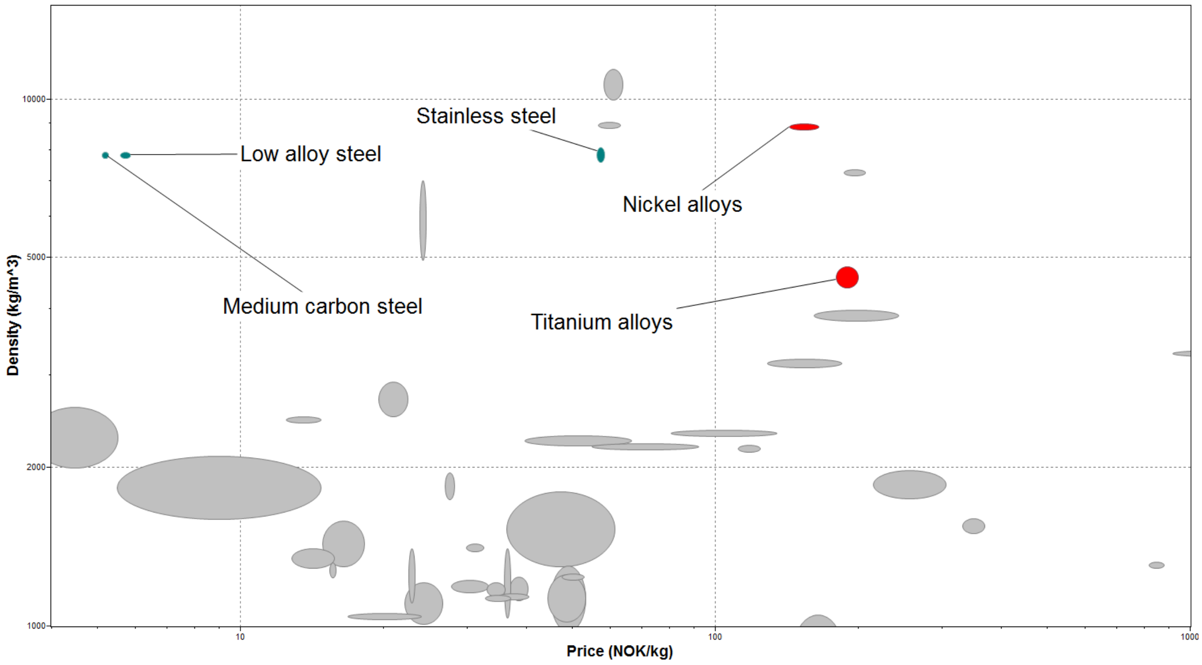
Appendix J Material selection charts



Appendix J - *Material chart. Hardness VS Tensile strength.*

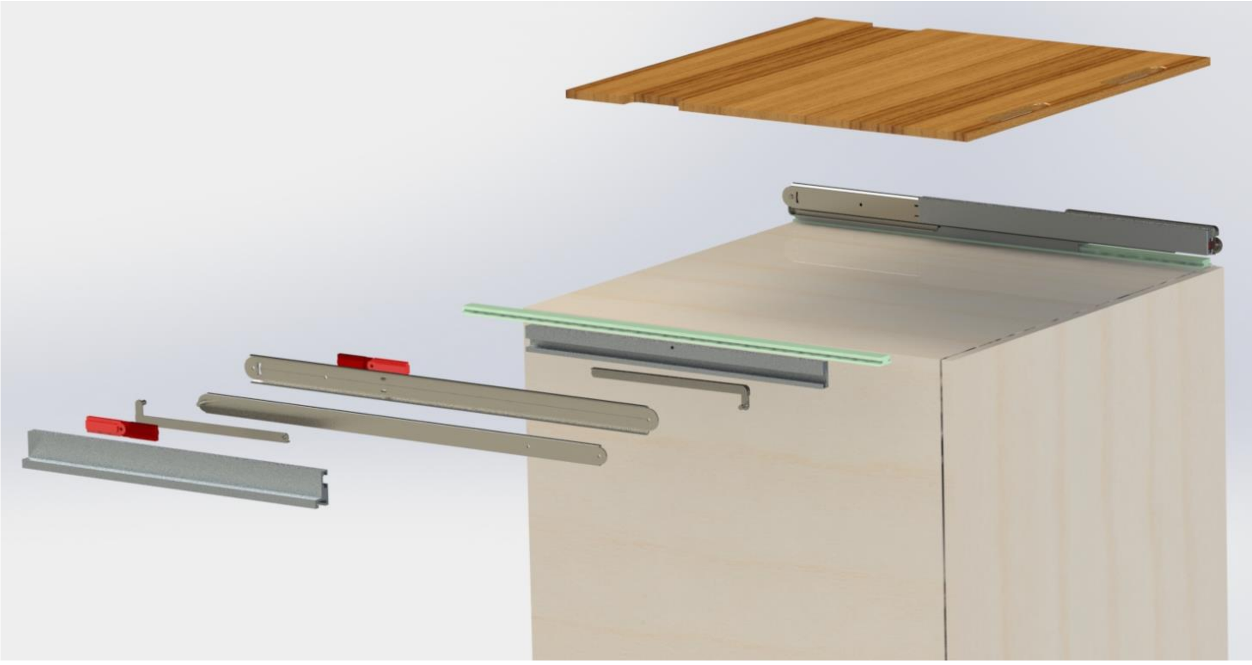


Appendix J Yield strength VS Fatigue Strength

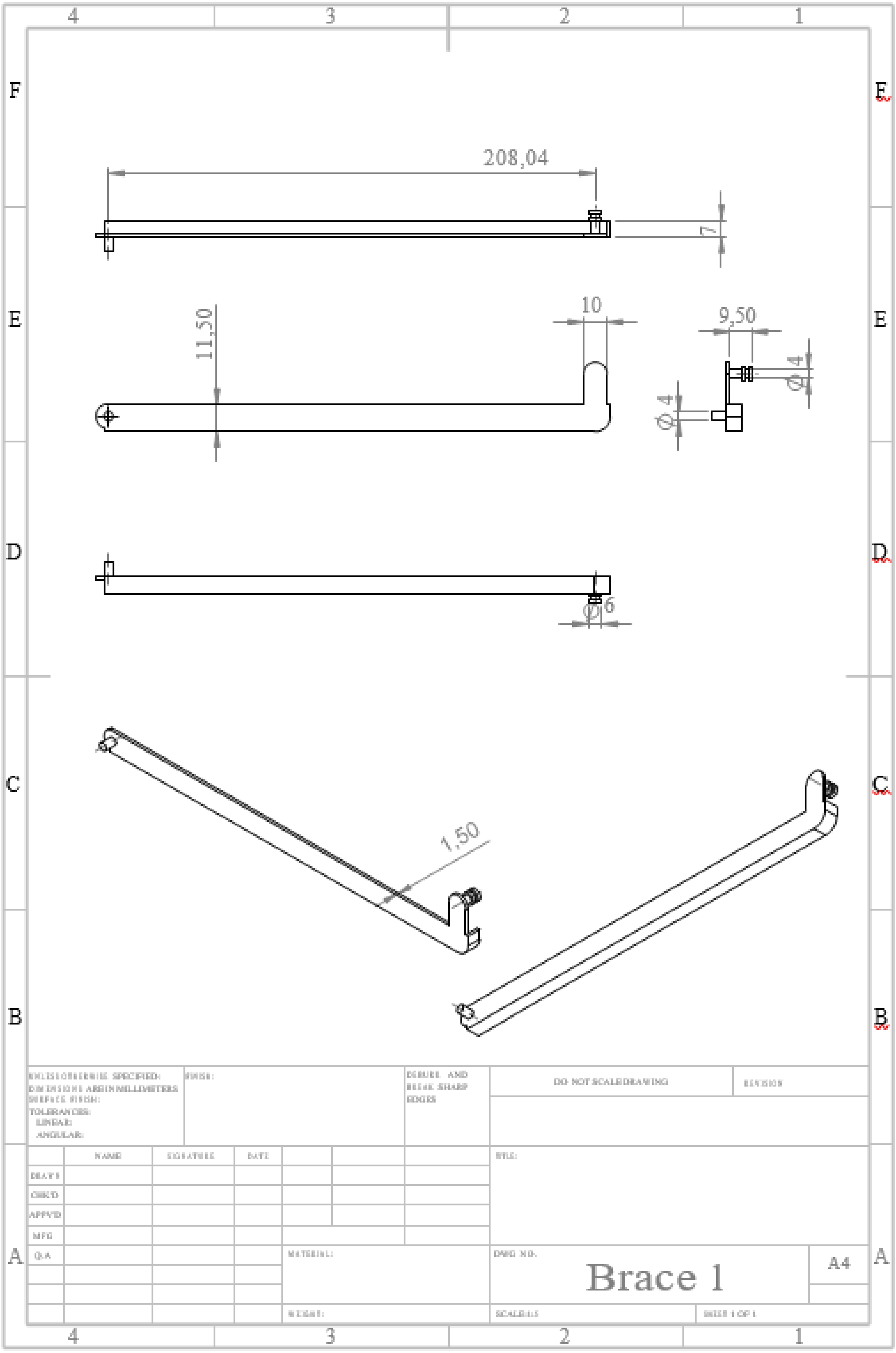


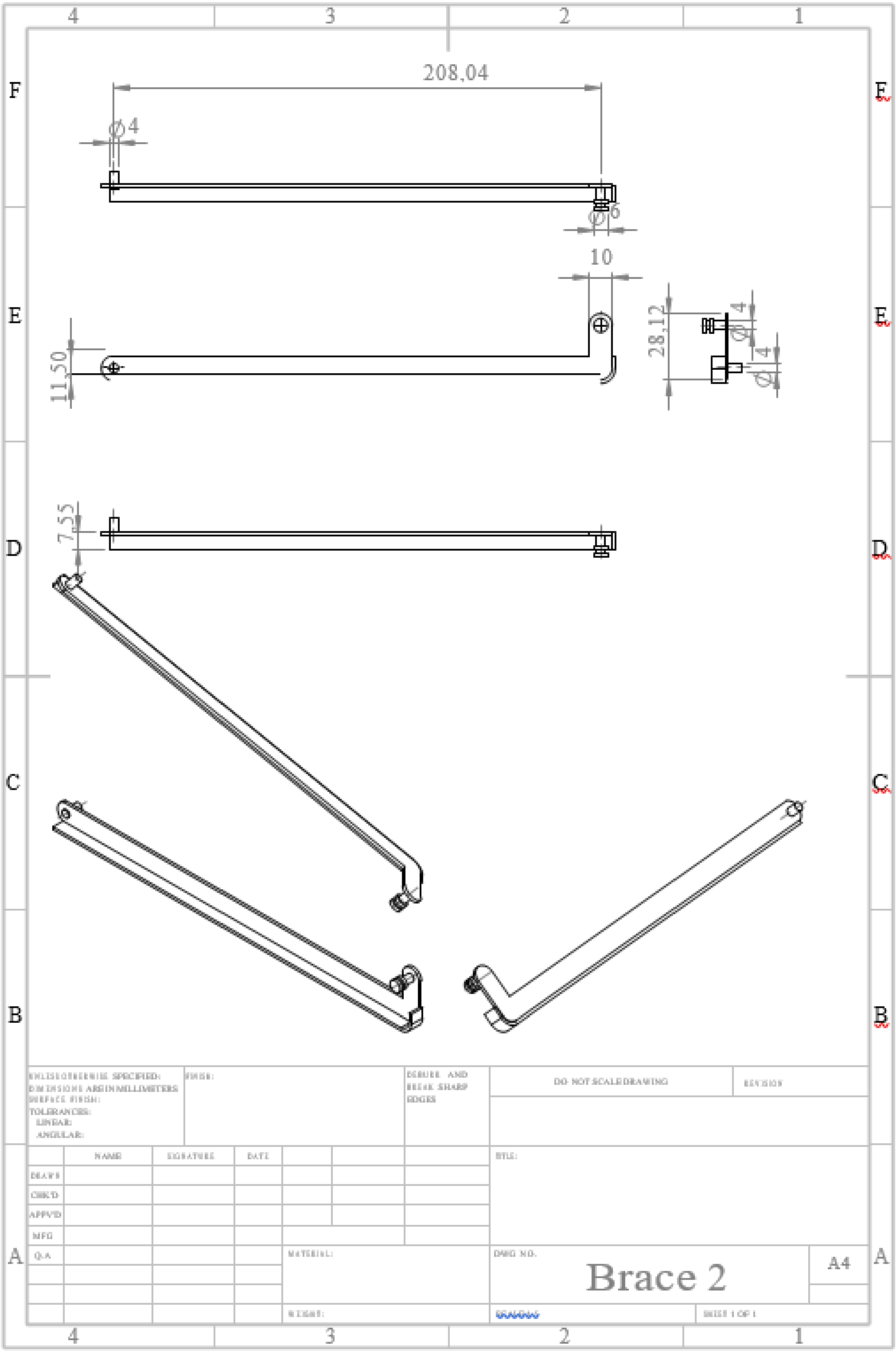
Appendix J - Material chart. Density VS Price

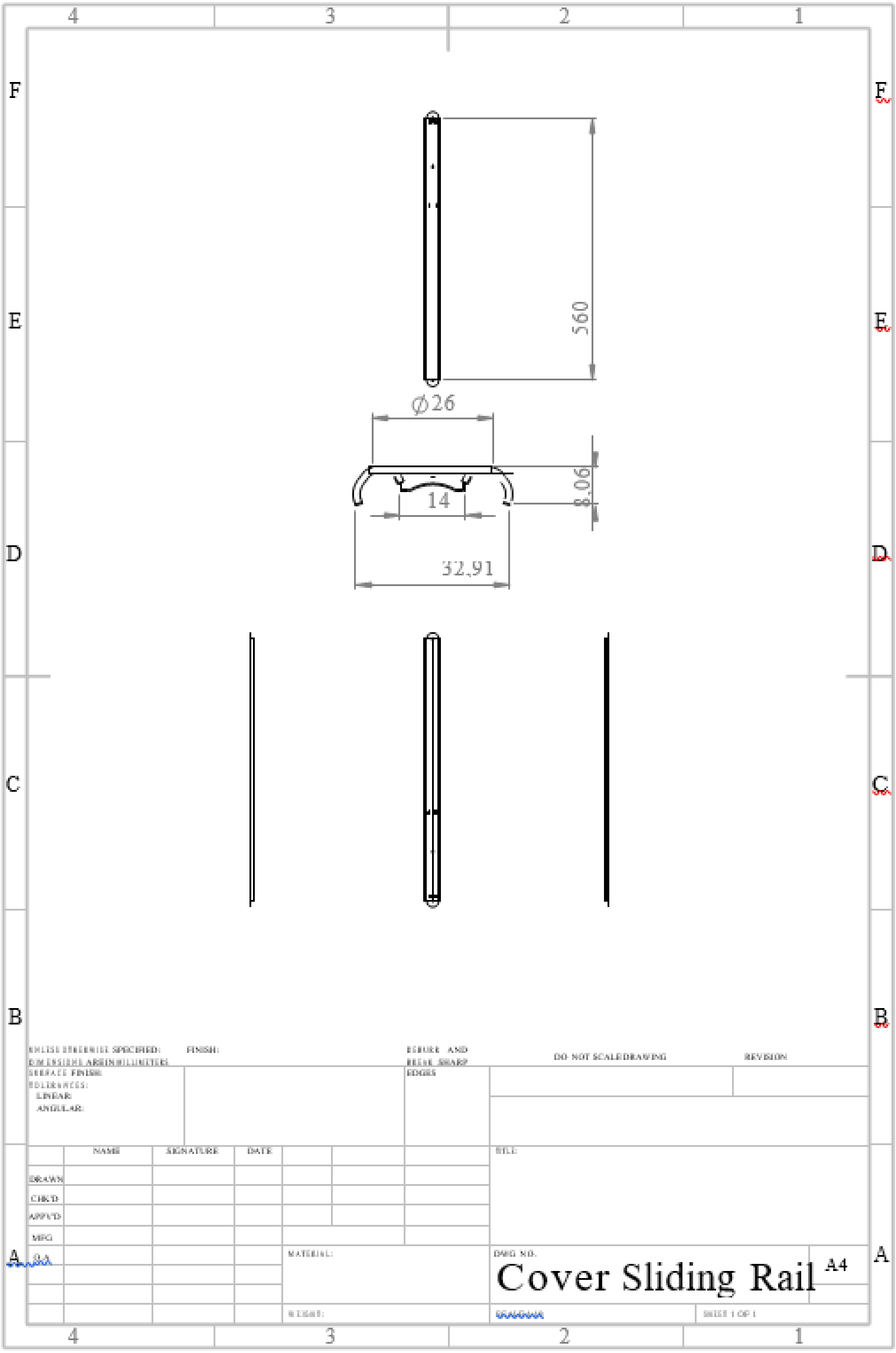
Appendix K Exploded view

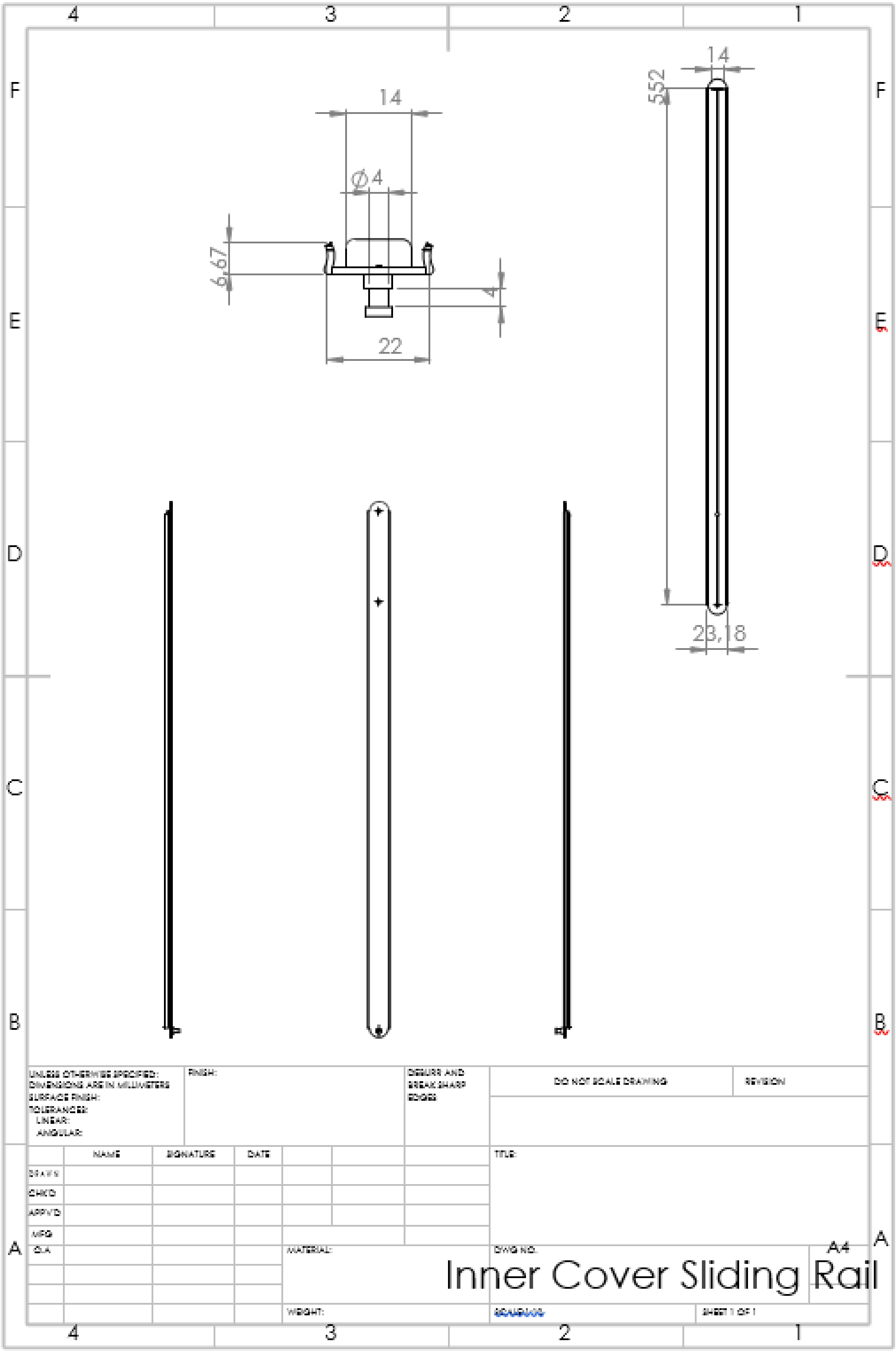


Appendix L 2D Drawings

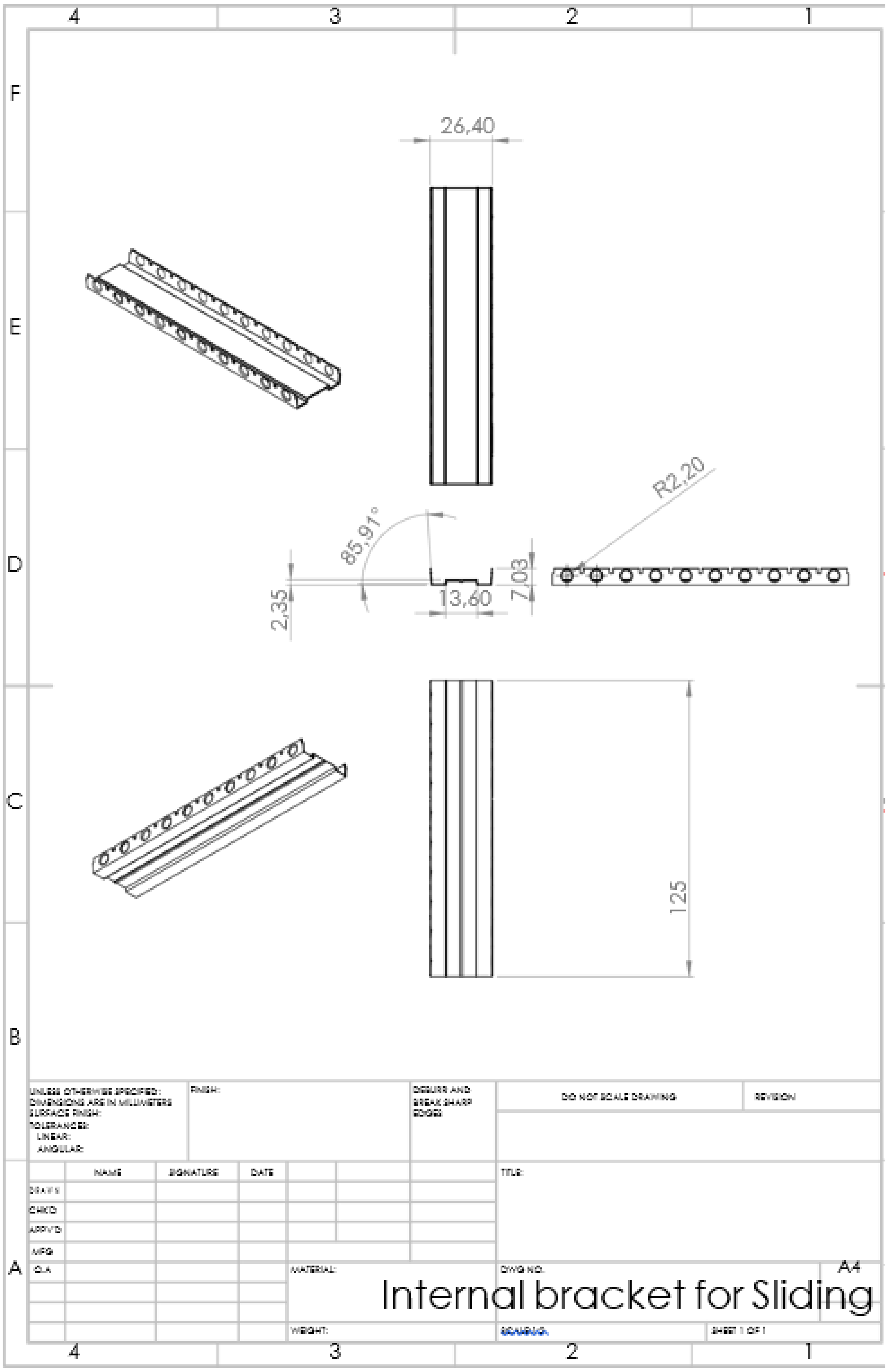


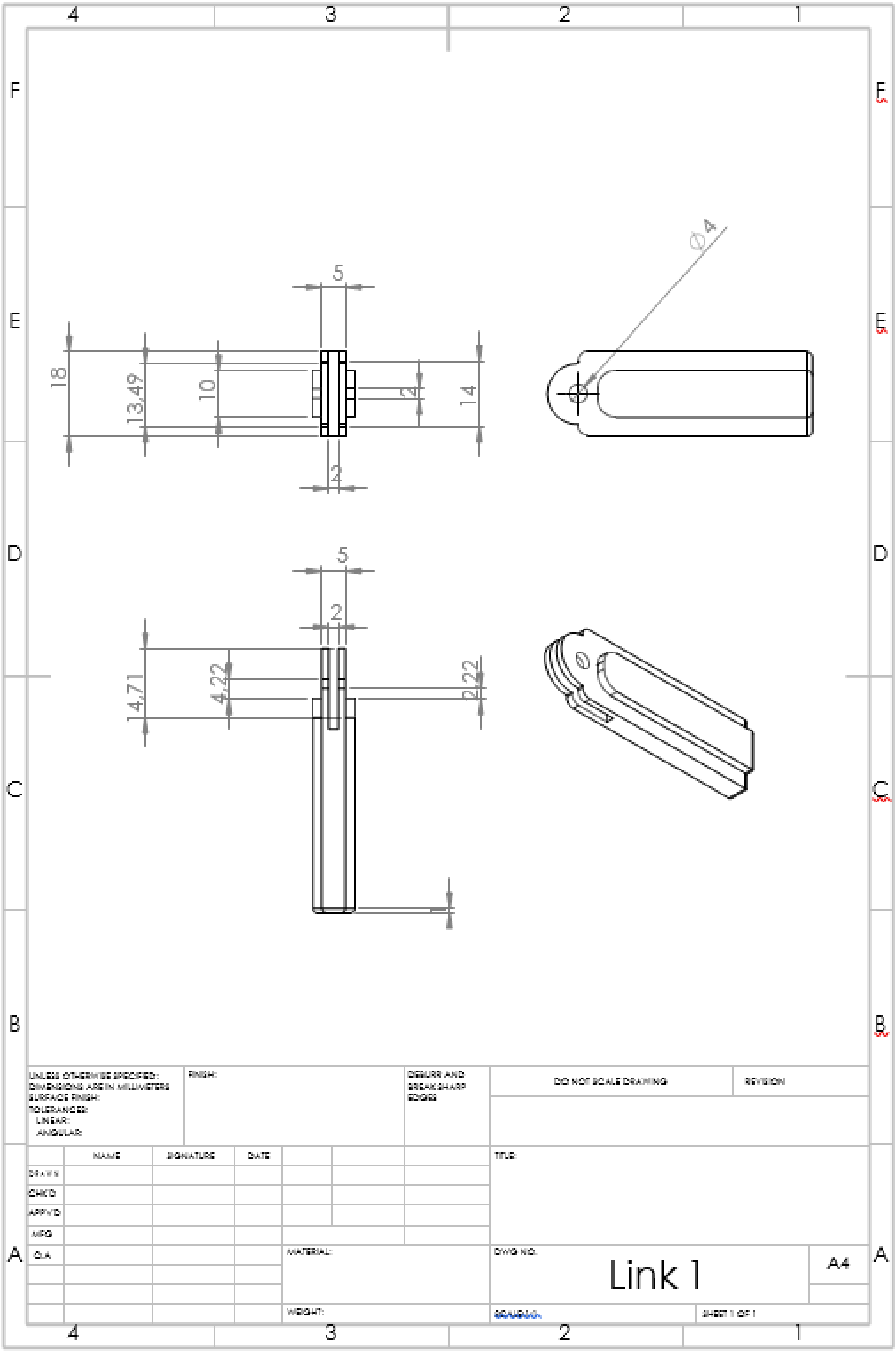

208,04
Ø4
Ø6
10
11,50
28,12
Ø4
Ø4
7,55
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
Brace 2
A4
WEIGHT:
SCALE:1:2
SHEET 1 OF 1

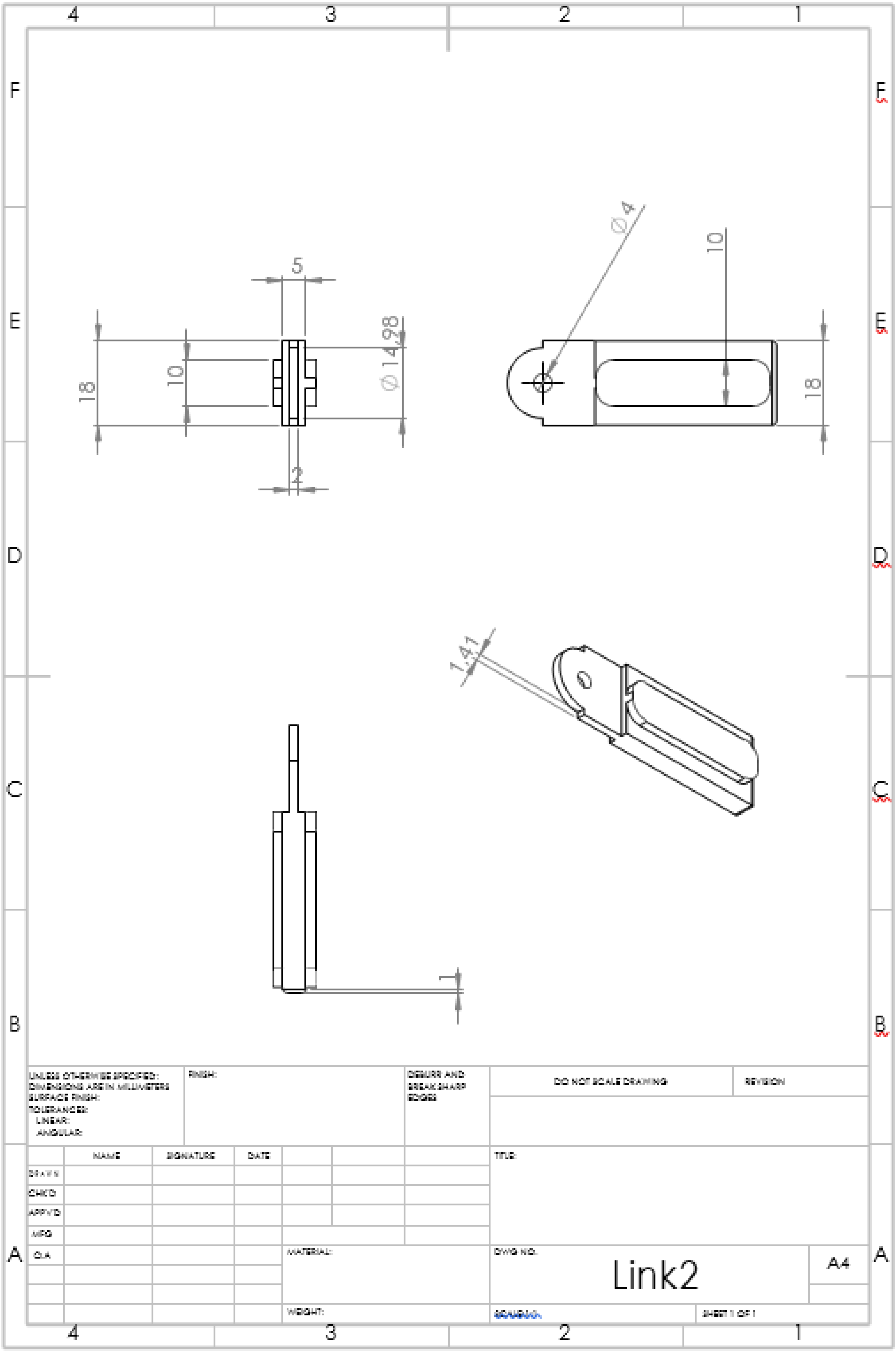

560
Ø26
8,06
14
32,91
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
DWG NO.
Cover Sliding Rail
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1

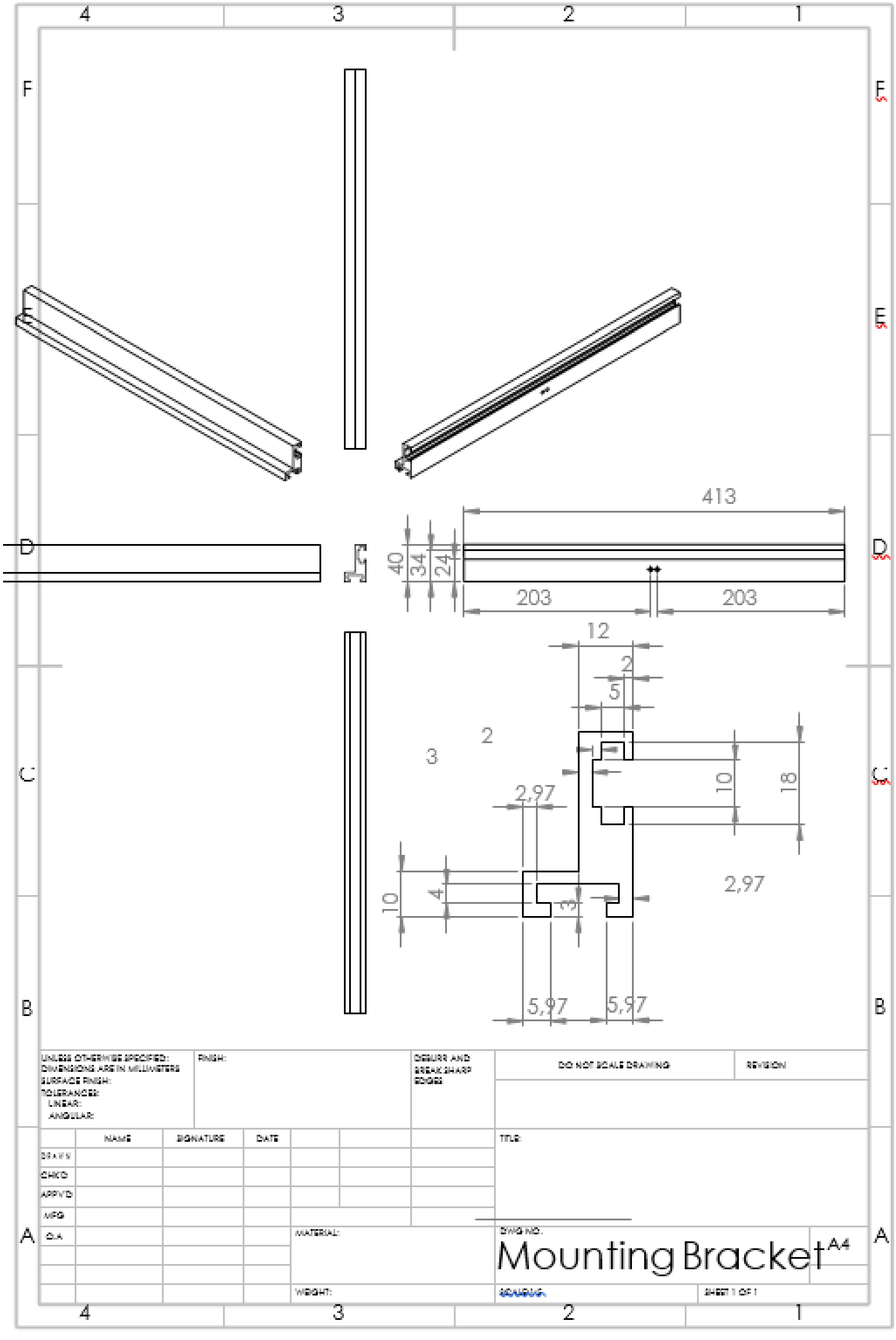


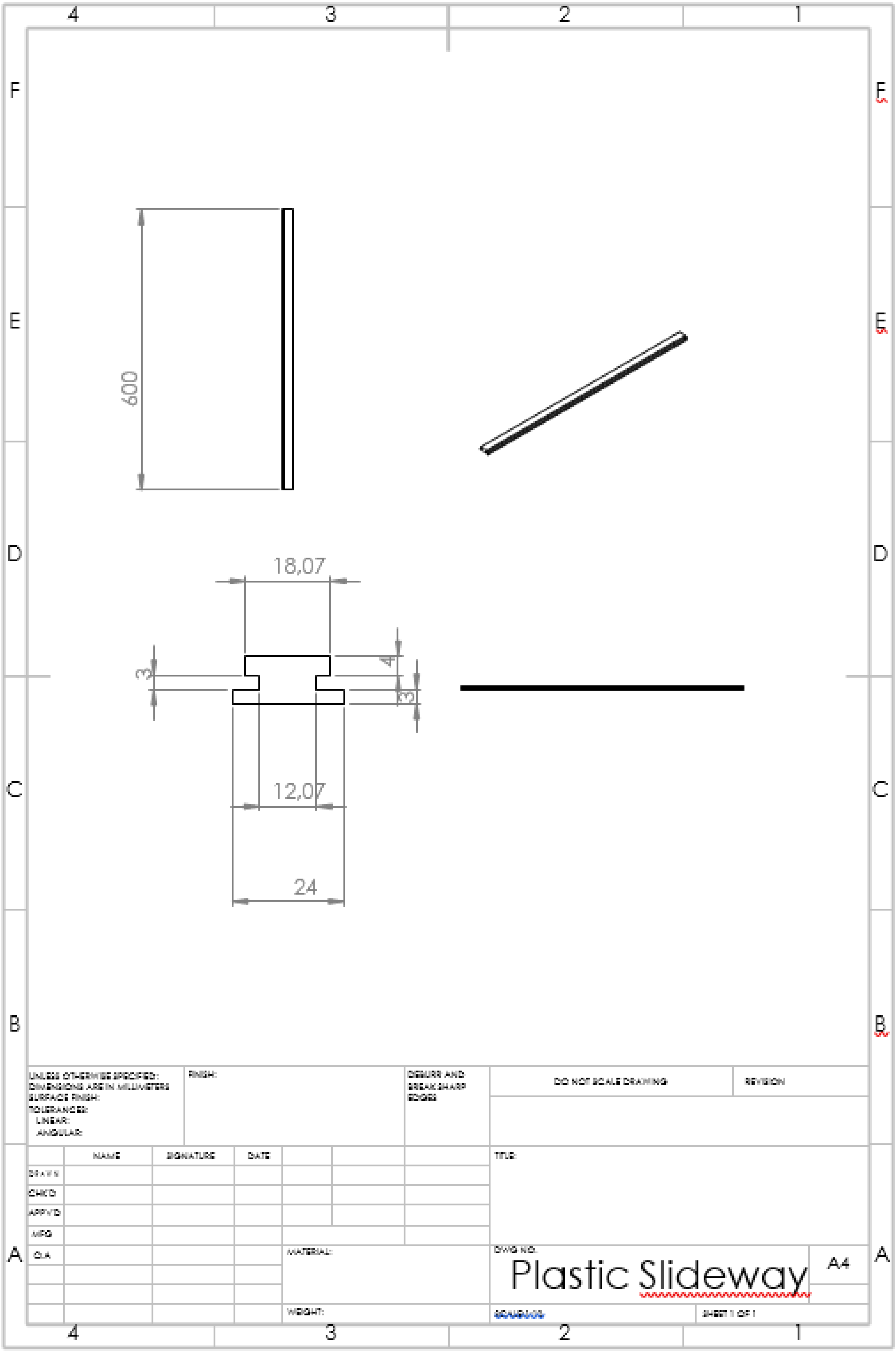
14
Ø4
6,67
4
22
14
552
23,18
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
A4
Inner Cover Sliding Rail
WEIGHT:
SCALE:1:10
SHEET 1 OF 1

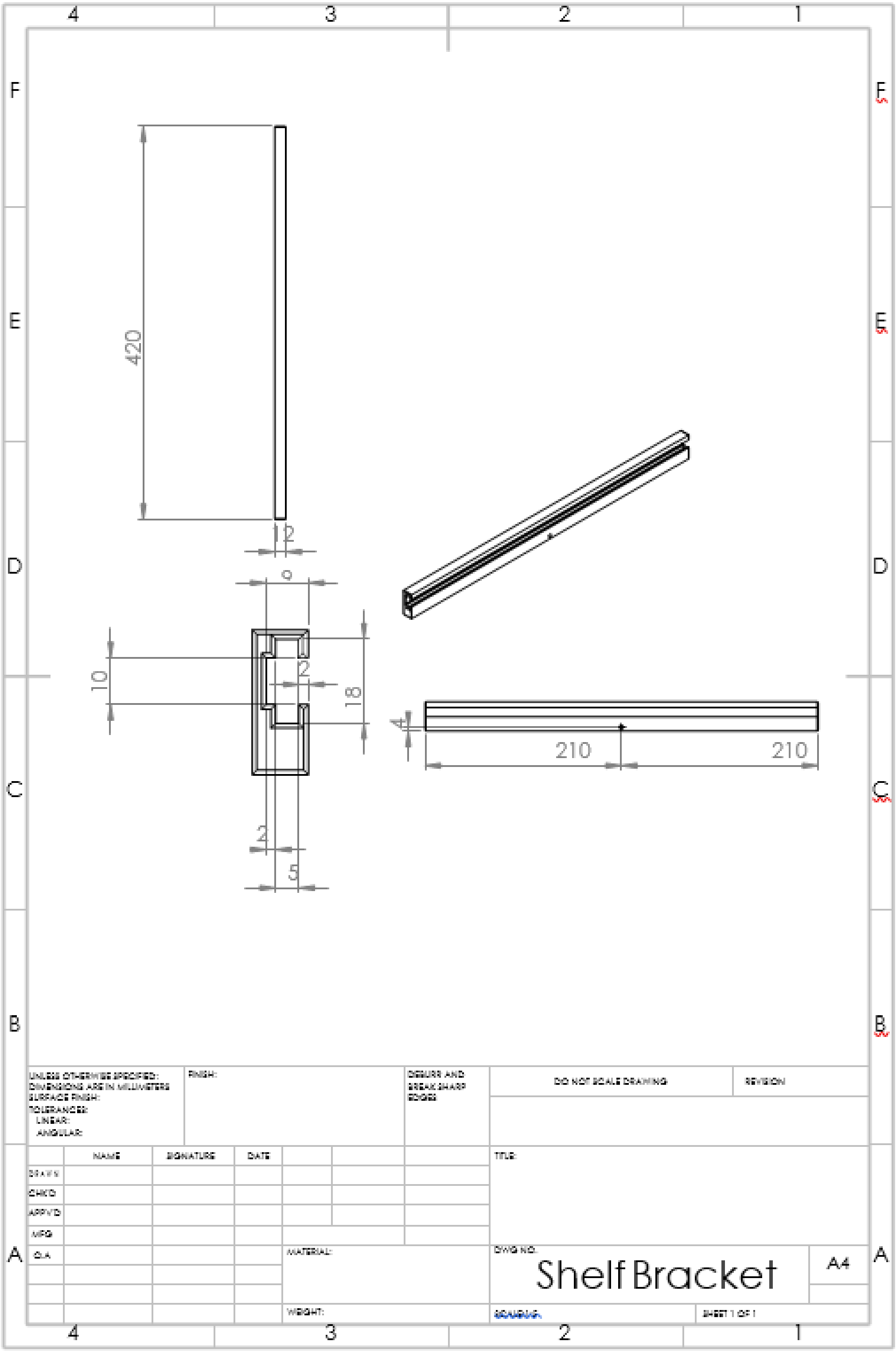

26,40
R2,20
85,91°
2,35
13,60
7,03
125
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
A4
Internal bracket for Sliding
WEIGHT:
SCALE:1:1
SHEET 1 OF 1


5
18
13,49
10
2
14
2
Ø4
5
2
14,71
4,22
2,22
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
DWG NO.
Link 1
A4
WEIGHT:
SCALE:1:1
SHEET 1 OF 1


5
18
10
Ø14,98
2
Ø4
10
18
1,41
1
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
WEIGHT:
DWG NO.
Link2
A4
SCALE:1:1
SHEET 1 OF 1


413
40
34
24
203
203
12
2
5
2
3
2,97
10
18
2,97
10
4
3
5,97
5,97
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
TITLE:
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
DWG NO.
Mounting Bracket
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1


600
18,07
4
3
3
12,07
24
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
TITLE:
MATERIAL:
DWG NO.
Plastic Slideway
A4
WEIGHT:
SCALE:1:5
SHEET 1 OF 1


420
2
9
10
2
18
4
210
210
2
5
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
DWG NO.
Shelf Bracket
A4
SCALE:1:5
SHEET 1 OF 1