BACHELOR THESIS

DESIGN OF A TRANSPORT SYSTEM FOR THE EVE R3 ROBOT

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Abstract

The Nakama Robotics Lab at the University of Twente owns a humanoid robot, the EVE-r3, which requires a transport device for longer distances. The current frame with wheels used for transportation is not suitable due to its size and inability to fit in a van. To address this, this design report presents a docking station that can be used as a transport device for the robot. A morphological overview is used to generate three concepts, from which a final design is chosen. The chosen design features a retractable top-part that can be lowered to allow the robot to sit lower and forklift tines to lift the robot up. This makes transportation of the robot possible. When the robot and the top-part are in their lowered positions, the transport device is compact enough to fit in a van. The design is then evaluated against the established requirements to ensure its suitability.

Contents

1 Problem analysis

1.1 Problem statement

At the Nakama robotics lab, located at the University of Twente, research and development is conducted on robots that possess the capacity to learn and interact with their environment. This so-called EVE-r3 robot (Figure 1) is created by the company Halodi Robotics and can be utilized to assist humans in a number of tasks [1]. It can for example be used in the security sector to carry out basic tasks such as patrolling and navigating within buildings, monitoring entrances and welcoming visitors or it can assist in the retail sector to perform tasks like locating empty shelves, stocking shelves and packing goods.

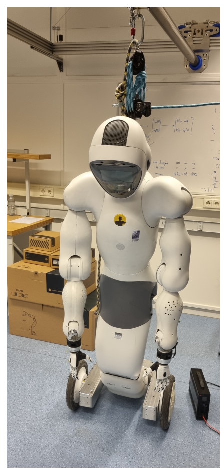

Figure 1: The EVE-r3 robot that is used in the Nakama robotics lab.

The EVE-r3 at the Nakama robotics lab is equipped with a pair of BeBionic hands, created by the company Ottobock [2]. These hands imitate the movements and appearance of a real human hand, providing a more naturalistic experience. The aim for the lab is to implement this system in the healthcare sector, such as aiding nursing staff with various tasks.

Unfortunately, transporting the robot outside of the lab and the University of Twente is a difficult endeavour due to its size and weight (approximately 90 kilos and 1.80 meters tall when standing upright). Furthermore, its lack of stability when not powered (due to the highly backdrivable motors) makes it even more challenging to manually place and keep it in a position suitable for transport. To add on, the current docking station for the robot is higher than the standard door size (2,1 meter) and therefore it can not leave the room. Furthermore, as a requirement for this design assignment, the robot should fit in a standard-sized van with a load height of approximately 1.80 meter [3]. Therefore the docking station must transform into a transport device, in which the robot fits, that can fit in the van. To overcome these difficulties, it is beneficial to ensure that the robot can be placed in a docking station which can also be converted into a transport device for easy and safe transport to different locations.

Last year (2022), an initial version of a transport device was designed for a bachelor assignment. Nonetheless, the design itself must be re-examined and more precisely defined, since the existing design does not include the details necessary for actual production. Therefore, the aim of this thesis is to design and define a transport device which can also be used as a docking station for the EVE-r3 robot for actual production.

1.2 Current state

To begin with, it is necessary to review the design which had been made last year (figure 2) [4]. The design consists of a mechanism that can tilt a plate, where the robot is attached, from a horizontal position to a vertical position. The plate consists of a foam structure in which the robot lies, which act as a protected layer. The robot is then tied and secured with velcro straps. Two gas springs on each side ensure that a 90 degree rotation is possible in a controlled way. This mechanism ensures that the plate with the heavy robot will not drop with a high speed when the plate needs to be tilted to a horizontal position, which could endanger the user, and it ensures that lifting the plate to a vertical position will not be a heavy task. The wheels on the bottom of the device make it easy for transportation. However, this design is missing the exact details in order to make it production ready. For example, it is necessary to know which bolts to implement for the connections between the beams, how the connection of the wheels and the frame will be realised, how the connection between the frame and the gas springs will be realised and which exact gas spring will be used. Some safety precautions should be taken into account. For example, fingers can be caught between the frame and the plane when tilting the plane.

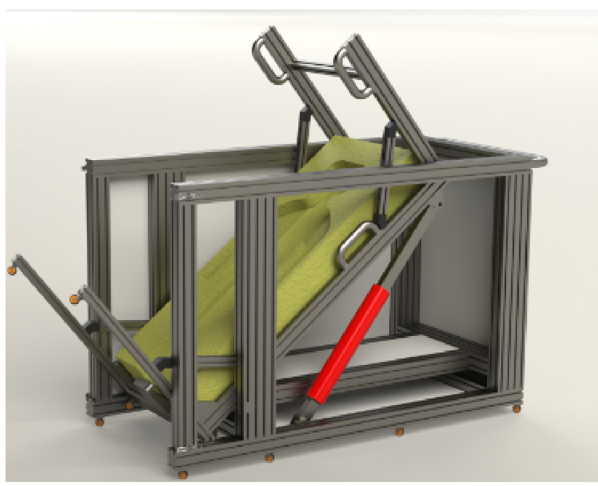

Figure 2: A graphical representation of a transport device for the EVE-r3 robot, which had been made in 2022 [4]

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1.3 Stakeholders

The previous design report has stated that the demands of the stakeholder needs to be taken into account [4]. The three stakeholders are: the user of the transportation device, the building supervisor and the production company. The most important stakeholder is the user of the transportation device. It is important that the user can transport the robot to different locations and that the transport device can be used as a docking station. When the robot is in the docking station, the user should be able to start and calibrate it. The user should also be able to use as little force as possible when working with the transport device and there must be no dangers to the user and its surroundings when working with it . The next stakeholder is the building supervisor. The transport device must not cause damage to the building during the use and transport of it. The production company is the last stakeholder. For the production company it is useful if the transport device can be produced and repaired easily. Furthermore it is favorable for them if the costs for the production is as low as possible.

2 Requirements

This section explains the requirements for the design of the transport vehicle/docking station for the EVE-r3 robot. First, the steps to be taken during the entire process of stationing and transporting the robot are set out. These steps are: 1) connecting and disconnecting the robot from the docking station, 2) converting the docking station, with the robot attached, into a transport device and vice versa and 3) transporting the transport device to different locations (table 1, 2 and 3). The general requirements for the device is also noted (table 4). After these steps are established, the requirements for the design are described. These requirements are then broken down into user and functional requirements. User requirements describe what the user needs the product to do, while functional requirements define the functionality of the product. Subsequently, the method to validate the requirement is shown where possible. Some requirements from last year's report have been included and are marked with * [4].

Table 1: List of requirements and its validations for connecting and disconnecting the robot from the docking station

Connecting and disconnecting the robot from the docking station		
Requirement	***Type of requirement***	***Validation and specification***
Putting the robot from the start position in the docking station and taking it out of the docking station to the start position is a task that is quick to complete. The start position is when the robot is one meter in front of the docking device.	User	The process can be completed in 5 minutes with at least two people.
Putting the robot from the start position in the docking station and taking it out of the docking station to the start position is a task that is able to be performed with no more lifting than official working regulations.	Functional	A individual user is not allowed to lift more than 23 kilos when putting and taking the robot in and out of the docking station in accordance with the working conditions decree [5].
The docking station can hold the weight of the robot with an appropriate load limit.	Functional	The minimum weight that the docking station must be able to support is 220 kg in accordance with the International Electrotechnical Commission [6].

The docking station can hold the robot when the power of the robot is off.	Functional	The minimum hanging height required for the robot in the docking station is 180cm , so that it will not topple even when the power is off due to the weight of the robot. The robot's mounting point is located in the neck, as this is the only way to link the robot to any anchor point.
The docking station fits in a room with the following minimum dimensions: 4.00 x 4.00 x 2.50 m (L x W x H).	Functional	The maximum dimensions of the docking station are 3.00 x 3.00 x 2.30 m (L x W x H).
The robot is chargeable when it is positioned in the docking station.* It does not need to be chargeable in the transport device	Functional	Wiring must be possible in the docking station to charge the robot. The charging-point is at the back of the robot.
When the robot is in docking state, the arms can be moved. The encoders of the arms need to be calibrated after starting.	Functional	The arms can be moved in an area that is needed for the calibration.
When the robot is in docking state, the wheels of the robot can not move and turn.	Functional	The wheels can not spin, turn and move in any direction. This ensures that when the robot is in the docking state, the docking state can be rolled around without the wheels of the robot interfering with the docking station.

Table 2: List of requirements and its validations for converting the docking station with the robot attached into a transport device and vice versa.

Converting the docking station with the robot attached into a transport device and vice versa.		
Requirement	***Type of requirement***	***Validation and specification***
Converting the docking station with the robot attached into a transport device and vice versa is a task that is quick to complete.	User	The process can be completed in 10 minutes with at least two people.

Converting the docking station with the robot attached into a transport device and vice versa is a task that is able to be performed with no more lifting than official working regulations.	User	A individual user is not allowed to lift more than 23 kilos per person during the conversion in accordance with the working conditions decree [5].
There should be no dangers for the users during the conversion of the device.	User	All metal edges should be rounded or covered with a non-slip material. All moving parts should be securely guarded. Any potential pinch points should be eliminated. Body parts of the users must not be trapped during the conversion.
When the docking station is converted into a transport device, the robot is firmly attached to the transport device.*	Functional	The robot must be attached to the docking station in a way to limit its movements in any direction (x, y and z direction) up to 5 cm. The robot's arms should not swing and the hip and head should not sway along the way.

Table 3: List of requirements and its validations for transporting the transport device

Transporting the transport device to different locations.		
Requirement	***Type of requirement***	***Validation and specification***
Transporting the transport device with the robot is a task that is quick to complete.*	User	The process of putting the transport device in a van can be completed in 5 minutes with 2 people.
Transporting the transport device with the robot is a task that is able to be performed with no more lifting and pushing than official working regulations.*	User	The weight of the transport device and coefficient of friction between the ground and the device must be taken into account in the design so that no more than 23*9,81 = 225 Newton is lifted and pushed during the transportation of the transport device with the robot.

The transport device is easily maneuverable.*	User	The transport vehicle must be able to drive up a 1:12 slope, which is a suitable slope size to push objects [7]. The transport device must be able to make perpendicular turns of 90 degree. The device can rotate around its own centre. The transport device must be able to withstand canted and uneven paths and it can drive over 10 cm bumps and pits. The wheels of the robot can not interfere with the wheels of the vehicle during the transportation.
When outside, the robot is protected from the rain.	User	During the transportation, the robot can not become wet.
The transport device can hold the weight of the robot with an appropriate load limit.	Functional	The minimum weight that the docking station must be able to support is 220 kg in accordance with the International Electrotechnical Commission [6].
The transport device is able to pass through double doors, it must fit in a van and it must fit in an elevator.*	Functional	The maximum dimensions of the transport device is 2.30 x 1.50 x 1.80 m (L x W x H) (It is therefore possible that the dimensions differ from the docking station).
When loading and unloading in a van, the transport device is able to bridge a certain height.	Functional	The maximum height that needs to be bridged is 50 cm.
It is possible to brake the vehicle during transport state.	Functional	When the brakes are applied, the transport device can not move in any direction.

Table 4: List of general requirements and its validations

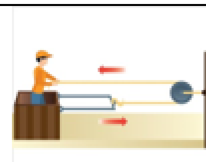
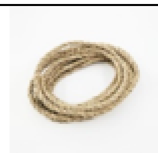
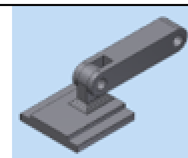
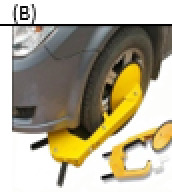
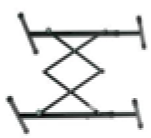
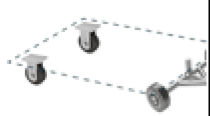
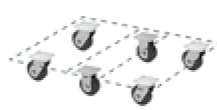
General requirements for the docking station / transport device		
Requirement	***Type of requirement***	***Validation and specification***
Different components of the mechanism are connected in a way so it is able to be disassembled.	User	It can be validated by disassembling the device.
The design should incorporate mechanisms that are easy to manufacture.	User	-

3 Concepts

This chapter describes the process of designing 3 different concepts for the device that can transport and dock the EVE-r3 robot. Firstly, a morphological overview with sub-solutions for each requirements will be given. After that, different sub-solutions will be combined to get 3 different concepts.

3.1 Morphological overview

Figure 3 gives the morphological overview that is needed to design 3 concepts. For each requirement in chapter 2, several sub-solutions are listed, which are then combined to form 3 different concepts. The sub-solutions that are used for each concept (Concept A, B and C) are noted with A,B and C in the figure. It is important to note that not all sub-solutions are used.
In row A, only sub-solution A1 (small ramp) is implemented because this solution is much easier to construct and the mechanism is a simple way to put the robot in the docking station.
Solution B2 (ropes) is not used, because the solution B1 (carabiner hook) and B3 (pin connection) both gives a quicker way to connect the robot to the frame, without having any disadvantages compared to B2.
Solution E1 (elastic bands) is not applied, because elastic bands do not provide a secure hold. They are likely to stretch due the weight of the transportation device and the vibrations of the van, which could cause the object to become loose and possibly move around in the van. Additionally, ropes (E2) are more likely to be damaged or frayed with repeated use, whereas ratchets or velcro straps can be tightened and released multiple times without breaking down. Solutions E3 (ratchet straps) and E4 (velcro straps) provide a much stronger and more secure hold, making it more difficult for the object to come loose.
Furthermore, a 3 wheeled base (F3) would not be as stable as an even numbered wheel base (F1 and F2) or 2 wheeled base (F4) because it would be more open to tipping over on bumpy roads and taking sharp corners. Also a 3 wheeled base would be more difficult to balance which can lead to the transportation device tipping over. Therefore, solution F3 is not applied.
Solution H3 (hydraulic lift) is not used because of the complexity to add a hydraulic lift in the design. Solution H4 (hydraulic forklift) is not applied, because it would not be realistic to purchase a hydraulic forklift for this design assignment.
Regarding to row I, solution I3 (one single bar-break) is not applied, because of the complexity of the mechanism. Solutions I1 (foot brakes) and I2 (hand-activated break pads) are an easier method for the break mechanism to implement in the concepts.
In rows C, D and G, all solutions present no major drawbacks when compared to one another, so they are all implemented in each concept.

	Requirement	Solution 1	Solution 2	Solution 3	Solution 4
A	Putting/taking the robot in/out the docking station quickly and without lifting too much.	 The robot drives in the docking station with the help of a small ramp [8].(A)(B)(C)	 Putting the robot in the docking station using a hydraulic small lift table [9].	 Horizontal pulley system to pull the robot on the docking station [10].	
B	Holding the robot in the docking station through the connection in the neck of the robot.	 Carabiner hook to connect the neck of the robot to a frame [11]. (A)(C)	 Rope to connect neck of the robot to a frame [12].	 Pin connection between neck of the robot and a frame [13]. (B)	
C	Preventing the wheels of the robot from moving and turning in docking state.	 Wheel chock [14]. (B)	 Placing bars across the path of the wheels [15]. (A)	 Wheel clamp [16].(C)	
D	Lower the frame in order to convert the docking station into a transport device quickly and with ease.	 Tipping mechanism. During the docking state the robot can stand up, but when it is in transport state, the robot will lay down [17]. (B)	 Vertical extendable frame. During the shortening of the frame, the robot's knees bend, causing the robot to sit lower [18]. (A)(C)		
E	Attaching the robot firmly to the transport device	 Elastic bands [19].	 Rope [12].	 Ratchet straps [20]. (A)(C)	 Velcro straps [21]. (B)
F	Transporting the transport device to different locations with easy manoeuvrability.	 Only 2 wheels are swivel wheels [22]. (B)	 All wheels are swivel wheels [22]. (C)	 3-wheel configuration with a swivel wheel at the front [23].	 2-wheel hand trolley[24]. (A)

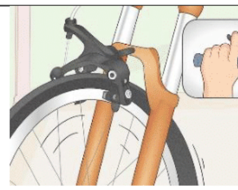
G	Protecting the robot from rain during transport.	 Rain cover [25]. (A)(C)	 The transport device is enclosed [26]. (B)		
H	The transport device is able to bridge a certain height to load it in a van.	 Hand crank to adjust the hight of the transport device after which the robot is slid into the van [27]. (C)	 Van loading ramp [28]. (A)(B)	 Using a hydraulic lift [29].	 Using a manual hydraulic forklift [30].
I	Braking the transport device during transport.	 Foot brakes [31]. (B)(C)	 Brake pads which are activated with hands [32]. (A)	 Brake handle which brakes the back wheels with one single bar [33].	

Figure 3: Morphological overview with different sub-solutions for each requirement. The solutions that are used in the concepts are noted with an A, B and C for each concept respectively.

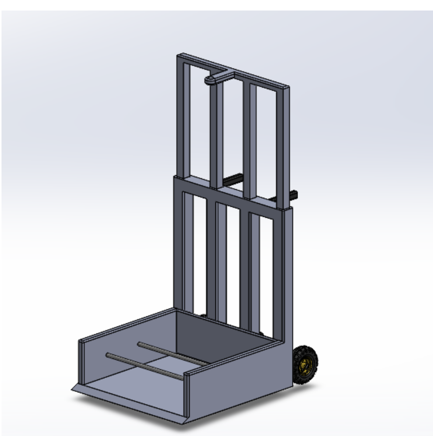
3.2 Concept A

Table 5: Concept A with its sub-solutions given in Figure 3.

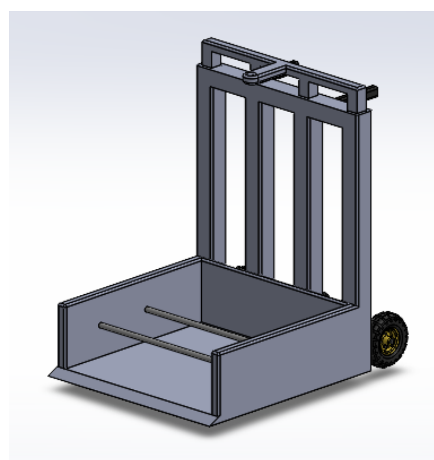
Sub-solution	Description
A1	Small ramp to put the robot into the docking station.
B1	Carabiner hook to connect the neck of the robot to a frame.
C2	Placing bars across the path of the wheels to prevent the wheels from moving.
D2	Vertical extendable frame to lower the frame in order to convert the docking station into a transport device.
E3	Ratchet straps to attach the robot to the transport device.

F4	2-wheeled hand trolley, as the wheelbase configuration.
G1	Rain cover to protect the robot from rain during transport.
H2	Van loading ramp to put the transport device into a van.
IA	Hand-activated brake pads to break the transport device during transport.

Concept A (Figure 4) is inspired by a hand-truck. Table 5 shows which sub-solutions, drafted in Figure 3, are used in this concept. When the robot is in its starting position in front of the docking station (figure 4a), it will drive backwards over a very small ramp to enter the docking station. The wheels will be secured by two beams in the middle of the base. The connection point in the neck of the robot can be connected with the corresponding connection point of the base, which is a projection at the top of the device. The body of the robot can be tied to the frame. To transform the docking station into a transport device (figure 4b), the upper part of the device is lowered, causing the whole device to lower. The robot must also lower into a crouched position. After the transformation, transport is possible. A person can use the handles to tilt the device and move it to the desired location. The robot should remain securely in place on the platform. Once the robot has been moved to its destination, the person can tilt the platform back onto the ground. Brakes will be installed, which can be activated at the handles. With the use of a van loading ramp, the transport device can be loaded into a van. A rain cover will protect robot from rain.



(a) Concept A in docking mode.



(b) Concept A in transport mode.

Figure 4: Concept A

Strengths

- Simple way to transform the docking station into a transport device, because only one frame needs to be lowered.

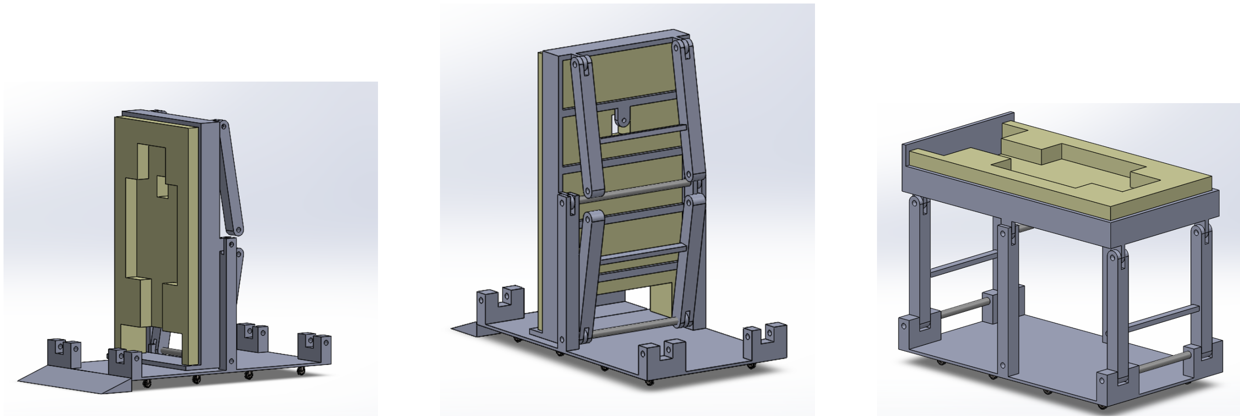
Weaknesses
- It can be difficult to maneuver it.
- It requires some degree of physical strength in order to operate.
- It can be difficult to use on rough terrain.
- It can be difficult to load the transport device into a van.

3.3 Concept B

Table 6: Concept B with its sub-solutions given in Figure 3.

Sub-solution	**Description**
A1	Small ramp to put the robot into the docking station.
B3	Pin connection to connect the neck of the robot to a frame.
C1	Wheel chocks to prevent the wheels from moving.
D1	Tipping mechanism to lower the frame in order to convert the docking station into a transport device.
E4	Velcro straps to attach the robot to the transport device.
F1	Only 2 wheels are swivel wheels. The rest of the wheels are non swivel wheels.
G2	Box to protect the robot from rain during transport.
H2	Van loading ramp to put the transport device into a van.
I1	Foot brakes to break the transport device during transport.

Concept B (Figure 5) is based on last year's design [2]. Table 6 shows which sub-solutions, drafted in Figure 3, are used in this concept. The robot drives up a ramp to get onto the docking station and foam structure (Figure 5a). The gap at the bottom of the foam structure allows for the wheel structure of the robot. The foam structure is enclosed in a frame with a pin connection point which attaches to the neck of the robot, and the body is held in place with velcro straps. When in docking mode, the four legs at each corner are folded in (Figure 5b), and the bottom two legs are connected with a beam to make the frame stand vertically. To switch to transport mode (Figure 5c), the beam connecting the bottom legs is removed and the frame with the robot rotates 90 degrees around its middle axis so it lies horizontally. The four legs are then unfolded and secured with a beam at the base. The device has eight wheels, with the front two wheels being swivel wheels and the back two wheels having breaks. To load the device into a van, a van loading ramp is used, and a box is constructed to cover it and protect it.



(a) Concept B in docking mode from the front.

(b) Concept B in docking mode from the back.

(c) Concept B in transport mode.

Figure 5: Concept B

Strengths
- The robot is protected by the foam structure.
- It is easy to maneuver the transport device.

Weaknesses
- The mechanism that must be implemented to flip the frame is complex.
- Converting the docking station into a transport device might be a complex and time consuming task.
- The flipping action of the mechanism can be dangerous for the user, as body parts can become trapped.
- If the frame flips quickly, it can cause a severe impact on the user if the user gets hit.
- It can be difficult to load the transport device into a van.

3.4 Concept C

Table 7: Concept C with its sub-solutions given in Figure 3.

Sub-solution	Description
A1	Small ramp to put the robot into the docking station.
B1	Carabiner hook to connect the neck of the robot to a frame.
C3	Wheel clamps to prevent the wheels from moving.
D2	Vertical extendable frame to lower the frame in order to convert the docking station into a transport device.

E3	Ratchet straps to attach the robot to the transport device.
F2	All wheels are swivel wheels.
G1	Rain cover to protect the robot from rain during transport.
H1	Hand crank to eventually put the robot inside the van.
I1	Foot brakes to break the transport device during transport.

Concept C has a similar design to Concept A for its hand truck, with some of the same mechanisms. Table 7 shows which sub-solutions, drafted in Figure 3, are used in this concept. The robot drives into the docking station via a foldable ramp. The neck of the robot can be connected to the corresponding connection point on the top of the frame. The robot's body can then be secured to the frame. To convert the docking station into a transport vehicle, the upper part can be lowered, causing the robot to sit in a crouched position. The main difference between this concept and Concept A is its movement mechanism and the method of putting the transport device into a van. It has four wheels, two wheels at the back can be braked. This concept consists of two bases: an upper base and a lower base. To put it into a van, the mechanism underneath the lower base can raise or lower the whole device. When raised, the upper base, with the robot attached, will be disconnected from the lower base where after it can be slid out into the van. The floor of the lower base has rolling bars to enable sliding of the upper base. Lastly, a rain cover will protect the robot from rain.

(a) Concept C in docking mode.

(b) Concept C in transport mode.

(c) Concept C, the rolling bars allow the upper base to slide inside a van.

Figure 6: Concept C

Strengths
- The transport device is easy to maneuver.
- No separate ramp needed to put the transport device into a van.

Weaknesses
- Designing the leg mechanism to raise and lower the device can be a complicated task.
- It is challenging to get the transport device into and out of the van due to the absence of rolling bars inside the van. These rolling bars are needed to slid the upper base out of the van with ease.
- If the lower base is too heavy and big to pick up, a van loading ramp is still needed to put the lower base inside the van.

3.5 Concept selection

Table 8 gives an overview of the quantitative assessment for the 3 concepts. The requirements were rated weighted on a scale of 1 to 5, with 1 representing not important and 5 representing critical importance. The concepts were then assigned a score of 1 to 10, with 1 being 'poor' and 10 being 'excellent' based on their performance against the requirement. The scores were multiplied by their relative weights and then all totaled to determine the final score.
Concept A has the highest score of 654 points, while concept C has 648 points. Concept B has the lowest score, at 593 points.
Concept A scores highly in terms of requiring minimal effort from the user. It also scores highly in terms of its easy manufacturability and straightforward design implementation. Additionally, the conversion method to transform the docking station into a transport device of concept A scored high. These requirements are weighted highly, thus they are amongst the most important requirements that need to be met. However, concept A lacked in maneuverability. Concepts B and C scored high on the maneuverability aspects. However, the conversion method to transform the docking station into a transport device of concept B scored low. The tilt-mechanism may require more strength of the user and it can be dangerous for the user. While the mechanism to put the transport device into a van of concept C is useful, its design is complex. Therefore, a van loading ramp would be easier to implement and achieve the same goal as well. To conclude, concept A will be detailed further and the wheelbase of concept B will be considered to incorporate in the final design.

Table 8: Quantitative assessment of the concept selection

Requirement	**Weight (1-5)**	**Score A (1-10)**	**Total A**	**Score B (1-10)**	**Total B**	**Score C (1-10)**	**Total C**
Connecting and disconnecting the robot from the docking station							

Putting the robot from the start position in the docking station and taking it out of the docking station to the start position is a task that is quick to complete. The start position is when the robot is one meter in front of the docking device.	3	8	**24**	6	**18**	8	**24**
Putting the robot from the start position in the docking station and taking it out of the docking station to the start position is a task that is able to be performed with no more lifting than official working regulations [5].	5	8	**40**	8	**40**	8	**40**
The docking station can hold the weight of the robot with an appropriate load limit.	5	7	**35**	8	**40**	6	**30**
The docking station can hold the robot when the power off the robot is off.	5	9	**45**	9	**45**	9	**45**
The docking station fits in a room with the following minimum dimensions: 4.00 x 4.00 x 2.50 m (L x W x H).	4	8	**32**	6	**24**	7	**28**
The robot is chargeable when it is positioned in the docking station.	3	8	**24**	8	**24**	8	**24**
When the robot is in docking state, the arms can be moved.	3	8	**24**	6	**18**	8	**24**
When the robot is in docking state, the wheels of the robot can not move and turn.	3	7	**21**	5	**15**	7	**21**
Converting the docking station with the robot attached into a transport device and vice versa.							

Converting the docking station with the robot attached into a transport device and vice versa is a task that is quick to complete.	3	9	**27**	5	**15**	7	**21**
Converting the docking station with the robot attached into a transport device and vice versa is a task that is able to be performed with no more lifting than official working regulations [5].	5	9	**45**	5	**25**	9	**45**
There should be no dangers for the users during the conversion of the device.	5	9	**45**	5	**25**	8	**40**
When the docking station is converted into a transport device, the robot is firmly attached to the transport device.	4	7	**28**	8	**32**	7	**28**
Transporting the transport device to different locations.							
Transporting the transport device with the robot is a task that is quick to complete.	3	6	**18**	8	**24**	7	**21**
Transporting the transport device with the robot is a task that is able to be performed with no more lifting and pushing than official working regulations [5].	5	5	**25**	8	**40**	8	**40**
The transport device is easily maneuverable.	4	5	**20**	9	**36**	8	**32**
When outside, the robot is protected from the rain.	2	10	**20**	10	**20**	10	**20**
The transport device can hold the weight of the robot with an appropriate load limit.	5	6	**30**	8	**40**	7	**35**

The transport device is able to pass through double doors, it must fit in a van and it must fit in an elevator.	5	9	**45**	6	**30**	7	**35**
When loading and unloading in a van, the transport device is able to bridge a certain height.	4	6	**24**	6	**24**	8	**32**
It is possible to brake the vehicle during transport state.	3	7	**21**	7	**21**	7	**21**
General requirements for the docking station / transport device							
Different components of the mechanism are connected in a way so it is able to be disassembled.	2	8	**16**	6	**12**	6	**12**
The design should incorporate mechanisms that are easy to manufacture.	5	9	**45**	5	**25**	6	**30**
Total			**654**		**593**		**648**

3.6 Concept discussion

During a concept discussion, it was clear that concept A was the preferred option, given that concepts A and C are close in points, due to its simplicity. However, for the requirement 'When the robot is in docking state, the wheels of the robot can not move and turn' must be revised. The robot must be able to move around independently, while the docking station moves with the robot and functions as a holding frame to intercept the robot in the event of a shutdown. The current frame presents an issue where the wheels of the robot interfere with the frame when the robot is moving around (Figure 7). This issue must be addressed in the final design. Additionally, when the robot is in the docking station, the wheels of the robot must be touching the floor so the robot can move around. This means that row A in the morphological overview (Figure 3) is not in use, as the robot will not be put on top of the base-floor of the docking station. When the docking station is transformed into a transport device, the robot should be able to be lifted off the ground in order to make transportation possible. Because the concepts are made without the changed requirements in mind, the changed requirements will be adjusted in the validations of the requirements for the final design (Table 9) in chapter 4 and are marked with **.

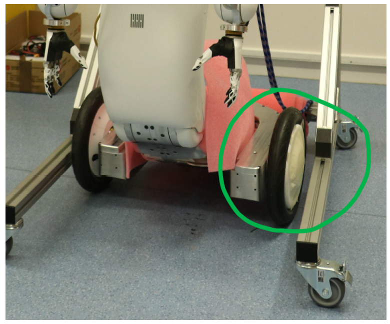


Figure 7: The wheels of the robot may not interfere with the frame when it is moving around [4].

4 Final design

This chapter outlines the final design, including improvements to Concept A and the addition of fine details. The design will then be validated against the requirements outlined in chapter 2 to ensure it meets all necessary criteria. It is important to note that in concept A, the mechanism to move the upper part of the device is not specified. A hydraulic jack and rail-mechanism will be applied as the mechanism to move the upper part of the device in the final design. This will be further discussed in this chapter. Appendix A.1 provides a list of materials and Appendix A.2 presents technical drawings.

4.1 Description of the final design

Figure 8 shows the front of the docking station, while figure 9 shows the front of the transport device. It is made out of several aluminium slot profiles, which are connected with each other with several corner brackets.

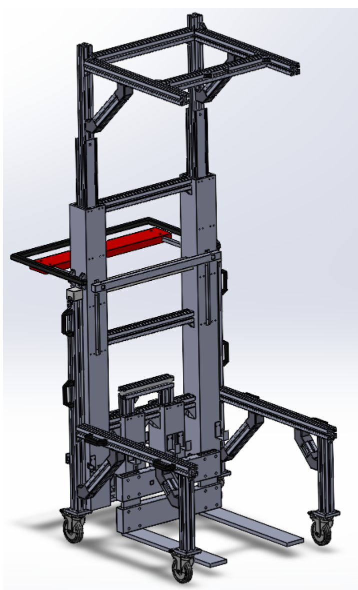


Figure 8: Front view of the docking station

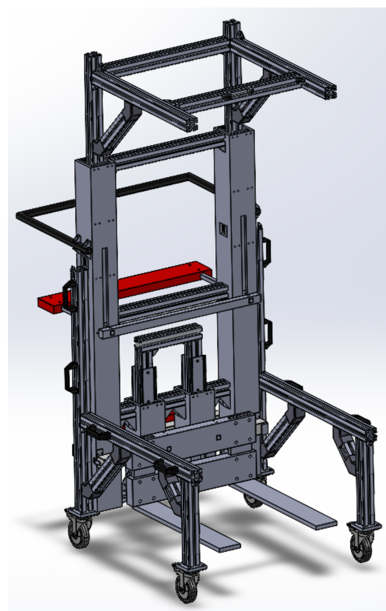


Figure 9: Font view of the transport device.

When the device is in its docking station mode, the forklift tines are in the lowest position, while the top-part is extended upward. The robot is standing upright (Figure 10), with its wheels in contact with the ground (Figure 11) and its neck connected to the top-part. The top-part has a connection point to connect the robot (Figure 12). The back of the robot is facing the back of the docking station and the robot is situated above the forklift tines. However, the robot does not touch the forklift tines.
The docking station measures a height of 205 cm, a length of 112 cm and a width of 82 cm. It has four small handles on each side and a large handle at the back. The handles could act as a connection point to secure the device inside a van. The handles are coloured black in Figure 8 and 9.

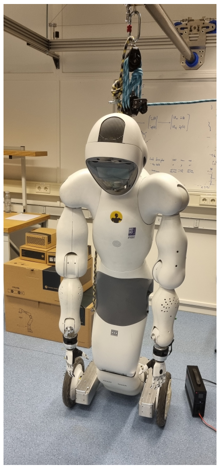


Figure 10: The robot standing upright.

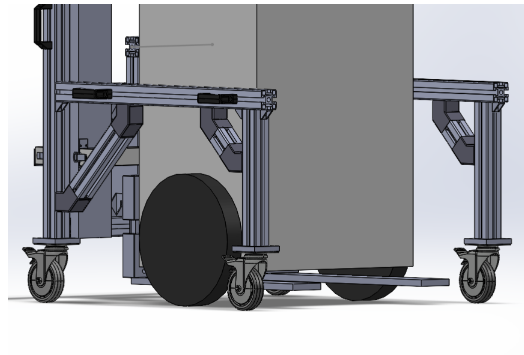


Figure 11: The forklift are in its lowest position. The robot is situated above the forklift tines, while the wheels of the robot are touching the ground.

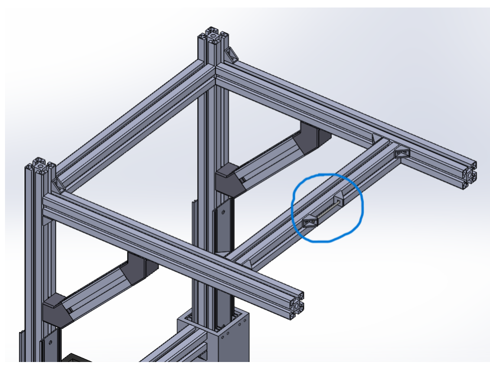


Figure 12: Connection-point to connect the robot with the top-part of the frame.

To convert the docking station into a transport device, the forklift tines will be lifted up, while the top part will be lowered (Figure 13). The top-part is lowered 27.5 cm, making the height of the transport vehicle 177.5 cm. The in-extendable top-part allows the height of the device to be reduced, enabling the robot to be lowered and to be in a kneeling position when the top part is moved down (Figure 14). The forklift tines are pushed up 12 cm, causing the robot to be lifted up from the ground (Figure 15).

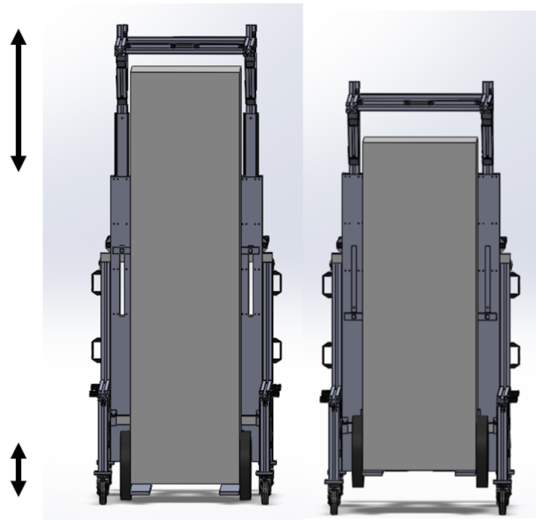


Figure 13: When converting the docking station into a transport device, the top part will be lowered and the forklift tines will be lifted up.

Figure 14: The robot in a kneeling position [34].

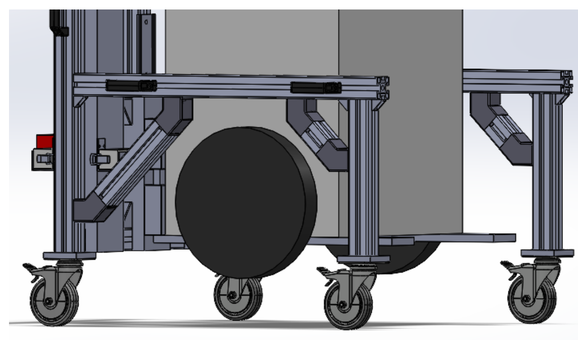


Figure 15: Font view of the transport device.

A hydraulic jack, such as the one shown in Figure 16, can be used to lift and lower the top-part and the forklift tines of the device. To lift the top-part, the upper red bar needs to be pushed up by the hydraulic jack, causing the top-part to expand. To lower the top-part, the jack must be raised until it reaches the upper red bar and then slowly moved down. Figure 17 shows a schematic view of the hydraulic jack to push the upper red bar up, and thus extending the top-part of the frame. Similarly, when the lower red bar is pushed up by the jack, the forklift tines will be raised. To lower the forklift tines, the jack needs to be lifted until it reaches the bar and then slowly moved down.

Figure 16: Example of a hydraulic jack that can be used to move the top-part and the forklift tines [35].

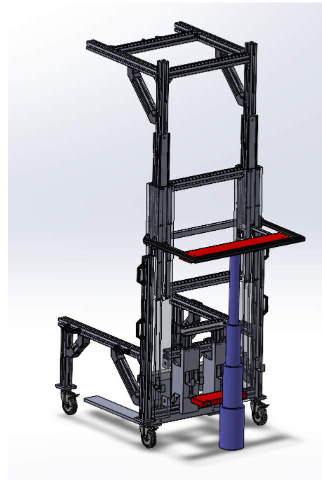


Figure 17: Hydraulic jack implemented to move the top-part.

The slots inside the beams allow vertical movement of the top-part and the forklift tines. The red bar for the top-part can be moved up 27.5 cm to raise the top-part (Figure 18).
The red bar for the forklift tines can be moved 12 cm to raise the forklift tines (Figure 19).

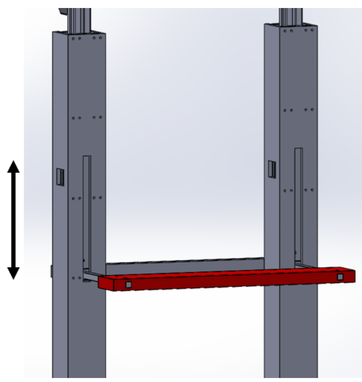


Figure 18: The red bar can be moved up 27.5 cm to raise the top-part.

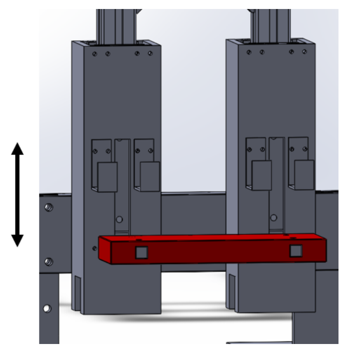


Figure 19: The red bar can be moved 12 cm to raise the forklift tines.

When the top-part is pushed up, it will rest on the white support beam that needs to be placed when the top-part is pushed up (Figure 20). The support beam makes sure that the top-part can not move down. The white support beam goes through the pink vertical beams and can be locked with snap locks on each side. When the top-part is lowered, the support beam will be removed. There are no locks installed when the top-part is retracted, as the gravitational force of the robot and the top-part and the interior space of the vertical beams (shown in pink) will make sure that the top-parts stays in place.
Similarly, when the fork lift tines are pushed up, they will rest on the two white support beams (Figure 21). These support beams also make sure that the forklift tines can not move down, even when the robot is lifted. One support beam is located in the front and the other one in the back. There are 8 hooks, 4 on each side, which can hold the support beams. These hooks are attached to the 2 pink vertical beams and 2 green vertical beams. There are 4 snap locks in total, 2 on each side, to secure the support beams. When the fork lift tines are lowered, the 2 support beams will be removed. There are no locks installed when the forklift tines are retracted, as the gravitational

force of the forklift tines and the interior space of the vertical beams (shown in green) will make sure that the forklift tines stay in place.

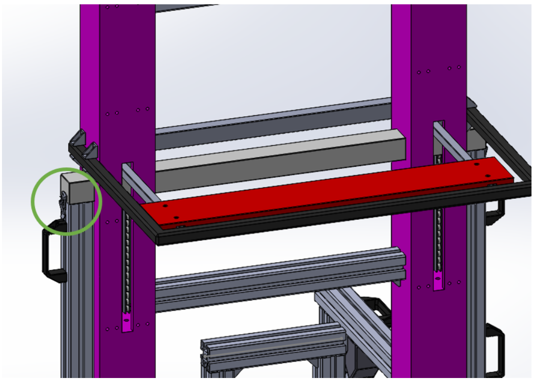


Figure 20: The top-part is pushed up and is resting on top of the white support beam. The white support beam is put through the pink vertical beams and locked with snap-locks (circled).

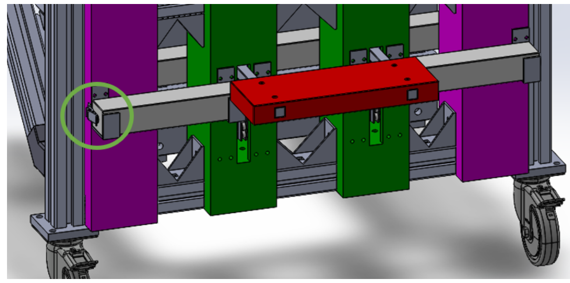


Figure 21: The fork lift tines are pushed up and is resting on top of the 2 white support beams, which are held by the hooks. The support beams are locked with snap-locks (circled).

Figure 22 shows the top-part construction without the pink beams (as seen in Figure 20) that enclose the profiles of the top-part. The two blue cube-shaped connection points connect the red bar with the top-part via two shafts.
Likewise, Figure 21 shows the forklift tines construction without the green beams (as seen in Figure 21) that enclose the profiles of the forklift tines construction. The two blue cube-shaped connection points connect the red bar with the forklift tines via two shafts.

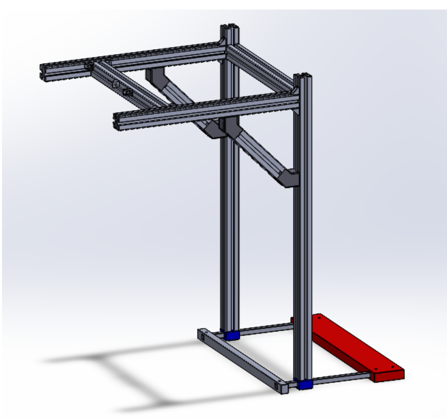


Figure 22: View of the top-part construction without its enclosure.

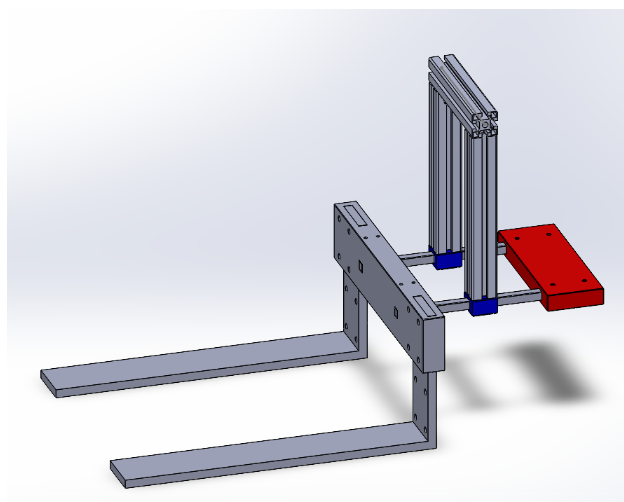


Figure 23: View of the forklift tines construction without its enclosure.

Within the pink and green vertical beams, an aluminum profile is connected inside each beam (Figure 24). Each profile is connected by 2 rail-mechanisms, shown in yellow, allowing the top-part and the forklift tines to be moved up and down. The rail-mechanisms, with the top-part and the forklift tines attached, slide inside the pink and green beams.

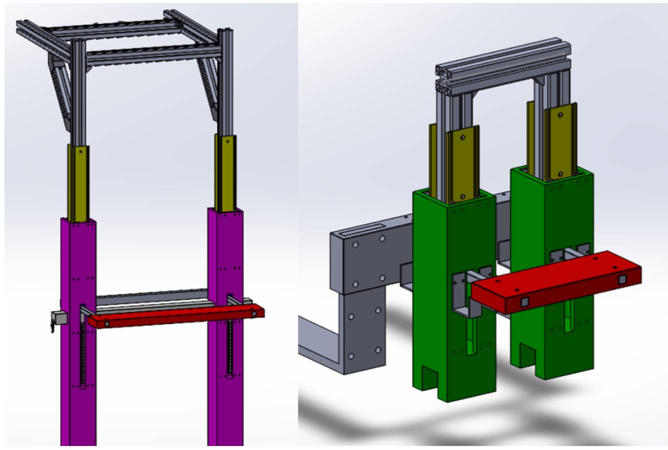
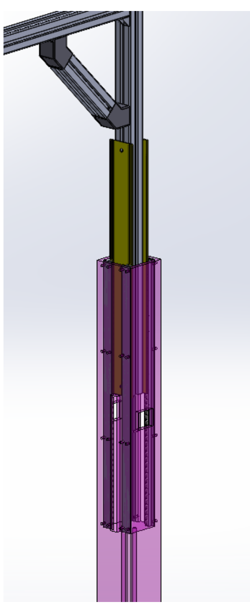


Figure 24: Left: 4 rail-mechanisms, 2 on each side, are implemented to move the top-part (yellow). Right: 4 rail-mechanisms, 2 on each side, are implemented to move the forklift tines (yellow).

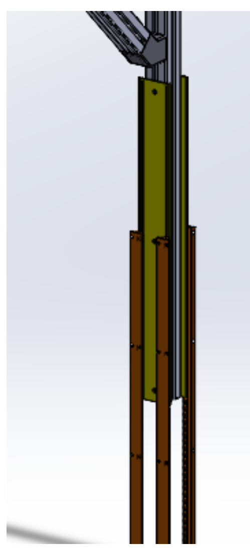
Figure 25a shows a view of the rail mechanism, inside the pink vertical beam of the top-part. This rail mechanism is the same between the top-part and the forklift tines, with the only difference being the difference in length of the mechanism.

Each profile, consisting of 4 in total, has 2 yellow rails attached to it, as seen in Figure 25b. Each vertical beam (shown in pink and green in Figure 24) has 4 rows of orange wheels installed within its corners.

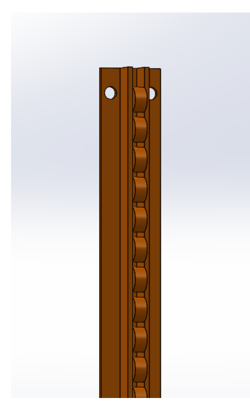
Figure 25c presents a view of these rows of wheels, which allows the rails to slide through the vertical beams.



(a) View of the rail-mechanism (yellow), within a beam (pink).



(b) View of the connection between rails (yellow) and the row of wheels (orange).



(c) View of the rows of wheels.

Figure 25: View of the rail-mechanism.

The device consists of four swivel wheels with brakes (Figure 26), connected to each other by an elevated profile (shown in blue) that is 45 cm from the ground. This allows the wheels of the robot to move without interference from the frame, while the docking station serves as a holding frame to intercept the robot should a shutdown occur. Because the the radius of the wheels of the robot is 30 cm, it can not touch the frame when the robot is turning. The horizontal profile is connected to the vertical profile with two brackets on each side. The horizontal profile (shown in blue) is connected to the vertical profiles (shown in green) by two brackets on each side, with the front brackets being shorter than the back brackets to provide space for the robot's wheels to rotate.

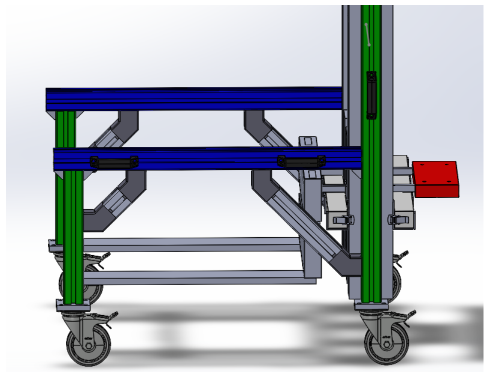


Figure 26: Side view of the wheel construction of the device.

Strengths
- The transport device is easy to maneuver.
- Simple way to transform the docking station into a transport device, because only one frame needs to be lowered.
- Not much strength is necessary to convert the docking station into a transport device.

Weaknesses
- A van loading ramp is needed to put the transport device into a van.
- There are 3 supporting beams that constantly needs to be taken out and putting back.
- A separate hydraulic jack is needed.
- The fact that both the top-part and the forklift tines are not locked when in the lowest position might not provide adequate security.
- The extended top-part of the frame may begin to bend over time due to the weight of the robot, making it increasingly difficult for the mechanism to slide the top-part up and down. The same may occur for the fork-lift tines.
- The lack of support for the front wheels may lead to instability.

4.2 Validation of the final design

Table 9 shows the validation of the requirements of the final design. Some requirements can only be fully validated when a prototype has been made and tested. These requirements are noted with unknown in the table and can be evaluated once the prototype has been created.

*Table 9: Validations of the requirements for the final design. Adjusted requirements are marked with **.*

Requirement	*Validation and specification*	*Requirement met?*
Putting the robot from the start position in the docking station and taking it out of the docking station to the start position is a task that is quick to complete. The start position is when the robot is one meter in front of the docking device.	The process can be completed in 5 minutes with at least two people.	Unknown
Putting the robot from the start position in the docking station and taking it out of the docking station to the start position is a task that is able to be performed with no more lifting than official working regulations.	A individual user is not allowed to lift more than 23 kilos when putting and taking the robot in and out of the docking station in accordance with the working conditions decree [5].	Yes
The docking station can hold the weight of the robot with an appropriate load limit.	The minimum weight that the docking station must be able to support is 220 kg in accordance with the International Electrotechnical Commission [6].	Unknown
The docking station can hold the robot when the power off the robot is off.	The minimum hanging height required for the robot in the docking station is 180cm, so that it will not topple even when the power is off due to the weight of the robot. The robot's mounting point is located in the neck, as this is the only way to link the robot to something else.	Yes
The docking station fits in a room with the following minimum dimensions: 4.00 x 4.00 x 2.50 m (L x W x H).	The maximum dimensions of the docking station are 3.00 x 3.00 x 2.30 m (L x W x H).	Yes
The robot is chargeable when it is positioned in the docking station.	Wiring must be possible in the docking station to charge the robot. The charging-point is at the back of the robot.	Yes
When the robot is in docking state, the arms can be moved.	The arms can be moved in an area that is needed for the calibration.	Yes

The robot can move around, while the docking station functions as a holding frame to intercept the robot should a shutdown occur.**	The robot can move around with the docking station following it. The wheels of the robot are not allowed to interfere with the docking station.	Yes
Converting the docking station with the robot attached into a transport device and vice versa is a task that is quick to complete.	The process can be completed in 10 minutes with at least two people.	Unknown
Converting the docking station with the robot attached into a transport device and vice versa is a task that is able to be performed with no more lifting than official working regulations.	A individual user is not allowed to lift more than 23 kilos per person during the conversion in accordance with the working conditions decree [5].	Yes
There should be no dangers for the users during the conversion of the device.	All metal edges should be rounded or covered with a non-slip material. All moving parts should be securely guarded. Any potential pinch points should be eliminated. Body parts of the users must not be trapped during the conversion.	Yes
When the docking station is converted into a transport device, the robot is firmly attached to the transport device.	The robot must be attached to the docking station in a way to limit its movements in any direction (x, y and z plane) up to 5 cm. The robot's arms should not swing and the hip and head should not sway along the way.	The robot is tied up during transport, but the level of swinging of the robot is unknown.
Transporting the transport device with the robot is a task that is quick to complete.	The process of putting the transport device in a van should take 5 minutes with the help of two people.	Unknown
Transporting the transport device with the robot is a task that is able to be performed with no more lifting and pushing than official working regulations.	The weight of the transport device and coefficient of friction between the ground and the device must be taken into account in the design so that no more than 23*9,81 = 225 Newton is lifted and pushed during the transportation of the transport device with the robot.	The weight of the device is unknown, so the amount of force needed to push the device is also unknown.
The robot can be lifted off the ground to make transportation of the robot possible.**	In order to avoid contact with the ground, the robot needs to be lifted a minimum of 10 cm.	Yes

The transport device is easily maneuverable.	The transport vehicle must be able to drive up a 1:12 slope, which is a suitable slope size to push objects [7]. The transport device must be able to make perpendicular turns of 90 degree. The transport device must be able to withstand canted and uneven paths and it can drive over 10 cm bumps and pits.	It is unknown if it can drive up a 1:12 slope, It can not drive over 10 cm bumps and pits, as the radius of the wheels are 5 cm. It can make 90 degree turns.
When outside, the robot is protected from the rain.	During the transportation, the robot can not become wet.	Yes
The transport device can hold the weight of the robot with an appropriate load limit.	The minimum weight that the docking station must be able to support is 220 kg in accordance with the International Electrotechnical Commission [6].	Unknown
The transport device is able to pass through double doors, it must fit in a van and it must fit in an elevator.	The maximum dimensions of the transport device is 2.30 x 1.50 x 1.80 m (L x W x H) (It is therefore possible that the dimensions differ from the docking station).	Yes
When loading and unloading in a van, the transport device is be able to bridge a certain height.	The maximum height that needs to be bridged is 50 cm.	Yes
It is possible to brake the vehicle during transport state.	When the brakes are applied, the transport device can not move in any direction.	Yes
Different components of the mechanism are connected in a way so it is able to be disassembled.	It can be validated by disassembling the device.	Yes
The design should incorporate mechanisms that are easy to manufacture.	-	The rail mechanism can be difficult to manufacture.

5 Discussion and conclusion

In conclusion, the design of the transport device meets almost all the requirements that were outlined in Chapter 2 and allows the robot to be transported from location A to B. The design is easy to maneuver and requires no strength to convert the docking station into a transport device.

The design of the transport device has some weaknesses, such as the need for a van loading ramp to put the device into a van and the requirement for three separate supporting beams that need to be taken out and put back. To address these issues, the next design could implement a mechanism that can secure the extended parts without the need for additional beams, such as extended ladders. When the top-part and the forklift tines are extended, the mechanism should be able to lock the profiles to prevent the top-part from falling down.

A separate hydraulic jack is needed to move the different parts of the device. As an improvement, this hydraulic system could be implemented in the design, so that a separate hydraulic jack is not needed.

Furthermore, the extended top-part of the frame may start to bend over time due to the weight of the robot, which can make it difficult to slide the top-part up and down. To improve this, the vertical extendable profiles can be made thicker, which will increase the strength and prevent bending. Additionally, the profiles that form the frame can also be made thicker to increase its firmness and allow it to support heavier weights.

The hooks that hold the support beams of the forklift tines need to be thickened in order to ensure that the device can reliably carry the weight of the robot. This improvement will help to prevent the tines from bending or breaking under the stress of the load.

Additionally, the shafts that holds the forklift tines might not robust enough to hold the weight of the robot.Therefore these shafts must be strengthened in order to support the weight of the robot. This can be done by either increasing the thickness of the shafts or choosing higher-grade materials that are more capable of bearing the load. By making these necessary alterations, the shafts will be able to withstand the weight of the robot.

The transportation device currently stands at 177.5 cm tall, with the potential to lower the slide-mechanism of the top-part by up to 30 cm. This will reduce the height of the transport device and therefore it can fit in even smaller vans.

To improve the stability of the device's front wheels, the connection brackets connecting the vertical profile of the front wheels to the horizontal profile can be lengthened. Another solution is to increase the width of the design by up to 68 cm, while still meeting the requirements. This would allow the horizontal profile to be placed closer to the ground, thus improving the stability of the front wheels and avoiding any contact with the robot's wheels due to the increased distance between them.

For future studies, structural analysis is needed in a design to ensure that the design is safe and structurally sound. It is needed to evaluate the stresses, strains, and deformations that the device is subjected to and determines how the device will react to these forces. Structural analysis also helps to identify areas of weakness and/or stress concentrations and determine if additional reinforcement is needed.

Material research is also important for future studies. This research helps to identify the best material to be used in the design, as different materials can have different effects on the performance of the device. It is important to understand the properties of different materials, such as their strength, stiffness, and thermal properties, in order to choose the best material for the design. The material also needs to be considered for its cost-effectiveness, weight, and durability.

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A Appendices

A.1 Appendix A: List of materials

Table 10: List of materials (dimensions in mm).

ITEM NO.	PART	DESCRIPTION	QTY.
1	45 Degree Connector	45 x 45	12
2	Beam	100 x 100 x 1245	2
3	Beam	16 x 16 x 410	2
4	Beam	100 x 30 x 640	1
5	Beam	25 x 30 x 638	1
6	Beam	40 x 45 x 750	1
7	Beam	100 x 100 x 345	2
8	Beam	100 x 40 x 500	1
9	Beam	100 x 30 x 280	1
10	Beam	45 x 40 x 640	2
11	Beam	100 x 40 x 500	1
12	Big Handle		1
13	Connector	76 x 76 x 12	4
14	Connector	45 x 45 x 30	4
15	Cornerbracket	18 x 22	32
16	Double-Cornerbracket	51 x 45 x 81	4
17	Double-Cornerbracket	51 x 45 x 100	2
18	Forklift Tines		2
19	Hook		12
20	Profiile	245 x 45 x 45	1
21	Profile	1000 x 45 x 45	2
22	Profile	700 x 45 x 45	2
23	Profile	310 x 45 x 45	2
24	Profile	750 x 45 x 45	1
25	Profile	50 x 45 x 45	2
26	Profile	1300 x 45 x 45	2
27	Profile	515 x 45 x 45	2
28	Profile	550 x 45 x 45	2
29	Profile	200 x 45 x 45	4
30	Profile	240 x 45 x 45	2
31	Profile	80 x 45 x 45	2
32	Profile	460 x 45 x 45	2
33	Profilfe	100 x 45 x 45	1
34	Rails	4.5 x 64 x 580	4
35	Rails	4,6 x 64 x 240	4
36	Row Of Wheels	2 x 25 x 610	8
37	Row Of Wheels	2 x 25 x 270	8
38	Shaft	R 2, 90	1
39	Shaft	16 x 16 x 355	2
40	Small Handle		8
41	Snap Lock		6
42	Wheel	R. 50	4

A.2 Appendix B: Technical drawings

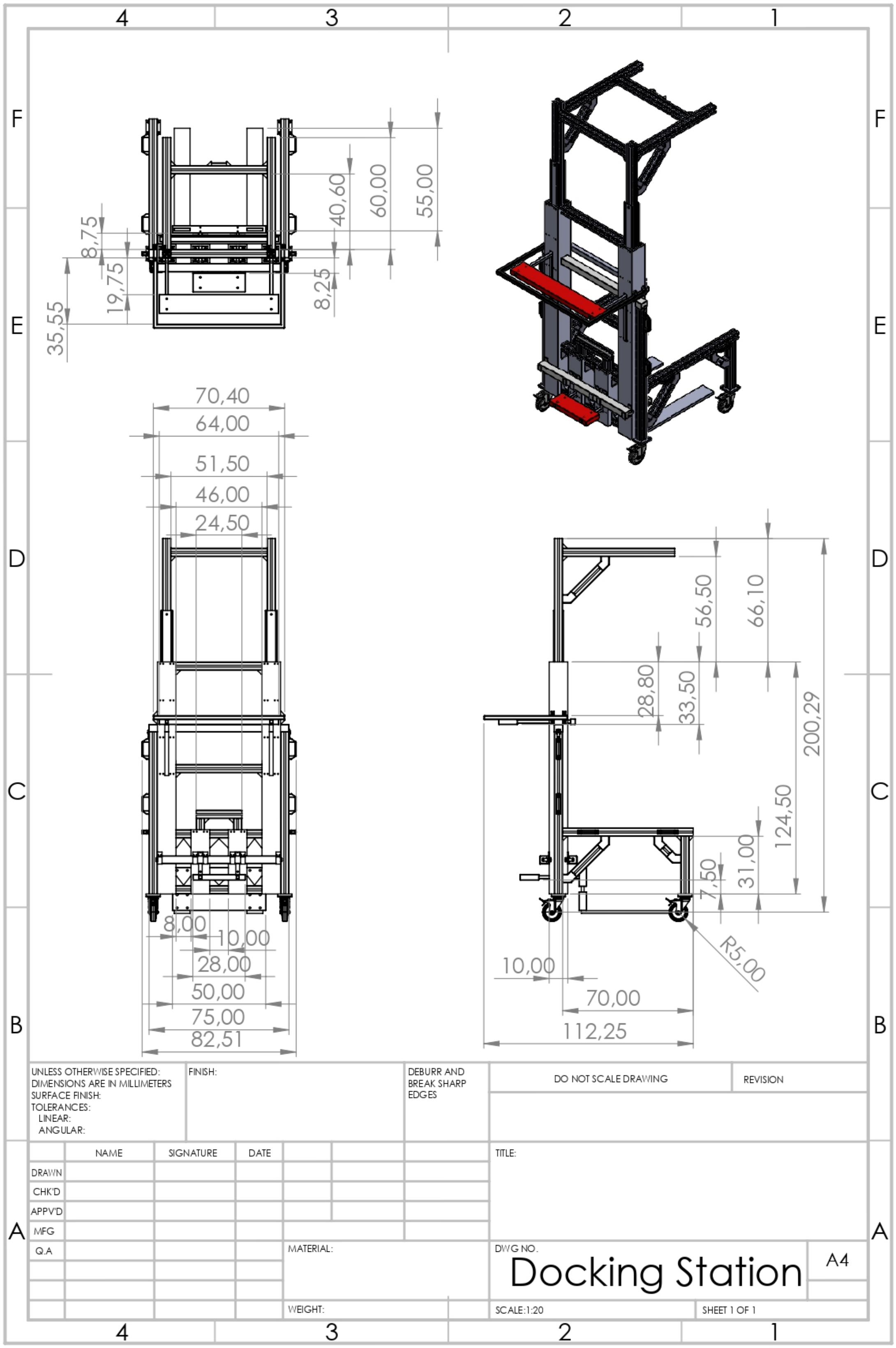

Figure 27: Technical drawing of the docking station

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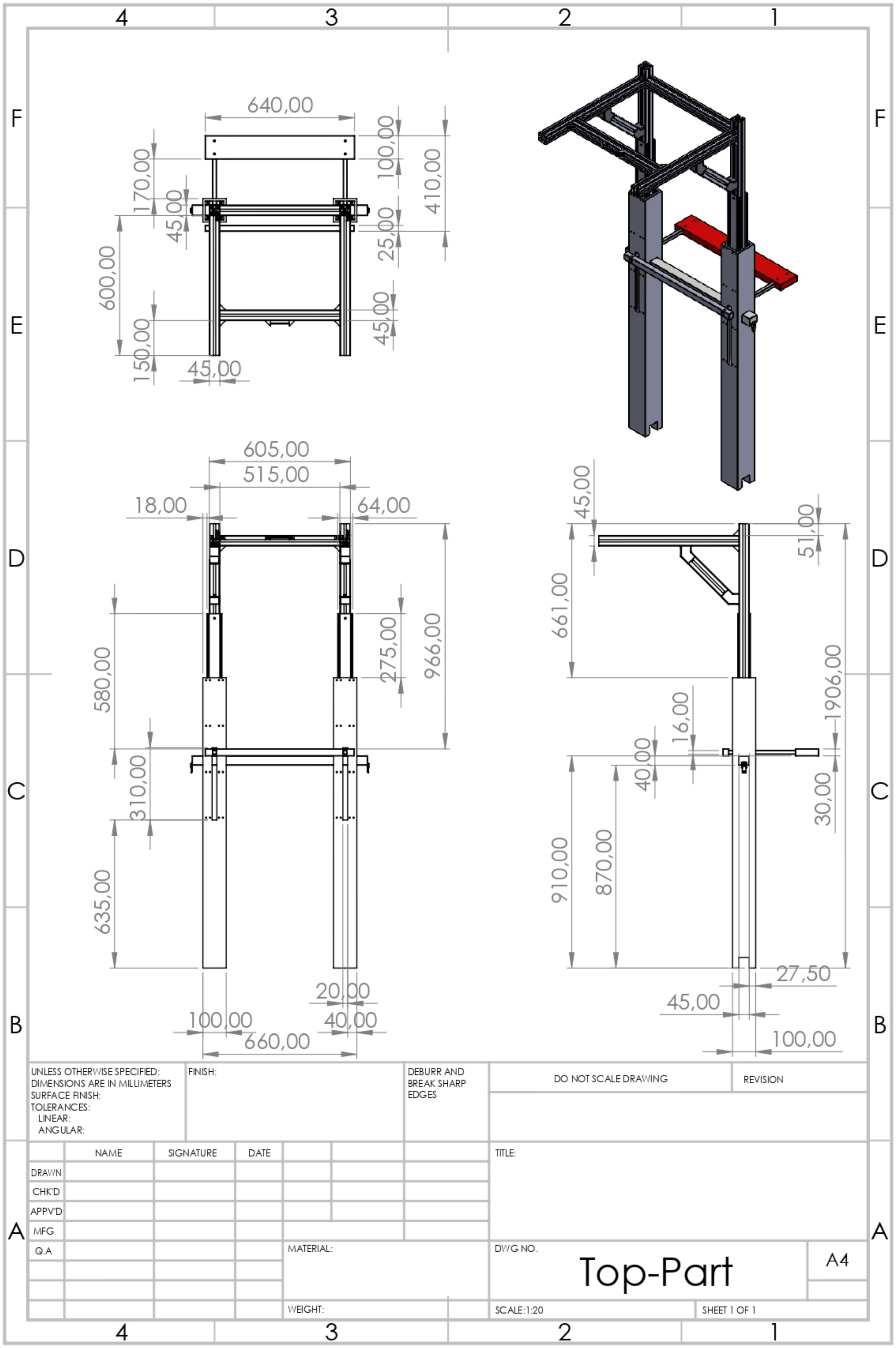

Figure 28: Technical drawing of top-part

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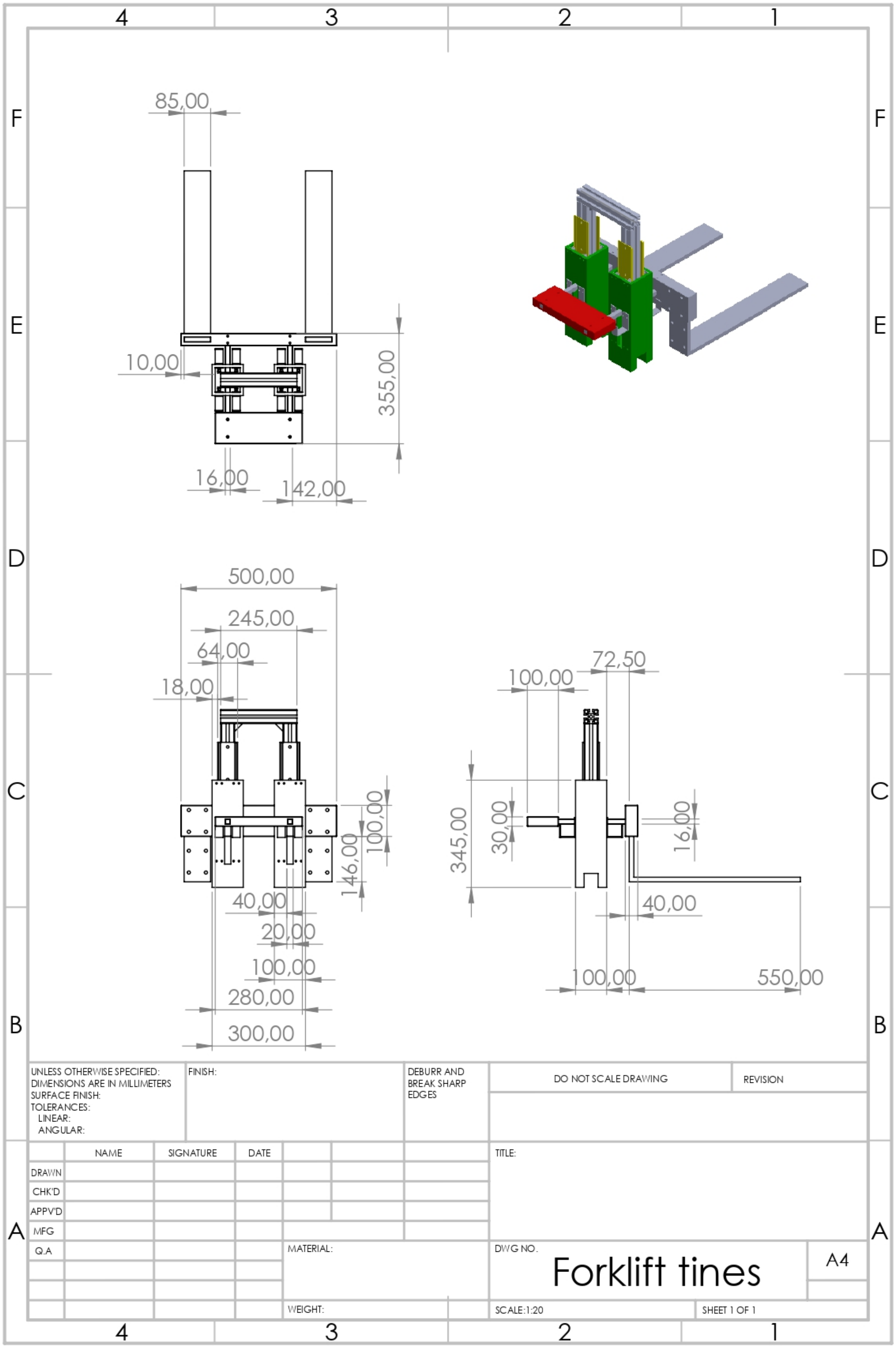

Figure 29: Technical drawing of the forklift tines

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