Fall 2016

Compact Furniture Dolly

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Have you ever had difficulty moving your furniture when you want to vacuum the floor? Have you ever had trouble using furniture sliders or shoulder dolly simply because they are not designed for the type of floor in your house? Our project called Compact Furniture Dolly can help you resolve all these issues in a stable, durable, and safely way.

MEMS 411 Senior Design Final Report

Compact Furniture Dolly

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1 INTRODUCTION

1.1 PROJECT PROBLEM STATEMENT

One problem faced by people during moving is how to move large pieces of furniture, i.e. sofa, mattress, table, refrigerator, etc., conveniently without damaging them. A typical small dolly is incapable of carrying such large pieces, and a bulky dolly is inappropriate for an indoor use because it can damage the furniture and the floor. Besides, in either case, the user should lift up and put the load on the dolly. People who want to change positions of their furniture regularly to get a fresh look for the house, it is cumbersome to call a moving company every time. Our team aims to design a dolly system that can load large pieces of furniture onto adjustable frames with multiple wheels so that the user can tow or push furniture without hassle. The lift function of the dolly can jack up the furniture by pushing up the bottom of the furniture. The lift system does not require much power so that most people can easily load furniture onto the system. The frames are extendable for various types of furniture. When not in use, the system can be disassembled and stowed easily.

1.2 LIST OF TEAM MEMBERS

Gary Hu, B.S. Mechanical Engineering, Class of 2017
Jason Xie, B.S. Mechanical Engineering, Class of 2017
Jiayi Hou, B.S. Mechanical Engineering, Class of 2017
Jieun Yim, B.S. Mechanical Engineering, Class of 2017

2 BACKGROUND INFORMATION STUDY – CONCEPT OF OPERATIONS

2.1 DESIGN BRIEF

We are going to design a compact dolly system to help people easily move heavy pieces of furniture. The dolly system consists of a lifting system, wheels, fixing frames, and a towing handle. The lifting system enables people to slightly lift the corners of the furniture without stoop or squat. The wheels can be attached under the furniture and detached after use. The fixing frames help retain relative position of the wheels and provide an attachment point for the towing handle. The towing handle provides a place to hold and drag while towing, minimizing human power input.

2.2 BACKGROUND INFORMATION

Two existing designs we found are furniture slider and shoulder dolly. Details are included in Appendix D.

Furniture sliders are square or round pads which have one smooth side and one rough side. Lift each corner of the furniture and put a slider underneath so that the smooth edge is towards the floor, which will reduce the friction and make moving much easier. The rough side of slider is designed to retain furniture on the pad.

Shoulder dollies are lifting straps that connect to your shoulders and help take the weight off your back. They help you utilize your stronger muscle groups while also giving you added leverage.

3 CONCEPT DESIGN AND SPECIFICATION – DESIGN REQUIREMENTS

3.1 OPERATIONAL AND DESIGN REQUIREMENTS

3.1.1 Customer interview

Prompt/Question 1 - How do you move your furniture?

- Call some friends to help me move them together
- A furniture dolly that can be operated by one person
- Importance 5

Prompt/Question 2 - Why do you move your furniture?

- To vacuum the space under furniture. To rearrange furniture. And I do that once a year. But I'd like to be able to arrange my furnitures every other month for vacuuming.
- A dolly that can be easily disassembled and stored in a small place
- Importance 4

Prompt/Question 3 - What do you like/dislike about existing furniture moving device, i.e. furniture slider/shoulder dolly?

- Pros: Portable, easy to use, cheap. Cons: Do not work on all types of floor (furniture slider). Need at least two people to operate (shoulder dolly)
- The dolly can run on various types of floor. One person can install/uninstall it.
- Importance 5

Figure 1. Summary of customer interview on three questions

3.1.2 Operational requirements

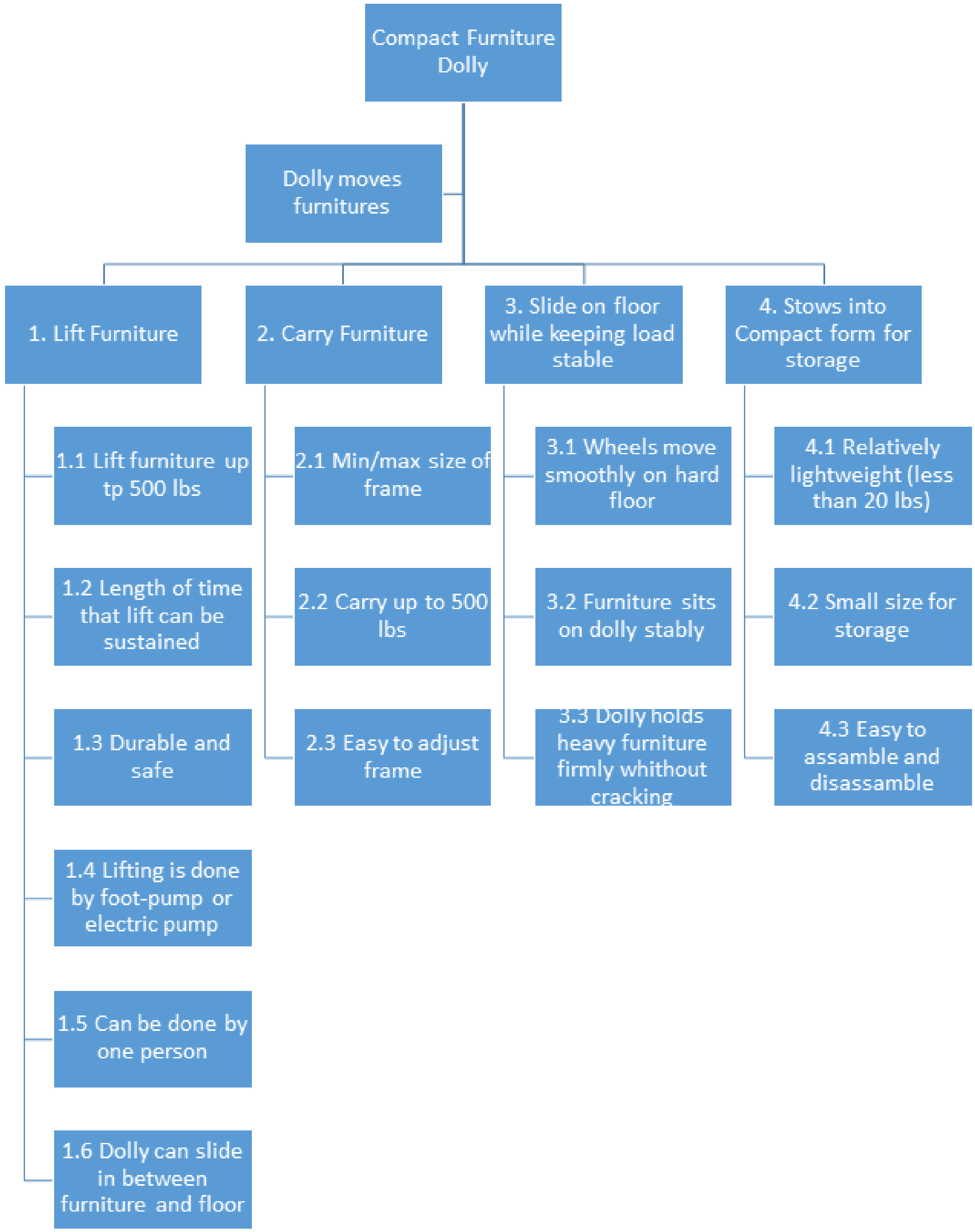


Figure 2. Operational requirements of the furniture dolly

3.1.3 Design requirements

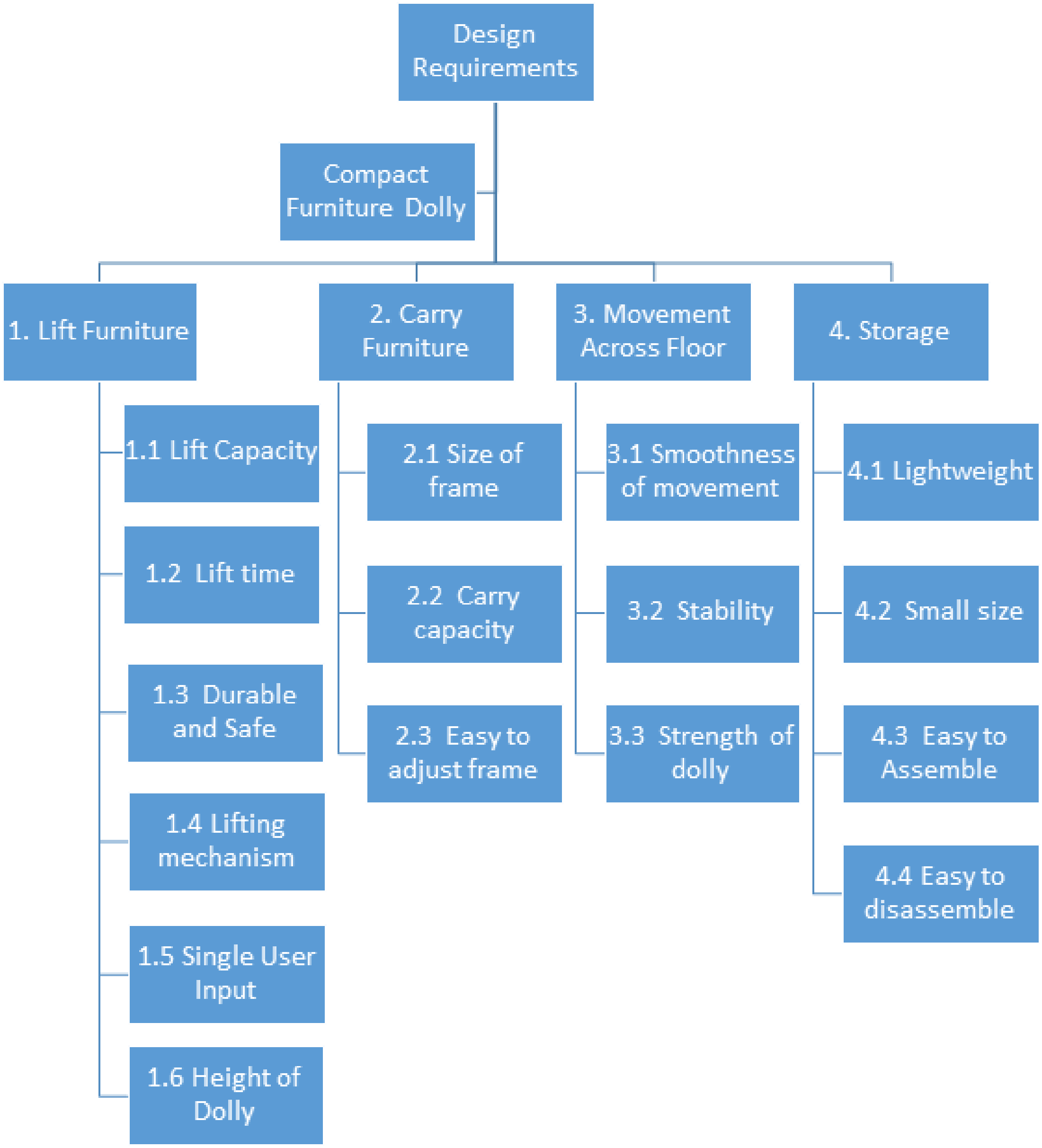


Figure 3. Design requirements of the furniture dolly derived from operation requirements and results of customer interview

3.1.4 Metric list

Table 1. Metric list to evaluate concept designs

Metric Number	Associated Needs	Metric	Units	Worst Value	Best Value	Actual Value	Normalized Score*
1	1.1, 1.3, 2.2, 3.3	Weight capability	kg	225	300		
2	1.2	Lifting time	s	10	60		
3	1.4	Lift using foot-pump or electric pump	binary	0	1		
4	1.5	Number of people needed to operate	nondim.	3	1		
5	2.1, 4.2	Minimum length of frame	m	1.9	1.5		
6	2.1, 4.2	Minimum width of frame	m	0.9	0.6		
7	2.1, 4.2	Maximum length of frame	m	2.6	2.3		
8	2.1, 4.2	Maximum width of frame	m	1.3	0.9		
9	1.6, 4.2	Height of dolly	cm	20	8		
10	2.3	Difficulty of adjusting frame size	rating	5	0		
11	4.1, 4.2	Total weight of dolly	kg	15	3		
12	4.3	Length of time to assemble/install	s	600	15		
13	4.3	Length of time to disassemble/detach	s	600	15		
14	1.3, 4.2	Reusable	binary	0	1		
15	1.5, 3.1	Force input to tow the dolly	N	200	45		
16	1.3	Number of sharp edges	nondim.	10	0		
						Total Score**	

*Normalized Score = |Actual Value - Worst Value| / |Best Value - Worst Value|
**Total Score ranges from 0 to 16. Higher Total Score means better design according to this metrics list.

3.2 FOUR CONCEPT DRAWINGS

3.2.1 Concept drawing 1

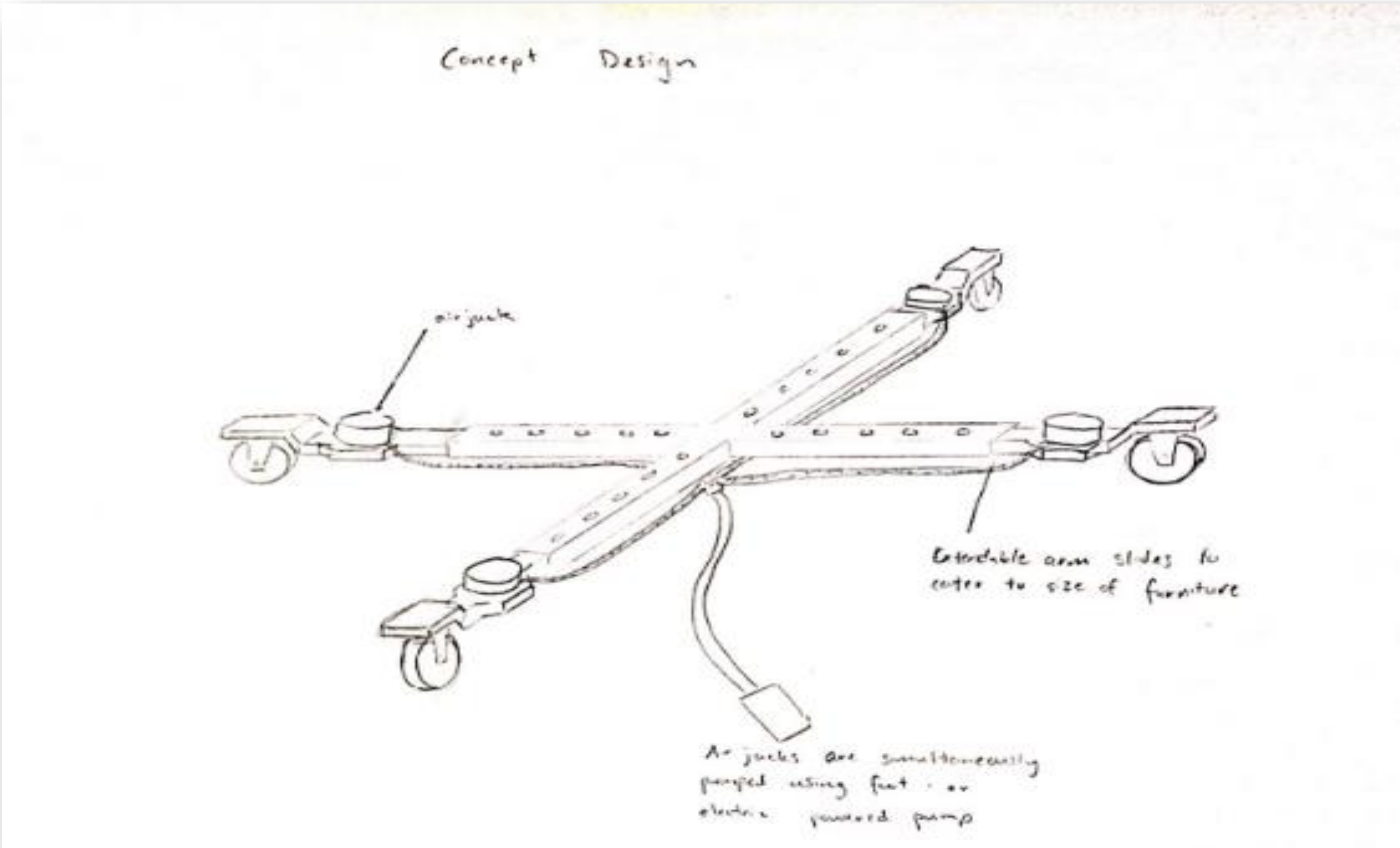


Figure 4. Concept drawing 1 -- Cross-shaped frame

3.2.2 Concept drawing 2

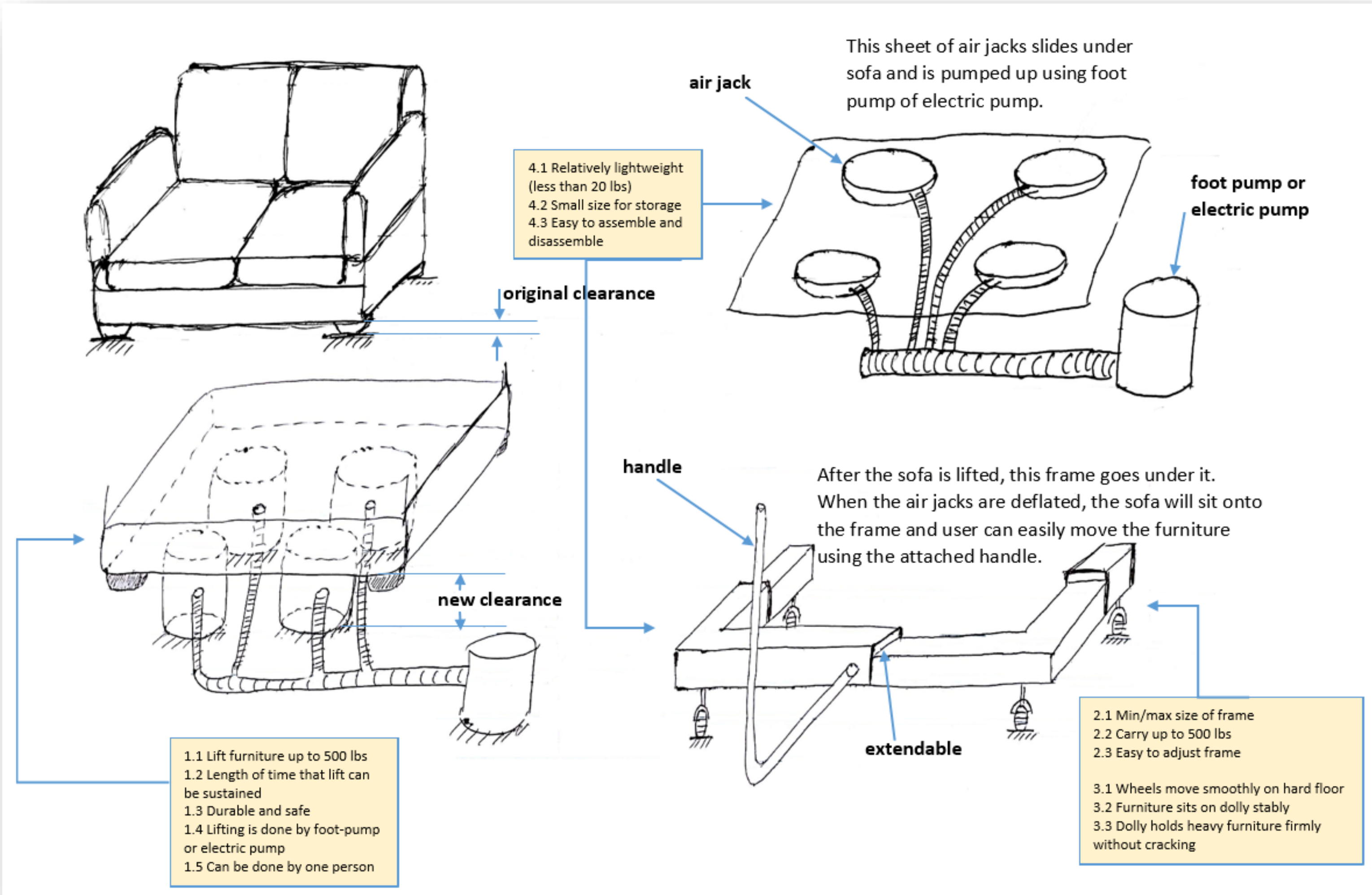


Figure 5. Design concept 2 -- C-shaped frame

3.2.3 Concept drawing 3

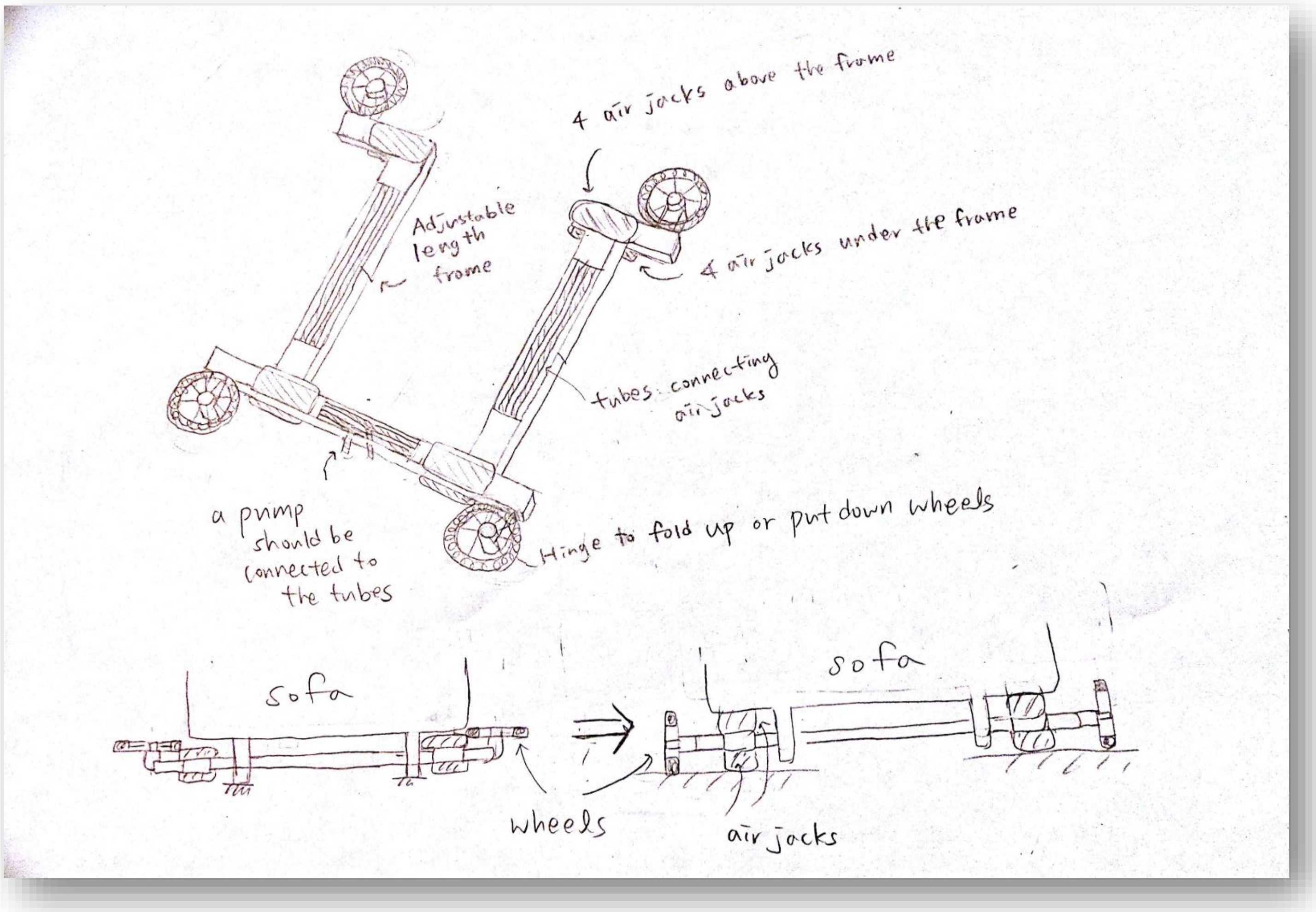


Figure 6. Design concept 4 -- C-shaped frame with foldable wheels

3.2.4 Concept drawing 4

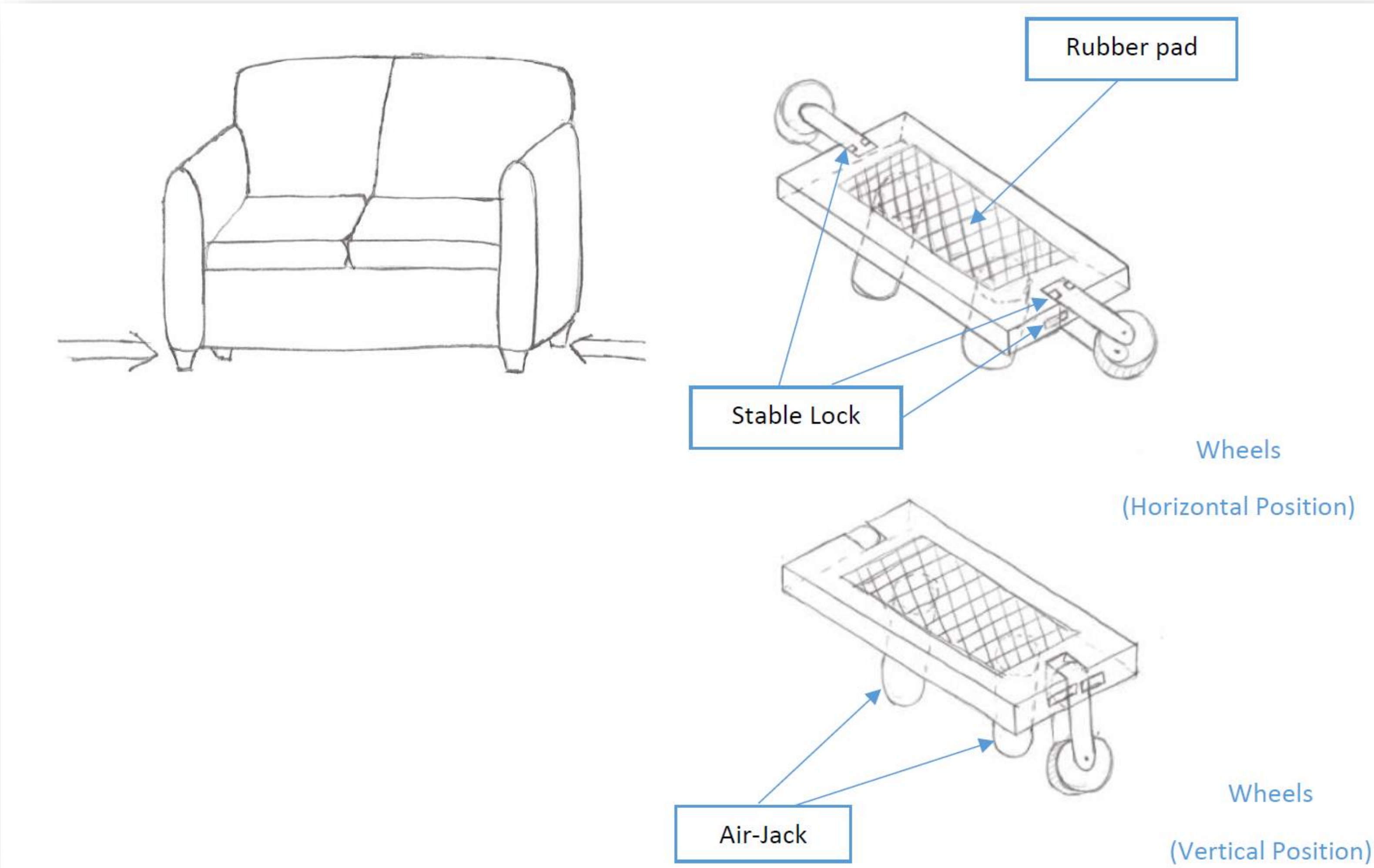


Figure 7. Design concept 4 -- Mini pads with foldable wheels

3.3 CONCEPT SELECTION PROCESS

3.3.1 Preliminary analysis of physical feasibility

Concept #1

Concept 1 utilizes adjustable bars that slide inwards/outwards a slot to achieve a collapsible, modular base frame that will fit to virtually any rectangular-shaped furniture. There is a center cross that has four slots, each of which has an arm bar that would slide in and out according to the length and width of the furniture. A locking mechanism secures the slide-able bars to a desired position by using spring-loaded button locks the bar into place similar to what most crutches have. The button can then be pressed to release the bars. At the end of each bar are wheels which allow horizontal movement across a smooth, hard surface or a carpeted surface. At the ends are also air jacks which are used to lift the furniture up. These air jacks are inflated simultaneously using a foot or electric air pump. Since this concept aims to lift the furniture at the edges, most of the loading will be near the wheels. Failure at the wheels and connections near the wheels is of concern, thus proper material and part selection must be carried out to make sure each component part can withstand the expected load with a factor of safety. Depending on the radius of the wheel, the size of the concept can vary. Smaller wheels allow a lower clearance and the design allows it to fit under more furniture. Larger wheels would subsequently make the design have a greater clearance, thus it would not fit under furniture with small gaps between it and the floor. Ideally, the wheels are small yet sturdy to allow the design to have as low a clearance as possible. This design also requires a powerful air pump that is capable of inflating four air jacks with loads of up to 500 lbs. Another risk is the stability of carrying the load. Since the furniture rests atop four air jacks once it is completely lifted, the furniture must not wobble and tip over. With this design, the elevated portion of the bar and wheels act to stabilize the furniture and prevent it from potentially wobbling or sliding off when the user is moving the furniture. Once the lifting and moving is completed, the user would deflate the air jacks so that the furniture rests on the surface and slide the arms in and retrieve the dolly. One consideration to make is the ease of unlocking the arms from the fixed positions to remove the dolly.

Concept #2

The design of concept 2 poses disadvantages in operational easiness. Total time taken to assemble, install, operate and disassemble is estimated to be as long as 10 minutes, which is in violation of a critical design requirement derived from customer needs -- easy to use and operate. Since the air jacks are sitting on a sheet or a thin flat plate, the relative positions of air jacks are fixed (or difficult to change), which shows difficulty in adapting different sizes of furniture. The 3-sided frame needs to slide under sofa after air jacks are pumped up, where tubes coming out of air jacks and connecting to the pump can be obstacles on its way. Users might have to push the frame to the other side of sofa to slide it in, which is sometimes difficult because the sofa is usually positioned against the wall. While the frame goes under the sofa, user needs to deflate the air jacks slowly to let the sofa sit onto the frame. However, since the deflation process of air jacks is hard to control, and the deflation speed of different air jacks vary, the stability of sofa during deflation process is not guaranteed at this conceptual design stage without simulation, which directly influences one performance goal and design requirement -- safe, stable, and durable. The same problem rises again when user wants to pump up air jacks and detach the dolly frame.

Concept #3

The biggest disadvantage of concept3 is the number of air jacks. The air jacks are a significant part of this design because they are attached to overcome problems related to the clearance between the furniture and the floor. 4 air jacks attached under the frame are inflated to lift the frame and give enough space for the wheels to be put down into an upright position. If the clearance is really small, the air jacks above the frame don't have to be inflated, because the furniture is already lifted up while the air jacks under the frame are ballooned. If the bottom surface of the furniture cannot be pushed up by the frame even after the wheels stand on the floor, the air jacks on the frame can be inflated to lift up the furniture. This process won't be as quick as the process involving only 4 air jacks, and makes this dolly more structurally complicated and less cost-effective. The design complexity might result in more frequent occurrence of the product required to be repaired. In addition, the user should fold down the wheels after the air jacks under the frame are inflated, which can be cumbersome to some users. On the other hand, the tubes connecting the air jacks can be troublesome because they make it difficult for the frame to be adjustable. The air jacks on the frame have one air inlet and the air jacks under the frame have another one air inlet. The inlets can come out of the frame through the two holes as presented in the drawing. Therefore, the length can be freely adjusted because the end of tubes can come out of the frame. However, there is a limit to the width change, because the air jacks along the width are connected by tubes without any inlet between them. If the user wants to change the width, the tubes should be coiled or crumpled in the frame, which is not really desirable because there is a risk of tubes being tangled or snapped. The tubes also limit the disassembly of the product because the frames cannot be completely separated.

Concept #4

Although the design of concept 4 fit design requirement for customer easy-use-need, it does not appear to be the most reliable frame for the users. Since this design consists of two identical parts with two air-jacks under them, it could be unsafe for users to use if instruction is not strictly followed. Two air-jacks under a small dolly does not seem to be stable during lifting, because this concept is designed to be small for easy use and storage. Being a small design can help the users to carry and store the dolly easily, however, the users might have limited control with the dolly during use. After the furniture is lifted by the air-jack, the distance between two wheels on the same dolly pad can be too short to keep the dolly system balanced when the users push the furniture. On the other hand, in order to keep furniture balanced on such small dolly pads, it is necessary to put the center of gravity of the furniture on dolly pads, which is challenging for users. Although this concept is designed easy for users to carry around without assembling and disassembling process needed, this dolly is not designed to adjust its length; plus, there need to have enough space for both wheels to be locked in horizontal position, which means the dolly has to be short enough to fit between two furniture leg on the short end. Moreover, stable locks are added to this design to keep wheels either in horizontal position or vertical position; which means every time users switch the wheel position, they will have to unlock the stable locks and relock it after switching wheel positions. This process could also be troublesome for the elders, our target customers.

3.3.2 Concept scoring

Table 2. Scores of each concept design according to the metric list

Metric List						Concept 1		Concept 2		Concept 3		Concept 4	
Metric Number	**Associated Needs**	**Metric**	**Units**	**Worst Value**	**Best Value**	**Actual Value**	**Normalized Score***	**Actual Value**	**Normalized Score***	**Actual Value**	**Normalized Score***	**Actual Value**	**Normalized Score***
1	1.1, 1.3, 2.2, 3.3	Weight capability	kg	225	300	300	1	300	1	300	1	250	0.5
2	1.2	Lifting time	s	10	60	30	0.6	40	0.6	40	0.6	60	0.5
3	1.4	Lift using foot-pump or electric pump	binary	0	1	1	1	1	1	1	1	1	1
4	1.5	Number of people needed to operate	nondim.	3	1	1	1	1	1	1	1	1	1
5	2.1, 4.2	Minimum length of frame	m	1.9	1.5	1.5	1	1.5	1	1.5	1	1.5	1
6	2.1, 4.2	Minimum width of frame	m	0.9	0.6	0.6	1	0.6	1	0.8	0.33	0.6	1
7	2.1, 4.2	Maximum length of frame	m	2.6	2.3	2.3	1	2.3	1	2.3	1	2.3	1
8	2.1, 4.2	Maximum width of frame	m	1.3	0.9	0.9	1	0.9	1	0.9	1	0.9	1
9	1.6, 4.2	Height of dolly	cm	20	8	12	0.67	15	0.42	8	1	10	0.8
10	2.3	Difficulty of adjusting frame size	rating	5	0	3	0.4	2	0.6	1	0.8	0	1
11	4.1, 4.2	Total weight of dolly	kg	15	3	5	0.8	12	0.25	6	0.75	5	0.9
12	4.3	Length of time to assemble/install	s	600	15	60	0.92	180	0.72	60	0.89	15	1
13	4.3	Length of time to disassemble/detach	s	600	15	60	0.92	180	0.72	120	0.82	15	1
14	1.3, 4.2	Reusable	binary	0	1	1	1	1	1	1	1	1	1
15	1.5, 3.1	Force input to tow the dolly	N	200	45	45	1	45	1	45	1	80	0.6
16	1.3	Number of sharp edges	nondim.	10	0	0	1	2	0.8	0	1	8	0.5
Total Score						**14.31**		**13.11**		**14.19**		**13.80**	

*Normalized Score = |Actual Value - Worst Value| / |Best Value - Worst Value|

**Total Score ranges from 0 to 16. Higher Total Score means better design according to this metrics list.

3.3.3 Final summary

Concept 1 has several advantages over the other three designs in terms of operational easiness, structural stability, durability and safety. It is a truly integrated dolly system which has the lifting system (air jacks) attached to four ends of the frame, and the positions of air jacks are automatically adjusted when the length of each frame is adjusted, which makes it suitable for various sizes of sofa (unlike design 2). It is also very easy to use because the operations required to use the dolly are reduced to simply slide, pump it up, and tow (unlike designs 2 and 3).The time required to lift the sofa up is also minimized because the design requires only minimal amount of clearance between the sofa and the floor, thus the air jacks only need to be pumped up to about 2 inches, and for the same reason, stability of the entire structure during lifting and towing processes is guaranteed as well (unlike design 2~4). Design 2 and 3 have inevitable sharp edges which can be a risk for safety and can potentially damage the furniture during operation. All sharp edges of design 1 can be filleted and smoothened, and should pose no significant danger and little damage possibility to customer and furniture. Unlike design 2, design 1 is easier to detach and store as well -- minimal amount of lifting makes it easy to deflate the air jacks, and the integrated system makes it easy to be disassembled and stored in a small place.

Though concept 1 is the winner according to the metrics list derived from customer needs and design requirements, some nice features of designs 2, 3, and 4 will definitely be added to design 1 per needed as our team moves to following stages, i.e. “folded wheels” idea from design 3 and 4 will further reduce the height of the dolly. Embodiment design, fabrication, engineering analysis, and simulation will continue to improve this design concept and at some point meet all design requirements.

3.4 PROPOSED PERFORMANCE MEASURES FOR THE DESIGN

- Each of the assemble/install/detach/disassemble process should take less than 2 minutes.
- Total height of the dolly system should be less than 20 cm.
- The lifting system can lift up 500 lbs to at least 10 cm, and maintain stability for at least 1 minute.
- Structural components of the dolly can support 500 lbs without failure with a factor of safety at least 2.
- Human force input to operate the lifting system should be less than 50 N.
- Human force input to tow the dolly should be less than 200 N.
- No sharp edges are exposed to user or in contact with furniture.
- Wheels (if used) should work smoothly for all types of flat floor (or floor with a slope less than 10 degrees)
- The entire dolly system can be stowed into space less than 1 m^3 when not in use.
- The dolly system should be reusable -- poses no damage to itself while assembling and disassembling.

3.5 DESIGN CONSTRAINTS

3.5.1 Functional

- The dolly can be stored in compact form to minimizing required storage space.
- The dolly arms can be extended to fit different sofa sizes.
- The airbags can lift both dolly and sofa so that the wheels can be put down for moving.
- The wheels can hold both dolly and sofa.

3.5.2 Safety

- All parts must use strong and durable materials.
- All parts must be connected firmly.

3.5.3 Quality

- The dolly must be light enough for people of all ages to carry it around easily.
- The dolly must be functional for heavy sofas, which can be as heavy as 500lbs.

3.5.4 Manufacturing

- All parts must be easily ordered or manufactured at a relatively low cost.
- The dolly must be designed for easy assembling.

3.5.5 Timing

- The entire setup for a single person to operate must be less than 5 minutes.
- The first prototype must be finished before the prototype demo scheduled by instructors.

3.5.6 Economic

- The total cost of all ordered parts must be less than $ 276.00, which is the budget set by the MEMS department of Washington University in St. Louis.
- The dolly height cannot be higher than 14 inches, so that it can be used for more than 64% of sofas in market.

3.5.7 Ergonomic

- The dolly must be designed to for easy and comfortable usage for people of all ages.
- All sharp edges must be carefully burnished or sanded, especially the frame ends.

3.5.8 Ecological

- All parts must be able to be recycled or reused when the dolly is disposed.
- When broken parts go into waste bin, it must not contain any material that can harm the environment.

3.5.9 Aesthetic

- The dolly must be as compact as possible while not in use, but it does not necessary need to be very aesthetical since the dolly should be designed simple.
- The 4 in 1 airbag tube can be hided inside the frames if needed.
- Future manufacturing can allow customers to select from multiple color to match with their furniture if wanted.

3.5.10 Life cycle

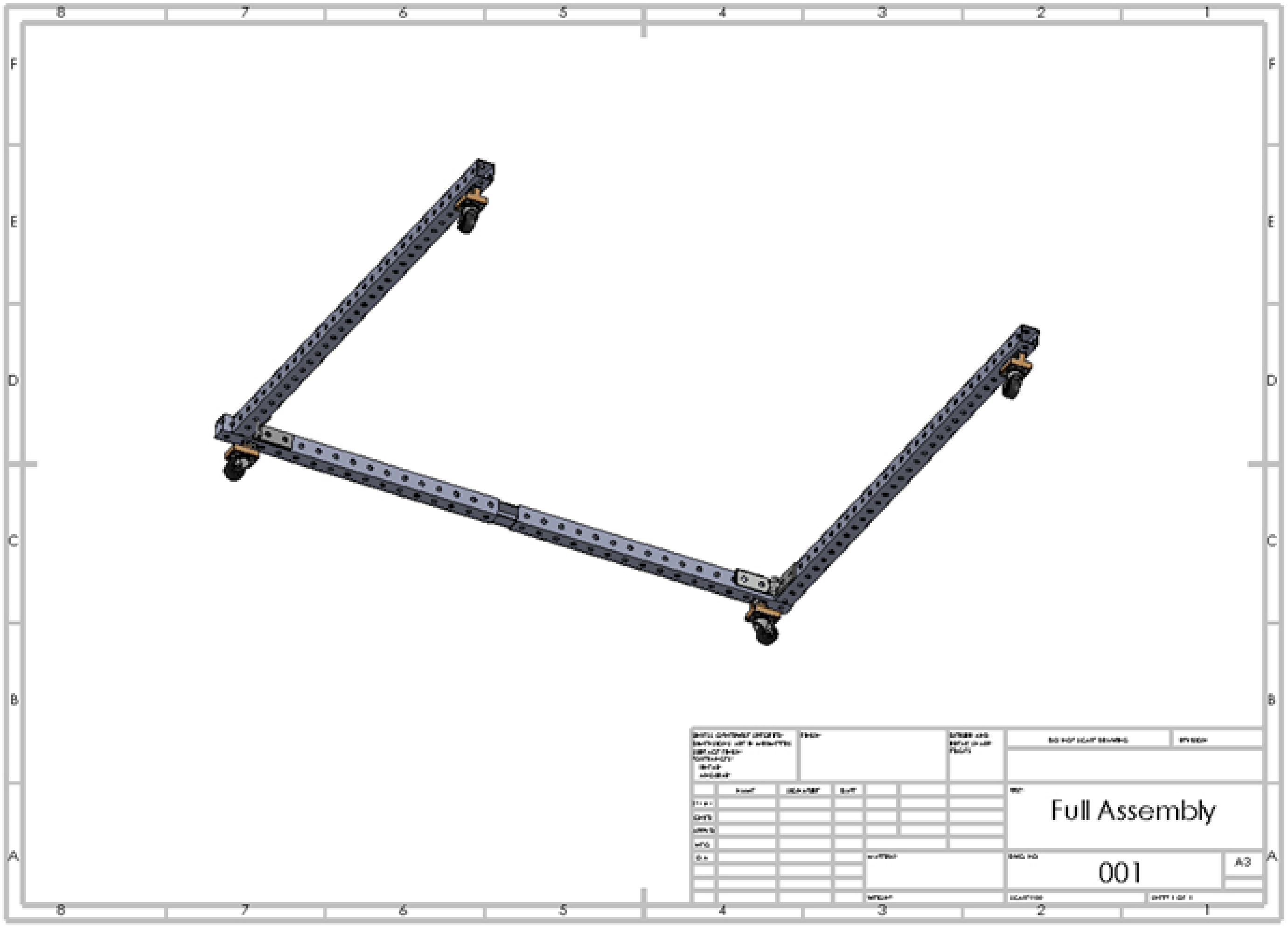
- The dolly must last sufficiently long so that customers can use it as long as they want.
- If broken, all parts must be easily reordered from the manufactures and easily be replaced by customers.

3.5.11 Legal

- The dolly must be a unique design. The dolly must not contain any kinds of patent infringement or legal concerns.

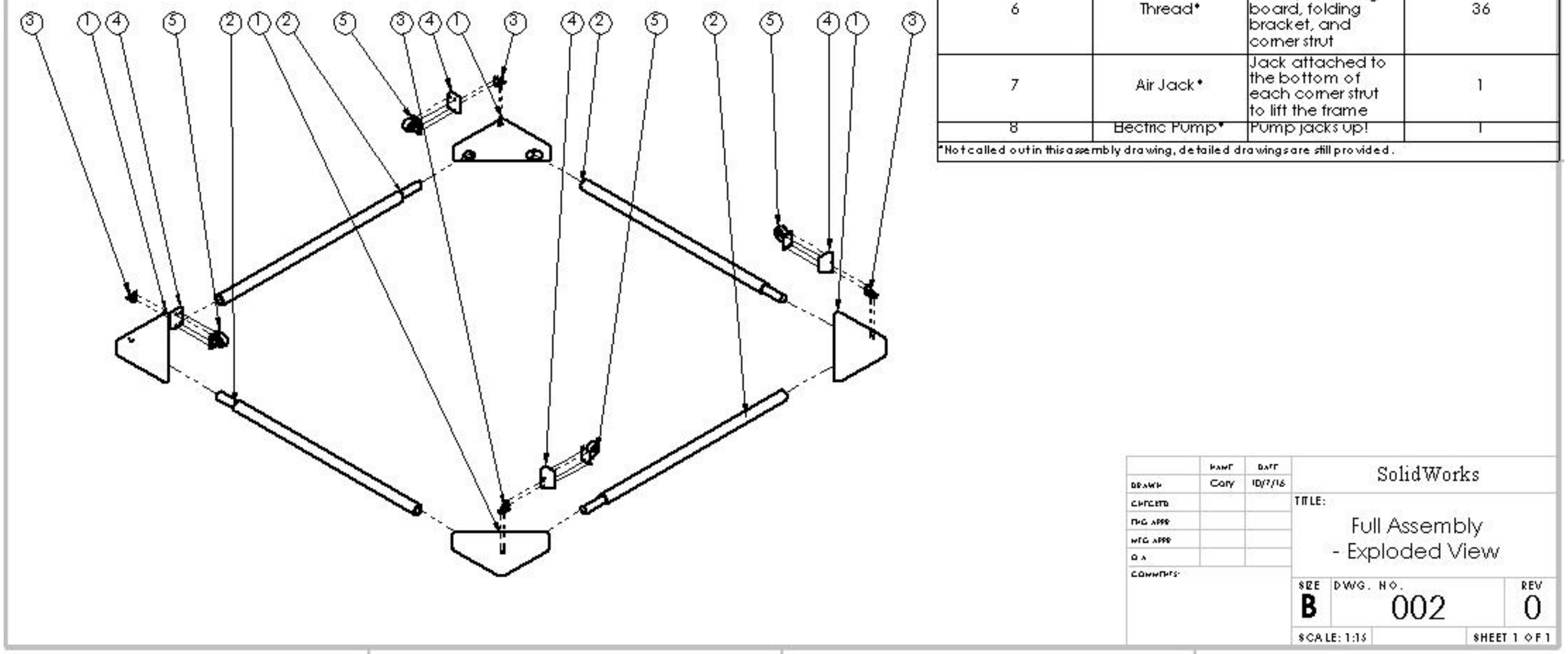
4 EMBODIMENT AND FABRICATION PLAN

4.1 EMBODIMENT DRAWING



Part #	Part Name	Part Description	Qty
1	Corner Strut	Triangular strut connecting two extension rods and a folding wheel	4
2	Extension Rod	Extendable rod held by two corner struts	4
3	Folding Bracket	Foldable bracket threaded onto corner strut	4
4	Mounting Board	Wooden board connecting folding bracket and caster	4
5	Caster	Rolling wheel mounted on mounting board	4
6	Thread*	Threads together caster, mounting board, folding bracket, and corner strut	36
7	Air Jack*	Jack attached to the bottom of each corner strut to lift the frame	1
8	Electric Pump*	Pump jacks up!	1

*Not called out in this assembly drawing, detailed drawings are still provided.



4.2 PARTS LIST

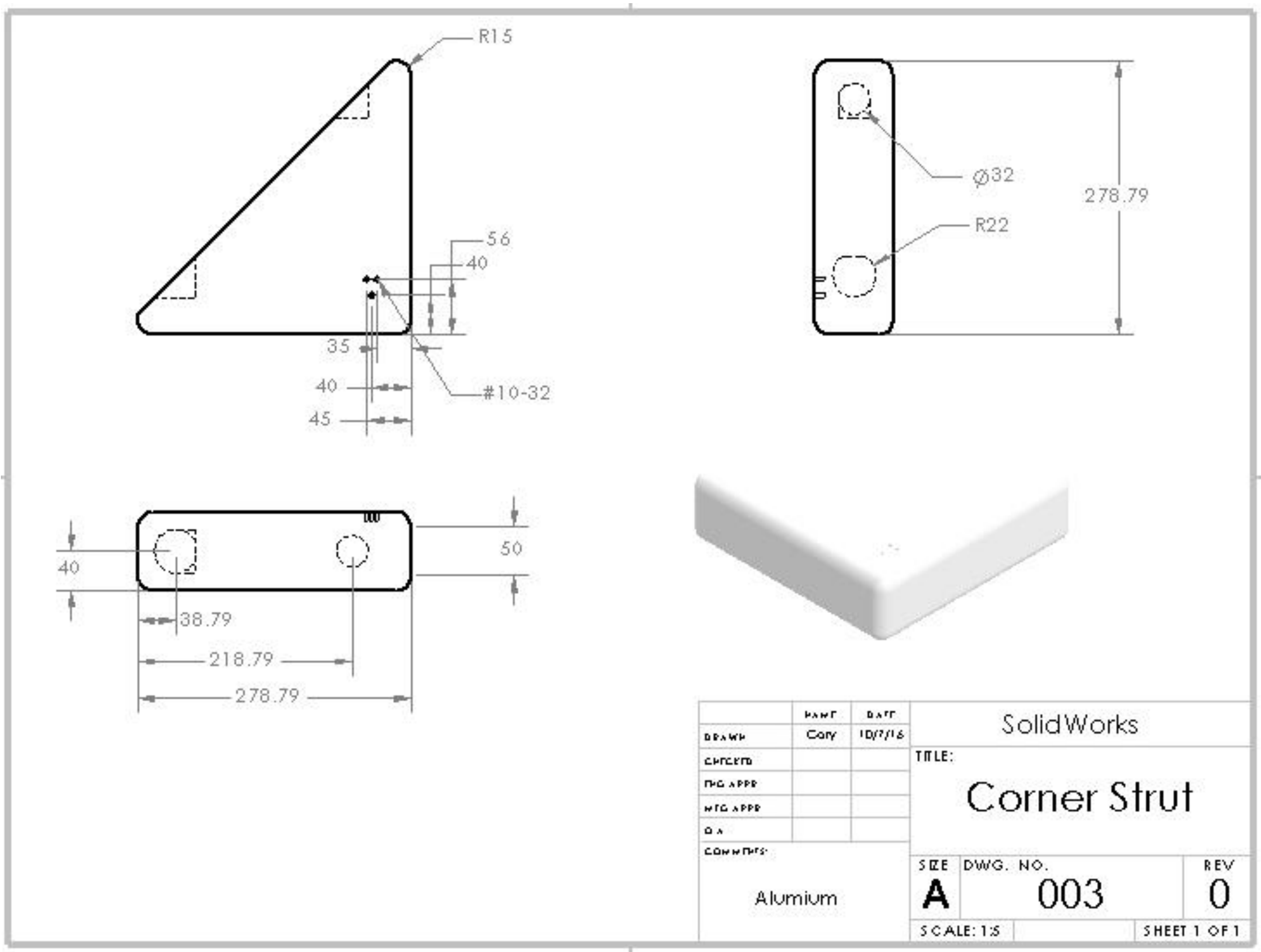
Table 3. Part list and cost accounting

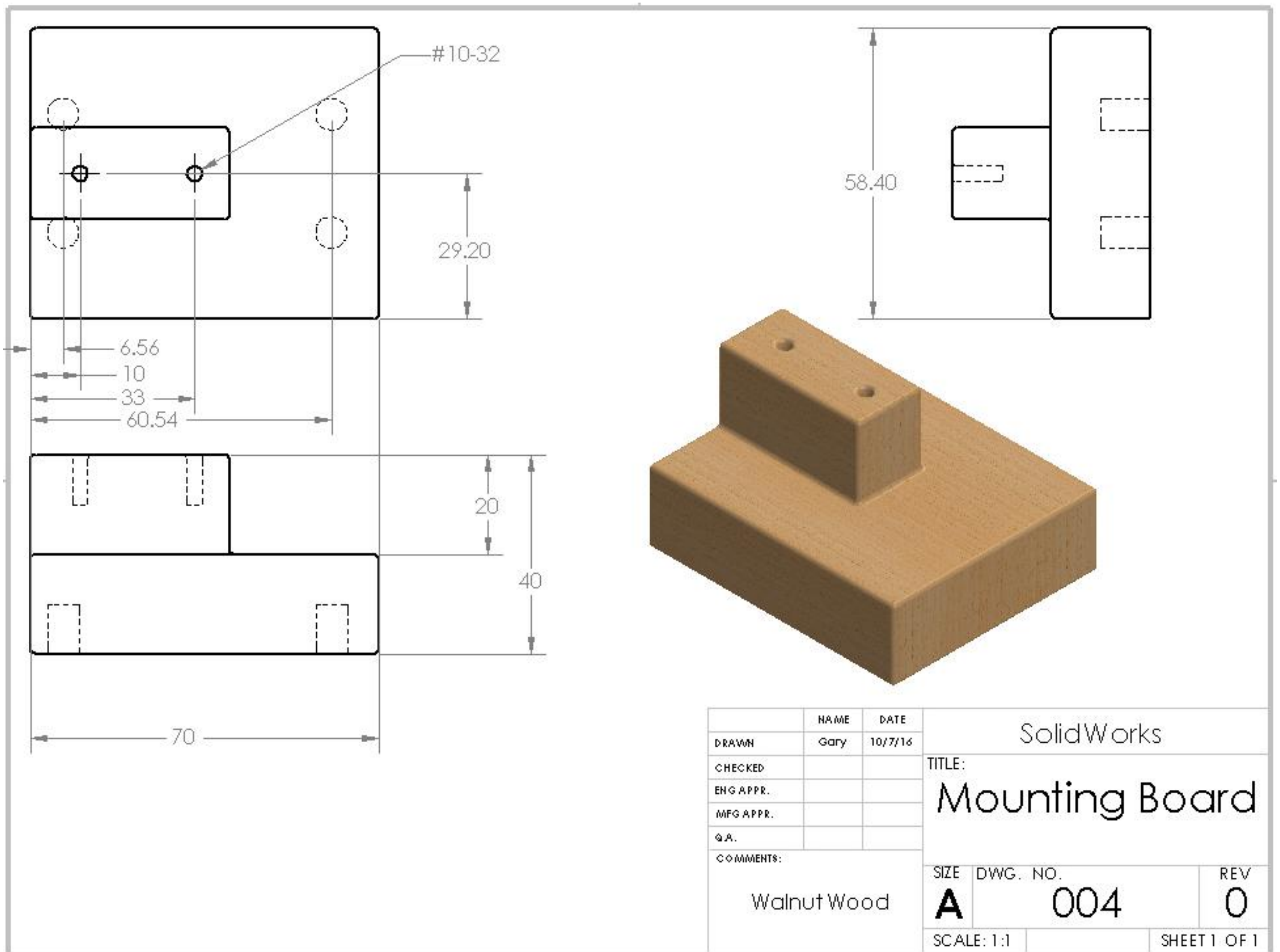
	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Tax	Shipping	Quantity	Total price
1	Caster Wheel	McMaster Carr	2358T53	Black	$6.83	$0.00	$0.00	4	$27.32
2	Telescoping Strut Tube*	McMaster Carr	3138T3	Zinc-Plated Steel, 10ft	$99.81	$0.00	$0.00	1	$99.81
3	Telescoping Strut Channel	McMaster Carr	3138T6	Zinc-Plated Steel, 5ft	$21.16	$0.00	$0.00	1	$21.16
4	Folding Leg Bracket	Amazon	32754	Set of 2	$18.95	$0.00	$0.00	2	$37.90
5	Strut Channel Hinge	McMaster Carr	3505T12	Zinc-Plated Steel	$13.81	$0.00	$0.00	2	$27.62
6	Surface-Mount Hinge	McMaster Carr	16175A32	Unfinished Steel	$5.75	$0.00	$0.00	1	$5.75
7	KLOM AUTOMOTIV ToolAirBagPump Wedge	Amazon	186389533	Black	$9.95	$0.00	$0.00	4	$39.80
								Total	$259.36

*The 10-ft telescoping strut tube was cut into four pieces – two 2-ft tubes and two 3-ft tubes. 2-ft tubes were used as extending arms along the middle strut channel, and 3-ft tubes were used as folding legs.

4.3 PART DRAWINGS

The only parts we are going to alter after purchase are corner struts and wheel mounting boards.

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4.4 DESIGN RATIONALE

Choosing extension rod – According to the derived design requirements, the size of the frame should be adjustable to accommodate for different furniture sizes. A good way, while not losing much of stability, of fulfilling this requirement is to use extension rods. The contact resistance between inner and outer rods, along with friction between furniture and strut surface should be able to prevent extension rods from contraction or extension (Engineering Analysis/Simulation).

Scope of extension rod – Based on the derived design requirements "min/max length", "min/max width" of the frame, we decided to use extension rods that extend from 36 in. to 70 in. (0.91 ~ 1.78 m). Power input from one person should be able to extend the rods (Engineering Analysis/Simulation).

Shape of corner strut – In order to connect extension rods as well as folding brackets, we need to customize its configuration from raw material piece. Given the price of raw aluminum blocks, we want to optimize the surface area of corner strut to distribute as much weight as possible. The pressure on top surface of corner strut should not buckle or distort any structural components of the frame and the folding wheels (Engineering Analysis/Simulation).

Size of wheel mounting board – Our project is aiming for furniture with 15 cm clearance, so the folded height of the entire system should not exceed this limit. To minimize operational time consumption, we are only going to lift the frame by 2 ~ 2.5 cm, which means that the difference between folded height and unfolded height of the wheel board should be at least 2 cm. SolidWorks motion analysis can be a good way to check if the size of the mounting board meets all the requirements, and if any moving components overlap while extending/contracting, folding/unfolding.

4.5 GANTT CHART

Preview:

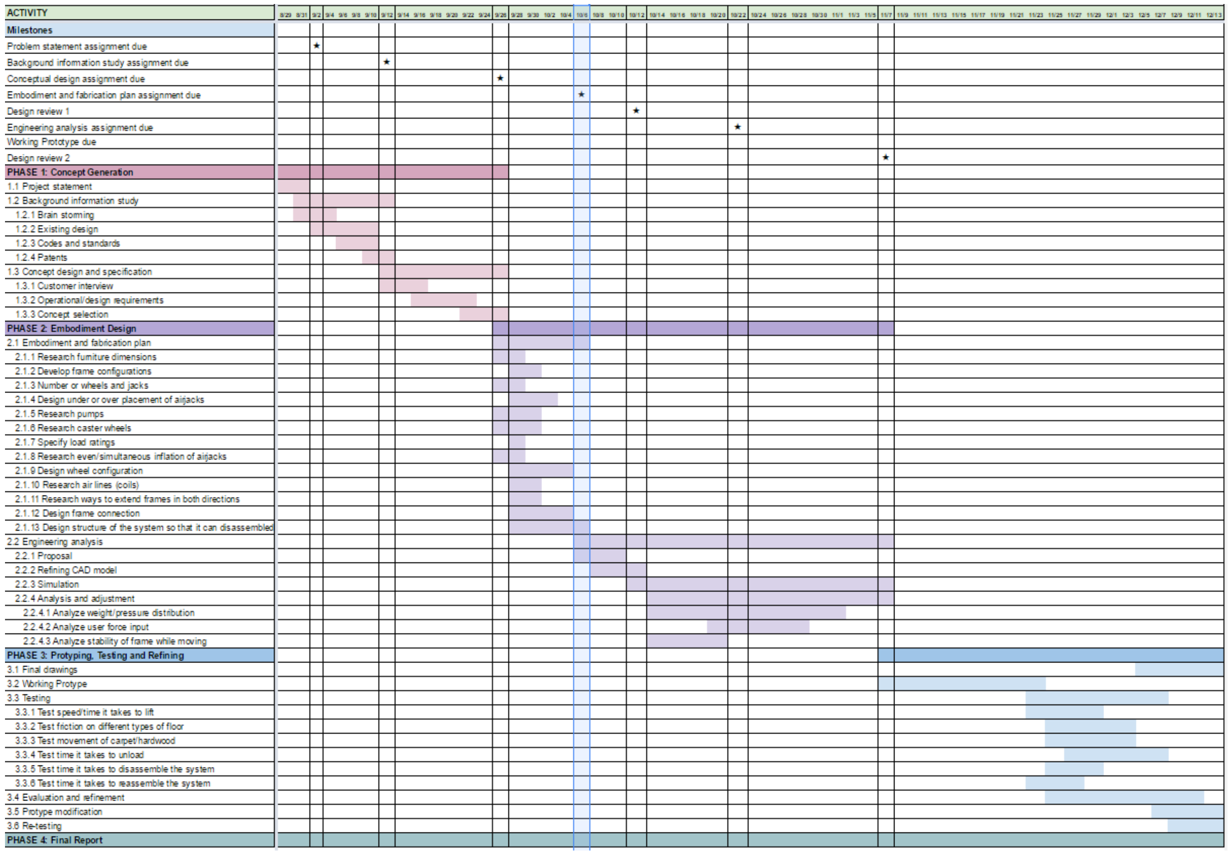


Figure 8. Preview of Gantt chart

Full Gantt chart:

Gantt Chart.xlsx

5 ENGINEERING ANALYSIS

5.1 MOTIVATION

Weight carrying is the No.1 fundamental feature of a dolly. Our project is designed to lift and support furniture – sofa as a demo in the current prototype – with weight up to 500 lbs. Key frame of the dolly should not fail, deflect, or deform significantly while in use. Any unrecoverable deformation will prevent customers from repeatedly using our project.

Compact is another important feature that makes our project unique in the market. Hinge and combination of hinges are used to fulfill this functionality – possibility of parts interference during folding and unfolding processes should be carefully excluded.

We claim that the project can be operated by individuals without hassle. Easiness of operations have been considered and examined in the preliminary design stage. Total weight of the dolly is a leftover for engineering analysis – the dolly cannot be too heavy for one person to use.

The most fragile part of the dolly is the wood board used to connect the folding bracket and the caster. Both the folding bracket and the caster are threaded into the wood. A significant amount of normal stress due to the weight of the dolly and the furniture and shear stress due to pulling force input can challenge the strength of this fragile part.

Different materials or designs have to be considered if the current design fails the engineering analysis and simulation tests.

5.2 SUMMARY

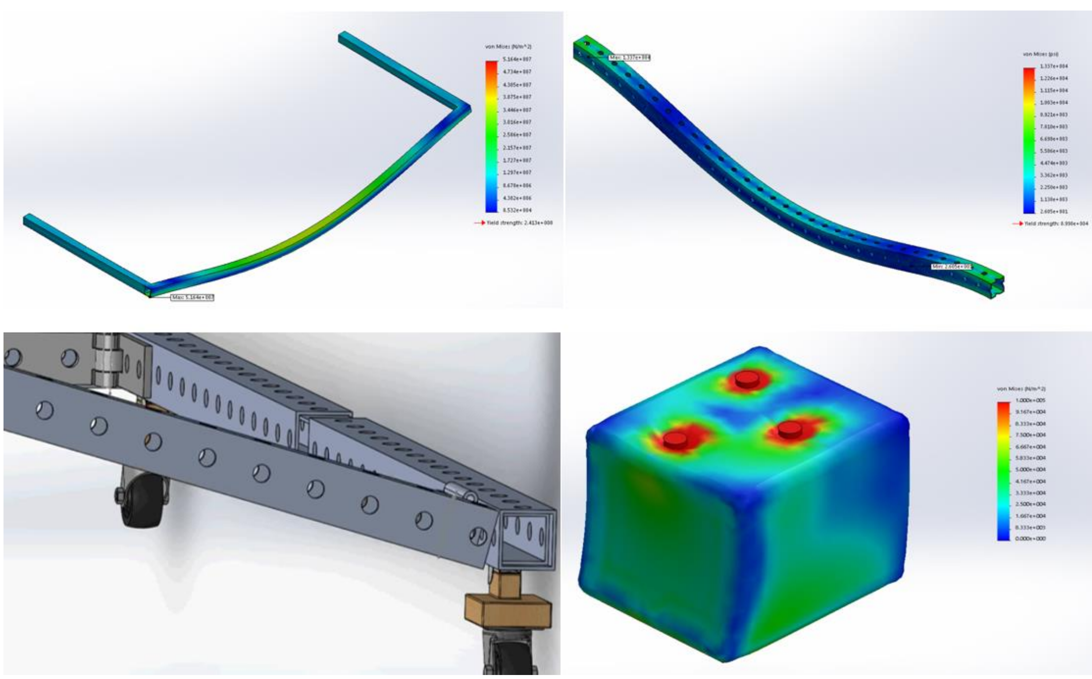


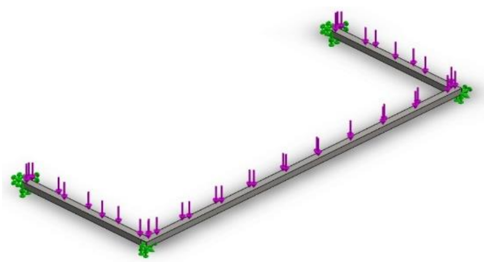
Figure 9. Summary of simulation results

As shown in Figure ??, we performed three simulations using SolidWorks Simulation, a mass property check using SolidWorks CAE, and an interference check using SolidWorks Motion Study:

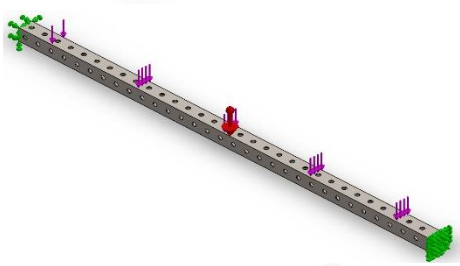
- We first performed a simulation on a simplified model representing fully extended frame (middle leg fully extended, side legs unfolded) subject to an overall distributed load representing weight of the furniture reside on top of the frame. It was verified that the middle leg would fail first if the frame would have to fail.
- Given the result of the first analysis, we did a detailed simulation analysis with the tube of the middle leg. The maximum von mises in the structure is well below the strength of the material, with a factor of safety of about 3.
- Simulation with the wood block suggests that the block will be broken and threads will potentially come off – material other than wood has to be used for padding between folding bracket and caster.
- Interference check shows that no parts are blocking each other during folding/unfolding processes. Our designed folding mechanism works!
- Mass property evaluation shows that the total weight of our project excluding bolts, nuts and threads is 53.2 lbs – too heavy to be considered lightweight, composite struts, instead of stainless steel as currently, can be used to construct frame.

5.3 METHODOLOGY

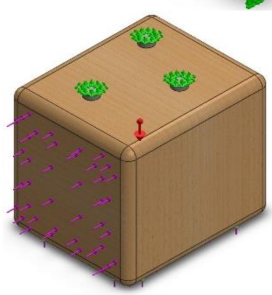
FEA software package we used for simulation is SolidWorks 2016 Simulation. In each simulation configuration, fixture, external loads, contact sets and gravity are defined as appropriate. Key results are shown in Section 5.4. Full reports of simulations can be found in Appendices E through G.



In the first simulation study with extended frame, the model is composed of entirely linear elastic isotropic beam elements. Holes and connections are excluded for simplicity. Four corners of the frame are fixed, and 500 lbs uniformly distributed load in (-z) direction is applied upon top of the frame. 8115 elements are generated using solid, standard, high quality mesh.



The second simulation study with the tube is defined similarly to the first one, with two ends fixed and uniformly distributed load applied on top of the surface. Holes are included in the model to justify the effect of stress concentration. It is meshed with a higher quality resulting in 14393 meshes.



In the simulation study with the wood block, three threads and a wood block are meshed into 14905 meshes. Top of the threads to invoke the shear from caster. Bottom of the wood block is fixed to invoke the shear from the folding bracket. 150 lbs uniformly distributed load is applied to the bottom of the block representing load from the furniture and self-weight of the dolly. 25 lbf external force is applied to one side surface to account for user force input.

The folding bracket – wood block – caster subassembly was first tested before full assembly started. SolidWorks Motion Study was used to check for interference among components. Tolerance of interference detection is set to be 1e-16. Full simulation animation is included in the Critical Design Review.

5.4 RESULTS

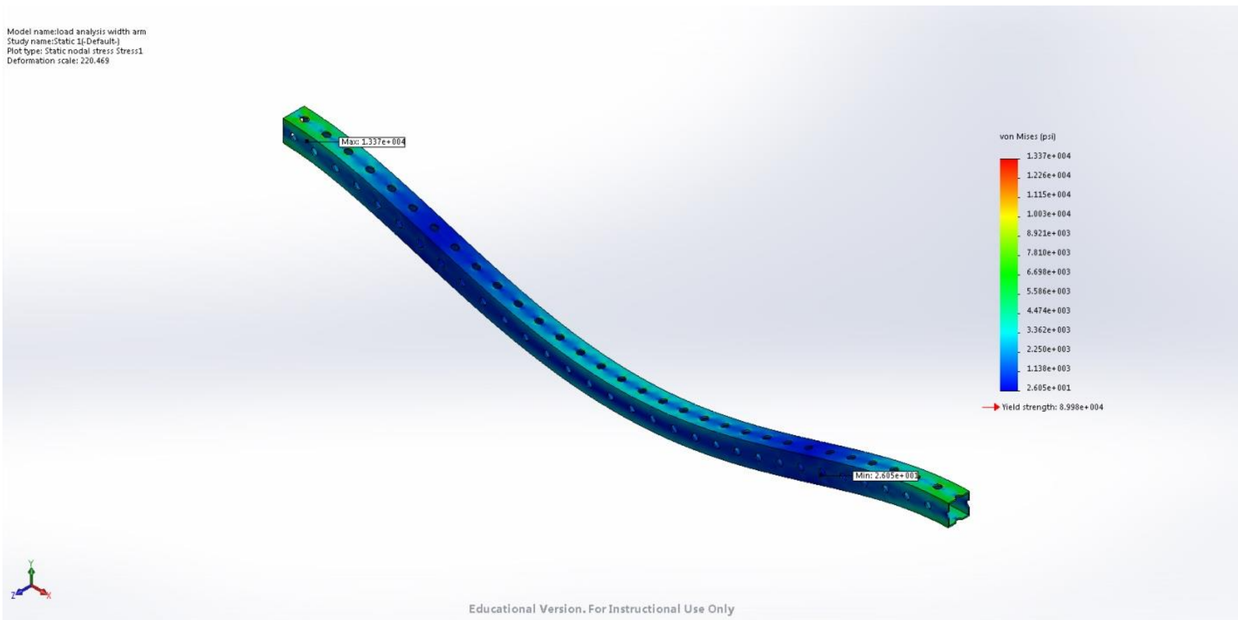


Figure 10. Stress distribution of extending tube subject to uniformly distributed load

- Simulation result with the tube shows that maximum von mises occurs at ¼ away from the end of the beam with a maximum stress of 92.17 MPa, while the material yield strength is 620.4 MPa – it is not likely to fail due to static loading of the furniture. The maximum displacement occurs at the middle of the beam with a maximum displacement of 0.68 mm – it will not cause any component interference, penetration, unrecoverable deformation or damage.
- Interference check passes with no components touching or running into each other during folding processes of the frame and the wheels.
- Total mass of the furniture dolly is evaluated to be 53.2 lbs with estimated mass densities.

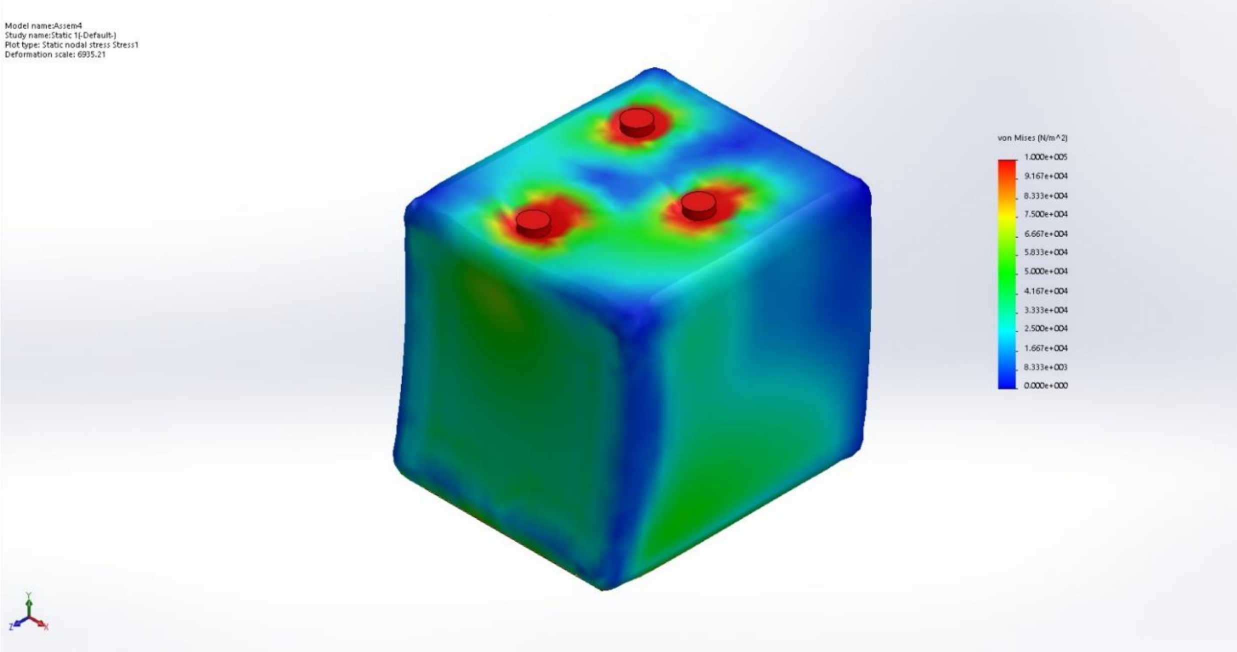


Figure 11. Stress distribution of wood block subject to external loading

- Maximum von mises stress in the wood block is 41.5 MPa, while yield strength of the material is 20 MPa as documented in SolidWorks. Significant stress concentration around the threads is observed.

All simulation results make sense and have been checked with a finer (extremely fine) mesh setting. Relative errors between trials stay below 5%.

5.5 SIGNIFICANCE

Mass Property Evaluation shows that the dolly is too heavy. Since the frame contributes the most to the total weight, **we are going to replace the stainless steel channels and tubes with composite material** (i.e. E-class Glassfibre-reinforced plastics). Young's modulus of GRP is comparable to that of steel, and it will be sufficient for the scope of our project as shown in the first and second simulation studies with the frame and the tube. **Total mass of the dolly will be reduced from 53.2 lbs to 23.3 lbs by 67%**.

Rerun of interference check and motion study with updated dimensions after receiving actual parts shows that the spacing between side legs and the middle leg will cause the leg to open over 90 degrees. To prevent over-bending and parts interference, **we have decided to 3D print paddings to occupy the space between end of legs** as shown in Fig. 12.

Figure 12. Added 3D printed caps

Due to the dimension update for folding brackets, we have to update the originally L-shaped wood block to a simple cubic block. Section 5.2 through 5.4 are showing simulation analysis with the updated wood block. Updated CAD drawings (before and after) are shown on the next two pages.

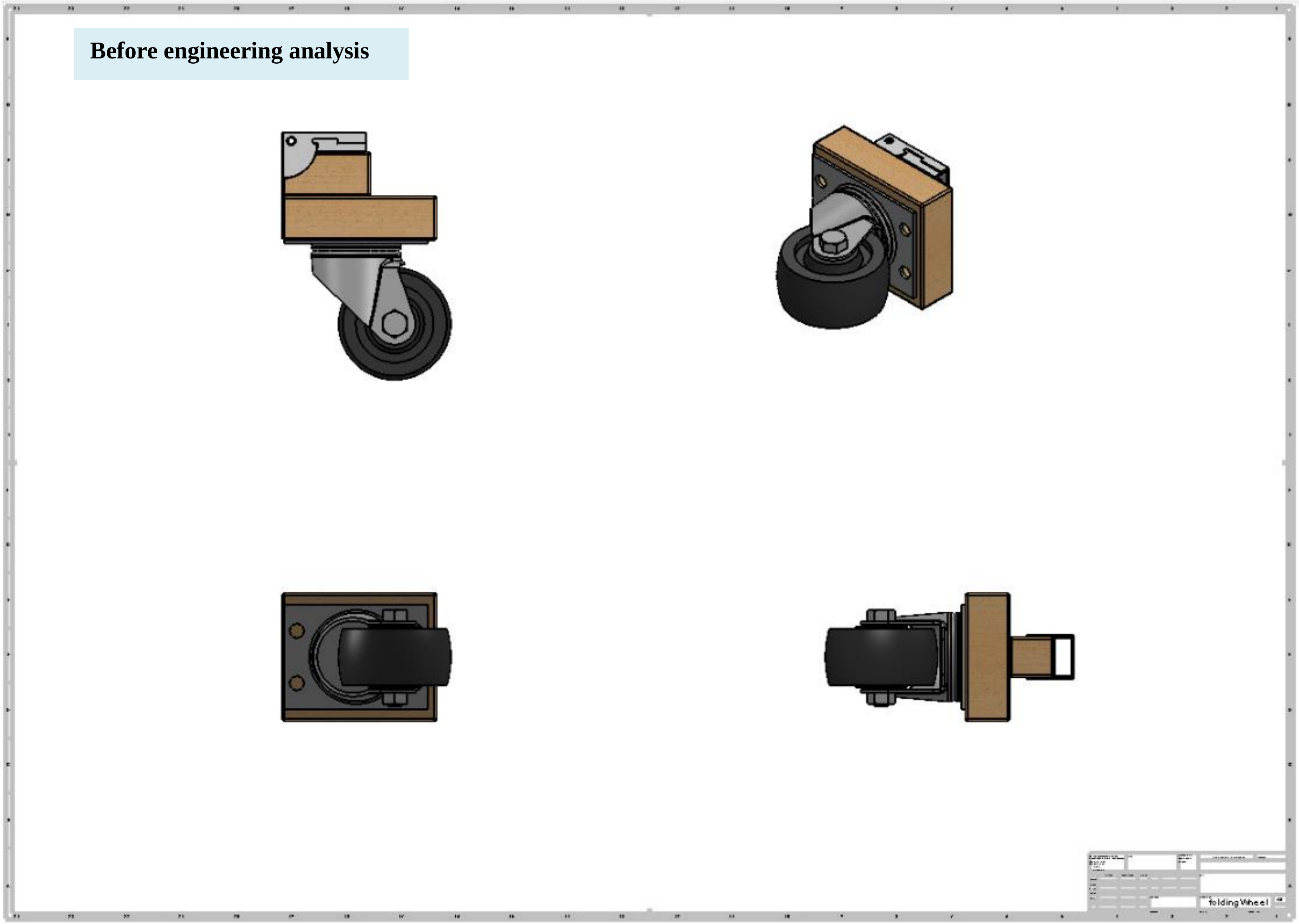


Figure 13. CAD drawing of folding wheel before engineering analysis

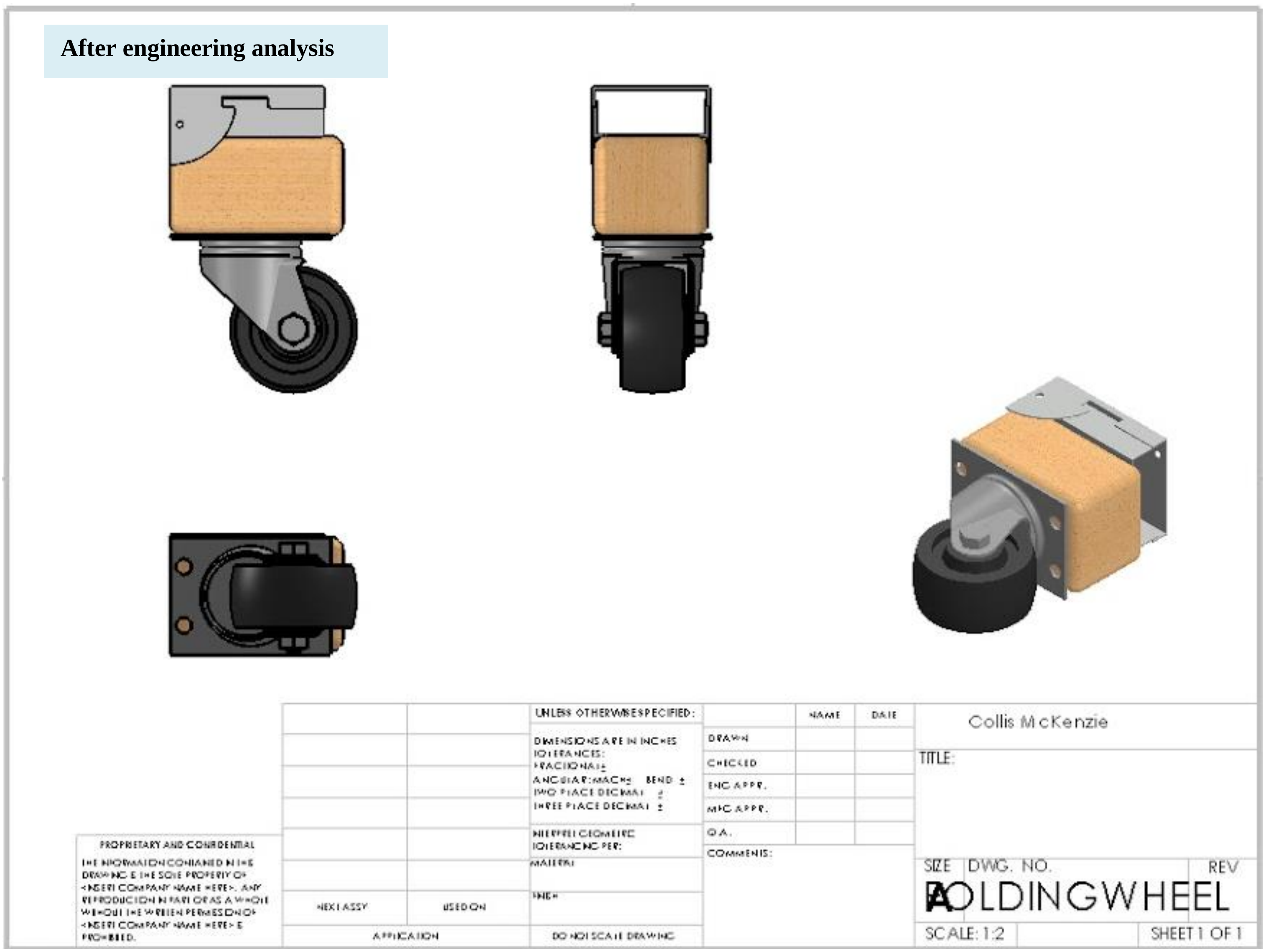


Figure 14. CAD drawing update according to engineering analysis

Engineering analysis shows that the wood block experiences a maximum von mises stress of 41.5 MPa while the yield strength of the material is 20 MPa – The part will fail at where the maximum von mises occurs when subject to loading condition specified in the simulation configuration! One quick fix for this problem is to use stronger material, instead of wood, for the padding between folding bracket and caster. Design changes and model update at this stage can be expensive. Due to budget limit, material was not changed for the first prototype demo (the idea of the prototype was to demo our design and mechanism). However, if future prototype is possible, or if some other group would like to pursue a similar project based on ours, it is strongly recommended to consider a stronger material to connect folding bracket and caster.

5.6 RISK ASSESSMENT

5.6.1 Risk Identification

Even though the overall design of our product is straightforward, there exist risks related to building a prototype that reflects the design, mainly due to the budget limit. Therefore, our risk assessment is focused on how we can realize the main functions of the dolly by using resources allowed. The main functions of the dolly that are essential in this project are lifting function and “compactability”.

Due to the budget limit, we have to buy cheap parts, and the quality of the purchased parts might not be as good as expected. Because we use cheap air bags instead of air jack system which we wanted at first, the lifting function might not work in the way we want. In addition, parts can be broken because the whole system is heavy due to the weight of the purchased steel frames. We have to connect the parts by drilling holes and using bolts and nuts, and the resultant connection might not be stable enough. Besides, in the manufacture process in which we drill holes and build wood blocks, even small errors can cause misfitting of parts.

Group members’ injury while dealing the machinery in the machine shop and the heavy prototype can be an additional risk. Because the frames are bulky and heavy, it won’t be easy to move them around or process them on the milling machine.

5.6.2 Risk Impact or Consequence Assessment

If air bags cannot properly serve the lifting function, we might have to come up with other ways to realize the function. Because we don't have enough budget left to buy another part, we will try to solve the problem with the existing air bags. As long as the air bags can be inflated and support the weight of the dolly, we can add some blocks between frames and air bags to overcome the small volume of the inflated air bags. We already checked that the air bags are highly sturdy from the product usage video before we purchased them, so they won't fail easily.

The parts that we purchased at relatively low prices might not work as efficiently or conveniently as we wanted in the beginning design stage, but they won’t fail because we checked allowable loads. However, if any of them fails, we will delay our schedule and there will be extra cost.

If we make some mistake during the processing, which can happen because we are not really skilled in dealing with processing machinery, we might need to modify our design to cut out messed-up parts. It is better to start processing early so that we would have more time to adapt our prototype to some unexpected situation.

If any injury occurs, it will cause not only monetary damages due to following medical expenses but also time pressure because other people should undertake the injured person's work.

The identified risks and their impact assessments are tabulated below.

Table 4. Risk identification and management

What is the risk?	Describe the identified risk	How is risk currently managed?	Comments/Concerns	Impact	Likelihood
Poor quality of purchased parts	Purchase of low quality parts due to the budget limit	Allocate funds in order of importance; Cheap air bags are enough for one-time use; The basic parts such as frames and wheels should be sturdy enough to support the whole system.	Malfunction of some parts can debase the whole system.	Moderate	Medium
Parts being broken	Fragile connection between parts can be caused because some parts are not purchased, but made by us.	Use stronger materials should be used between wheels and brackets;	Stronger materials are hard for us to deal with by ourselves.	Significant	Medium
Lifting function	Poor performance of air bags	Add blocks between the frame and air bags to enable enough initial height of the frame before lifting the dolly.	Adding unessential parts to the system can cause unexpected problems.	Moderate	Medium-High
Defects in manufacturing	Imprecise drilling and cutting of the parts can cause parts not fitting one another	Use exact numbers given in drawings. Use drills of proper sizes	Utilize what we learned in machine shop classes	Significant	Low-Medium
Small Parts being missing	Missing bolt and nuts	classify bolts and nuts by size and store them in separate bags	keep spare parts, just in case.	Mild	Low
Injury from heavy weight	Team members can be injured while dealing with the product due to its heavy weight.	Strict attention is required when lifting the product. At least two people should collaborate together.	Choose light materials if possible.	Moderate	Low

5.6.3 Risk Prioritization

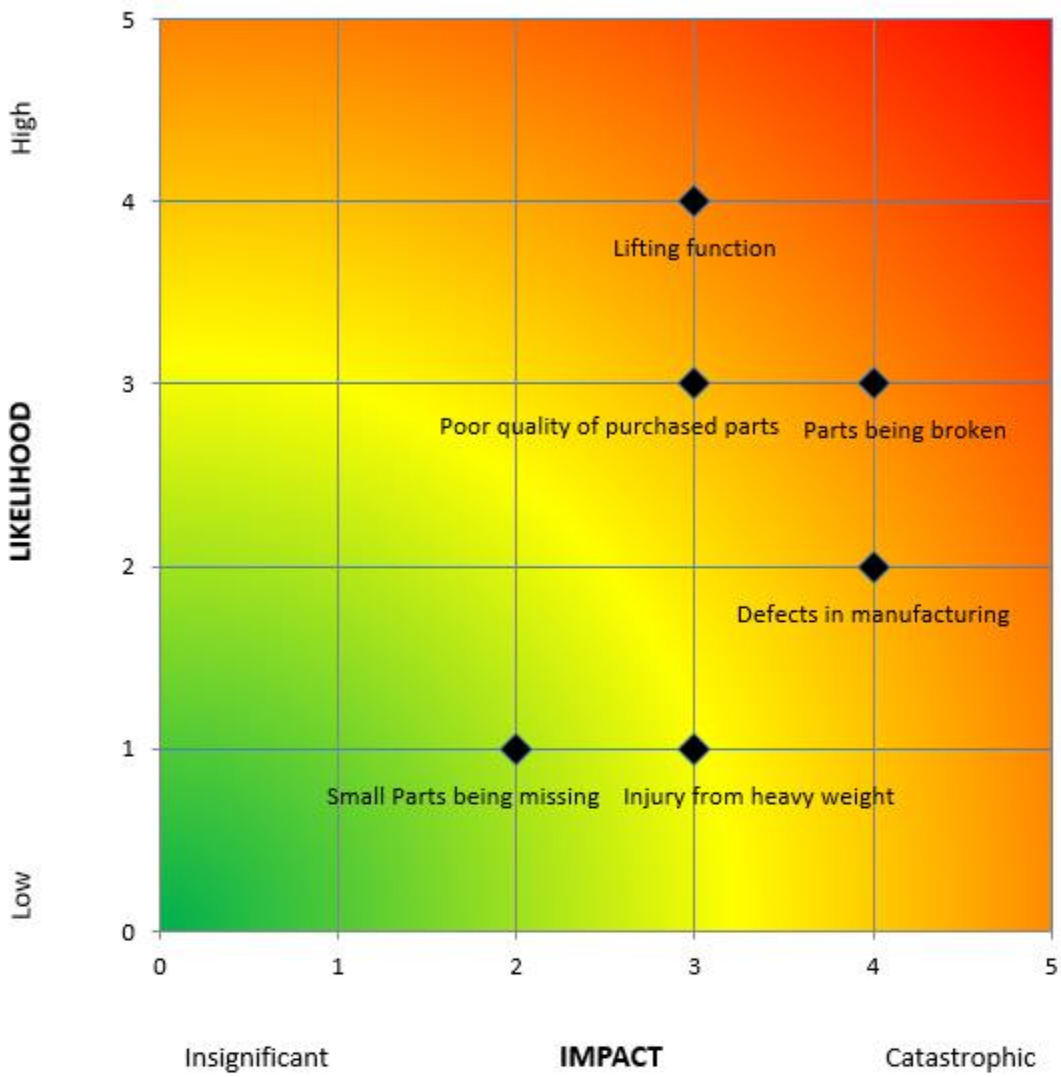


Figure 15. Risk assessment heat map

We created a heat map according to the table above, and this shows the significance of each risk. The most likely and most significant risks are malfunction of lifting function and parts being broken. It is highly likely that lifting function cannot work perfectly, but we can still build our prototype, which is not really catastrophic. Parts won't be broken easily, but if any broken parts can cause a huge impact on the whole system because we would have to buy new parts and assemble them. Regarding the poor quality parts, we already check necessary numbers about the allowable load, so it is addressable. Defects in manufacturing also can cause a significant damage but it won't occur if we are careful enough. We wouldn't be worried too much about small parts missing or injury because their likelihood is very low even though we should still be careful to prevent their occurrence.

6 WORKING PROTOTYPE

6.1 FINAL PROTOTYPE

Figure 16. Furniture dolly in its compact form

Fig. 15 shows our final prototype in its most compact form – two side legs are folded inward and two extending arms are at their minimum stroke. To use the dolly, the user need to first take out the pins fixing the relative positions of extending arms and adjust the stroke according to the furniture size, and then unfold the side legs such that they are perpendicular to the middle frame as shown in Fig. 16.

Figure 17. Furniture dolly unfolded

Now the dolly is ready for use. Simply slide or push it under the sofa – make sure the four foot pumps are accessible after the dolly under the furniture. Then pump up four air wedges using the foot pump one by one. When the air wedges are fully inflated, there will be enough space to put the folding wheels down onto the floor – make sure the wheels are touching the floor and are locked in place (should hear a bright tick sound when locked). By pushing the button on the foot pump, the air wedges are then deflated, and the furniture and the dolly will sit on the wheels and ready to be moved.

6.2 KEY FEATURES OF PROTOTYPE

Figure 18. Double hinge

The double hinge is a combination of a strut channel hinge and a surface mount hinge. The strut channel hinge is bolted onto the sliding arm, and the surface mounting hinge is bolted onto the side tube. Future work could be done to perform engineering analysis including stress check on the double hinge to ensure its durability.

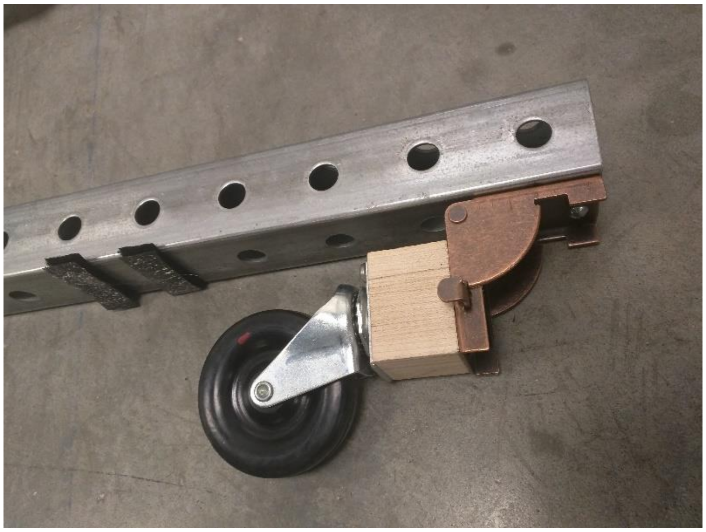


Figure 19. Folding wheel

The folding wheel is a combination of folding bracket, wood padding, and caster. Components are threaded together. Current problem with the folding wheel is that human input is still required to manually press the key and then unfold the bracket – future investigation can be made to explore substitutions to this mechanism.

Figure 20. Wood padding - Air wedge

The pumping system can be easily attached and detached from the side legs and the middle frame using strips. Currently each air wedge has a separate pump, which makes it more time consuming to pump up all four. Given more budget, one could tube together all four air wedges and use one pump to operate.

Figure 21. Sliding arms and pins

Two 2-ft tubes can slide back and forth along the C-shaped channel. Two pins (nuts with sealing) are used to fix the relative position of the extending arms, therefore reaching a desired stroke for the size of the furniture.

6.3 VIEDEO OF PRELIMINARY TEST OF PROTOTYPE

https://youtu.be/i1_I2mzv5HU?list=PLpaIgTgYdmcLjSiXEt6mo26GsC4ohV1Fs

One of the wood pad cracked during test. Reasons for the failure have been discussed in Section 7 and changes have been made accordingly in the final prototype.

6.4 VIDEO OF FINAL PROTOTYPE DEMO

https://youtu.be/Q2ydgYFA9Nc

Performance goals were evaluated during the demo and are documented below in Table 5:

Table 5. Performance specifications and measurements

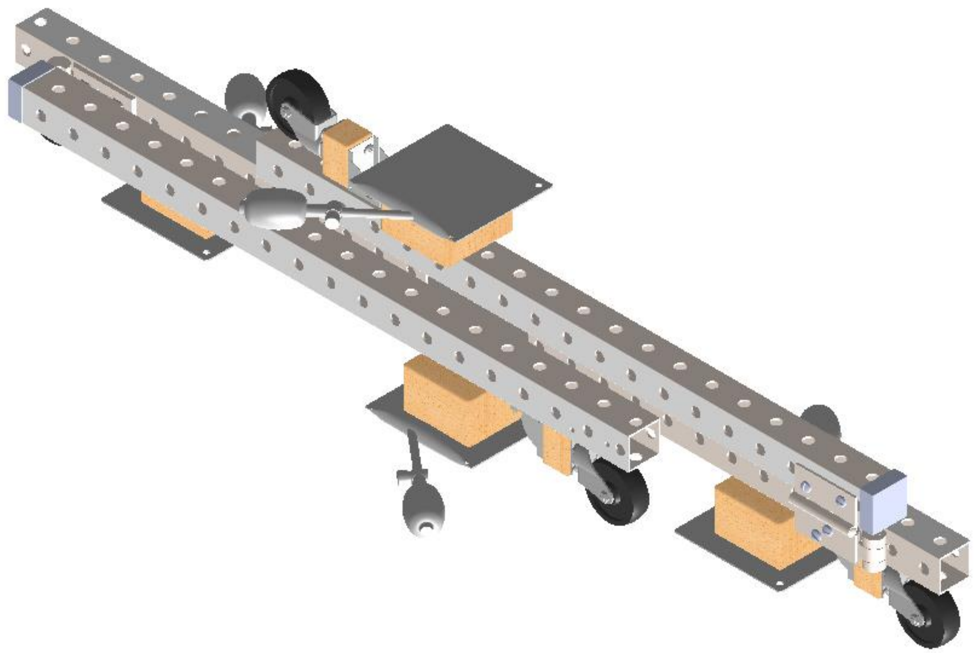
Performance Measures	Prototype Performance	Met or not?
Each of the assemble/install/detach/disassemble process should take less than 2 minutes.	Unfold side legs < 10 seconds Install under sofa < 90 seconds Detach from sofa < 50 seconds	√
Total height of the dolly system should be less than 20 cm.	Total height of the dolly = 16 cm	√
The lifting system can lift up 500 lbs to at least 10 cm, and maintain stability for at least 1 minute.	Verified using SolidWorks Simulation	√
Structural components of the dolly can support 500 lbs without failure with a factor of safety at least 2.	Verified using SolidWorks Simulation	√
Human force input to operate the lifting system should be less than 50 N.	Even though the exact value of force input was not measured, simply stepping on the foot pump requires a minimal amount of force.	√
Human force input to tow the dolly should be less than 200 N.	Same as above. Not measured exactly but the couch can be pushed rather easily.	√
No sharp edges are exposed to user or in contact with furniture.	No sharp edges. All are sanded or filleted.	√
Wheels (if used) should work smoothly for all types of flat floor (or floor with a slope less than 10 degrees)	Works on a smooth flat floor. Further testing on carpeted floor and inclined floor is needed.	√
The entire dolly system can be stowed into space less than 1 m^3 when not in use.	Total space occupancy ~= 0.56 m^3	√
The dolly system should be reusable -- poses no damage to itself while assembling and disassembling.	The furniture dolly did not damage the couch nor itself during use.	√

√ Performance goal is met.

√ Performance goal is partially met or further investigation is needed.

7 DESIGN DOCUMENTATION

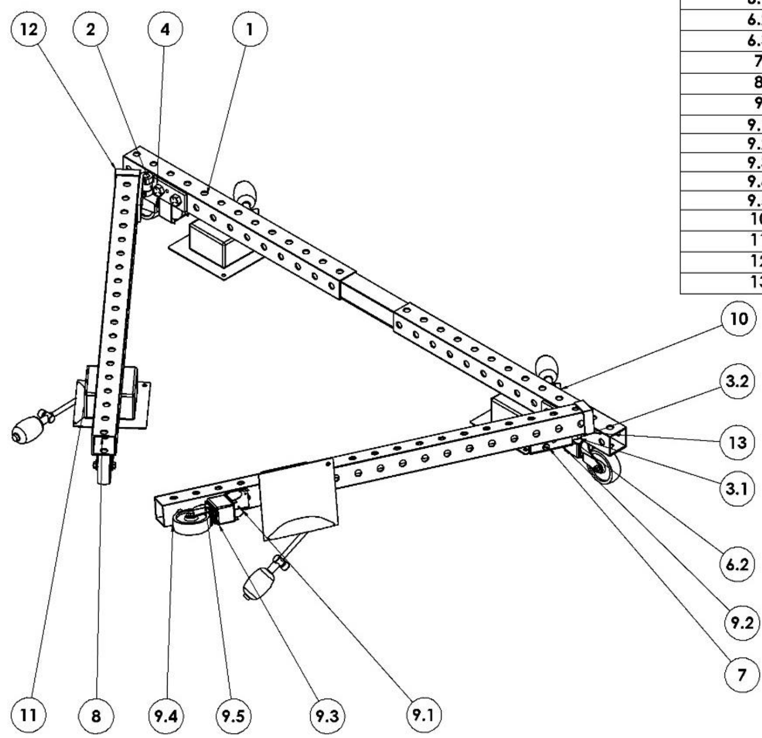
7.1 CAD DRAWINGS



	Full Assembly	12/08/16
Isometric view of entire model including all components		

Figure 22. CAD drawing -- full assembly

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	C-Channel	Middle frame's C-shaped channel	1
2	2-ft Tube	Extends along C-Channel	2
3	Strut Channel Hinge	Connects middle frame and side legs	2
3.1	Strut Channel Hinge -1		1
3.2	Strut Channel Hinge -2		1
4	Hex Bolt	Bolts Strut Channel Hinge onto extending tubes	4
5	Hex Nut	Sealing of Hex Nut	4
6	SurfaceMountHinge	Combines with Strut Channel Hinge to form a double hinge allowing right side leg to fold in two directions	1
6.1	SurfaceMountHinge-leaf1		1
6.2	SurfaceMountHinge-leaf2		1
6.3	SurfaceMountHinge-pin		1
7	1/4" Screw	Connection between double hinge	4
8	3-ft Tube	Side leg	2
9	FoldingWheel	Wheels at each corner of the frame. Can be folded up and down and locked in place with the folding bracket.	4
9.1	bracket1		1
9.2	bracket2		1
9.3	WheelMount		1
9.4	Caster		1
9.5	1/4" Screw		4
10	Air Wedge	A pump-wedge system to provide lift	4
11	Wedge Mount	A wood block to support air wedge	4
12	Pad-left	3D printed plastic paddings to prevent legs from running into extending tubes	1
13	Pad-right		1



	Bill of Materials	12/08/16
Compact Furniture Dolly		

Figure 23. CAD drawing -- BOM

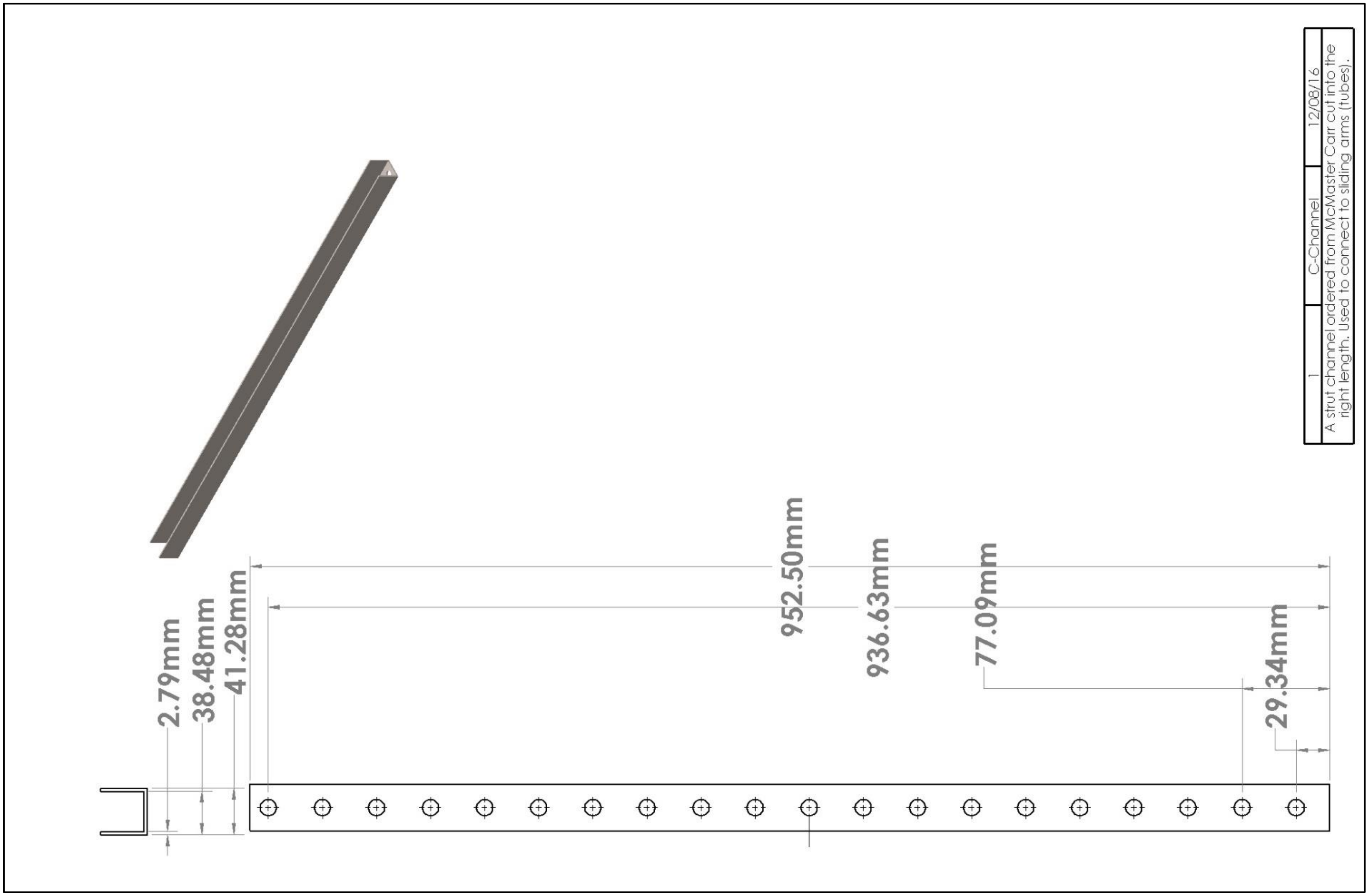


Figure 24. CAD drawing -- C-channel

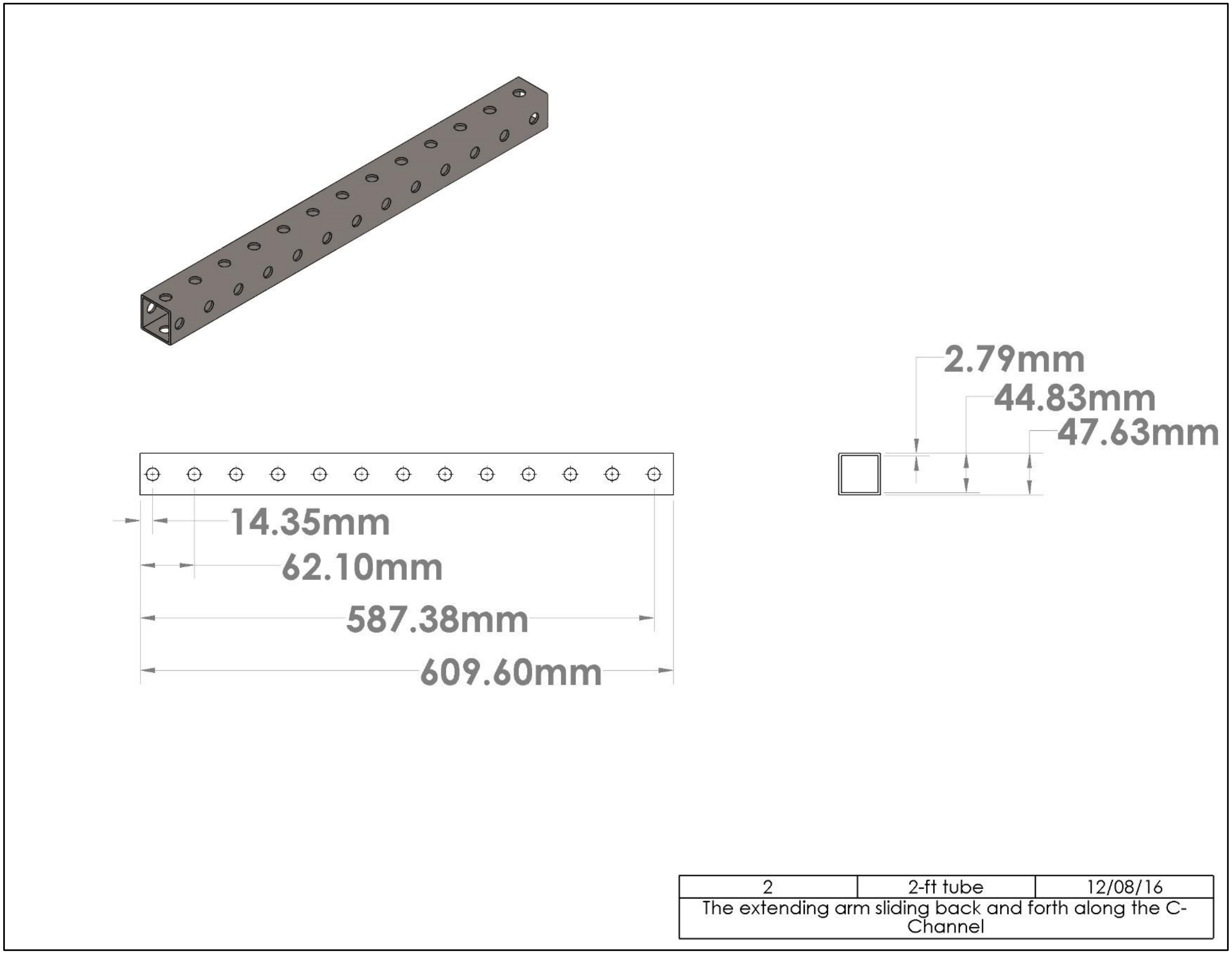


Figure 25. CAD drawing -- 2-ft tube

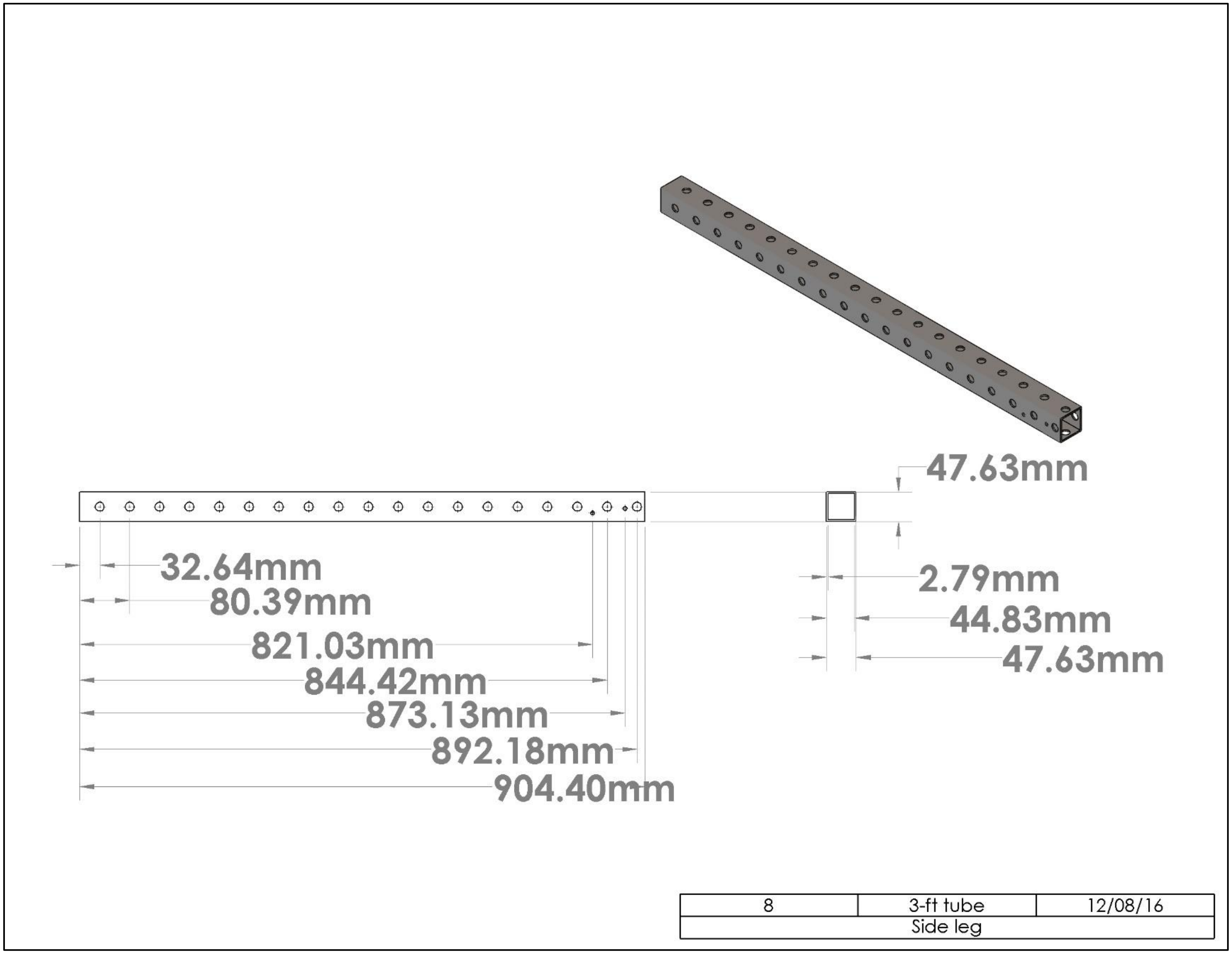


Figure 26. CAD drawing -- 3-ft tube

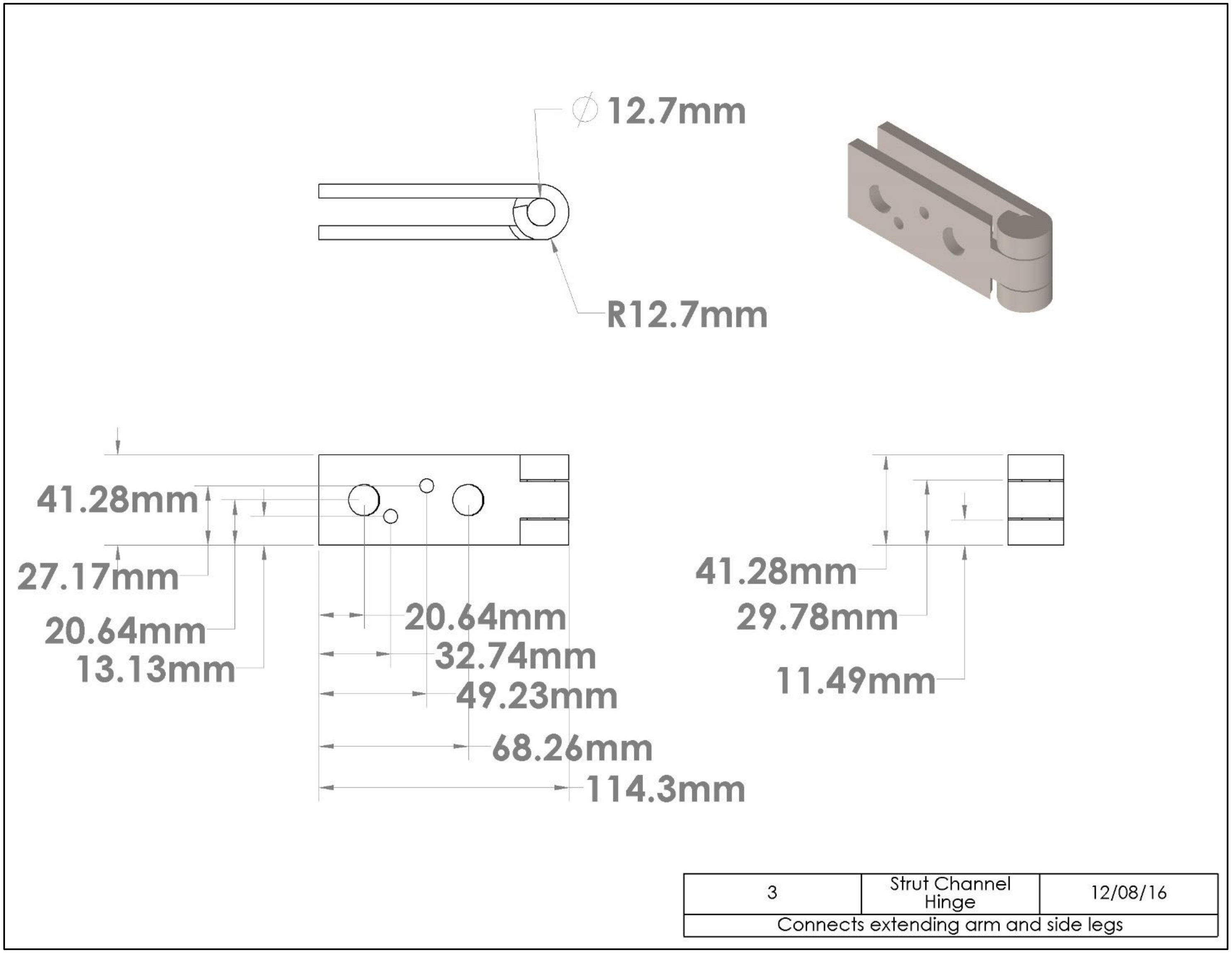


Figure 27. CAD drawing -- strut channel hinge

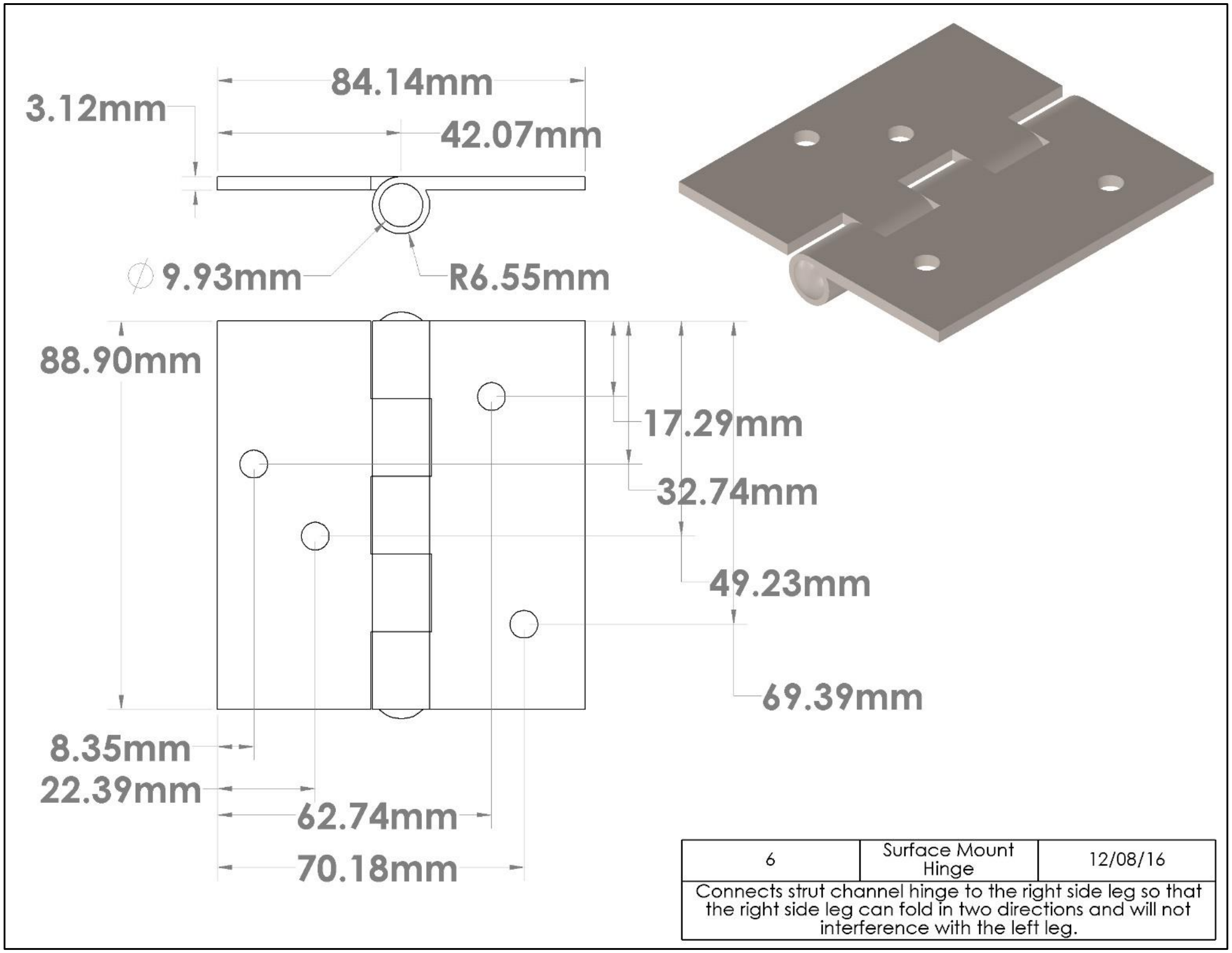


Figure 28. CAD drawing -- surface mount hinge

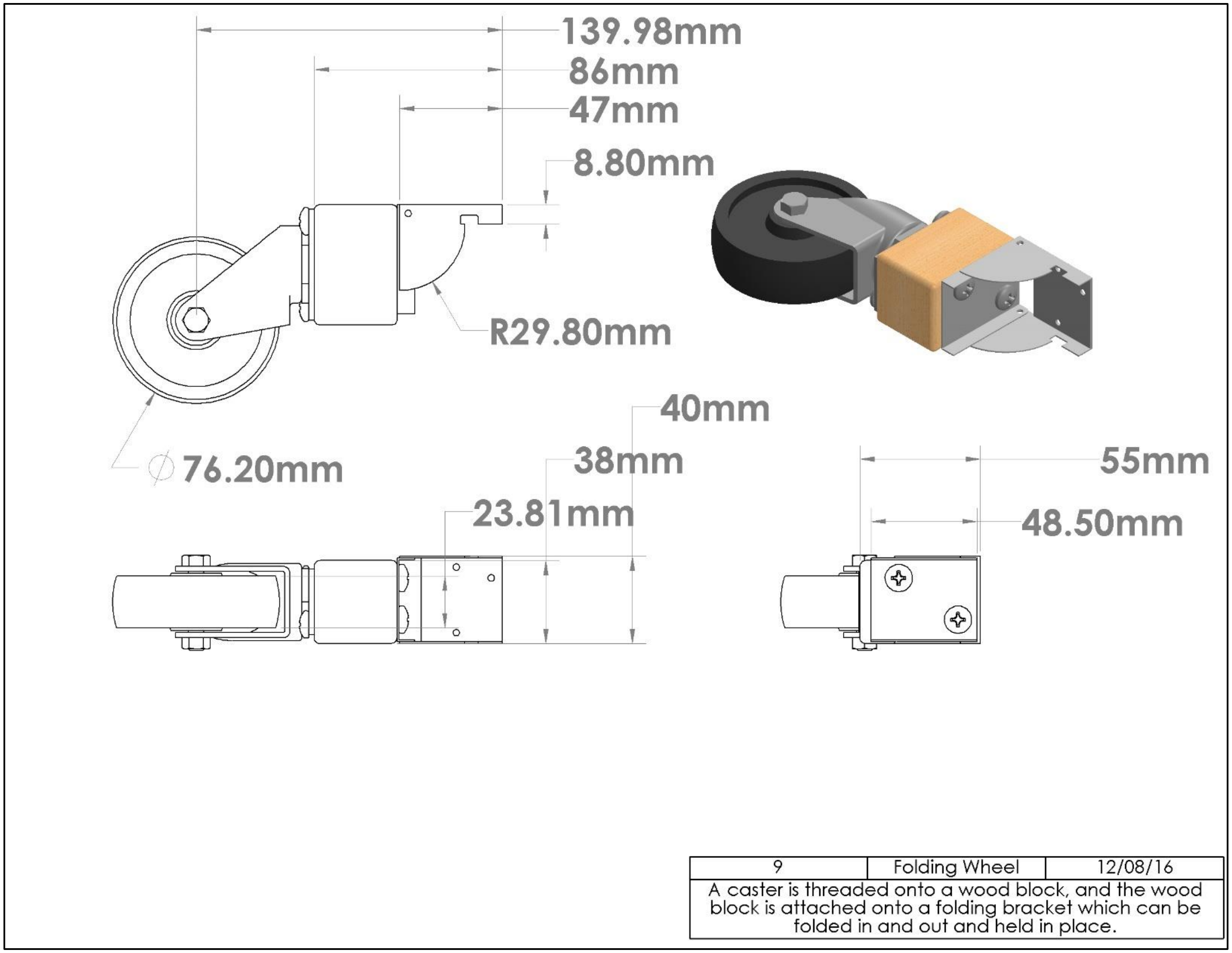


Figure 29. CAD drawing -- folding wheel

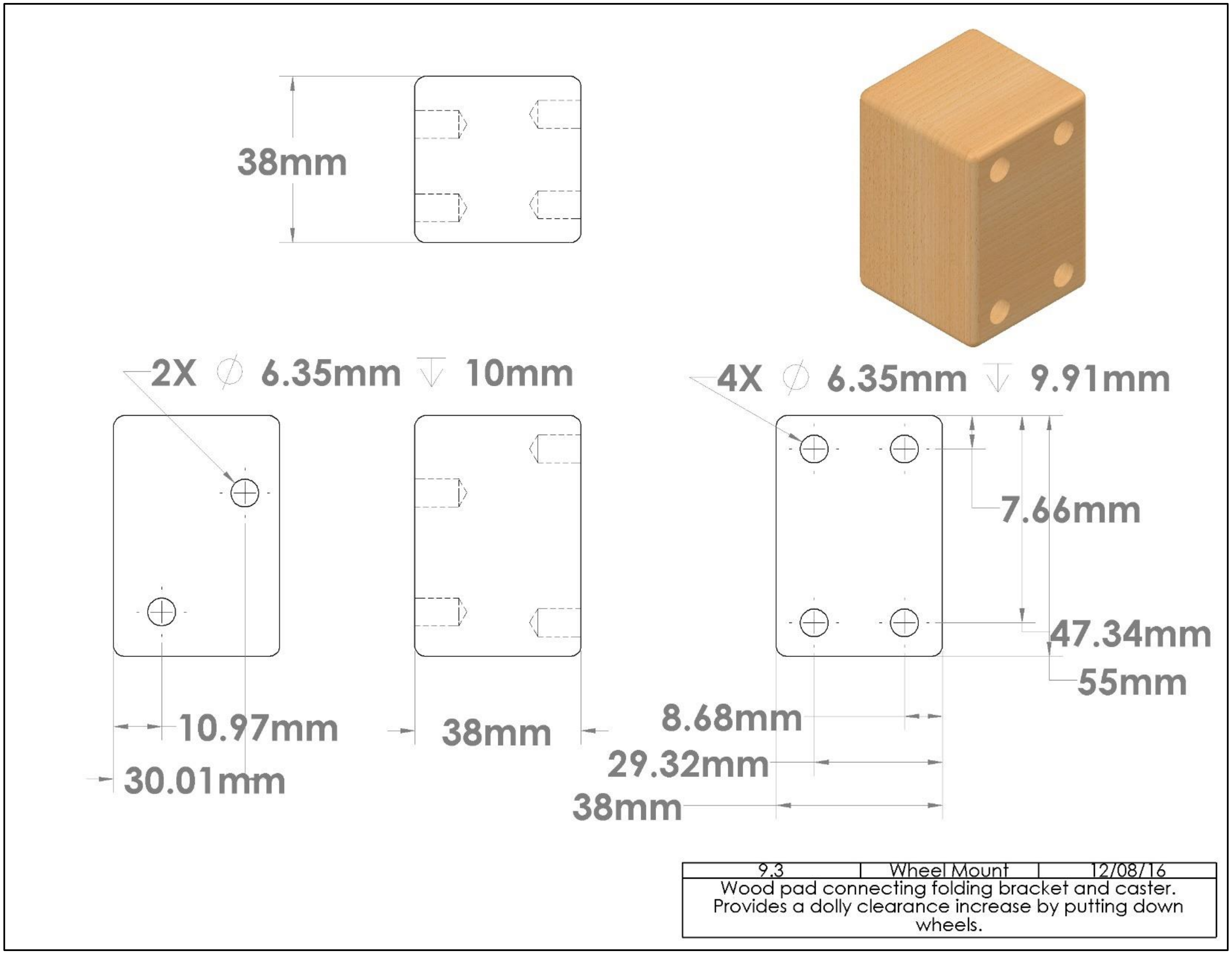


Figure 30. CAD drawing -- wheel mount

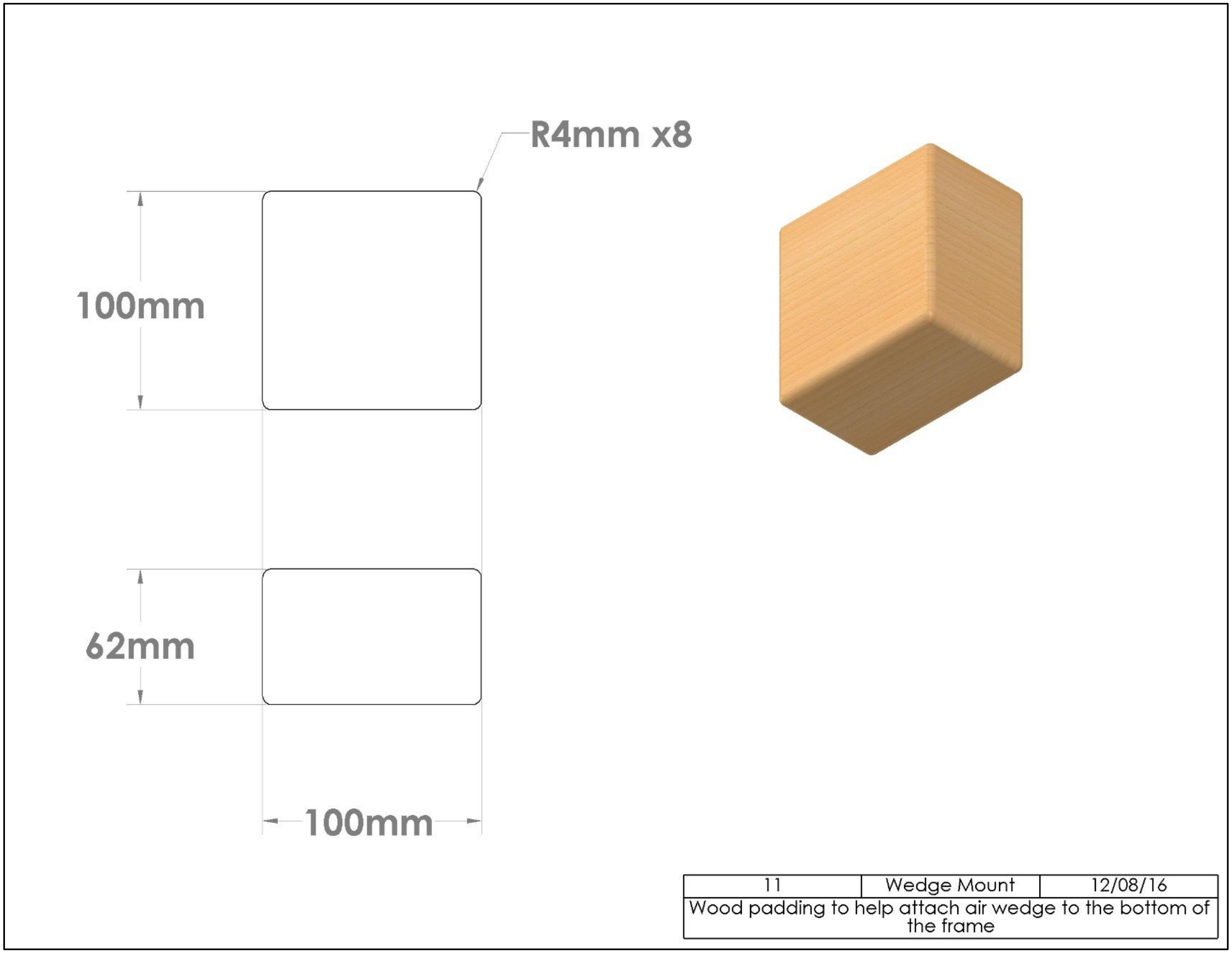


Figure 31. CAD drawing -- wedge mount

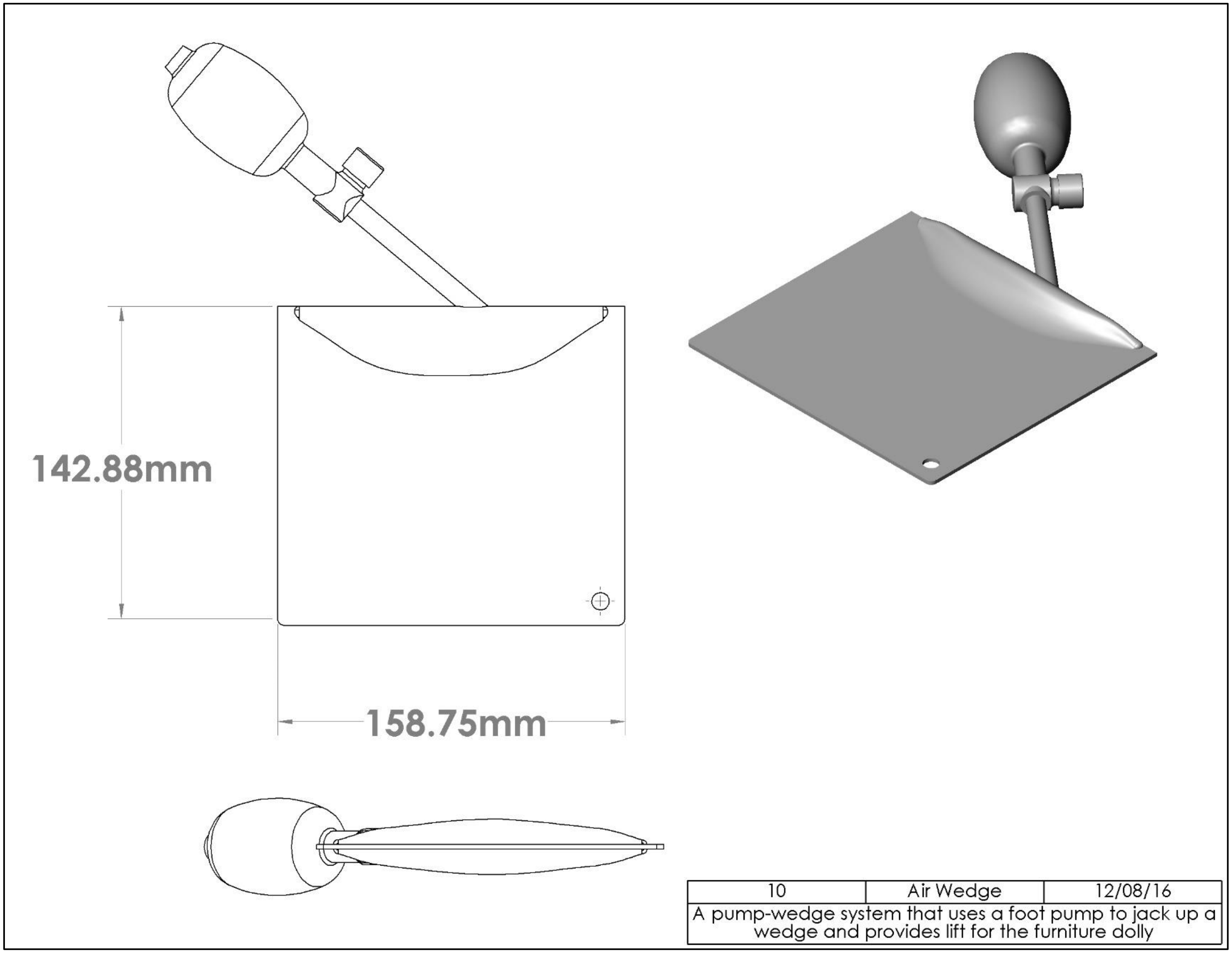


Figure 32. CAD drawing -- air wedge

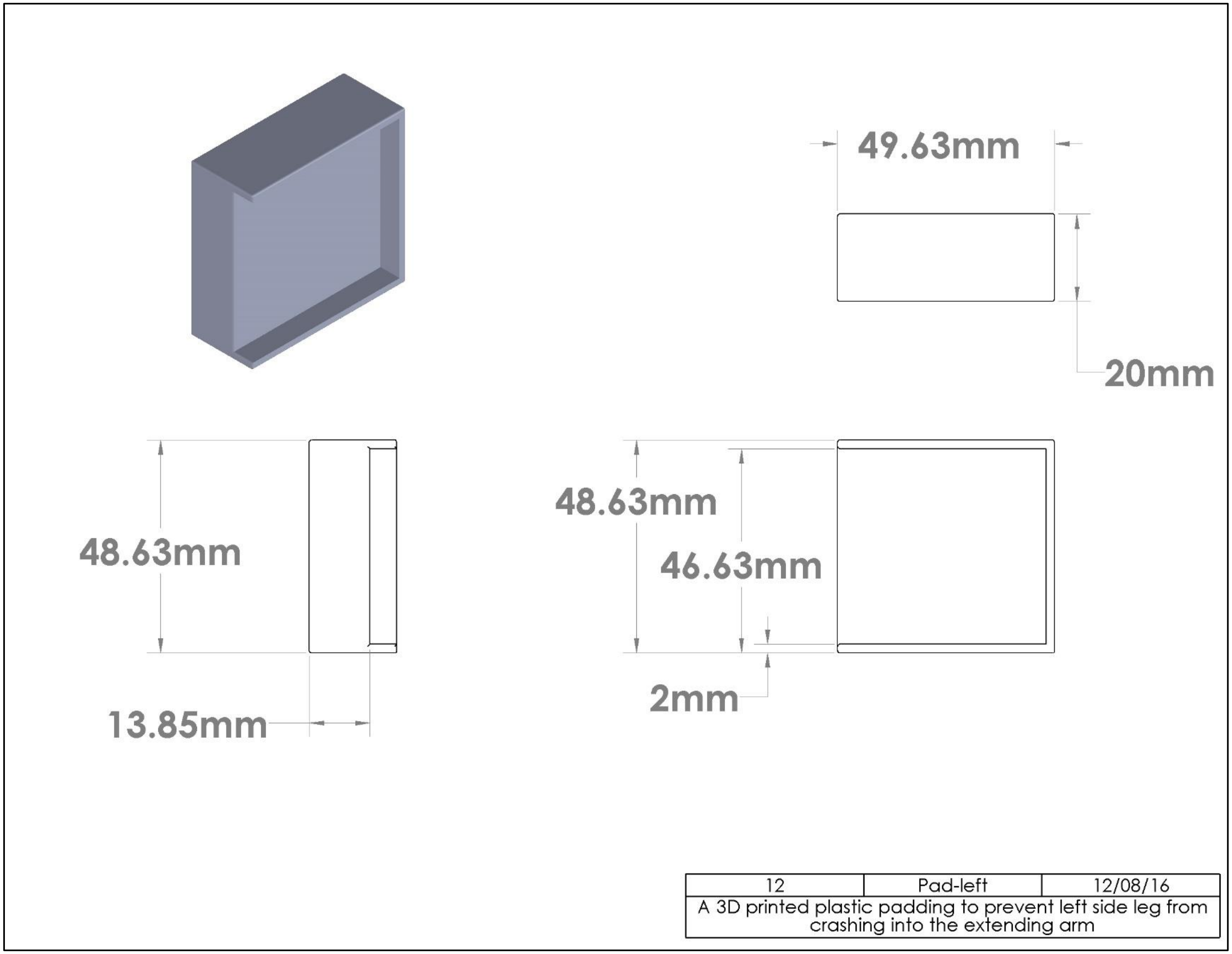


Figure 33. CAD drawing -- left pad

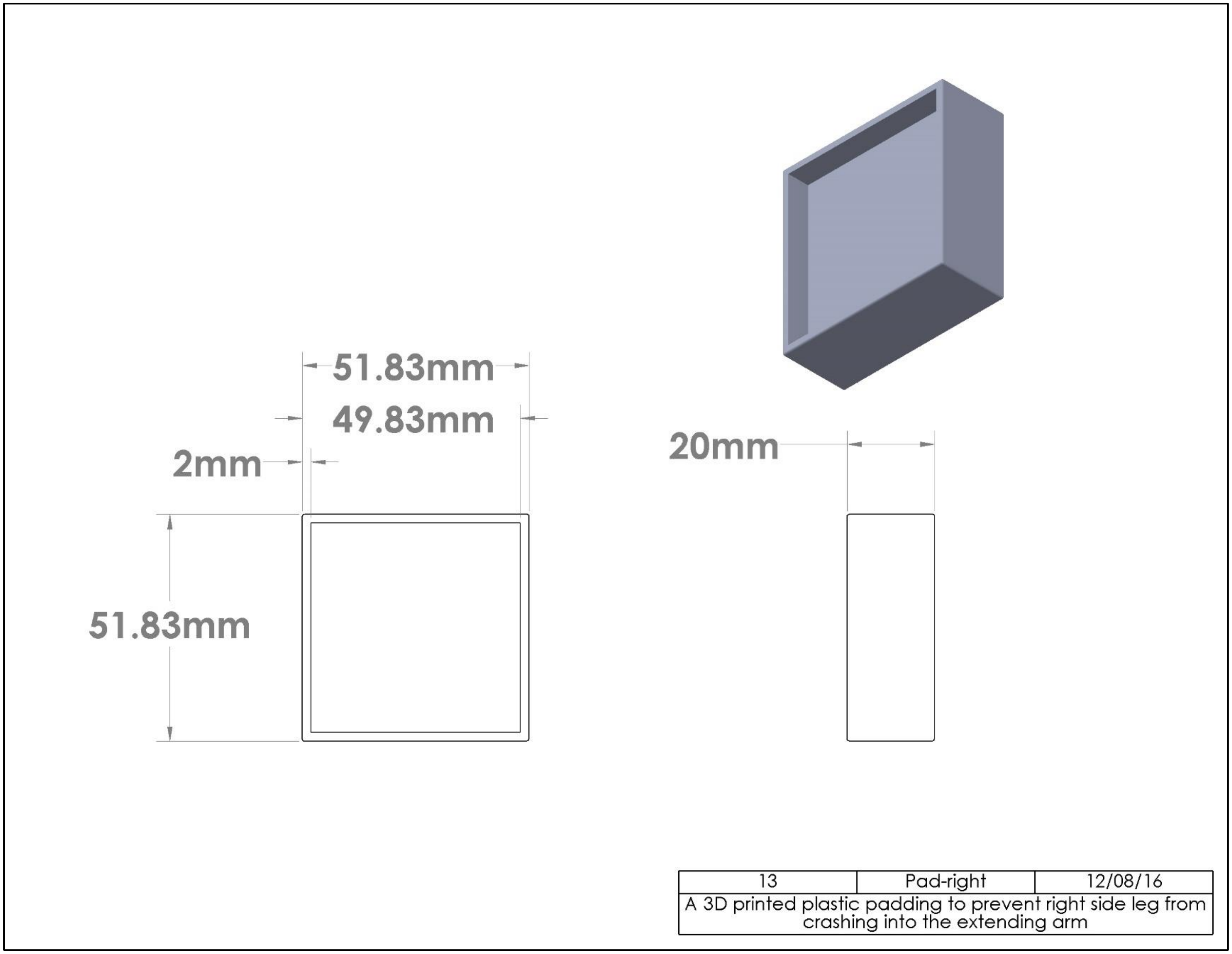


Figure 34. CAD drawing -- right pad

7.2 SOURCING INSTRUCTIONS

Item No.	Part Name	Source link	Part number	Description	Qty.
1	C-Channel	McMaster Carr	3138T6	Cut to 3.12 ft	1
2	2-ft Tube	McMaster Carr	3138T3	Cut to 2 ft	2
3	Strut Channel Hinge	McMaster Carr	3505T12	Zinc-Plated Steel	2
3.1	Strut Channel Hinge -1				1
3.2	Strut Channel Hinge -2				1
4	Hex Bolt	From Jolley Basement		Size described in CAD drawing	4
5	Hex Nut	From Jolley Basement		Size described in CAD drawing	4
6	SurfaceMountHinge	McMaster Carr	16175A32	Unfinished Steel	1
6.1	SurfaceMountHinge-leaf1				1
6.2	SurfaceMountHinge-leaf2				1
6.3	SurfaceMountHinge-pin				1
7	1/4" Screw	From Machine Shop		Size described in CAD drawing	4
8	3-ft Tube	McMaster Carr	3138T3	Cut to 3 ft	2
9	FoldingWheel	Amazon	32754		4
9.1	bracket1	Amazon	32754	Set of 2	1
9.2	bracket2				1
9.3	WheelMount	Wood piece picked up from Machine Shop		Size described in CAD drawing	1
9.4	Caster	McMaster Carr	2358T53	Black	4
9.5	1/4" Screw	From Machine Shop		Size described in CAD drawing	4
10	Air Wedge	Amazon	186389533	Black	4
11	Wedge Mount	Wood piece picked up from Machine Shop		Size described in CAD drawing	4
12	Pad-left	3D printed at Jolley Basement		Size described in CAD drawing	1
13	Pad-right				1

7.3 FINAL PRESENTATION

https://youtu.be/fr3u6HV7WrI?list=PLpaIgTgYdmcJ-6mZULCZl73bxzSJODK80

7.4 TEARDOWN

TEARDOWN TASKS AGREEMENT

PROJECT: Compact Furniture Dolly NAMES: Jason Xie INSTRUCTOR: Jakiela, Mabst

Geng Hu

Jieun Yim

Jiayi Hou

The following teardown/cleanup tasks will be performed:

- Dissassembly of dolly
- Return borrowed nuts and bolts to basement
- Scrap metal unistrut and channel, brackets, caster wheels, air jacks
- Scrap screws, wood blocks,
- Discard 3-D printed parts

Figure 35. Teardown plan and agreement page 1

Instructor comments on completion of teardown/cleanup tasks:

Instructor signature: [signature] Print instructor name: MARY MALAST

Date: 12/9/16

(Group members should initial near their name above.)

Figure 36. Teardown plan and agreement page 2

8 DISCUSSION

8.1 NEED-MET ASSESSMENT

The concept scoring criteria of Table 2 describe the metrics and quantified needs for the design that the final prototype aimed to fulfill. In the final prototype, a select list of needs was emphasized over the rest in the design and they were: weight capability, minimum length of frame, maximum length of frame, and height of dolly. It is evident that more attention to achieving the load capacity and dimensions of the frame to fit under the furniture overall. The need for the dolly to fit a low clearance and variety of furniture was successfully met through the adjustable frame and folding wheels. As a result, needs such as lifting time, number of people needed to operate, weight, length of time to assemble, and the pumping mechanism were not well met in this iteration. In the beginning, we were expecting to use some sort of motorized air pump, distributing air to all four jacks simultaneously; however, in budget limitations made us settle for four discrete, hand-pumped wedges that drastically increased our lifting and setup times.

With budget and load concerns, the steel frame provided the need strength and stability to support and move a piece of furniture as demonstrated in our working prototype; however, the weight of the dolly was quite heavy and does not match our goals of making it user-friendly, especially to older citizens. Our plan is to use composite materials in future iterations would preserve the strength needed and reduce the weight. If weight was not an issue, one person could operate the dolly though it would take a long time, a factor we would address also in further iterations. The time needed to pump all four jacks and subsequently deflate them took the most time, even with three or four members operating the dolly. The compact design of the final prototype was successful as it demonstrated to use of a hinge-double-hinge mechanism to fold the arms and transform the folly that could be easily and efficiently packed into a closet or compartment. Nevertheless, the design needed locking mechanisms to hold the arms in place and the unwanted movement of the frame in both its unfolded and compact forms. These factors present a hazard to appendages that may be caught while operating the dolly or between folding parts that were not addressed in the current prototype.

Overall, with the current air jack set up on the prototype, if one person were to operate the dolly, the assemble/install/detach/disassemble process takes more than the 2 minutes initially proposed. The total height of the dolly system is under 20 cm. During a prototype demonstration, a wood block supporting the caster wheel failed, thus design revisions must be made with the wood components to ensure adequate structural integrity. The rest of the frame was able to support the weight without failure. When furniture was loaded onto the dolly, it was relatively easy to push the dolly across a flat surface. The prototype is reusable, able to be assembled and disassembled multiple times. There were sharp edges on the part and locking mechanisms for the arms must be implemented to make the product safe for users.

8.2 PART SOURCE EVALUATION

Sourcing was not a significant issue in our process. The majority of parts ordered were from McMaster and were delivered in a timely fashion. Those from other online vendors also were acquired with no inconvenience. Parts such as nuts, bolts, screws, and wood blocks were the only materials scrounged for but were readily available in the storage in the basement of Jolley and/or the machine shop. A recommendation would be to check with the professors or machine shop supervisors first for more common parts like connections before ordering them online.

8.3 OVERALL EXPERIENCE

8.3.1 Project difficulty

There were challenging aspects in determining a extendable and compact design of a dolly that was supposed to carry up to 500 lbs. Two of the main design problems were the folding arms and folding wheels, in which we came up with the solution of using a double-hinge and folding bracket, respectively. We expected to have more trouble with the parts ordering, but that process went relatively smoothly for us. The main difficulty was finding an air jack under our budget and coming up with design modifications for the prototype to deal with the lack of the air jacks we intended in our initial designs.

8.3.2 Description-result alignment.

Our final project results align with the initial project description, though not without its limitations. Our working prototype does, in essence, work as we proposed; however, weight, safety, user-friendliness, time, and ease of operation are measures that need to be improved upon. The current prototype allows for heavy furniture to be loaded and pushed easily across horizontal surfaces.

8.3.3 Team experience

Everybody in the team was willing to help out and do what they could to develop to prototype. We communicated well and were able to find times outside of recitation to meet and discuss the project. Everyone was enthusiastic about seeing the project through and creating a working prototype. There was always at least one member in the team who was able to perform a skill. Examples include operating the mill, working with wood, design ideas, and presenting for the design reviews. Every team member was involved in the project and did so to contribute equally to developing to dolly, and we were able to develop a successful first iteration of our furniture dolly.

8.3.4 Design brief

We worked mostly to the original design brief. The design brief remained relatively constant with a few changes with the final design, such as the removal of the towing handle and removable wheels.

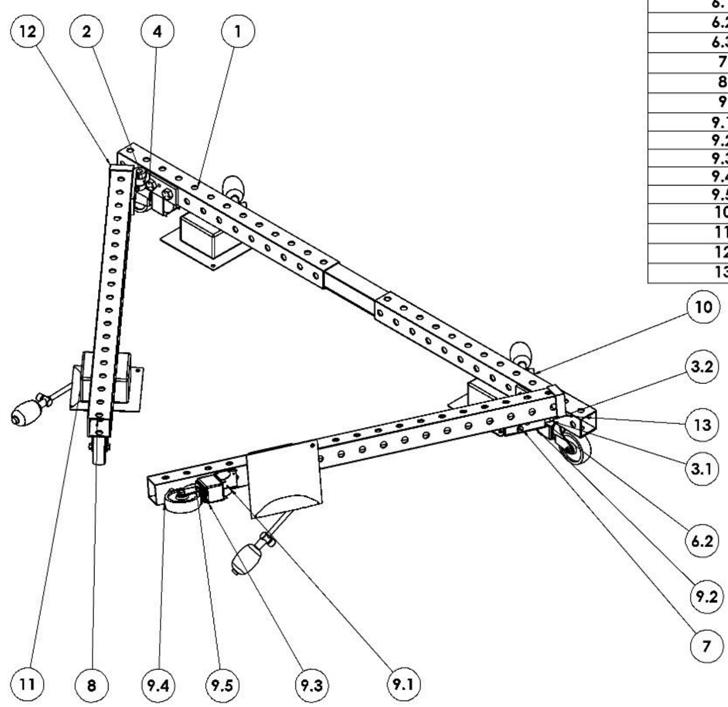
8.3.5 Design skills

There were many design challenges we faced in creating this compact furniture dolly. We learned how to communicate our ideas to one another and applied what we learned in class to use CAD. Going through the process developing a product definitely gives us some exposure and familiarization to a design project assignment. This project has given us confidence to create working deliverables in projects that otherwise we would only have drawings and models.

APPENDIX A - PARTS LIST

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	C-Channel	Middle frame's C-shaped channel	1
2	2-ft Tube	Extends along C-Channel	2
3	Strut Channel Hinge	Connects middle frame and side legs	2
3.1	Strut Channel Hinge -1		1
3.2	Strut Channel Hinge -2		1
4	Hex Bolt	Bolts Strut Channel Hinge onto extending tubes	4
5	Hex Nut	Sealing of Hex Nut	4
6	SurfaceMountHinge	Combines with Strut Channel Hinge to form a double hinge allowing right side leg to fold in two directions	1
6.1	SurfaceMountHinge-leaf1		1
6.2	SurfaceMountHinge-leaf2		1
6.3	SurfaceMountHinge-pin		1
7	1/4'' Screw	Connection between double hinge	4
8	3-ft Tube	Side leg	2
9	FoldingWheel	Wheels at each corner of the frame. Can be folded up and down and locked in place with the folding bracket.	4
9.1	bracket1		1
9.2	bracket2		1
9.3	WheelMount		1
9.4	Caster		1
9.5	1/4'' Screw		4
10	Air Wedge	A pump-wedge system to provide lift	4
11	Wedge Mount	A wood block to support air wedge	4
12	Pad-left	3D printed plastic paddings to prevent legs from running into extending tubes	1
13	Pad-right		1

APPENDIX B - BILL OF MATERIALS



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	C-Channel	Middle frame's C-shaped channel	1
2	2-ft Tube	Extends along C-Channel	2
3	Strut Channel Hinge	Connects middle frame and side legs	2
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3.2	Strut Channel Hinge -2		1
4	Hex Bolt	Bolts Strut Channel Hinge onto extending tubes	4
5	Hex Nut	Sealing of Hex Nut	4
6	SurfaceMountHinge	Combines with Strut Channel Hinge to form a double hinge allowing right side leg to fold in two directions	1
6.1	SurfaceMountHinge-leaf1		1
6.2	SurfaceMountHinge-leaf2		1
6.3	SurfaceMountHinge-pin		1
7	1/4" Screw	Connection between double hinge	4
8	3-ft Tube	Side leg	2
9	FoldingWheel	Wheels at each corner of the frame. Can be folded up and down and locked in place with the folding bracket.	4
9.1	bracket1		1
9.2	bracket2		1
9.3	WheelMount		1
9.4	Caster		1
9.5	1/4" Screw		4
10	Air Wedge	A pump-wedge system to provide lift	4
11	Wedge Mount	A wood block to support air wedge	4
12	Pad-left	3D printed plastic paddings to prevent legs from running into extending tubes	1
13	Pad-right		1

	Bill of Materials	12/08/16
Compact Furniture Dolly		

APPENDIX C – CAD MODELS

Come with this report as supplementary materials. A list of CAD models is shown below:

No.	File Name	Type	Referencing
1	AirWedge	SLDPRT	
2	bracket1	SLDPRT	
3	bracket2	SLDPRT	
4	caster	SLDPRT	
5	channel	SLDPRT	
6	FoldingWheel	SLDASM	2, 3, 4, 13, 24
7	FullAssembly	SLDASM	1, 5, 6, 8, 9, 10, 11, 15, 17, 21, 22, 23
8	HexHeadBolt	SLDPRT	
9	HexNut	SLDPRT	
10	Pad-left	SLDPRT	
11	Pad-right	SLDPRT	
12	RoundHeadScrew	SLDPRT	
13	RoundHeadScrew-longer	SLDPRT	
14	StrucChannelHinge-2	SLDPRT	
15	StrutChannelHinge	SLDASM	12, 14, 16
16	StrutChannelHinge-1	SLDPRT	
17	SurfaceMountHinge	SLDASM	12, 18, 19, 20
18	SurfaceMountHinge-leaf1	SLDPRT	
19	SurfaceMountHinge-leaf2	SLDPRT	
20	SurfaceMountHinge-pin	SLDPRT	
21	tube-2ft	SLDPRT	
22	tube-3ft	SLDPRT	
23	WedgeMount	SLDPRT	
24	WheelMount	SLDPRT	

APPENDIX D – EXISTING DESIGNS (COMPETITORS)

Furniture slider

Furniture sliders are square or round pads which have one smooth side and one rough side. Lift each corner of the furniture and put a slider underneath so that the smooth edge is towards the floor, which will reduce the friction and make moving much easier. The rough side of slider is designed to retain furniture on the pad.

Disadvantages: You have to stoop or sit down to manually lift corners of the furniture to insert slider between the furniture and the floor. The smooth edge of the slider only works well with certain types of floor, and it cannot reduce friction very well on carpet, grass, or stone. The slider can easily get stuck with dirt or small obstacles on floor. Moving heavier furniture using sliders still requires a decent amount of push.

www.harborfreight.com

www.realpropertymgt.com

Shoulder dolly

These are lifting straps that connect to your shoulders and help take the weight off your back. They help you utilize your stronger muscle groups while also giving you added leverage.

www.amazon.com

www.harborfreight.com

Disadvantages: Operation requires at least two people. Long time heavy duty usage will result in backache or spinal disease. Even a smallest tilt will shift the weight almost completely to one person. It cannot lift furniture with a large gap between its bottom and floor, i.e. tables.

Manual Lift and Roll Moving Dollies - Set of 2

This product consists of two separate dollies. The user should slightly tilt and load the stuff on the platform, and tie it down to each dolly. There is a hand crank lift up the load. This product is suitable for a load that has a firm bottom surface which can be positioned on the platform, such as a bookshelf, a mattress and a drawer. Because the size of the platform is not big, there is a limit to the size of the bottom surface of the load that the user would be able to move using this product. In addition, the hand crank might require more power than a hydraulic jack.

APPENDIX E – ENGINEERING ANALYSIS REPORTS

load analysis width arm-Static 1

frame extended analysis.docx

wood block analysis.docx