ARCH 365: STRUCTURAL DESIGN/BUILD WORKSHOP

CHAIR FOR SPIDERMAN

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DESIGN MANIFESTO

Client: Spiderman

Spiderman & Venom: Dual Personality

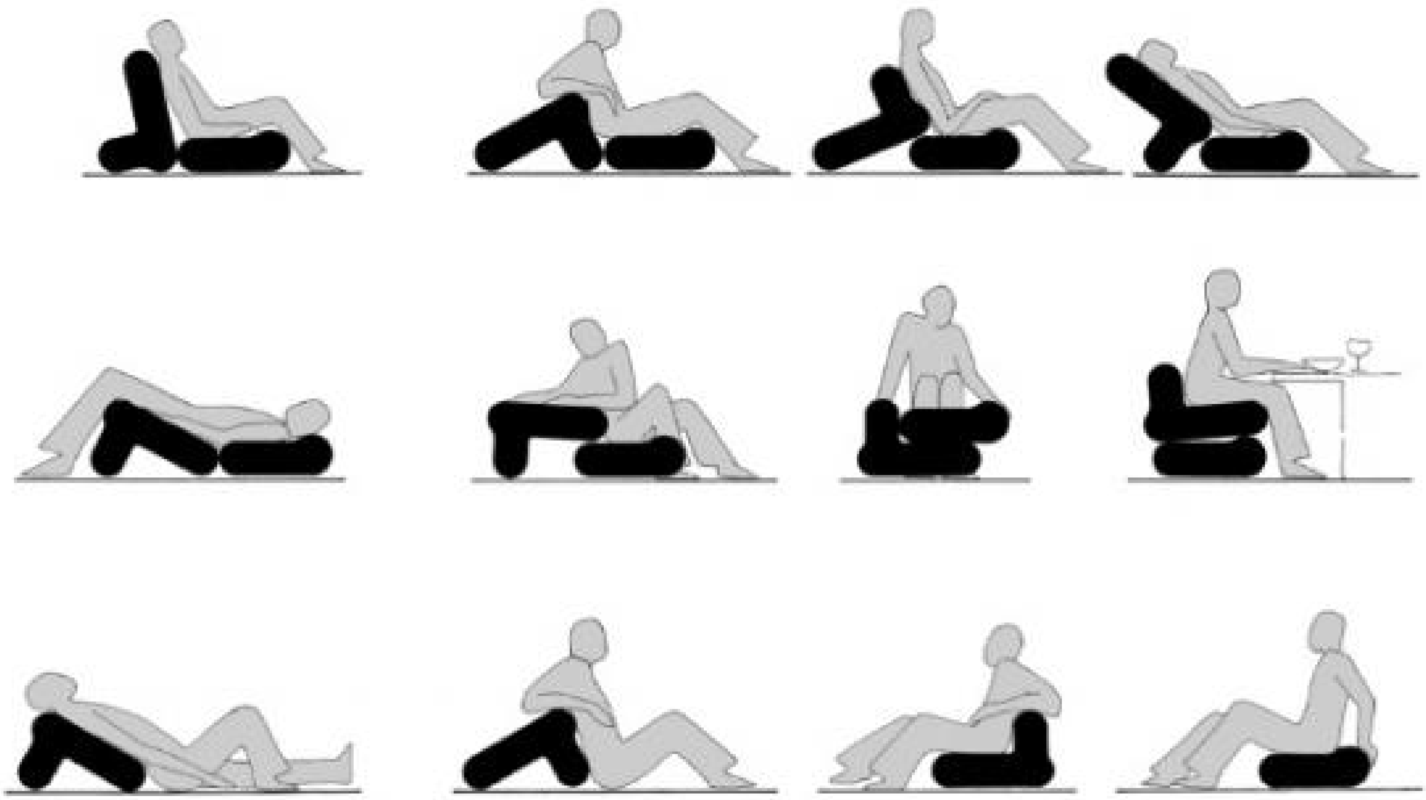
Adaptability to Dynamic Surfaces

Ever since his initial conception in the 1960s, Spiderman has been a prominent figure in the American pop culture. His unconventional powers, memorable story of transformation, and his connection to New York City make his character analogous to Hector, a Trojan hero from Greek mythology whose identity is deeply rooted in Troy. The one aspect of Spiderman that we would like to explore is his ability to cling onto any surface in various orientations. From an architectural standpoint, this completely changes the perception from which we base our instincts and intuitions in design; gravity. What differentiates a floor from a wall and a wall from a ceiling is that they are distinctly defined by their relative orientations to the gravitational axis.

What if one could experience the same phenomenon without being bitten by a radioactive spider? What if one could experience ordinary objects in our lives in a multi-faceted way? What if one could defy the fundamental law of physics: gravity?

Using this concept to launch our architectural imaginations, we would like to explore in designing a chair that would allow the user to interact with the object in a similar fashion as a Spiderman does; a dynamic form and function. We would like to design a sculptural chair that, in its form, will give rise to unique silhouettes relative to the changing position of the viewer and also defy the preconception of gravity. We would like the chair to be easily configurable and lightweight, to allow for the user to sit on many of its faces. In short, it is a chair where there is no standard orientation to gravity.

PRECEDENTS
Inspirations



Joe Colombo, B-Line Multichair
Multi-Functionality, Easy Configuration

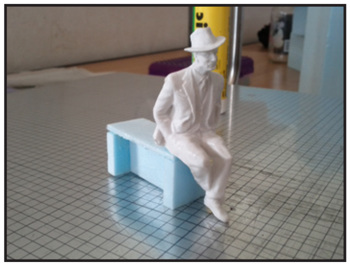
Marble Sculpture
Monolithic Object

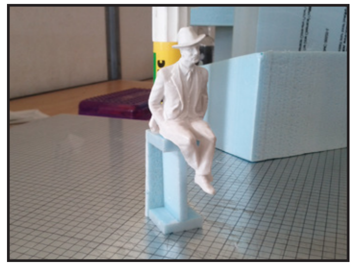
OMA, CCTV Headquarters Building
Gravity-Defying Geometry & Proportion

Bureau Schlp, Walnut Desk
Shell-Frame Structural Composition

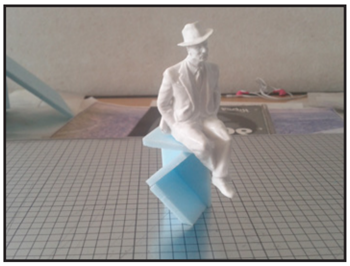
DESIGN DEVELOPMENT
Concept Iterations & Genealogy

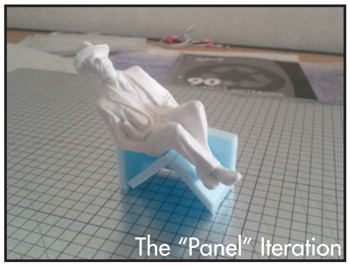

The "CCTV" Iteration



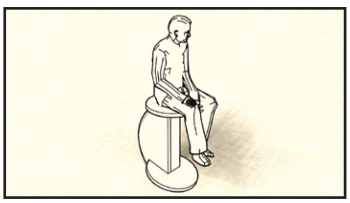


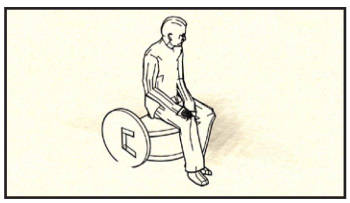

The "I-Beam" Iteration

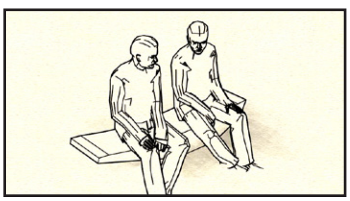


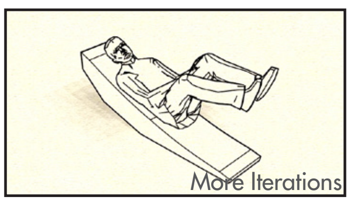

The "Panel" Iteration

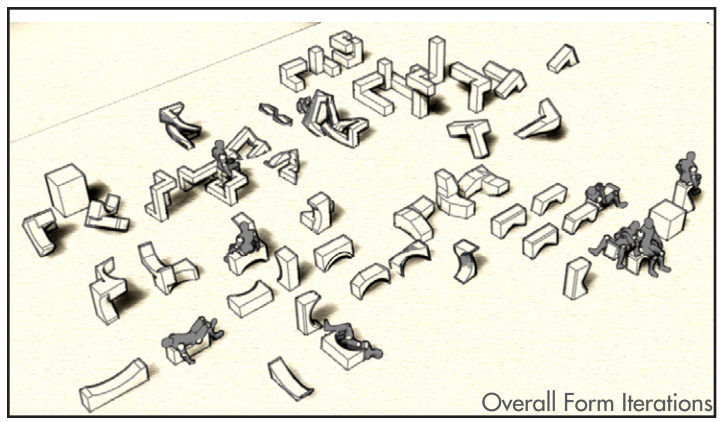

The "Arch" Iteration








More Iterations


Overall Form Iterations

Primary Design Parameters:

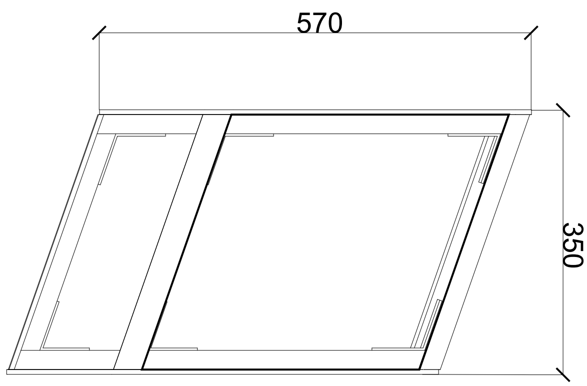
1. All faces of the chair must accommodate interaction with the user
- **FUNCTION ADAPTABILITY.**

2. The chair will appear different from multiple angles
- **DYNAMIC FORM.**

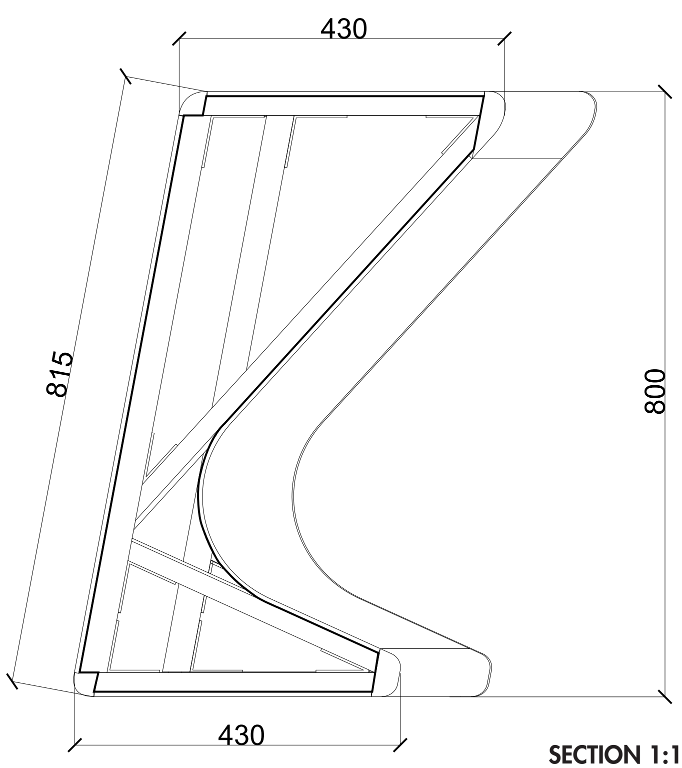
3. Shell envelope with lightweight internal framework
- **STRUCTURAL COMPOSITION.**

The design started off with a conventional I-beam-like shape that allowed for maximum flexibility in its functions using minimal surfaces to establish sitting planes. However, change in perceptions between different orientations were too abrupt; therefore a rather solid, monolithic form was pursued as an alternative. By treating the mass as a product of evolution from an elemental form, which in this case is a rectangle, numerous deformations were studied (twisting, carving, stretching, replicating, and shearing) to achieve a desirable aesthetic and dynamic-functional form.

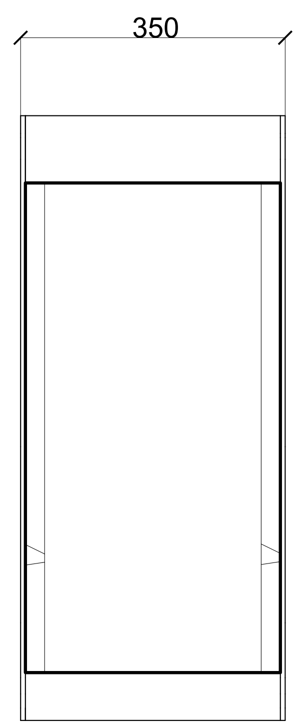
FINAL DESIGN
Overall Drawings



PLAN 1:10

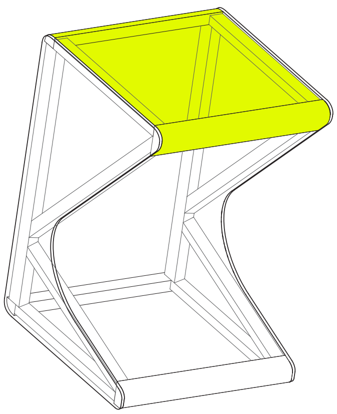


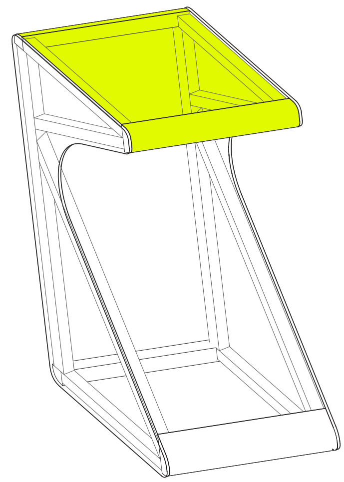
SECTION 1:10

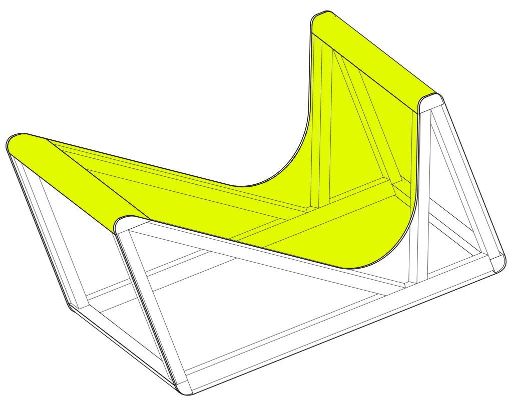


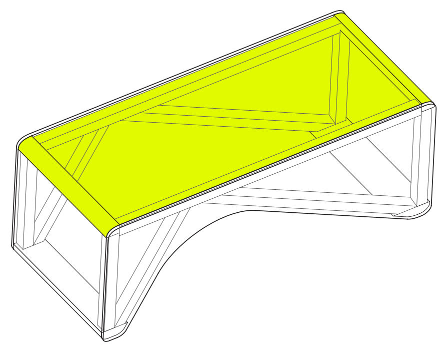
FRONT ELEVATION 1:10

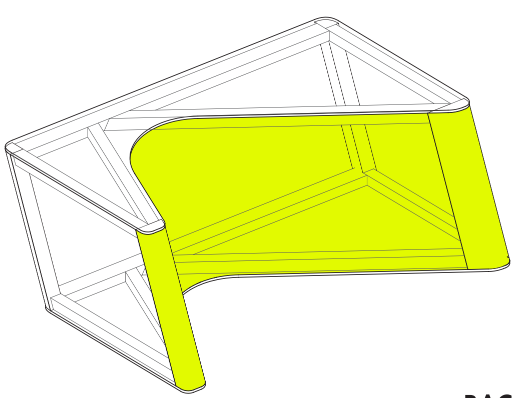
FINAL DESIGN
Orientations

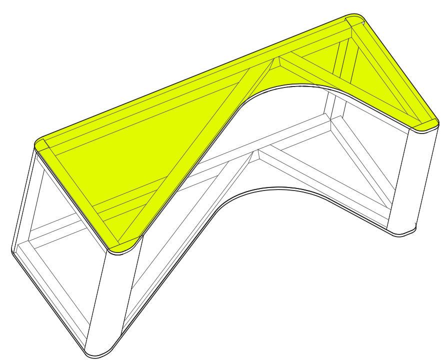

BAR STOOL 1


BAR STOOL 2


LOUNGE CHAIR


BENCH

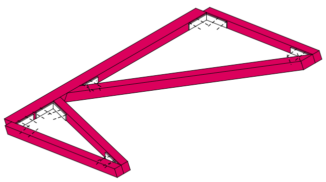

BACKREST


CHILDREN'S BENCH

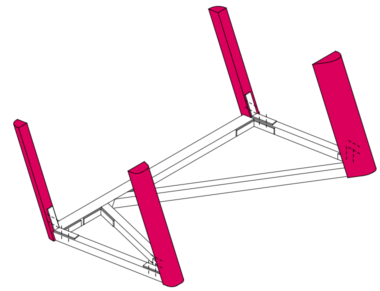
FINAL DESIGN

Method of Assembly

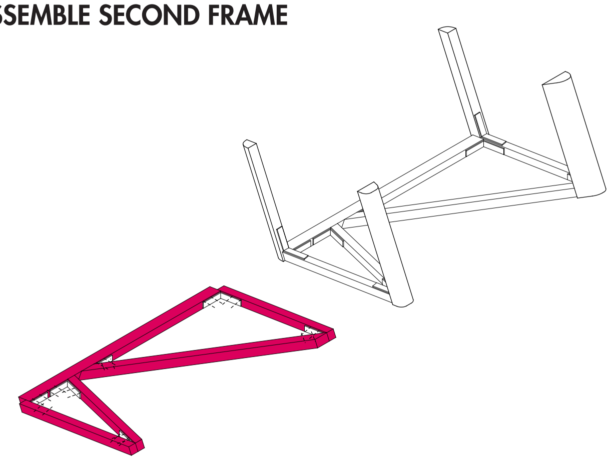
1. ASSEMBLE FIRST FRAME



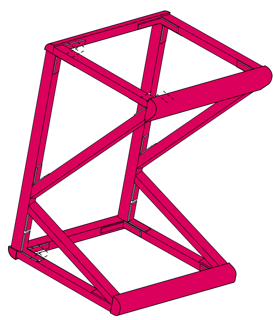
2. ATTACH FILLETED CORNERS



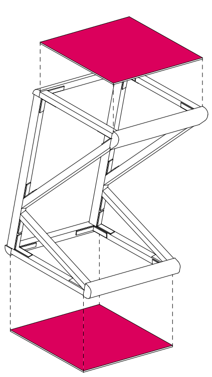
3. ASSEMBLE SECOND FRAME



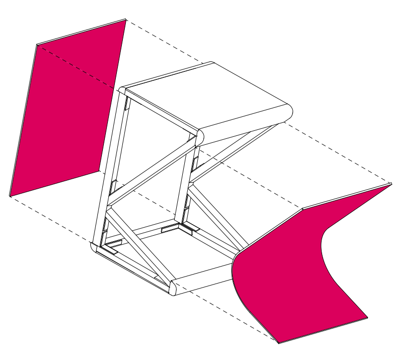
4. COMBINE FRAMES



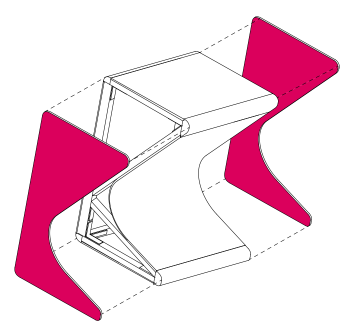
5. GLUE TOP & BOTTOM SHEATHING PANELS



6. GLUE BACK & FRONT SHEATHING PANELS



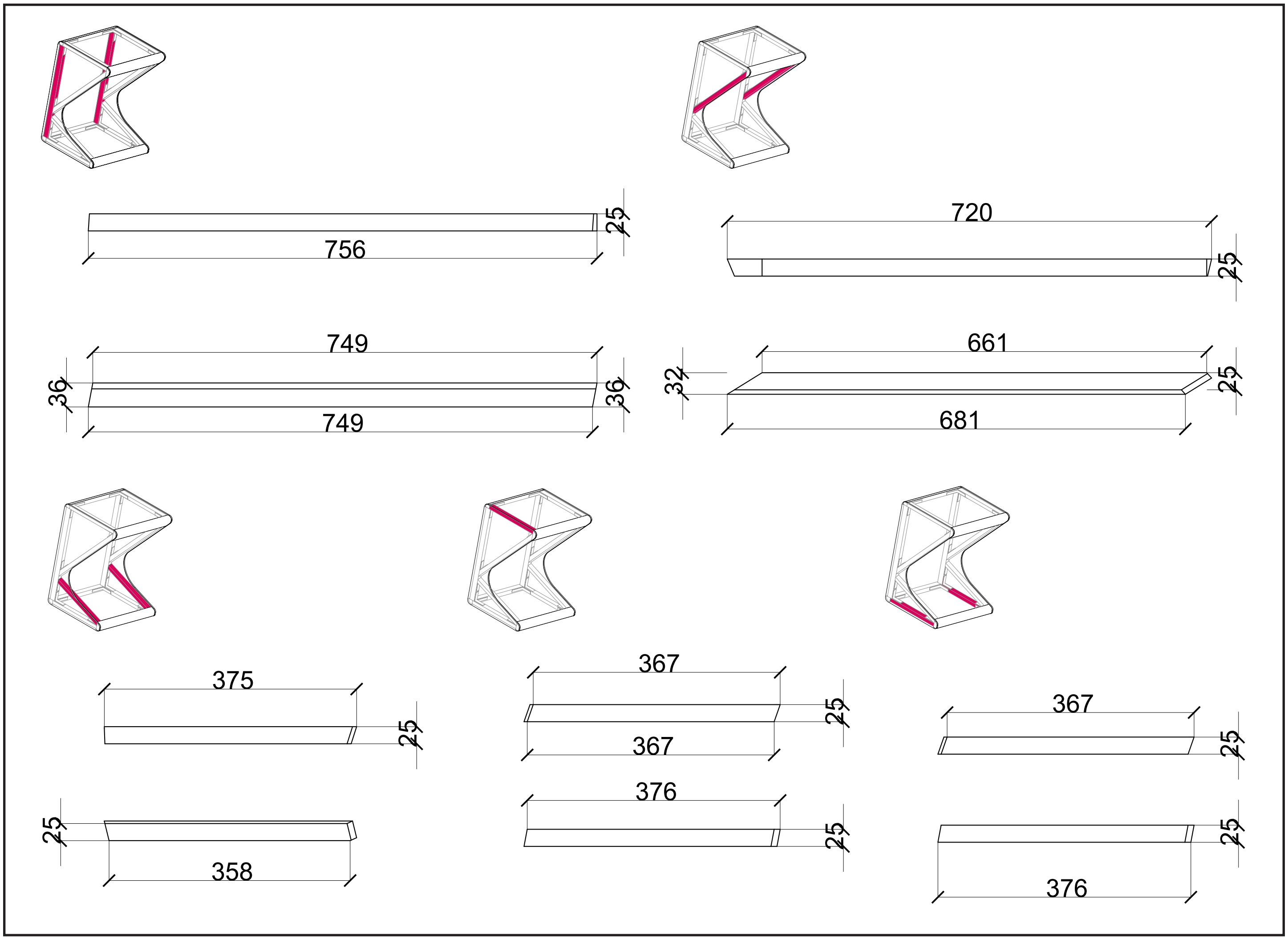
7. GLUE SIDE SHEATHING PANELS



FINAL DESIGN

Dimensioned Component Drawings of Fabricated Parts

FRAME MEMBERS



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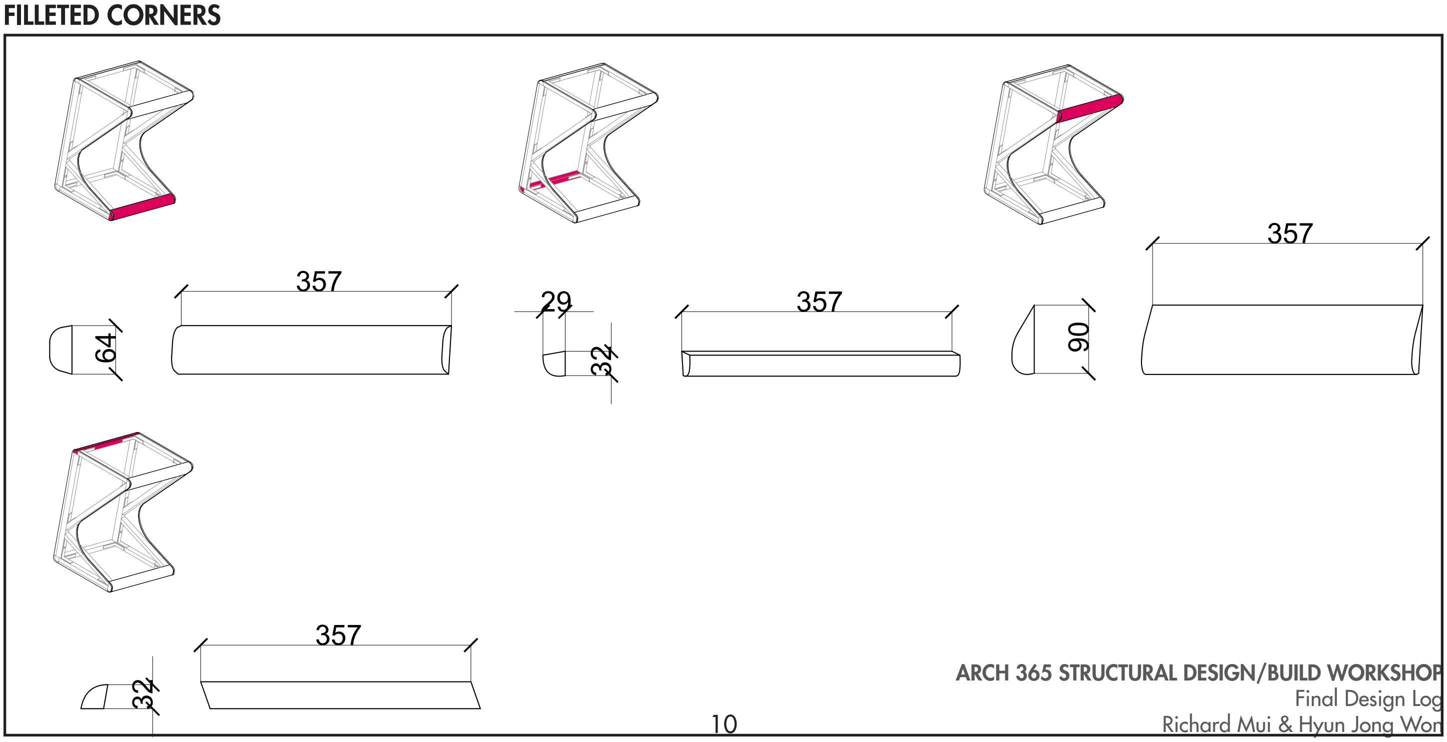
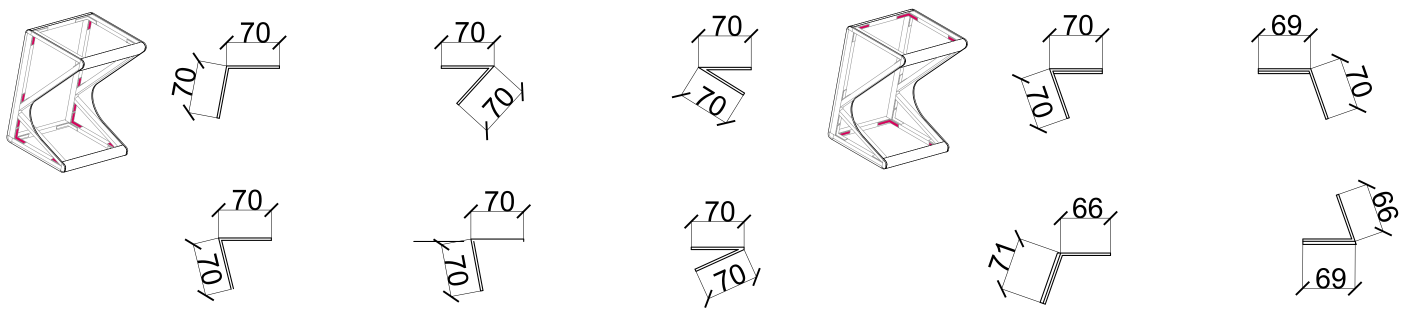
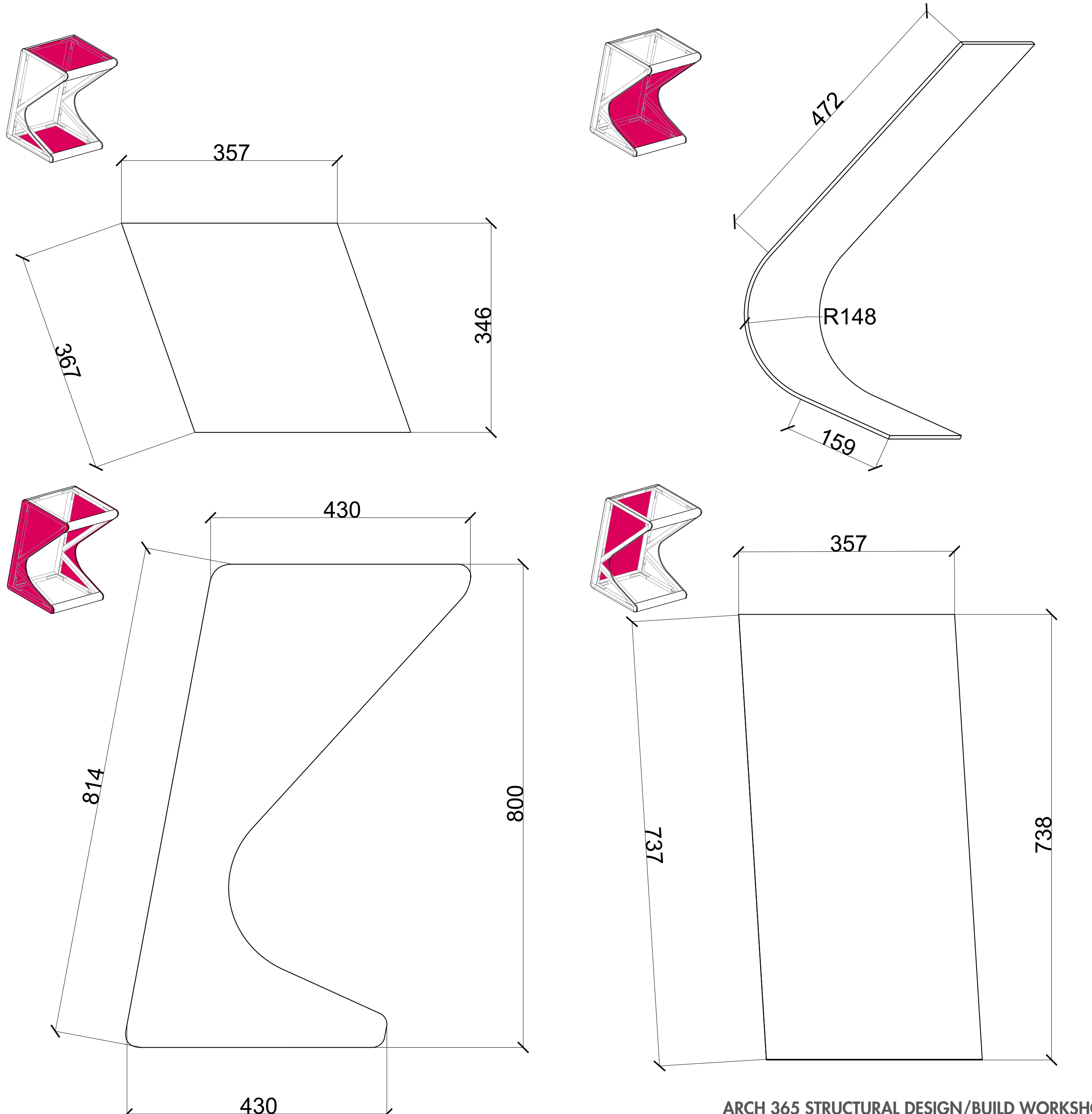


STEEL ANGLES



SHEATHING PANELS



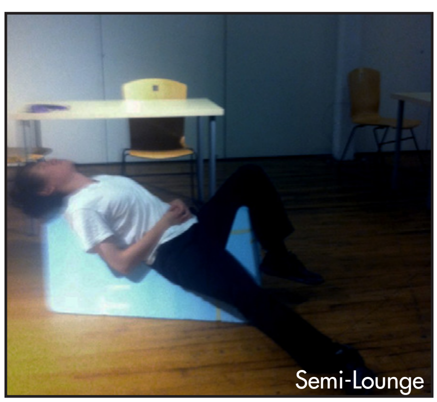
Bar Stool 1

Bar Stool 2

Backrest

Children Bench

Bench

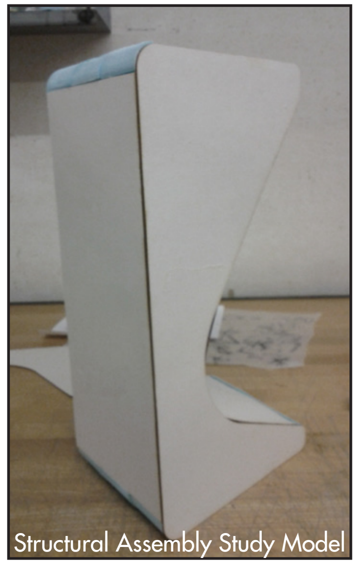


Semi-Lounge

Foam Ergonomics Mock-up (1:1)

As the overall form of the chair was strongly driven by the function it serves relative to its orientation, it was necessary to consider ergonomics in defining the geometry. Therefore, we constructed a 1:1 foam ergonomic mock-up to study the scale of the chair and the comfortability of sitting on the chair, especially on the semi-lounge orientation. As a result, we were able to observe that our initial massing was too enormous in comparison to a person, therefore we reduced the mass of the chair and made the radius of the curvature more generous.

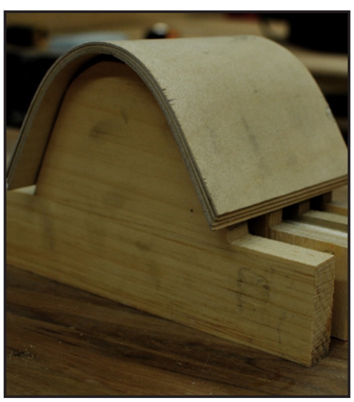




Structural Assembly Study Model

Component Assembly Mock-up (1:2)

As the geometry of the chair and the method of assembly was unprecedented, we made a component assembly mockup to help us visualize how the sheathing was fixed to the frame. In doing so, we were able to identify certain difficulties in implementing tools in assembling the frame, as acute angles made it almost impossible to screw the angles with a hand drill.

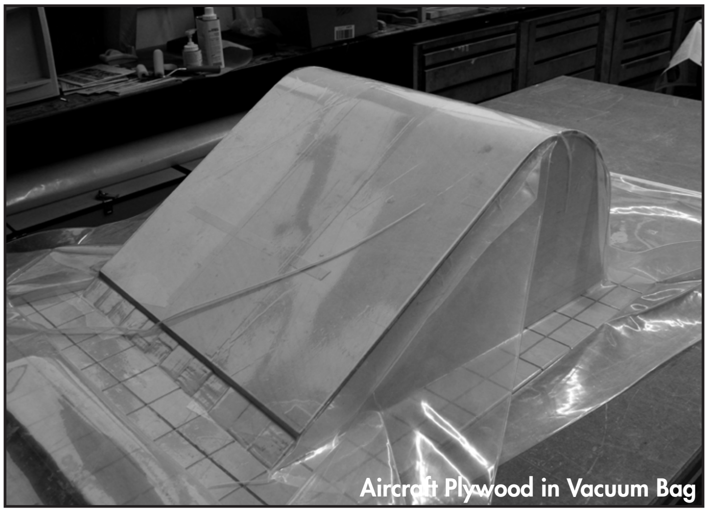


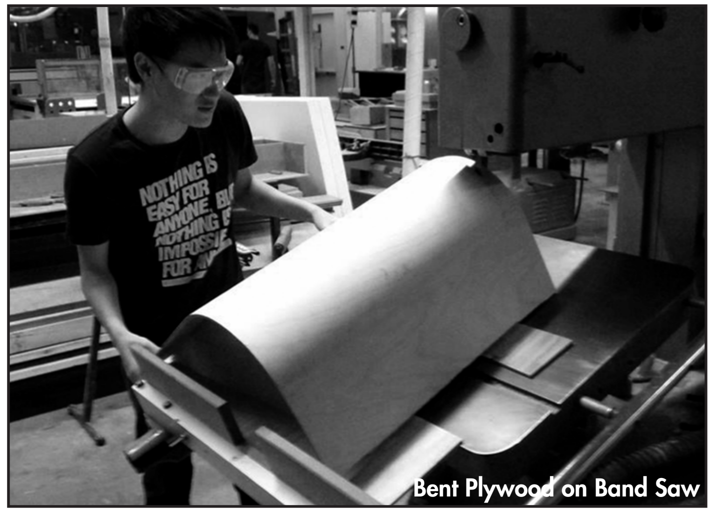

Aircraft Plywood on Jig

Lamination Bend Test

In order to test the maximum capacity to which aircraft plywood can bend without cracking, we constructed a small jig on which pressure was applied to maintain the plywood in its bent shape until the glue dried. The radius for the curvature was much tighter than the one on the chair however the outcome was fairly successful. It is strong enough for a full-grown adult to stand on it without breaking.

FINAL CONSTRUCTION
Fabrication & Assembly


Aircraft Plywood in Vacuum Bag


Bent Plywood on Band Saw


Frame Hand Saw


Fabricated Components


Custom Angles on Metal Band Saw


Blacksmithing


Assembled Frame

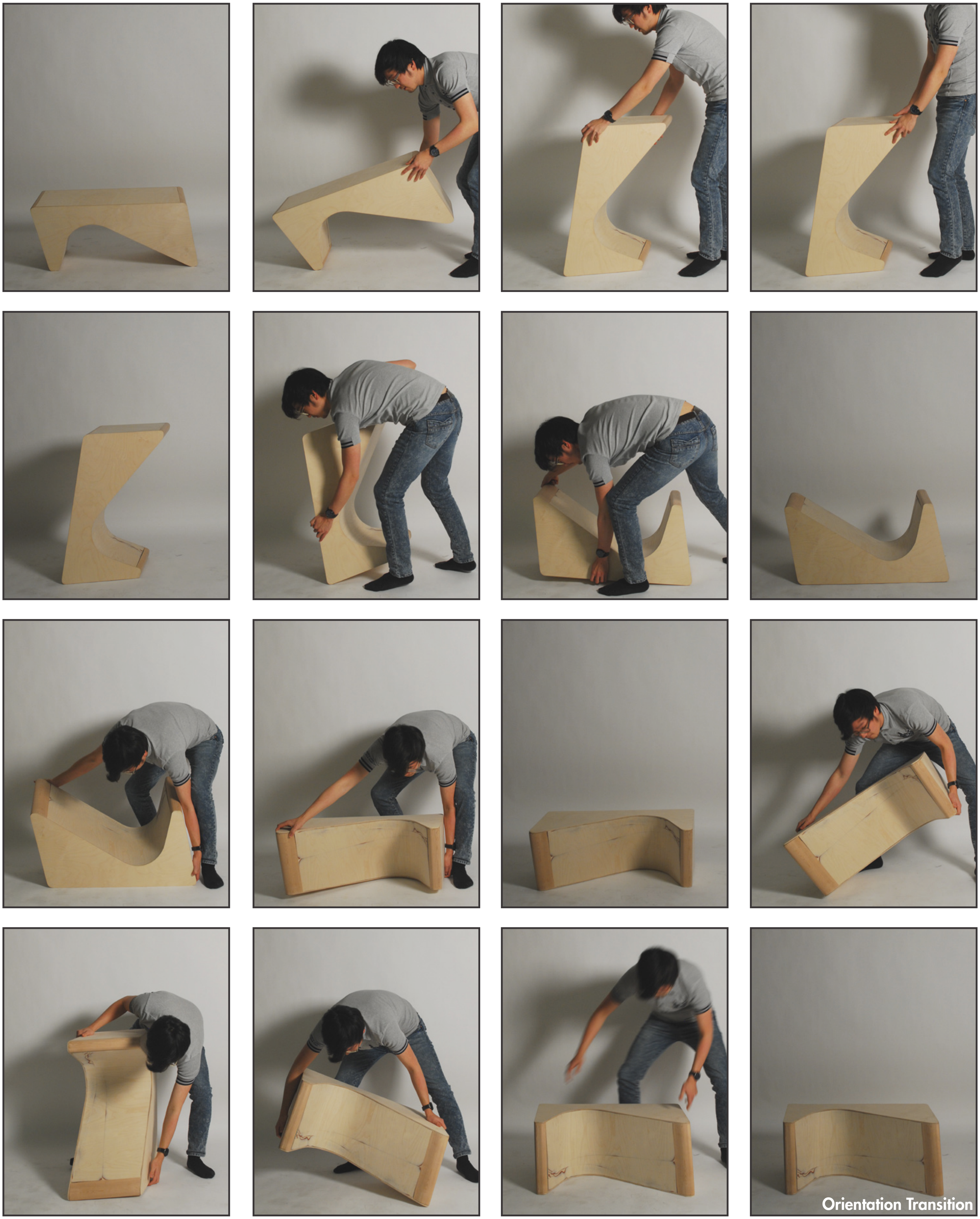

Angle Joinery Detail


Sheathing Assembly


Sheathing to Frame Detail

FINAL CONSTRUCTION
Completed Product

Functional Capabilities



Orientation Transition

MATERIALS

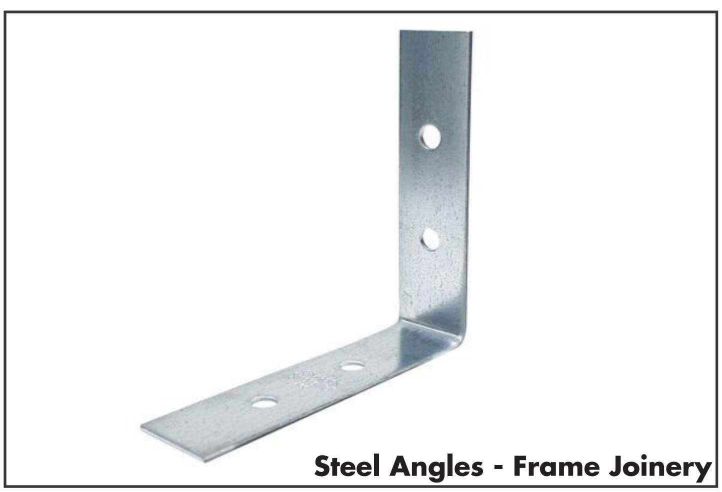
Component Manifesto & Material List

Baltic Plywood - Shell Sheathing

Aircraft Plywood - Bent Sheathing

Yellow Ash - Frame Structure

Yellow Birch - Fillet Corners



Steel Angles - Frame Joinery

No.3 Screws - Frame Joinery

Each component has been assigned its respective material with aesthetics and structural performance in mind. For the sheathing, birch has been chosen as it is the most commonly manufactured product. While the Baltic birch is used for majority of the sheathing, aircraft plywood had to be implemented in order to account for the curvature on one of the faces of the object. Not only is aircraft plywood relatively strong, it is flexible enough to be formed via lamination in a vacuum bag. On the other hand, ash has been chosen for the structural frame as hardwood allows for angle-joinery while providing a high level of rigidity and strength. Steel angles and screws were chosen as they allow flexible tolerances in the assembly process of the frame with the sheathing.

Material Weight

- Plywood (Shell) = 5714189 mm^3 -> 0.005714 m^3 / 0.00635 m = 0.8998m^2
(0.8998 m^2 * 5 N/m^2) / 9.8 m/s^2 = **0.46 Kg**
- Aircraft Plywood (Shell) = 1899698 mm^3 -> 0.001899 m^3 / 0.00635 m = 0.2991 m^2
(0.2991 m^2 * 5 N/m^2) / 9.8 m/s^2 = **0.15 Kg**
- Solid Birch (Corner Fillets) = 1648345 mm^3 -> 0.001648 m^3 * 690 kg/m^3 = **1.13 Kg**
- Solid Ash (Framing) = 5628658 mm^3 -> 0.005628 m^3 * 800 kg/m^3 = **4.5 Kg**
- Steel Angles = 0.22 Kg * 20 = **4.4 Kg**
- Screws = **0.25 Kg**

Total Weight = 0.46 Kg + 0.15 Kg + 1.13 Kg + 4.5 Kg + 4.4 Kg + 0.25 Kg = 10.89 Kg

Material Cost

A&M Wood Specialty Store

- Baltic Birch Plywood (Shell) = 3 60" x 60", 1/4" Thick Sheets ($30 * 3 = $90)
- Aircraft Birch Plywood (Shell) = 4 50" x 50", 1/16" Thick Sheets ($75 * 4 = $300)
- Solid Birch = 0.698 Board Feet * $7/BF = $4.89
- Solid Ash = 2.385 Board Feet * $6.4/BF = $15.26

Home Depot

- Rigid Polystyrene Foam = 6 24" x 96" Sheets ($30 * 6 = $180)
- Steel Angles = $8
- Screws & Washers = $10

Lee Valley Store

- Epoxy Resin Glue & Hardware = $85

Total Material Cost = $90 + $300 + $4.89 + $15.26 + $180 + $8 + $10 + $85 = $693.15
Includ. Tax = $783.26

Machining Cost

FabLab

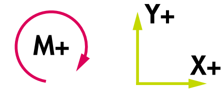
- CNC Router = $15 + $20 ($10/hour) = $35
- Laser Cutter = 2 hours * $10/hour = $20

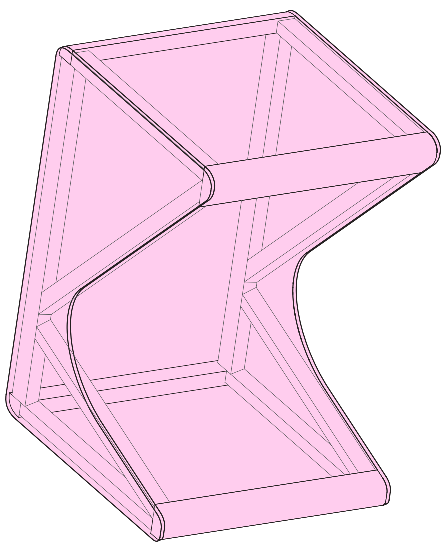
Total Machining Cost = $35 + $20 = $55

Total Cost = $783.26 + $55 = $838.26

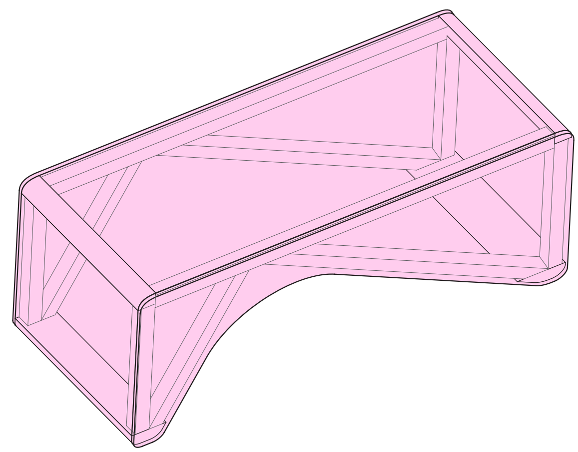
FINAL ANALYSIS

Worst Case Scenarios, Scale 1:10





WORST CASE SCENARIO A (BAR STOOL)

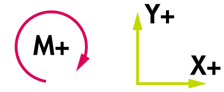


WORST CASE SCENARIO B (BENCH)

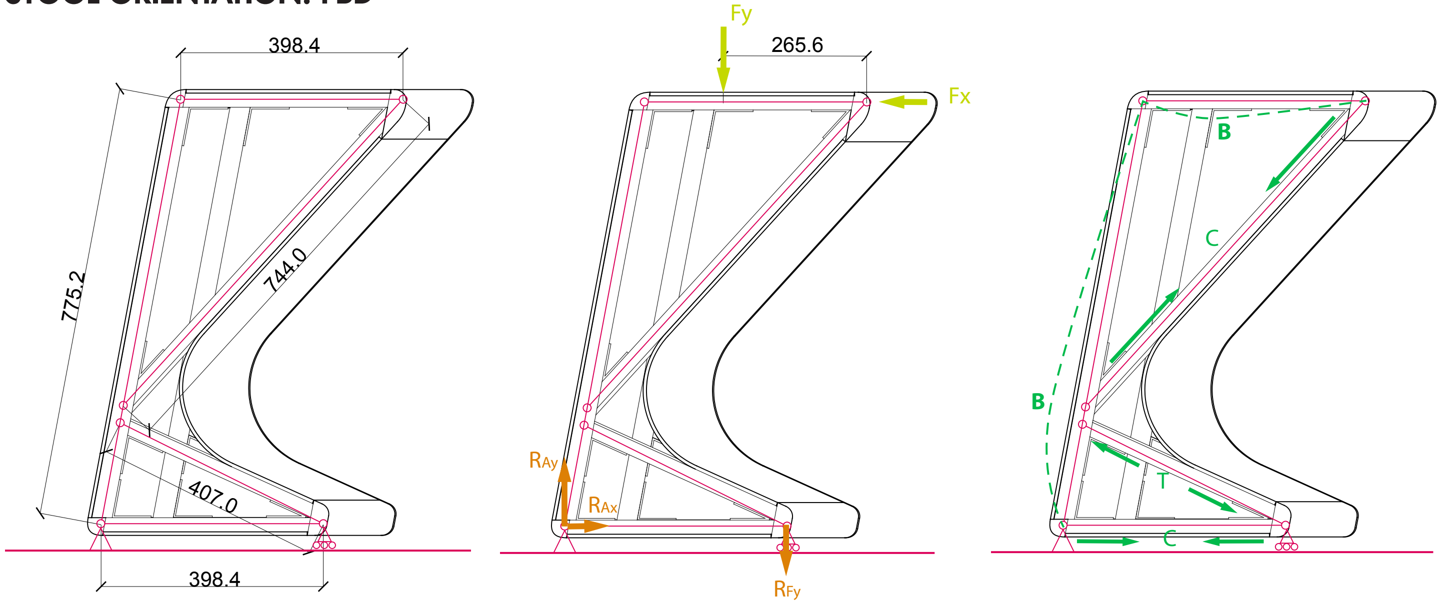
Out of the 6 possible seating positions of the chair, we have decided to analyze only two of the positions: in the top heavy stool position and the bench position. We decided that these two positions would represent the worst possible loading conditions because: While in the stool position, the moment created by the seated person is greatest because the chair is sheared forward in this position; therefore it will have the most distance accompanying the force. We choose the bench orientation because in this orientation the bench has the greatest span between two point supports.

STRUCTURAL BEHAVIOUR

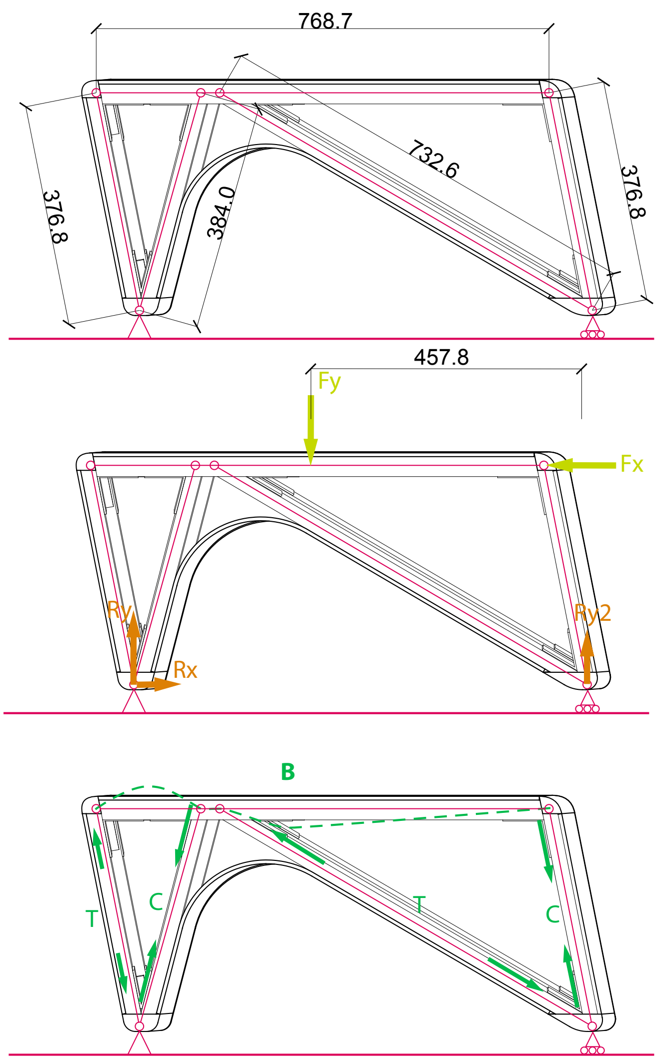
Simplified Free Body Diagrams



STOOL ORIENTATION: FBD

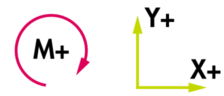


BENCH ORIENTATION: FBD

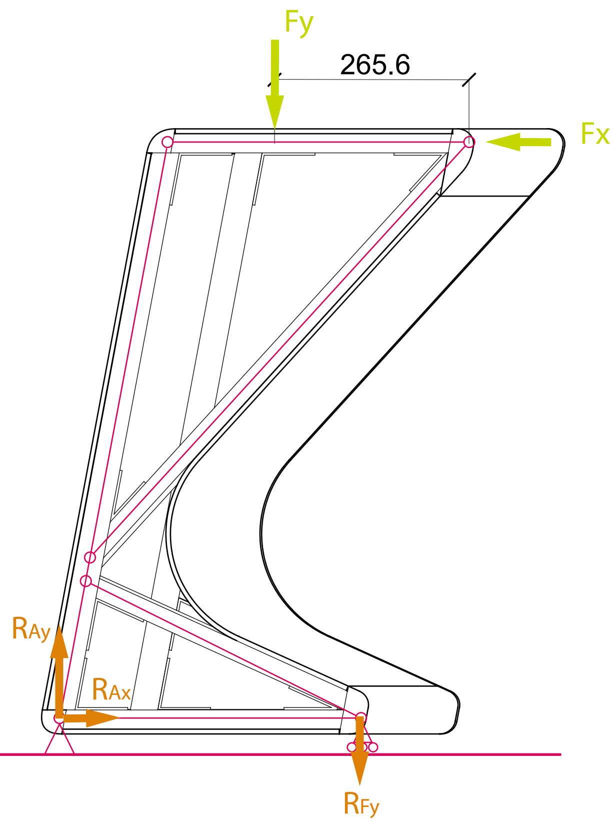


ANTICIPATED LOADS & REACTIONS

Simplified Free Body Diagrams

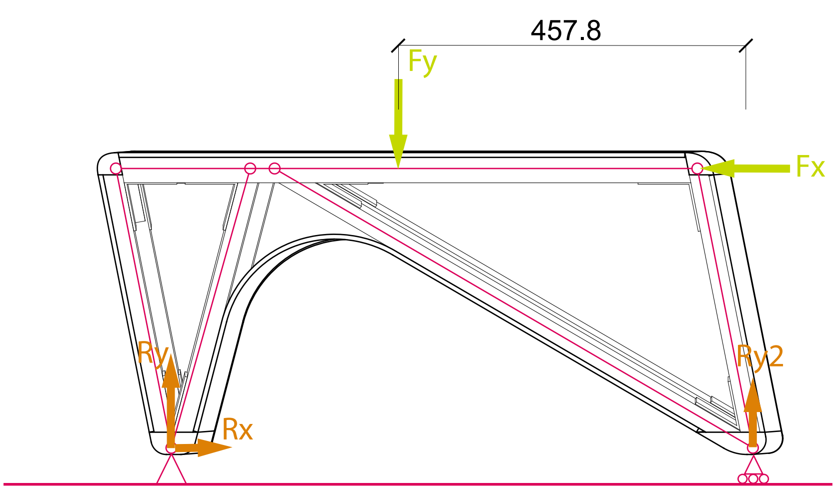


STOOL ORIENTATION:



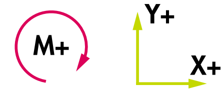
In the stool position, the force of person sitting on the chair can be simplified into two forces: One vertical force placed two thirds back on the seat will represent the center of gravity of a seated person and a horizontal force against the front on the seat will represent the person leaning back. In the bench position, a vertical force placed directly in the center of a bench represents a person sitting and a horizontal force at the end of the bench represents that person leaning to their right.

BENCH ORIENTATION:

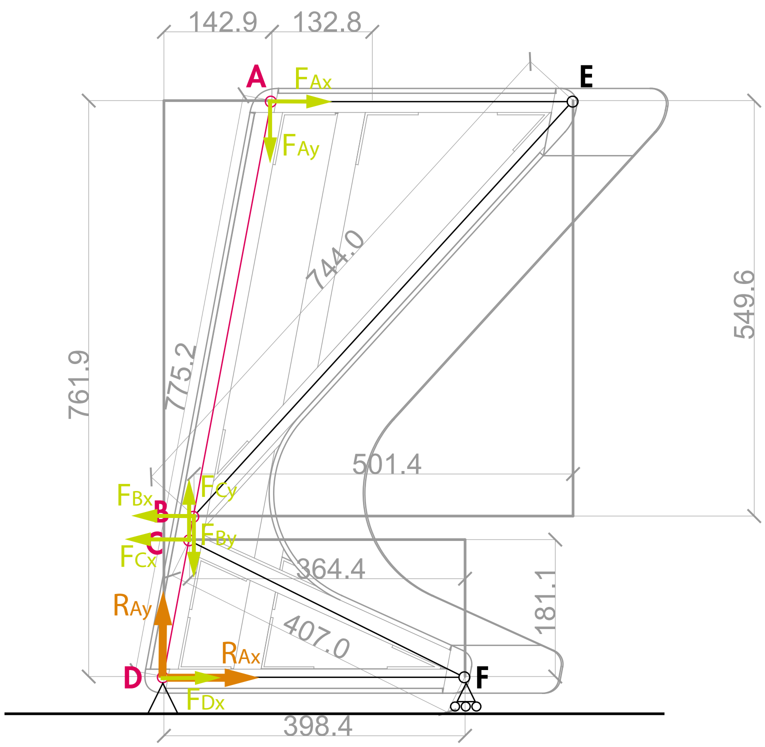


CRITICAL SECTION

Internal forces

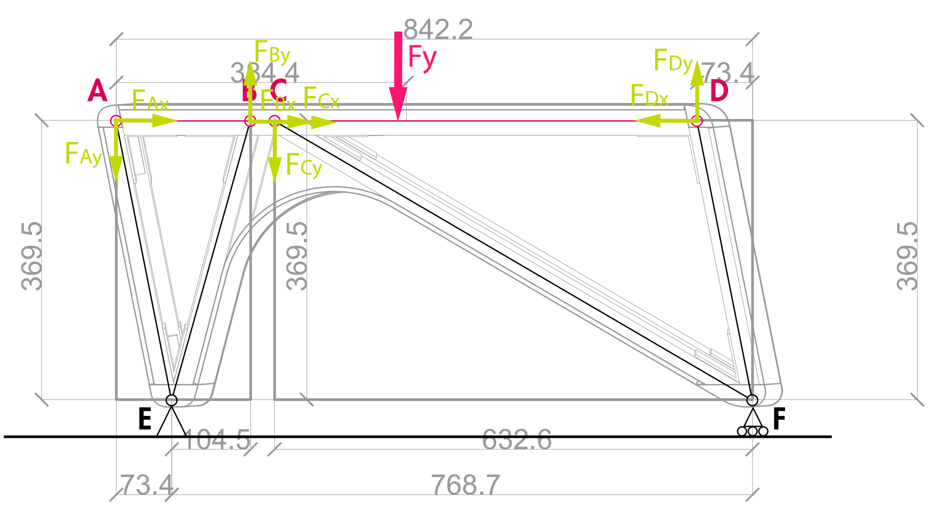


STOOL ORIENTATION: CRITICAL SECTION



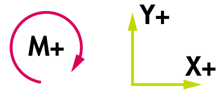
In the stool position the critical member would be the member A-D, which is the longest member and the member which all the members connect into. If a person is seated on the chair member A-D will have to resist the forces coming from all different orientations from the other members. In the bench position, the same member A-D would also be the critical section because it is the only member that is not a two way member. Since all materials are much more efficient in resisting axial load as opposed to bending, member A-D will undoubtedly undergo more intense internal stress.

BENCH ORIENTATION: CRITICAL SECTION

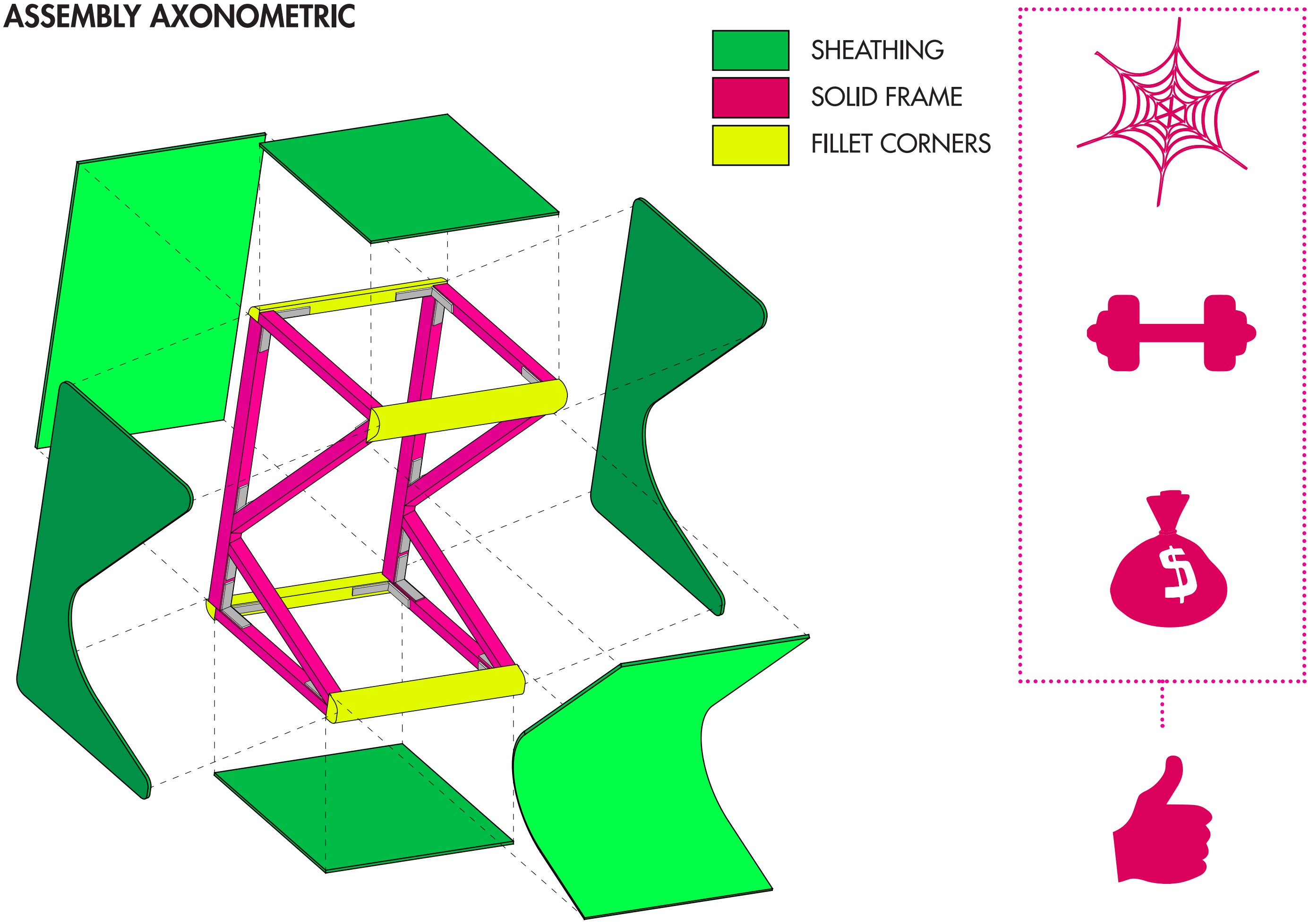


STRUCTURAL MANIFESTO

Notes on Structural Performance, Manufacturing, Cost, Use, and Design



ASSEMBLY AXONOMETRIC



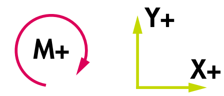
STRUCTURAL MANIFESTO

The Structure consists of 4 types of elements: the 1x1 inch frame, the solid filleted corners, 1/4 inch sheathing panels and 16 gauge steel angles. The frame functions as a basic "K" braced frame with pin connections; however, the real structural capacity comes from the sheathing itself. Since the sheathing is fully adhered to the frame, it is resistant against lateral-torsional bucking, therefore we can get the full bending capacity of the sheathing's depth. Since the "K" brace is inherently laterally stable, we are allowed to use all bolted connections. Furthermore, because we can count on the sheathing for bending resistance, we can reduce the frame member sizes significantly.

Since we could use metal angles, we could significantly simplify the assembly of the frame. If we could not use angles for the construction (if the frame was not inherently stable), then we would have to create complex mortise and tenon joints for the frame. Using frame and sheathing construction, we can minimize the amount of material used to construct the chair. If this chair were to be mass produced, the reduction in material will add up to an overall economic savings.

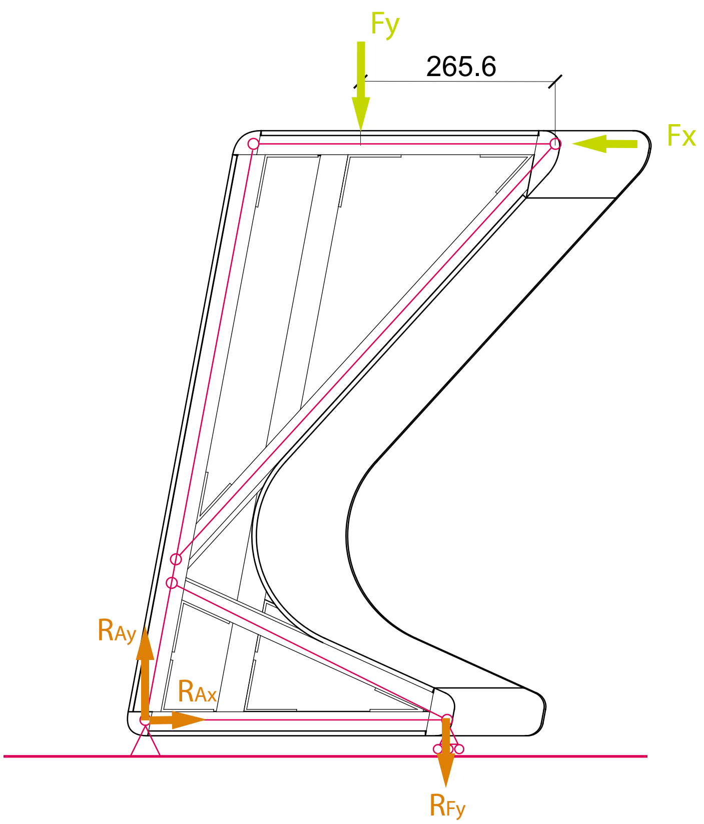
CALCULATION ANALYSIS

Assumptions & Base Reactions Calculation



Since the structure is relatively symmetrical, we can squash the diagram in two dimensions and disregard torsion.

STOOL ORIENTATION: BASE REACTIONS



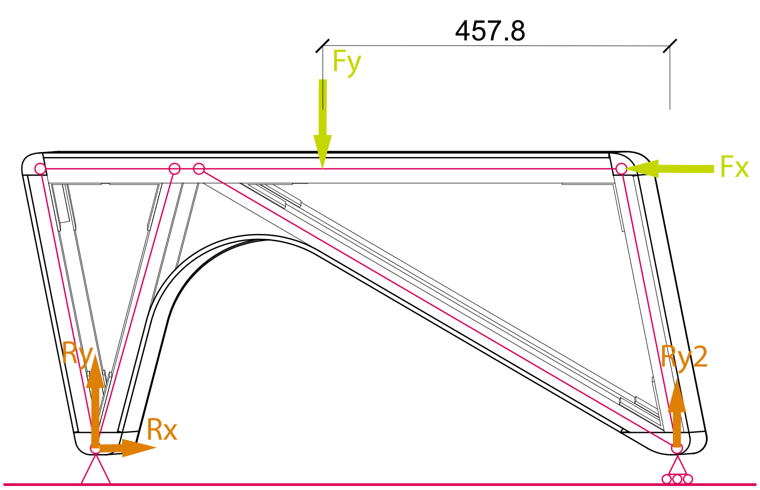
ASSUMPTIONS & CALCULATIONS

$$\Sigma F_x = 0$$
$$= R_{Ex} - 0.5\,kN$$
$$R_{Ex} = 0.5\,kN$$

$$\Sigma M_E = 1\,kN(0.311\,m) - 0.5\,kN(0.370) - 0.769\,m\,R_{Fy}$$
$$= 0$$
$$R_{Fy} = \frac{1\,kN(0.311\,m) - 0.370\,m(0.5\,kN)}{0.769\,m}$$
$$= 0.164\,kN$$

$$\Sigma F_y = 0$$
$$= R_{Ey} + R_{Fy} - 1.0\,kN$$
$$R_{Ey} = 1.0\,kN - 0.164\,kN$$
$$= 0.836\,kN$$

BENCH ORIENTATION: BASE REACTIONS



ASSUMPTIONS & CALCULATIONS

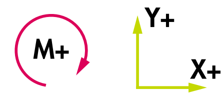
$$\Sigma M_A = 0$$
$$= 1.0\,kN(0.2756\,m) - 0.3\,kN(0.7619\,m) - R_{Fy}(0.3984\,m)$$
$$R_{Fy} = 0.118\,kN$$

$$\Sigma R_y = 0$$
$$= R_{Dy} + R_{Fy} - 1.0\,kN = 0$$
$$R_{Dy} = 1.0\,kN - 0.118\,kN$$
$$R_{Dy} = 0.882\,kN$$

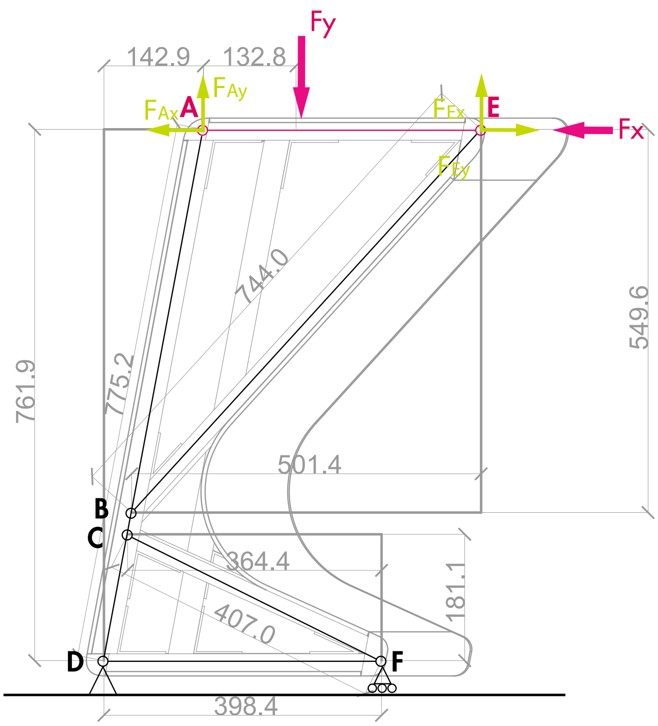
$$\Sigma R_x = 0$$
$$= R_{Ax} - 0.3\,kN = 0$$
$$R_{Ax} = 0.3\,kN$$

CALCULATION ANALYSIS

Component Reactions Calculation - Stool Orientation



MEMBER AE



CALCULATIONS

$\Sigma M_A = 1.0\text{ kN}(0.1328\text{m}) - F_{Ey}(0.3984\text{m})$

$F_{Ey} = \dfrac{0.1328\text{ kN m}}{0.3984\text{ m}}$

$= 0.333\text{ kN}$

Since member B-E is a two way member:

$\tan 47.6 = \dfrac{F_{Ey}}{F_{Ex}}$

$F_{Ex} = \dfrac{0.333\text{ kN}}{\tan 47.6}$

$= 0.304\text{ kN}$

$\Sigma F_y = 0$

$= F_{Ay} + F_{Ey} - 1.0\text{kN}$

$F_{Ay} = 1.0\text{kN} - 0.333\text{kN}$

$= 0.667\text{kN}$

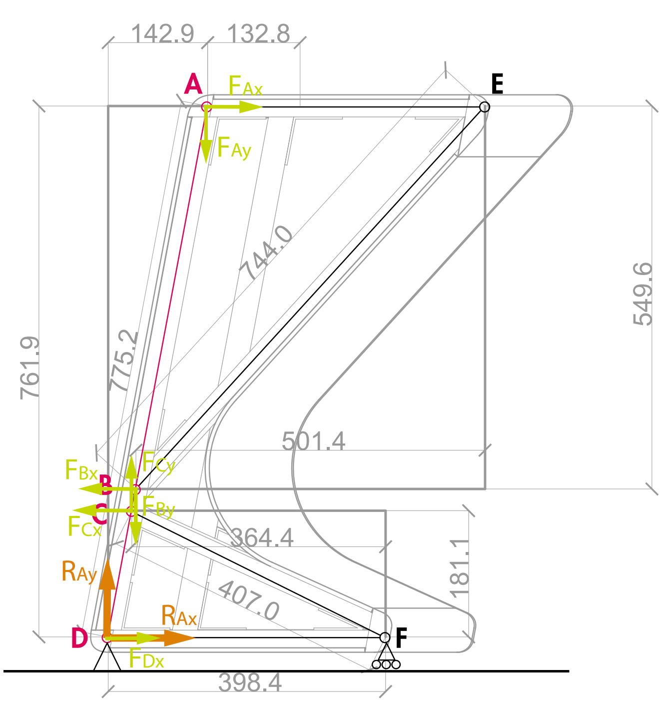
$\Sigma F_x = 0$

$= F_{Ax} - 0.3\text{kN} + F_{Ex}$

$F_{Ax} = 0.304\text{kN} - 0.3\text{kN}$

$= 0.004\text{ kN}$

MEMBER AD



CALCULATIONS

$\Sigma M_F = F_{Dy}(0.034\text{m}) + F_{By}(0.0058) + F_{Ax}(0.580\text{m}) + F_{Ay}(0.1089\text{m}) - F_{Bx}(0.0312) - F_x(0.1811\text{m})$

$F_x = \dfrac{[0.882\text{kN}(0.034\text{m}) + 0.333\text{kN}(0.0058\text{m}) + 0.004(0.580\text{ m}) + 0.667(0.1089) - 0.304\text{ kN}(0.0312\text{ m})]}{0.1811\text{m}}$

$= 0.538\text{kN}$

$F_x = F_{Dx} + 0.3\text{kN}$

$F_{Dx} = 0.538\text{kN} - 0.3\text{kN}$

$= 0.238\text{kN}$

$\Sigma F_x = 0$

$= F_{Ax} + F_{Bx} - F_{Cx} + F_{Dx} + 0.3\text{kN}$

$F_{Cx} = 0.004\text{kN} - 0.304\text{ kN} + 0.238\text{ kN} + 0.3\text{kN}$

$= 0.238\text{ kN}$

Since member C-E is a two way member:

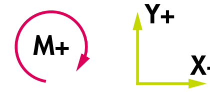
0.181m / 0.364m ; Fcy / Fcx

$\dfrac{F_{cy}}{0.181\text{kN}} = \dfrac{0.288\text{kN}}{0.364\text{kN}}$

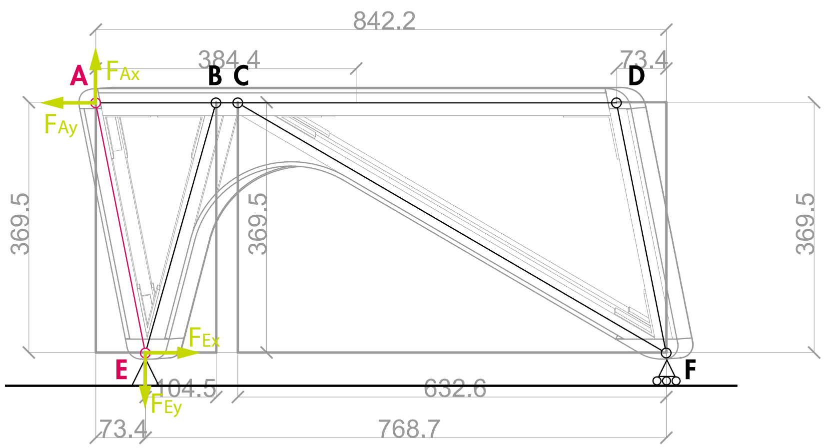
$= 0.118\text{kN}$

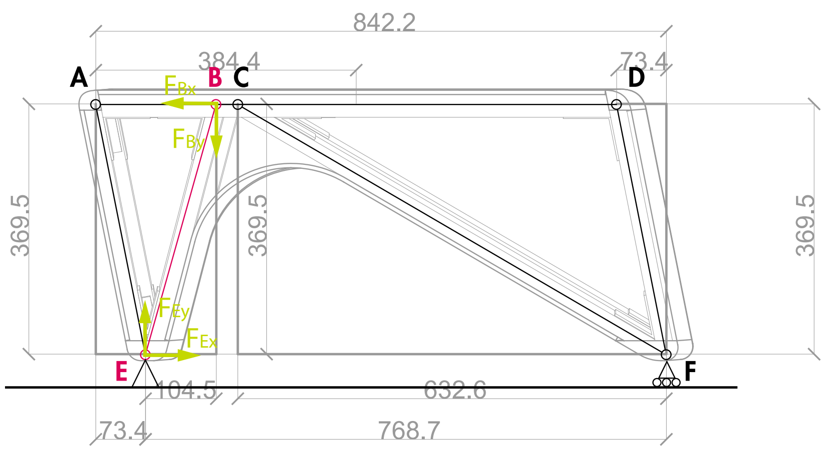
CALCULATION ANALYSIS

Component Reactions Calculation - Bench Orientation

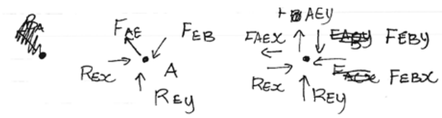


MEMBER AE & BE





CALCULATIONS



Since members E-A & E-B are two-way members:

$\tan 74.2 = \frac{F_{EBy}}{F_{EBx}}$

$F_{EBy} = F_{EBx}(\tan 74.2)$

$\tan 78.8 = \frac{F_{AEy}}{F_{AEx}}$

$F_{AEy} = F_{AEx}(\tan 78.8)$

$\Sigma F_y = R_{Ey} - F_{EBy} + F_{AEy}$

$= R_{Ey} - [F_{EBx}(\tan 74.2)] + [F_{AEx}(\tan 78.8)]$

$= R_{Ey} - 3.534 F_{EBx} + 5.05 F_{AEx}$

$F_{EBx} = \frac{0.836\,kN + 5.05 F_{AEx}}{3.534}$

$\Sigma F_x = R_{Ex} - F_{EBy} - F_{AEx}$

$= 0.5\,kN - \left(\frac{0.836\,kN + 5.05 F_{AEx}}{3.534}\right) - F_{AEx}$

$= 1.767\,kN - 0.836\,kN - 5.05 F_{AEx} - 3.534 F_{AEx}$

$F_{AEx} = 0.109\,kN$

$F_{AEy} = F_{AEx} \tan 78.8$
$= 0.548\,kN$

$\Sigma F_y = R_{Ey} - F_{EBy} + F_{AEy}$

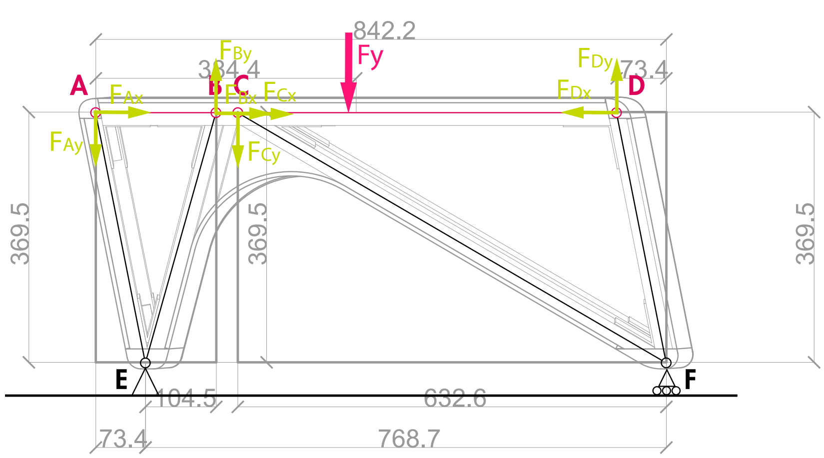
$F_{EBy} = 0.836\,kN + 0.548\,kN$
$= 1.383\,kN$

$F_{EBx} = \frac{F_{EBy}}{\tan 74.2}$

$= \frac{1.383\,kN}{\tan 74.2}$

$= 0.391\,kN$

MEMBER AD



$\Sigma M_D = 1.0\,kN(0.1748\,m) - F_{Dy}(0.5592\,m) + F_{EBy}(0.0317\,m) - F_{AEy}(0.2096\,m)$

$F_{Dy} = \frac{[1.0\,kN(0.1748\,m) + 1.383\,kN(0.0317\,m) - 0.548\,kN(0.2096\,m)]}{0.5592\,m}$

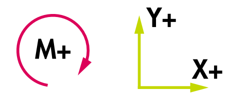
$= 0.186\,kN$

$\Sigma F_y = -F_{AEy} + F_{EBy} - F_{CFy} - 1.0\,kN + F_{Dy}$

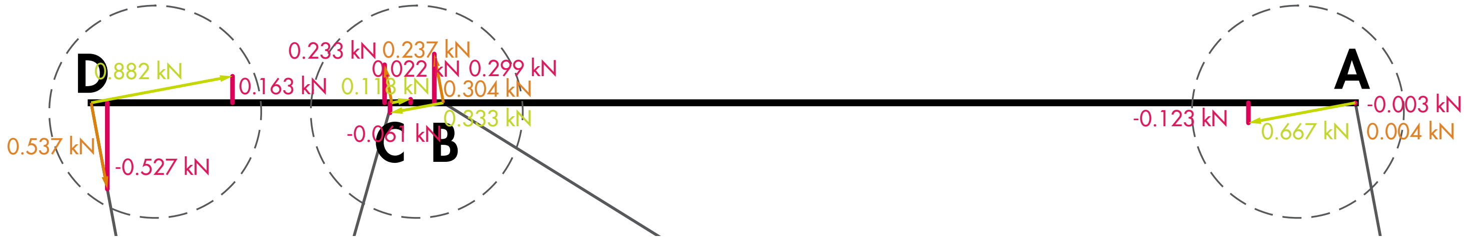
$F_{CFy} = -0.548\,kN + 1.383\,kN - 1.0\,kN + 0.186\,kN$
$= 0.022\,kN$

CALCULATION ANALYSIS

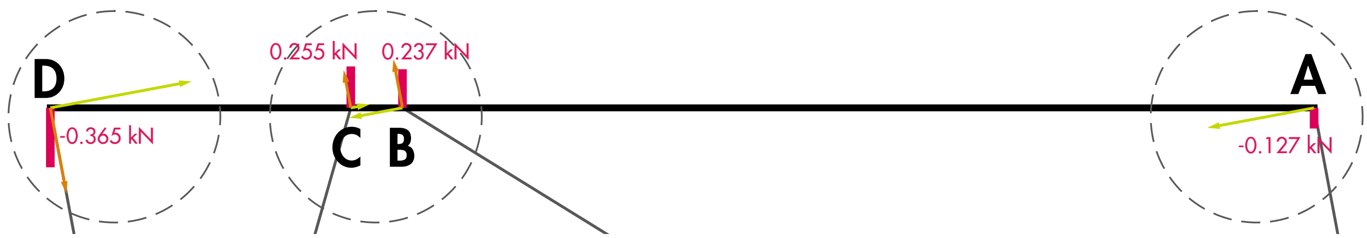
Shear & Bending Moment Diagram of Critical Section



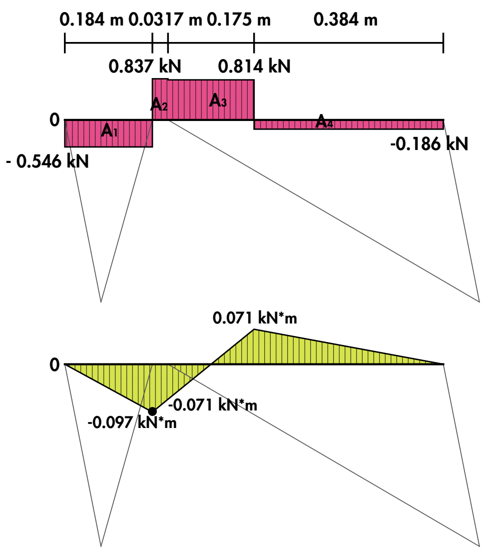
COMPONENT TRIANGULATION



COMPONENT SOLIDIFICATION PER POINT



STOOL: SHEAR & MOMENT DIAGRAM



CALCULATIONS

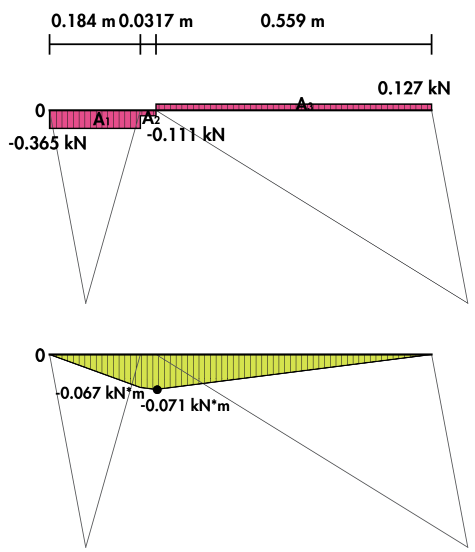
$A_1 = -0.546\,kN \cdot 0.184\,m = -0.100\,kN{\cdot}m$

$A_2 = 0.837\,kN \cdot 0.0317\,m = 0.0265\,kN{\cdot}m$

$A_3 = 0.814\,kN \cdot 0.1748\,m = 0.142\,kN{\cdot}m$

$A_4 = -0.186\,kN \cdot 0.3844\,m = -0.0714\,kN{\cdot}m$

BENCH: SHEAR & MOMENT DIAGRAM



CALCULATIONS

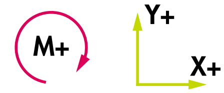
$A_1 = -0.365\,kN \cdot 0.184\,m = -0.0672\,kN{\cdot}m$

$A_2 = -0.111\,kN \cdot 0.0317\,m = -0.0035\,kN{\cdot}m$

$A_3 = 0.127\,kN \cdot 0.559\,m = 0.071\,kN{\cdot}m$

CALCULATION ANALYSIS

Maximum Stress at Critical Section



STOOL ORIENTATION STRESS CALCULATION

$\sigma = M/S \quad S = \frac{bd^2}{6}$

$S = 2731.2\,mm^3$

d = 138mm "d", 1/4" thick for sheathing
1" by 1" framing

$M = 0.071\,kN \cdot m \times 10^6 \Rightarrow 7.1 \times 10^4\,N \cdot mm / 2 = 3.55 \times 10^4\,N*mm$

$\sigma = \frac{M}{S} = \frac{3.55 \times 10^4\,N*mm}{2731.2\,mm^3} = 13\,MPa$ for FRAME itself

BUT...

$S = \frac{bd^2}{6} = \frac{6.35mm(138mm)^2}{6} = 20186.6\,mm^3$

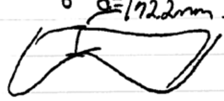
$\sigma = \frac{M}{S} = \frac{3.55 \times 10^4\,N*mm}{20186.6\,mm^3} = \boxed{1.8\,MPa}$ ∴ Within safety factor w/ support of sheathing.

BENCH ORIENTATION STRESS CALCULATION

$\sigma = M/S \quad S = \frac{bd^2}{6}$

$S = \frac{bd^2}{6} = \frac{25.4mm(25.4mm)^2}{6} = 2731.2\,mm^3$

d = 172.2mm



↳ critical section of sheathing "d", 1/4" thick
1" by 1" frame

$M = -0.097\,kN \cdot m \times 10^6 \Rightarrow -9.7 \times 10^4\,N \cdot mm / 2 = 4.85 \times 10^4\,N*mm$

$\sigma = \frac{-4.85 \times 10^4\,N*mm}{2731.2\,mm^3} = 18\,MPa$ → FRAME ITSELF

BUT...

$S = \frac{bd^2}{6} = \frac{6.35mm(172mm)^2}{6} = 31310\,mm^3$

$\sigma = \frac{M}{S} = \frac{4.85 \times 10^4\,N*mm}{31310\,mm^3} = \boxed{1.6\,MPa}$ ∴ Within safety factor with sheathing support

As shown above, **the frame member is not adequate to resist the load**; however, because we have fully adhered sheathing, the sheathing will act as a beam to resist the bending at the critical point. As calculated, **the sheathing can provide more than enough resistance to supplement the frame.**

CONCLUSION

Summary of Learnings & Application

The most important lesson from building the chair is the difference between accuracy and precision. Accuracy is about making sure the dimensions of a project match what is drawn, precision is about coordinating components to holistically complete the project. Drawing and digital modeling are activities preoccupied with accuracy, while making a real object is all about precision. This discrepancy is supplemented in the design by tolerances, and building this chair taught us a lot about how we can integrate tolerances into a design.

One lesson on how to design a buildable object was to work in the physical world as much as possible in the early phases of the design. We found that conceiving our design through scaled physical sketch models as opposed to paper sketches was an extremely effective process. By working with our hands we felt we had a better grip of the three dimensional geometry. After we had a grasp of which design direction to pursue, we moved into digital modeling. We found digital modeling to be somewhat more disconnected to the actual product; however, its strength lay in its speed. We were able to run through a lot more iterations than we could possibly ever do by hand using the tool of digital modeling, but it was our initial hand models that really laid the foundation for further digital exploration. Another design routine we learned was to work in cycles: going broad, and exploring many options, stepping back to evaluate these options, and repeating this cycle ultimately lead us to a beautifully subtle and carefully considered final design.

We found making a full size functional mock-up the only way to understand the ergonomics of the design. Things we thought would be comfortable proportions in digital space proved quite otherwise in reality. Working with models was an effective way to get our heads around the assembly of parts required to make the final product. Testing the actual materials through experiments to see the extremes capacity in bending gave us insights on how to use the materials effectively.

Things we learned about fabrication specifically were: dry fitting, use of full size templates, and order of assembly. We practiced the dry fit of the vacuum lamination multiple times before attempting the final pass. We think that this enabled us to achieve a good bend, despite it being our first attempt. We cut the frame members using full-sized laser cut templates as guides, which turned out to be both precise and accurate. However, when we cut the bent sheathing without a visual template, it was neither accurate nor precise. Therefore, if we were to make another chair, we would build the frame first, and fit the sheathing to the frame, instead of the other way around. Using epoxy to adhere the angles that we could not screw properly would definitely improve the rigidity of the frame. For the next iteration, we want to make the design cheaper and easier to fabricate. Since the most expensive and difficult piece to fabricate is the bent sheathing panel, we think it might be better to make the frame behind it relatively more robust. We could add incremental joists behind the bent plywood and use only one sheet of aircraft ply to reduce cost and avoid the complex lamination process. Also, we could cut the piece flat with a printed template instead of having to cut compound curvature.