Prototype: Phase I

Construction Team B1
GNG1103B – Engineering Design

Introduction

Given the number of subsystems required to meet the client's requirements and the tight timeline within which to implement them, analyses were conducted for a number of prototypes. Specifically, this document contains an analysis for a combined table and folding bed, a consideration of options for mounting the solar panel to the structure, and a computation of snow-load requirements given the properties of the shed and target location. Analytical models were chosen given the zero-cost requirements stipulated in the instructions for this deliverable.

Folding Bed: CAD Analysis

As discussed in our Conceptual Design deliverable, a standard twin-sized bed would occupy roughly 80% of the structure's available floorspace. In order to ensure that the structure can serve as a full residence – in accordance with the client's stated needs – rather than just as an enclosure for a bed, it is critical that the bed can be made to occupy less floor area when not in use. To this end, a CAD model (see Figure 1) for a foldable bed with combined table has been designed and analyzed to assess this concept's feasibility and overall compliance with the requirements for the structure.

This CAD prototype has been developed to:

- Determine whether or not the folding bed can be accommodated given the dimensional constraints of the structure
- Evaluate the functional space in the structure when the bed is in horizontal or upright position
- Determine the material requirements and cost of the bed
- Determine the mass, center of gravity, and forces on the bed to inform methods of joining components and restraining the bed in the upright position and to determine whether or not a mechanism for assisted lifting is required

The results of the above analyses are to be used in subsequent prototypes.

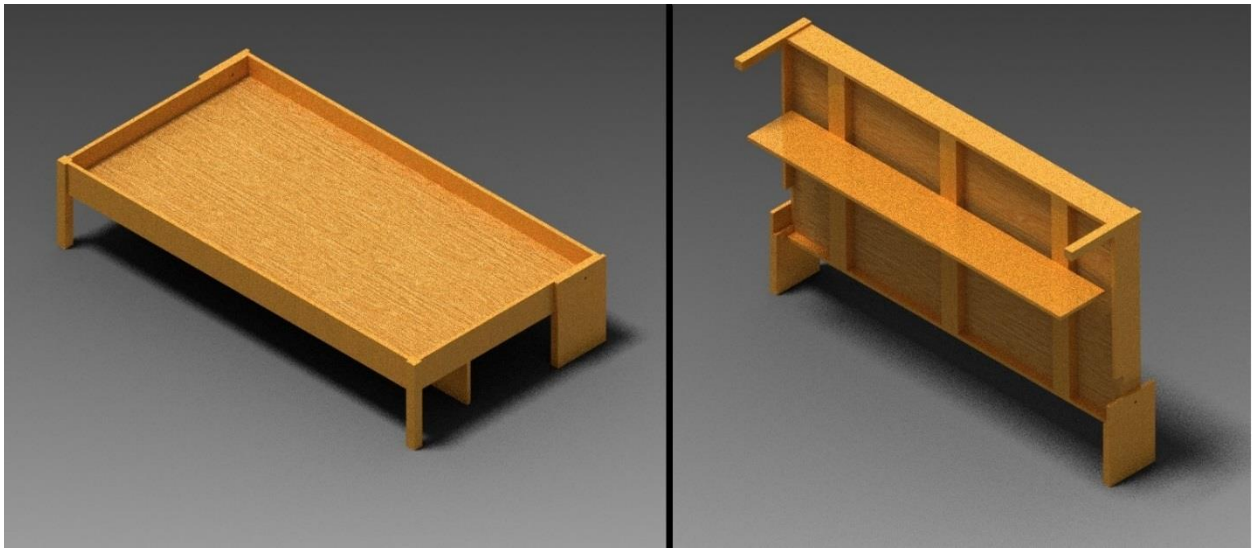


Figure 1: Isometric render of CAD model in both horizontal and upright position

Dimensions and Functional Space

Dimensional constraints – There are two dimensional constraints on the size of the bed. A twin-sized mattress, the smallest standard adult size, measures 39”x75”, and represents the lower bound. The structure itself, assuming stud and drywall thicknesses of 3.5” and 3/8”, respectively, has an interior space of 40.25”x88.25”. The difference between these bounds is 1.25”x13.25”, leaving very little space within which to place a bed.

Although the CAD prototype was designed to be space-efficient (see Figure 2), the width of the bed exceeds the upper bound defined above. Even the bare-minimum bed width of 40.5”, also shown in Figure 2, exceeds the interior width of the structure. These results suggest that in order to accommodate any twin-sized bed, with or without a folding mechanism, modifications may have to be made to the walls of the structure.

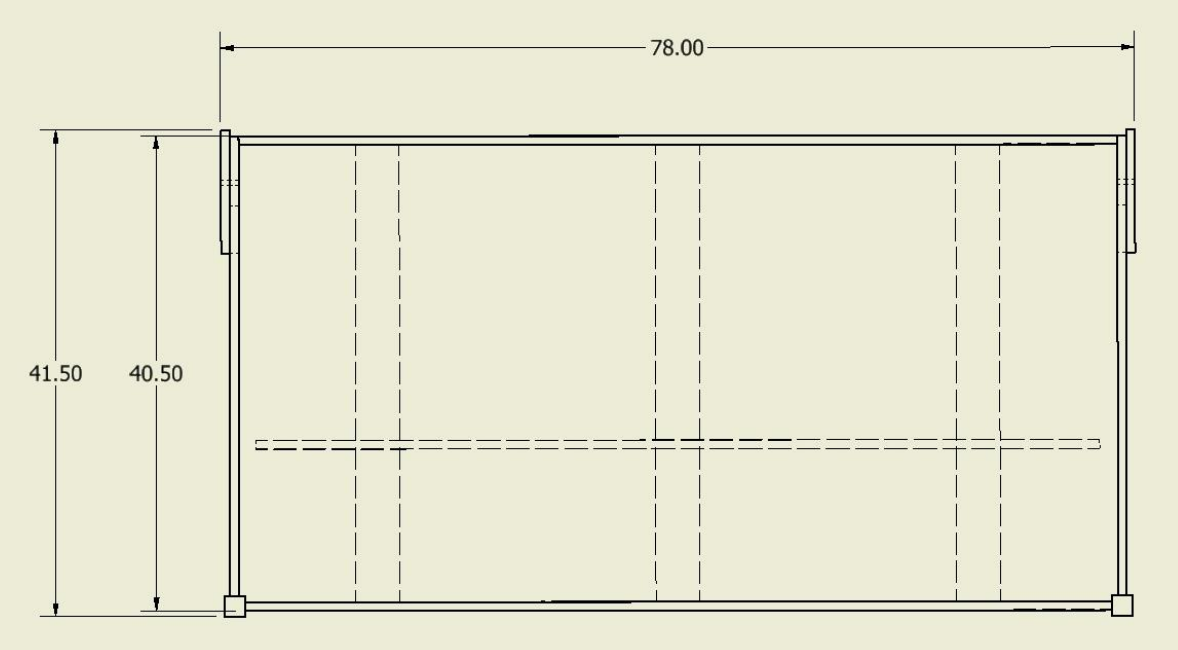


Figure 2: Base dimensions of bed, top view (all dimensions in inches)

The problems with the above dimensional constraints are further compounded by the fact that as the bed rotates from horizontal to upright position, its projected width varies. Referring to Figure 3, the maximum projected width is

$$w_{proj} = d + \sqrt{w^2 + h^2}$$

$$w_{proj} = 4.50 + \sqrt{(37.00)^2 + (16.00)^2} \cong 44.81$$

Although this value could be minimized in the current design by lowering the height of the bed and changing the point of rotation between the bed frame and support, $w_{proj} \geq d + w$ and any implementation of this design would still require structural modifications.

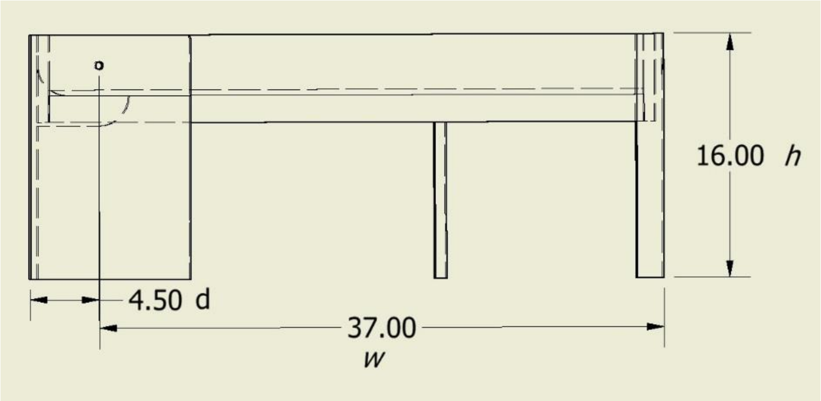


Figure 3: Relevant parameters for projected width, side view (all dimensions in inches)

Functional space – With respect to Figure 2 and the interior dimensions of the structure stated above, the area occupied by the bed while in horizontal position is

$$F_h = \frac{78.00 \times 41.50}{40.25 \times 88.25} \cong 91.1\%$$

Referring to Figure 2 and Figure 3 (dimension *h*), the area occupied by the bed in the upright position is

$$F_u = \frac{78.00 \times 16.00}{40.25 \times 88.25} \cong 35.1\%$$

It is worth noting that although this mechanism clearly offers additional floorspace when in the upright position, this space may prove difficult to utilize given that anything else which permanently occupies this space would have to be integrated into the folding structure of the bed.

Material Requirements and Cost

Despite the dimensioning problems discussed above, any bed for the structure will be similar with respect to form and materials. For this reason, the following material and cost breakdown provides useful information regardless of the bed's final implementation.

The materials have been selected by grouping bed components according to common dimensions and finding available sizes from Rona which minimize overall cost. Specific hardware requirements have not been considered in this prototype, so their cost is estimated at 20% of the combined cost of lumber.

Material	Unit Cost	Quantity	Total Cost
Knotty pine – 1"x6"x8'	$13.59	3	$40.77
Knotty pine – 1"x12"x6'	$20.29	2	$40.58
Spruce – 2"x4"x7'	$1.84	2	$3.68
White pine – 2"x2"x6'	$5.39	1	$5.39
Fir plywood – 3/8"x4'x8'	$19.03	1	$19.03
		Subtotal	$109.45
		Hardware (20%)	$21.89
		Tax	$17.07
		Total	$148.41

Physical Properties

Mass – The mass of the bed was determined by applying densities to each component consistent with the materials with which they will be constructed. These densities were obtained from material libraries built into Autodesk Inventor. The calculated mass of the bed is 66.5 lbs-mass, although the final mass will deviate from this value according to density variations in building materials and once hardware and mattress mass are considered.

Latching force – In order to determine the forces that will be applied to the latching mechanism for the bed in its upright position, it is necessary to consider both the torque exerted by the bed and those applied to the table around the pivot axis. In this analysis, several simplifying assumptions have been made:

- There are two latching mechanisms which are level with each other and positioned near the top of the bed.
- The mass of the rotating component is taken as the mass of the entire bed. Given that the mass of the mattress has not been explicitly considered, this assumption will likely provide a mass comparable to that of the actual rotating assembly combined with the mattress.
- A distributed load on the table is equivalent to a single load applied along its width.

With reference to Figure 4, and assuming a maximum F_{load} of 100 lbs, the maximum force applied to either latch is given by

$$2F_{\text{latch}}(36.12\text{ in}) = (100\text{ lbs})(8.80\text{ in}) + (66.5\text{ lbs})(2.62\text{ in})$$

$$F_{\text{latch}} = 14.6\text{ lbs}$$

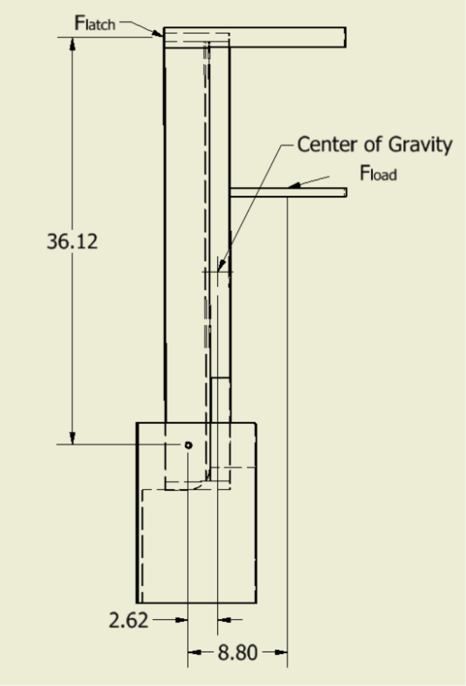


Figure 4: Forces applied about pivot axis, upright position (all dimensions in inches)

Lifting force – To determine the necessary force required to raise the bed to its upright position, only the torque exerted by the bed and the individual lifting it need be taken into account. In this analysis, two simplifying assumptions are made:

- The force applied by the individual is applied immediately next to the supporting leg, and the force is applied parallel to the leg throughout the entire range of motion (i.e. the force required diminishes with increasing angle).
- The mass of the rotating component is taken as the mass of the entire bed. Given that the mass of the mattress has not been explicitly considered, this assumption will likely provide a mass comparable to that of the actual rotating assembly combined with the mattress.

With reference to Figure 5:

$$F(19.24\text{ in} + 16.01\text{ in}) = (66.5\text{ lbs})(16.01\text{ in})$$

$$F = 30.2\text{ lbs}$$

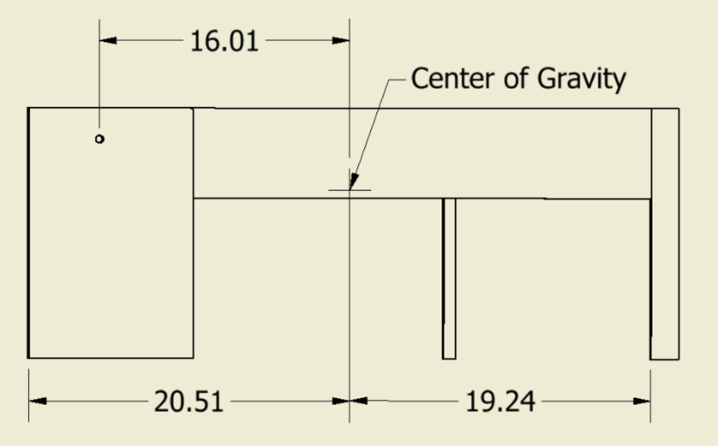


Figure 5: Forces applied about pivot axis, horizontal position (all dimensions in inches)

Although this required force is well within the physical expectations of a typical client, it may be worth considering an assistance mechanism – such as a counterweight or torsion spring – to further reduce this load, and to provide a force to slow the descent of the bed when moving it from the upright to horizontal position.

Solar Panel Mount

There are two options for affixing the solar panel to the structure: either the mounting bracket can be fixed in a single position, or it can provide a tilting mechanism to allow for a change in angle according to the seasonal position of the sun. These two options are described and compared below.

Fixed Bracket

A fixed bracket should be mounted in the middle and at the very top of the shed roof to maximize sunlight exposure. Two pipes with the same width as the solar panel would be connected to both the panel and the roof. These pipes would be used as level clearance for any cables which run from the panel through the structure. Four screws would keep the mount in place. Figure 6 depicts this arrangement.

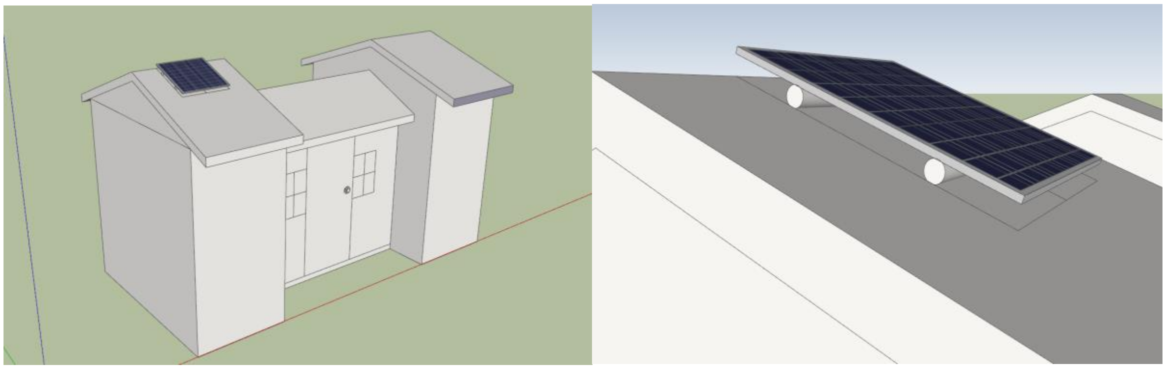
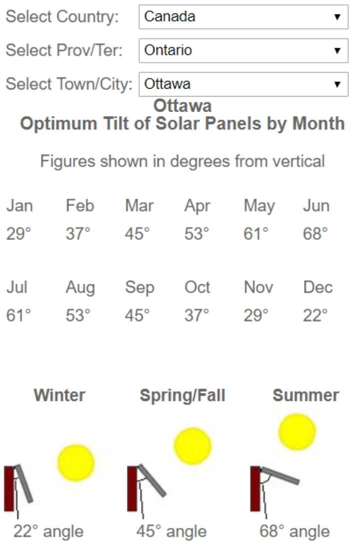


Figure 6: Placement of fixed solar panel

Tilt-Enabled Bracket

A tilt-enabled bracket allows for adjustment of the solar panel according to optimal seasonal angles, thus maximizing the amount of power generated by the solar panel. In Ottawa, optimal angles vary between 22 and 68 degrees (Figure 7). A tilt-enabled mounting bracket, available on Amazon, is shown in Figure 8.



Select Country: Canada
Select Prov/Ter: Ontario
Select Town/City: Ottawa

Ottawa
Optimum Tilt of Solar Panels by Month

Figures shown in degrees from vertical

Jan	Feb	Mar	Apr	May	Jun
29°	37°	45°	53°	61°	68°
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
61°	53°	45°	37°	29°	22°

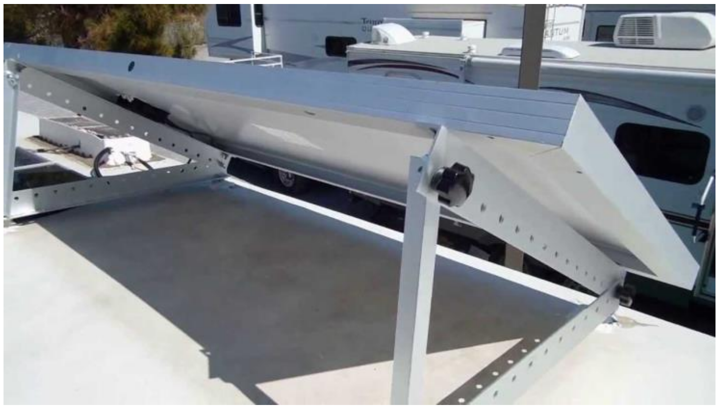


Figure 7: Seasonal angles for maximum irradiance, Ottawa (left)

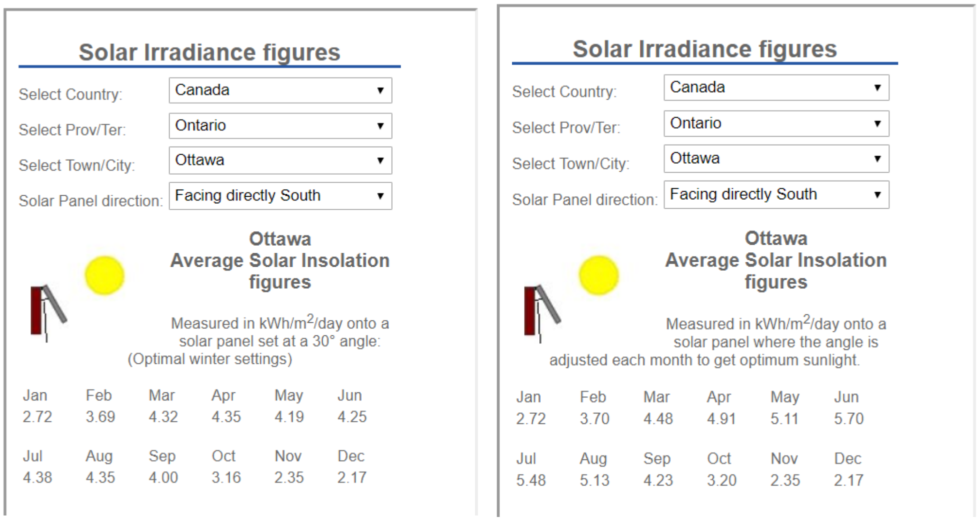
Figure 8: Tilt-enabled solar panel mount (right)

Comparison of Fixed and Tilt-Enabled Bracket

The method to be chosen is based on the client's electricity needs. A tilting bracket can cost anywhere between $30 and $100, whereas a fixed bracket can be produced at lower cost. The latter option in preferable if a fixed panel can provide all of the client's electricity needs. In this case can be set fixed at an angle which optimizes efficiency over the year.

The tilting bracket allows for maximum irradiance in each month of the year and is preferable if the fixed option cannot produce the power required by the client. Even if the power requirements are met by a fixed panel, if the client is able to sell excess power back to the grid, the additional initial cost of a tilting bracket could be recouped.

Figure 9 provides a comparison of the monthly irradiance for each of the two options described above, assuming the panels face due south, and can be used in a later cost-benefit analysis once client electricity requirements are confirmed.



Solar Irradiance figures

Select Country: Canada

Select Prov/Ter: Ontario

Select Town/City: Ottawa

Solar Panel direction: Facing directly South

Ottawa
Average Solar Insolation figures

Measured in kWh/m^2/day onto a solar panel set at a 30° angle:
(Optimal winter settings)

Jan	Feb	Mar	Apr	May	Jun
2.72	3.69	4.32	4.35	4.19	4.25

Jul	Aug	Sep	Oct	Nov	Dec
4.38	4.35	4.00	3.16	2.35	2.17

Solar Irradiance figures

Select Country: Canada

Select Prov/Ter: Ontario

Select Town/City: Ottawa

Solar Panel direction: Facing directly South

Ottawa
Average Solar Insolation figures

Measured in kWh/m^2/day onto a solar panel where the angle is adjusted each month to get optimum sunlight.

Jan	Feb	Mar	Apr	May	Jun
2.72	3.70	4.48	4.91	5.11	5.70

Jul	Aug	Sep	Oct	Nov	Dec
5.48	5.13	4.23	3.20	2.35	2.17

Figure 9: Comparison of monthly irradiance for fixed and tilt-enabled brackets

Snow Load Calculation

An important constraint identified in our Design Criteria deliverable is that the structure meets defined snow-load requirements. The Ontario Building Code defines an upper limit state (ULS), which ensures a structure does not collapse during peak load capacity, and serviceability limit state (SLS), which ensures a structure can remain functional for its intended use, according to a snow-load equation which is dependent upon the type, form, and location of a structure,

$$S = I_s[S_s(C_b C_w C_s C_a) + S_r]$$

The values of the above factors have been obtained from the properties of the structure and the intended location of use:

Importance factor: $I_s = 1$ for ULS and $I_s = 0.9$ for SLS as the structure is a normal residential building

Roof snow-load factor: $C_b = 0.8$ given the small size of the structure's roof

Wind-exposure factor: $C_w = 0.75$ as the structure falls within the normal importance category

Slope factor: $C_s = 1$ as the roof of the structure has a slope near 30 degrees

Shape factor: $C_a = 1$ as the roof of the structure has no curvature

Ground snow-load: $S_s = 2.5$ according to 1-in-50-year data corresponding to the target location

Rain load: $S_r = 0.4$ according to 1-in-50-year data corresponding to the target location

Substituting the above values into the snow-load equation yields the following ULS and SLS for the structure:

$$\mathrm{ULS} = 1.9\ \mathrm{kPa}$$

$$\mathrm{SLS} = 1.71\ \mathrm{kPa}$$