Tower Project Report

Team 8

Jennifer Hayward-Nandra

Seth Johnson

Edilberto Lopez

Taras Snitko

Michael Theisen

02/09/2021

Table of Contents

1.00 The Team 8 IDEO Process

1.01 Empathize:

The team had two different points of view on who was to ultimately be the consumer for the Tower Project. Tacoma Community College was the one accepting the bids, and ultimately decided which team was going to be responsible for designing the dorm. Utilizing *Tower Project: Background*, the team concluded that one of Tacoma Community College's primary goals would be to keep the final design under the $1.2 million budget.

The team took the time to see the college students as a consumer as well, considering they would be the primary occupants. This point of view leaned heavily toward what the students would like to see as aspects of the dorm building such as height, balconies, rooftop lounging areas, and even a dedicated indoor gym.

Through Discord, the team shared a variety of photographs of buildings and other structures that heavily utilized trusses as their primary structural component, such as the Eiffel Tower and a few truss bridges, in order to share ideas of possible designs. This was primarily done with the intent as serving for possibilities in aesthetic choice. Originally the team was going to lean on aesthetics as a focus after they built the bare minimum design that fit the structural integrity necessary to adhere to the rules within the *Tower Project Structural Specifications*. It was ultimately decided that safety came first. Ethically speaking, safety should be the primary goal in any and all situations. In doing a search on buildings that were considerably safe, the team remarked upon the CitiCorp building and its internal truss shape as well as a specific interest in the Pratt truss due to its repetitive use over the centuries as a safe and effective truss method. The Pratt truss focuses forces in the vertical direction reducing tension on the diagonal members. With such a tall building, making the members more efficient would allow for more of them in the final structure.

At this point, safety and budget were now the two primary goals to satisfy the consumer. This made the team strive for a working model that adhered to the specifications and pushed aesthetics to the wayside. Only after a structurally sound tower was finished, the team would then look at aesthetics as a final application if it fell within the budget.

1.02 Define

The first step in the design process was to list the requirements that the designs would be adhering to. According to the *Tower Project Structure Specifications* and *Tower Project Material Specifications*, the team's basic list of requirements were:

- Minimum width of 10 inches.
- Minimum height of 60 inches.
- Balsa wood material.

- Pass all Load Cases.
- Price under $1,200,00.

Table 1: List of Required and Preferred Criteria

Required	Preferred
The tower must be 60 inches	keep it 60 inches tall.
Tower must have a flat platform at the top	Other platforms? (too much heavy?)
And another platform at approx. mid height	|| lightest weight gets Extra credit
Each side must have min. length 10 inches	Max length?
Only truss elements allowed, no frames.	x
Base must be pin supported.	x
Top must hold 16 lbf	More weight?
Middle must hold 8 lbf	More weight?
100 lbf Top applied laterally	x
50 lbf Mid applied laterally	x
Incremental load until failure.	max?
Balsa wood material	x
Only the following cross sections (see list)	x
Budget max is $1.2 Million	Can it be lower? Extra credit
"height, width, aesthetics, strength, and meeting client needs"	do this last Extra credit
No evidence of stress or bending/buckling (LC1)	Lowest stress = Extra credit
Maximum deflection <H/100 (LC2)	As low as it can? Safety first!
Point distributed 5,4,3,2,1, to first fail (LC3)	
Submitted on time.	finish the product early, that way fixes can be made if need be.

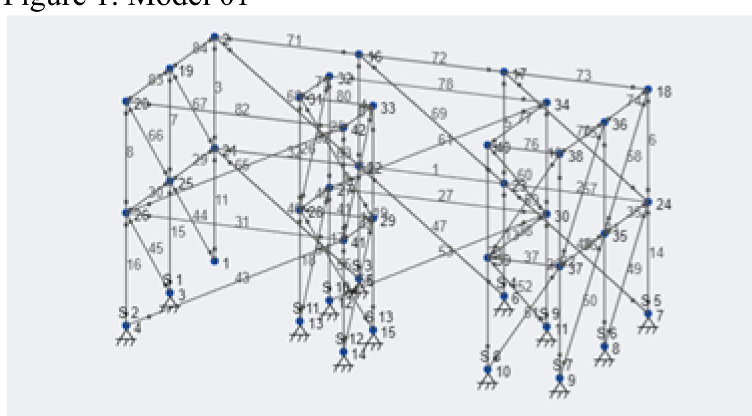
These details are presented in the List of Required and Preferred Criteria (Table 1). This list was created with the group present on Discord on January 25, 2021. The budget of $1.2 million was in debate but would only be looked at after the tower was finished. After finishing the tower and seeing the price, the structure of the tower would be adjusted accordingly by using material of a different size that would not compromise structural integrity. Building a tower at budget might be beneficial for the student because it would have extras that would make living in that dorm building a better experience. However, building a tower that is below budget would be beneficial for the employer, Tacoma Community College, because it would solely meet their minimum requirements. Thus, the price requirement was set aside as a checkbox for the final prototype.

The final requirement in the team's decision matrix was for the final model to pass all required load cases. This was not just one of the specifications for the model, but the ultimate set of tests to base any concurrent redesigns on if the design were to fail. The first Load Case was to have the tower withstand a divided force of 16 lbf on the top platform and a divided force of 8 lbf on the middle platform. The tower needed to keep from buckling while conducting the linear statics test. The second Load Case was for the tower to withstand a lateral force of 20 lbf on the top of the tower and 10 lbf on the middle of the tower. Once again the tower needed to keep from buckling to either side in the direction of the x-axis or z-axis while undergoing a linear statics test. The third and final Load Case was to see how long the tower could withstand an incremental load while undergoing a nonlinear static + p-delta analysis. All load cases would be conducted within the SkyCiv software.

With these primary details decided as the main goals, each team member was instructed to design a 2D model of their own that fit the specification. This step was primarily done for the group to brainstorm on what would become a future 3D model.

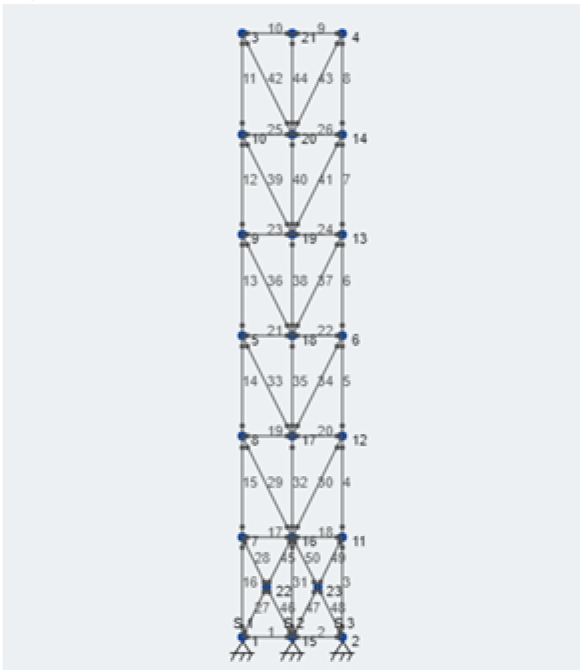
1.03 Ideate

Figure 1: Model 01



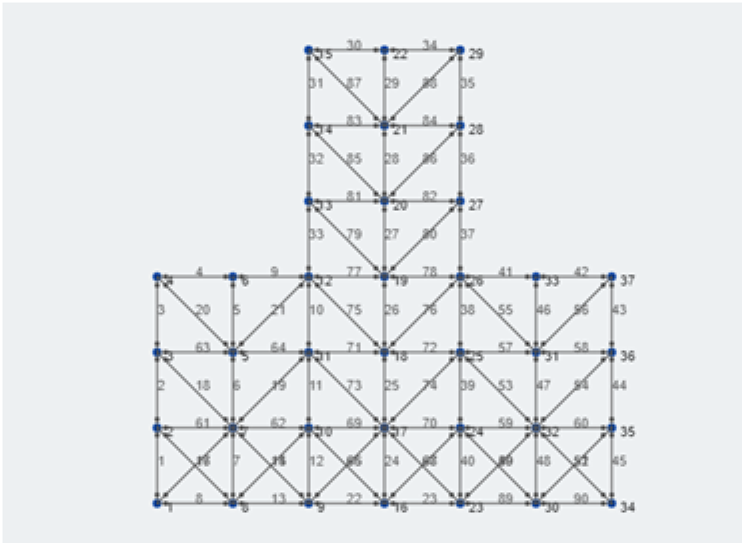
Edilberto Lopez designed Model 01 (Figure 1). He skipped the step of designing a 2D model because of his main focus of having a courtyard in the middle of the building. This exceeded the team's requirements of having the building's width and length 60 in x 120 in. Since it is in a C-shape, the challenge was in making it as rigid as possible. As far as the monetary aspect, it was going to be a challenge to keep it within budget because of the additional walls. If those two challenges were accomplished, Model 01's strength would have been that the students would have a courtyard near their rooms to relax in between their studies.

Figure 2: 2D Version of Model 02



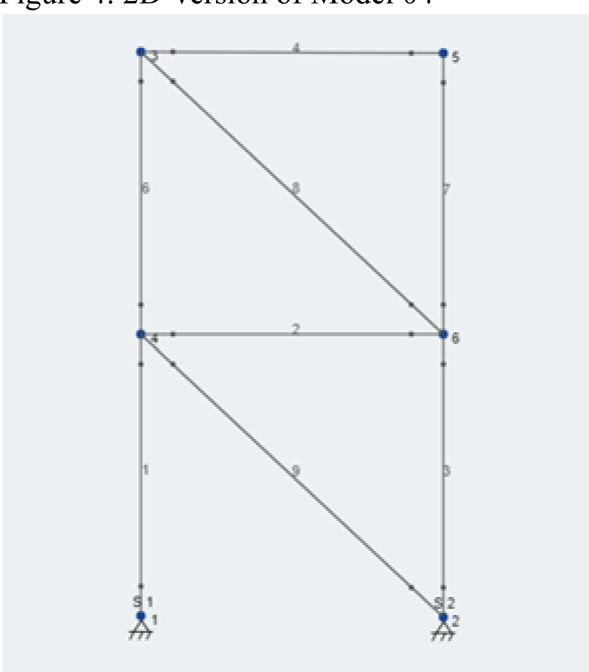
Michael Theisen designed Model 02 (Figure 2). He utilized a "pine tree" design termed by William LeMessurier similar to that of the CitiCorp building that served as his inspiration. This design was significantly skinny however and needed to be modified for the final product. The goal was to mimic the central trusses of the Pratt design in order to allow the building to maintain a significant height while using less material. In this design, no aesthetics whatsoever were going to be implemented. This design's primary focus was to adhere to the minimum specifications of a viable product.

Figure 3: 2D Version of Model 03



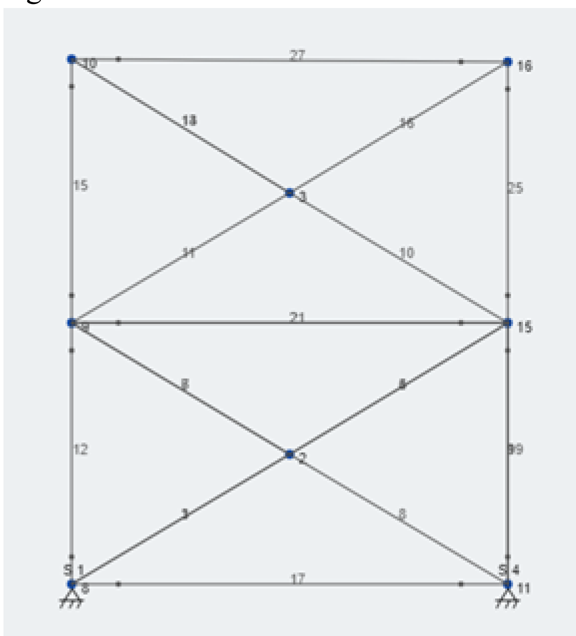
Seth Johnson designed Model 03 (Figure 3). The team's basic requirements were met on this model. The fact that the width is 60 inches helped strengthen the overall structure. Seth used more equal right triangles with better symmetry to facilitate a more structurally sound design. The roof of the sides would have tables and chairs for the students to congregate. This would allow them to have a safe meeting spot near their dorm rooms. Considering its size, this model would be close to the budget.

Figure 4: 2D Version of Model 04



Jennifer Hayward-Nandra designed Model 04 (Figure 4). She got her idea from watching Professor Lim's method, but did not get as far as others in the group did by the next group meeting. This was a simplistic design but it did not meet the minimum 60 inches in height. The base was going to be half that size, to ensure the building is structurally sound. Since it did not meet one of the team's basic requirements this model was not chosen to be a prototype.

Figure 5: 2D Version of Model 05



Taras Snitko designed Model 05 (Figure 5). This model met the team's basic requirements of height, width, and material. The width is 50 inches, giving this building a short rectangular appearance. He used big triangle shapes for all the truss frames. This was going to be another simplistic design to help persuade Tacoma Community College that this model ensures it will be a safe building for its students. The weakness was few truss frames for this model, also if the model did not have the middle node in the "X" it would have made the model stronger. Economically, it would be very near the maximum budget.

In order to decide which models would become the team's prototype, a meeting was held on Discord on February 1, 2021 where the Required Tower Design Criteria (Table 2) was filled out to see which model followed the criteria according to specifications. The grading system is as follows:

0. Terrible
1. Bad
2. Needs Improvement
3. Okay
4. Good
5. Great

According to the values in the "Total" field of the table, Model 02 (Figure 2) and Model 03 (Figure 3) were chosen as the two 2D designs that would be repurposed into the 3D models. At this point the team was split into two subgroups to better divide the work on both models. Taras and Michael would begin work on Model 02. Jennifer, Seth, and Edilberto would work on Model 03.

Table 2: Required Tower Design Criteria

Criteria	**Model 01 EL**	**Model 02 MT**	**Model 03 SJ**	**Model 04 JH**	**Model 05 TS**
Height 60 inches?	5	5	5	0	5
Flat top platform?	N/A	N/A	N/A	N/A	N/A
Side at least 10in wide?	5	5	5	5	5
All truss elements?	5	5	5	5	5
Balsa wood material?	5	5	5	5	5
Under $2.1 mil budget?	3	5	3	3	2
Evidence of stress?	2	5	5	2	2
Evidence of bending?	2	5	5	2	2
Evidence of buckling?	2	5	5	2	2
Under max deflection?	N/A	N/A	N/A	N/A	N/A
Total	**29**	**40**	**38**	**24**	**28**

1.04 Prototype

The goal of this phase in development was to take the two 2D models and create prototypes that could continue to hold up to the design specifications. The work on the model prototypes began immediately since there was only three days given to create a 3D dimensional model from a simple 2D model.

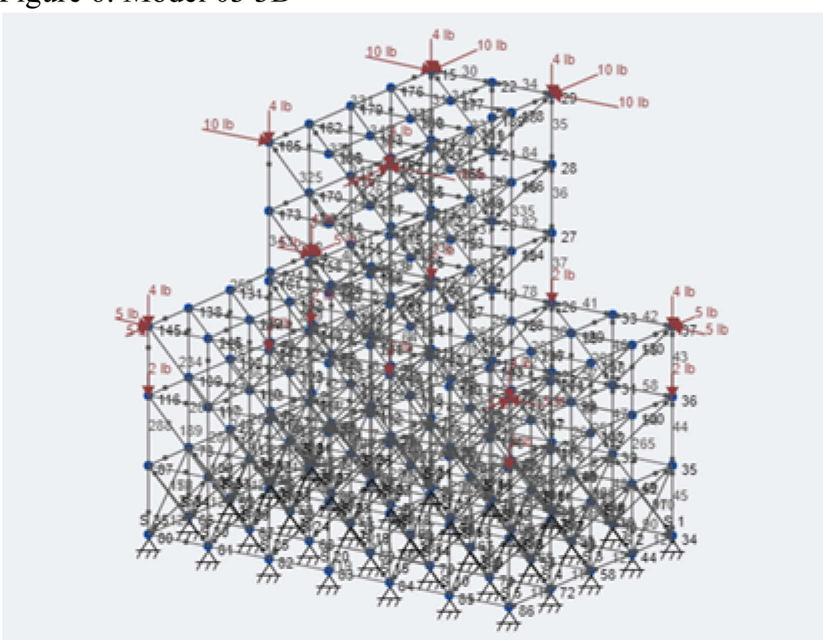
Model 02 (Figure 2) was turned into a 3D model utilizing the exact same style and size ratios but expanded in all three dimensions. Model 03 (Figure 3) was turned into a 3D model by taking its base design and stretching it in the z-axis direction.

After the prototypes were tested in SkyCiv, they were continuously sent back to the prototype phase to have their structure altered to fall in line with the Load Case specifications.

1.05 Test

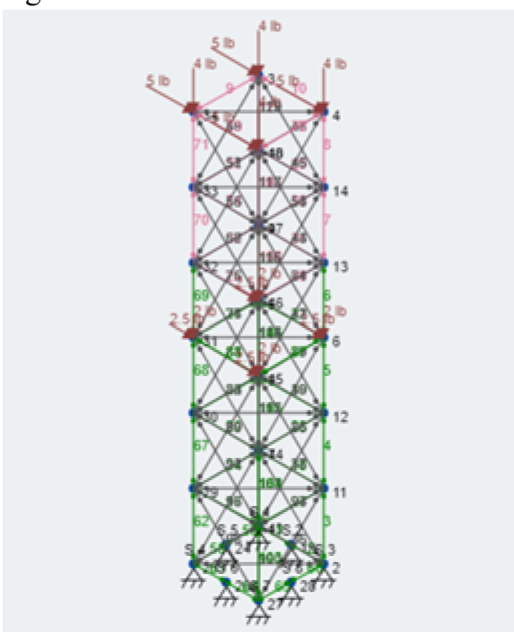
The testing was conducted on SkyCiv. During the Linear Static test, focus was on axial stress and displacement on the x, y, and z axis. The goal for the axial stress is to keep the compression yield strength under 1,300 psi, SkyCiv will display red if this were the case. The goal of the displacement was to not have any significant displacement on any axis. During the Linear Static + Buckling test, the focus was on buckling. If the buckling load factor was less than one, there was buckling.

Figure 6: Model 03 3D



The first test of the Model 03 (Figure 6) prototype went well. This was not a surprise given that it had a significant structural advantage over the team's other model designs. Two different cross sections were used, the 3/32 by 3/32 with its area being 0.008789 in^2, and the 3/32 by ¼ with its area being 0.023438 in^2. The total length of trusses used was 6,803 inches. During the linear static testing the axial stress showed all under 1,300 psi, with the highest at 1,137.786 psi. The highest displacement value for the x axis was -.003 in, and for the z-axis was .028 in. While being able to fulfill all of the required dimensions and Load Case tests, the model cost well over $3,000,000. With its dimensions being 60 inches wide and 40 inches long, this model would take up a lot of real estate. Even though there was no maximum length given, Tacoma Community College might want to add a parking lot next to their dorm building. With Model 03's size and cost the team believed the college would not be persuaded to choose this design.

Figure 7: Model 02 3D



The first 15 iterations of the Model 02 prototype followed the same style and shape of the original model, but more trusses were added due to a consistently failing model that always buckled. It was not necessary to return to any Ideate steps that dealt with the specifications with the model because the minimum height and width requirements were never altered. Michael chose to initiate a brainstorming session that resulted in an absolute design change in the 16th iteration of Model 02. It was determined that the "pine-tree" design and also the Pratt truss method, were both continuing to fail.
After much testing and multiple prototypes, a 34th iteration prototype was finally made that could withstand all three of the Load Cases. This model had a remaining budget of roughly $300,000 so the decision was made to switch the vertical trusses from the $\frac{1}{4}x\frac{1}{4}$ truss to the $\frac{1}{2}x\frac{1}{2}$truss. After this switch, the new 35th iteration prototype was stronger than the previous prototype and still fit under budget at a grand total of $1,082,000. The final design (Figure 7) fulfills all of the necessary requirements decided upon in the *Define* stage. This model was chosen as the team's final design for submission.

Model 02 represented this team's design submission during the Tower Competition. This competition took place on February 5th by Prof. Rebecca Sliger and Prof. Edwin Lim. It passed each test during this event. It won the honor of being the building least likely to buckle by having a pressure failure of 71.739.

Table 3. Tower Competition Results

Testing	
Height (in.)	60
Width (in.)	10
Flat Mid & Top	Yes
Cost ($)	1,082,000
Weight (lbf)	0.579
Load Case 1 Stress (Pass/Fail)	Pass
Load Case 1 Lowest Stress (psi)	0.000
Load Case 2 X-Direction Stress (Pass/Fail)	Pass
Load Case 2 X-Direction Max Deflection (in.)	0.48
Load Case 2 X-Direction Deflection Limit (in.)	0.6
Load Case 2 Z-Direction Stress (Pass/Fail)	Pass
Load Case 2 Z-Direction Max Deflection (in.)	0.48
Load Case 2 Z-Direction Deflection Limit (in.)	0.6
Load Case 3 X-Direction Pressure Failure (lbf)	71.739
Load Case 3 Z-Direction Pressure Failure (lbf)	71.739

2.00 Reflection of Process

The team followed the IDEO process well. With proper planning and a thorough understanding of the final goals of the project, there was no need to bounce back and forth between phases of the IDEO process that often. Design criteria was clear from the beginning and all team members were able to focus on this goal.

The *Empathise* phase was short due to the fact that the necessary requirements were generally already explained on the specification paperwork. There were no interviews conducted during the *Empathize* phase but considering the fact that each team member was already filling the shoes of college students, they reflected on what type of dorm building they would like. The team's *Define* phase was the greatest strength while maintaining a overy strong goal oriented approach. There was consensus early during the project on what the priorities should be for the building. That helped the team to stay on track. The Monday afternoon Discord voice conferences also helped answer any questions any team member had and assign duties. Doing a team project remotely can be impersonal, but those conferences established at least a bit of camaraderie between team members. Once a clear set of goals was established, there was no need to go back to the *Define* or *Empathise* step with Model 02. There was some going back and forth between the *Prototype* and *Define* phases of Model 03 while converting it from a 2D model into a 3D model. There were a couple different ways that transformation could have gone, so revisiting the *Define* phase allowed the team to find its direction.

The *Ideate* step was where the team separated into individual sections of the assignment. The team members created their own individual 2D models that they had each worked on. This step was generally straightforward and consisted primarily of individual brainstorming. The *Prototype* phase proved to be the most challenging for the entire group while working with the SkyCiv program. Becoming familiar with it took a lot of time and effort. With the short deadlines this was not always feasible and the team had to adapt. For example, the day that everyone had to present their 2-D model, Seth presented a sketch of his. He eventually created one on SkyCiv, and this became Model 03. However, SkyCiv usability did become an uphill battle throughout the project. Since no one has the college major of civil engineering, designing structures was not a familiarity.

After the transition of the two selected models from 2D to 3D, the challenge of creating a viable and stable tower proved to be the most difficult step, as seen from the many iterations of the prototype. With each failed *Prototype* phase, the prototype progressed only incrementally with the assumption that the problem with the model was only small. However, the problems with the Model 02 prototype eventually were found to be unfixable and needed to be restarted from scratch.

If the team could go back in time, they would spend more time getting a working 3D model before the due date. Instead of spending three days working on the 2D to 3D transition, the team could have created a potential base model first that fulfilled all the design criteria. The occurrence of the COVID-19 virus put a significant hindrance on the entire team and certain phases of the assignment felt rushed. The distanced learning also hindered the ability to communicate swifty with each other and the professors. More time in the final steps of the assignment would have allowed for the ability to clear up any confusion as well as optimization and aesthetic input.