TimberStrong Design-Build

CENE 486C

Friday May 3rd, 2024

PONDEROSA TIMBERJACKS

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Project Introduction

- Design and analyze a timber structure
- Create 2D and 3D models
- Construct and compete against other teams
  - American Society of Civil Engineers (ASCE)
  - Intermountain Southwest Student Symposium (ISWS)
  - April 11th, 2024
  - Logan, Utah – Utah State University (USU)
- Client: Mark Lamer

Figure 1: TimberStrong Structure [1]

Constraints

- Height ≤ 12ft
- Framing within 6’x6’ footprint
- Floor cantilever must extend 4’1”
- One floor overhang of 1’
- One opening in floor system
- One window per wall
- Door on first story front wall

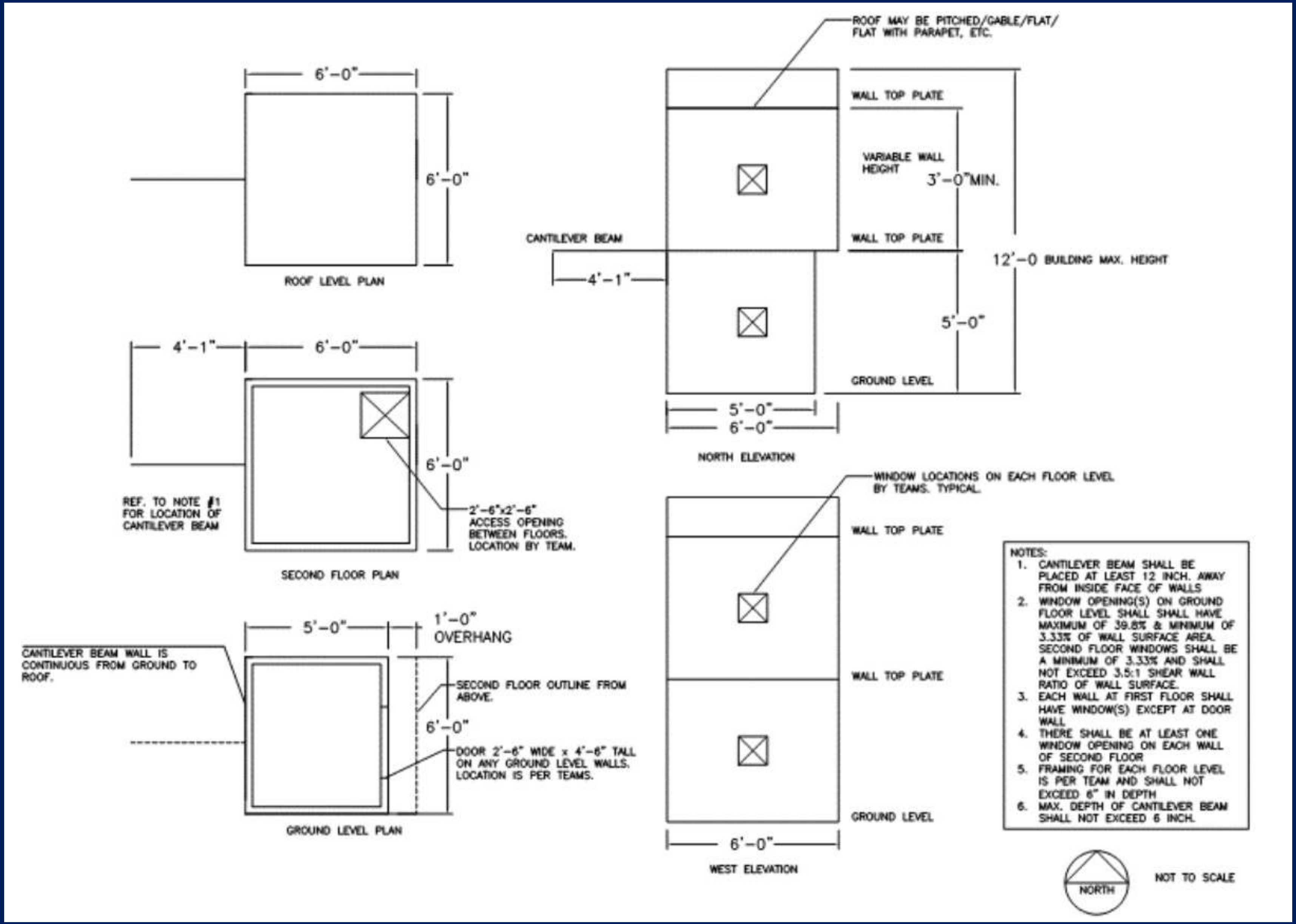


Figure 2: Competition Constraints [2]

Initial Design - Timber Grade

Table 1: Timber Grade Decision Matrix

Grade Decision Matrix		Grade 1		Grade 2		Grade 3		Grade 4		Grade 5	
Criteria	**Weight (%)**	**Score**	**Wtd. Score**	**Score**	**Wtd. Score**	**Score**	**Wtd. Score**	**Score**	**Wtd. Score**	**Score**	**Wtd. Score**
Cost *	30	1	0.3	2	0.6	3	0.9	4	1.2	5	1.5
Efficient Strength**	20	4	0.8	5	1	4	0.8	2	0.4	1	0.2
Availability **	50	4	2	5	2.5	2	1	2	1	1	0.5
Total	**100**		**3.1**		**4.1**		**2.7**		**1.7**		**2.2**

*Ranked scoring **Rated Scoring

Quality

- ***Cost:***
  Based on research of inventory at local stores
- ***Efficient Strength for Residential Construction:***
  Based on research of timber grades used in construction
- ***Availability Within Local Lumber Stores:***
  Based on research of inventory at local stores

Figure 3: Timber Grades [3]

Initial Design - Timber Species

Table 2: Timber Species Decision Matrix

Species Decision Matrix		Douglas Fir (DF)		Spruce Pine (SP)		DF Larch		Hem Fir		SP Fir	
Criteria	**Weight (%)**	**Score**	**Wtd. Score**	**Score**	**Wtd. Score**	**Score**	**Wtd. Score**	**Score**	**Wtd. Score**	**Score**	**Wtd. Score**
Cost *	30	2	0.6	1	0.3	3	0.9	4	1.2	5	1.5
Efficient Strength**	20	5	1	2	0.4	2	0.4	4	0.8	3	0.6
Availability **	50	4	2	2	1	3	1.5	5	2.5	2	1
Total	**100**		**3.6**		**1.7**		**2.8**		**4.5**		**3.1**

*Ranked scoring **Rated Scoring

- ***Cost:***
  Based on research of inventory at local stores
- ***Efficient Strength for Residential Construction:***
  Based on research of lumber species used in construction
- ***Availability Within Local Lumber Stores:***
  Based on research of inventory at local stores

Figure 4: Timber Species [4]

Initial Design - Design Alternatives

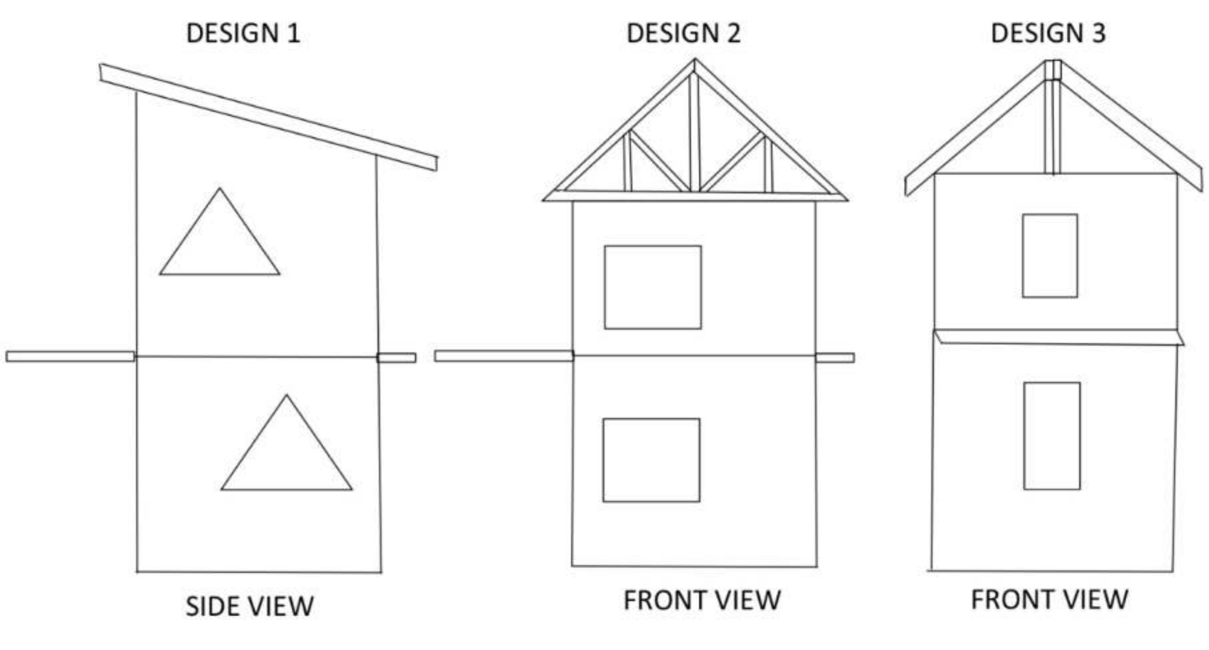


Figure 5: Initial Design Alternatives

Table 3: Initial Design Alternatives

Design Descriptions	Design 1	Design 2	Design 3
Roof	Mono-pitched	Trusses	Gable
Window Sizes	About 2' wide. Triangles	About 1.5' wide. Squares	About 1' wide. Rectangles
Window Placement	Off-Center and Not Stacked	Off-Center and Stacked	Centered and Stacked
Cantilever Beam Placement	Front Wall	Side Wall	Back Wall
Floor Overhang Placement	Back Wall	Side Wall	Front Wall
Aesthetic Theme	Mountains	Pine Tree	Log Cabin

Initial Design - Design Decision Matrix

Table 4: Initial Design Decision Matrix

Design Decision Matrix		Design 1		Design 2		Design 3	
Criteria	Weight (%)	Score	Weighted Score	Score	Weighted Score	Score	Weighted Score
Cost *	20	2	0.4	1	0.2	3	0.6
Aesthetics ** and Creativity	20	3	0.6	2	0.4	2	0.4
Prefabrication** Constructability	25	1	0.25	1	0.25	3	0.75
Roof* Constructability	35	1	0.35	3	1.05	2	0.7
Total	**100**		**1.6**		**1.9**		**2.45**

*Ranked scoring **Rated Scoring

- ***Cost:*** Based on estimates of material amounts in each design
- ***Aesthetics and Creativity:*** Based on originality and cohesion in design and theme
- ***Prefab. Constructability:*** Based on panel construction ease: repetition in framing
- ***Roof Constructability:*** Based on roof construction ease: 90 minutes at competition

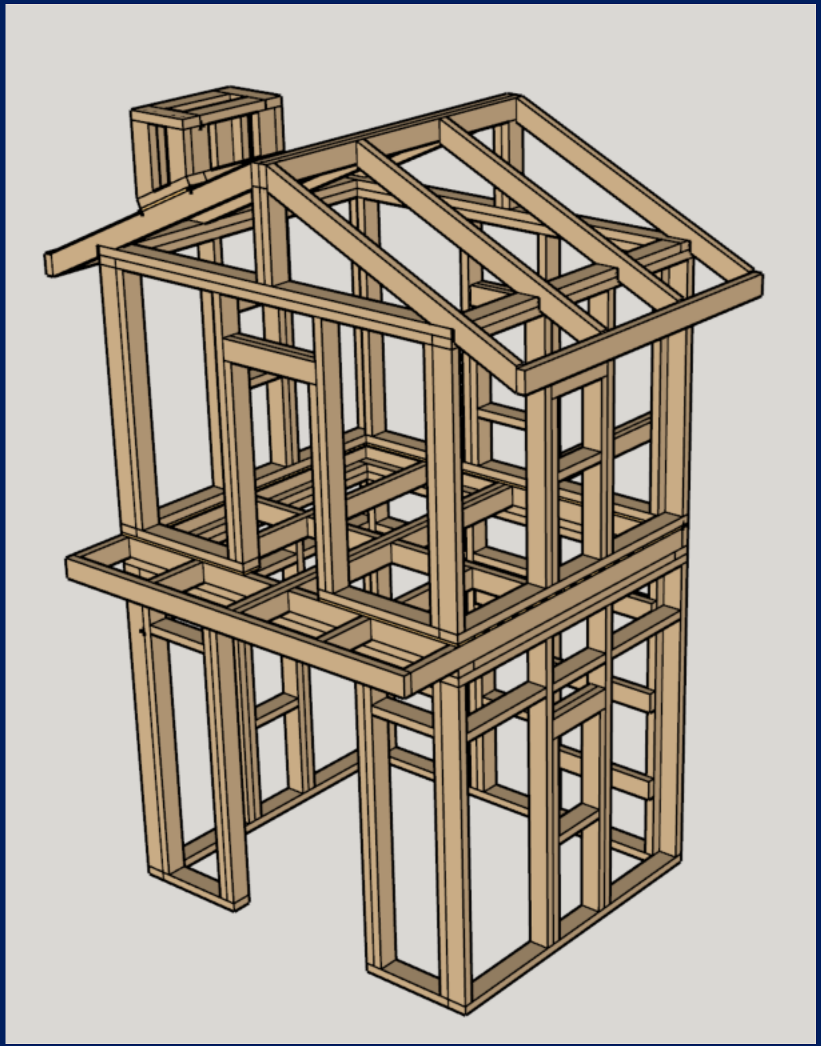


Figure 6: Chosen Framing Design

Final Design - Loads

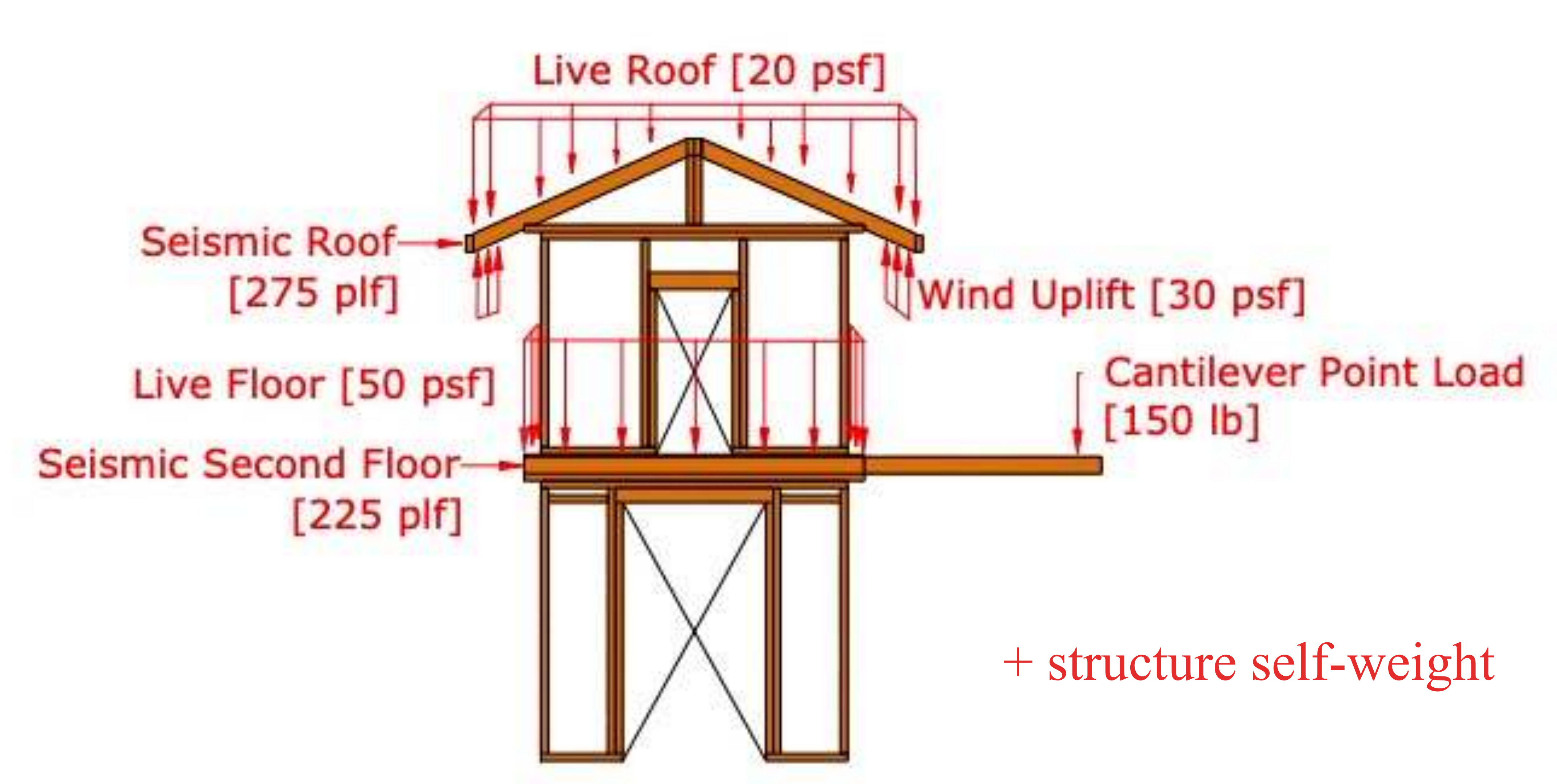


Figure 7: Loads and Placement

Final Design – Design Components

Gravity Design:

- Framing Member Sizes

Lateral Design:

Shear Walls & Diaphragms

- Sheathing Size
- Nail Size
- Nail Spacing
- Connections
  - Straps and Anchor Bolts

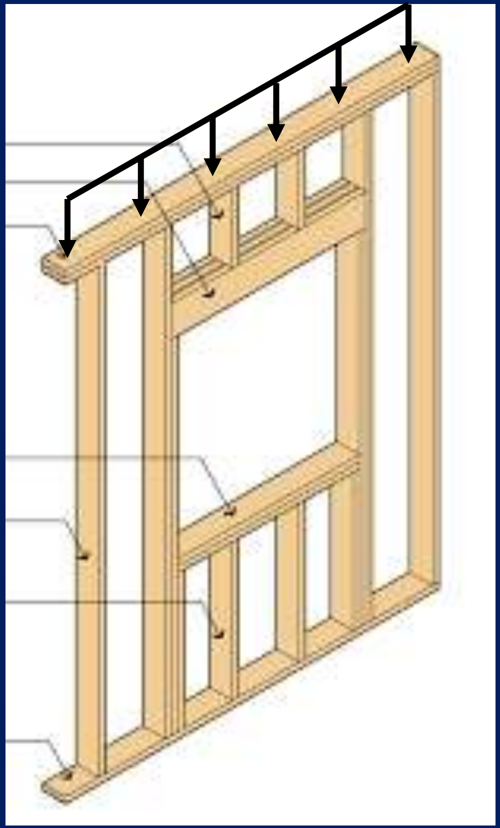


Figure 8: Framing Members [11]

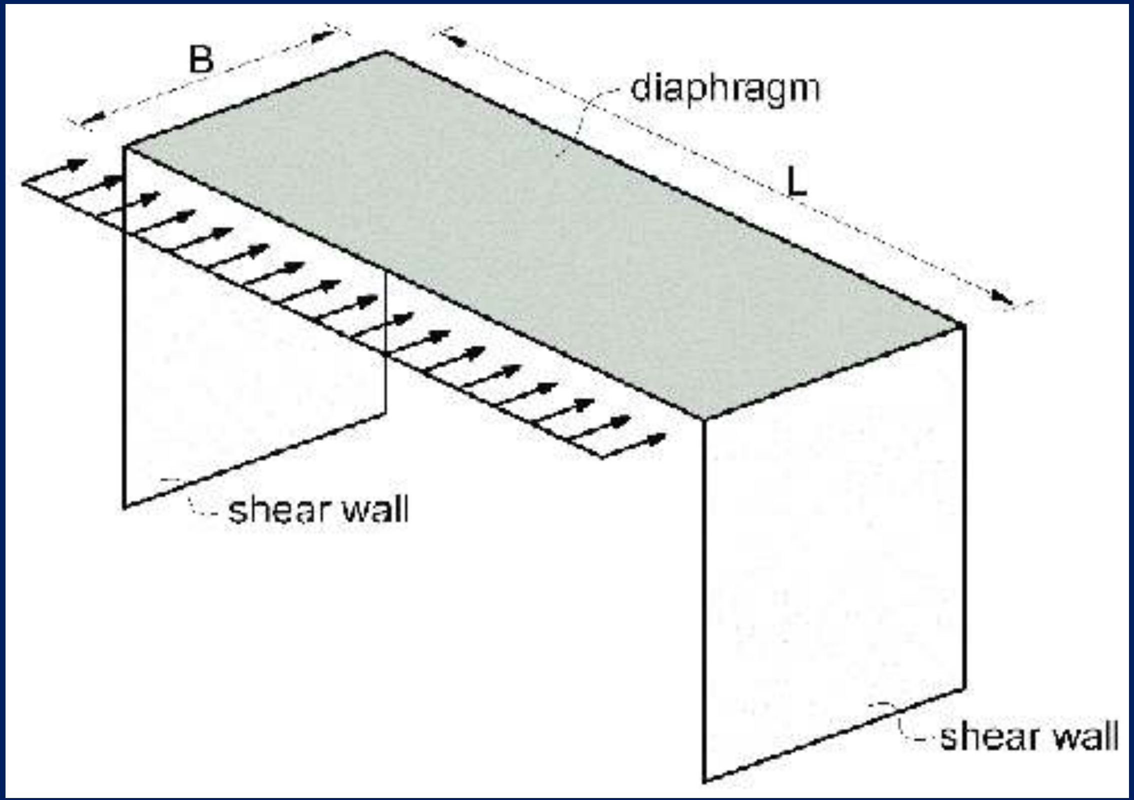


Figure 9: Shear Walls and Diaphragms [5]

Final Design – Factor of Safety

Factor of Safety = Capacity/Demand

Table 5: Lateral Factor of Safety (FS) Scoring

Average Lateral FS Results	Points Awarded
1.50 ≤ FS ≤ 1.65	Maximum
1.65 ≤ FS ≤ 1.80	Partial
FS < 1.50 or FS > 1.80	None

Table 6: Average Lateral Factor of Safety Results

Lateral Design Group	Average* FS
Diaphragms	1.54 ✅
Shear Walls	1.57 ✅

*Average FS for the lateral design groups was required for competition

Table 7: Gravity Factor of Safety Results

Gravity Design Group	Lowest FS
Roof	4.17
Floor	1.53
Wall Framing	17.0

No competition requirements, so FS>1.0 = ✅

Final Design – Predicted Deflection

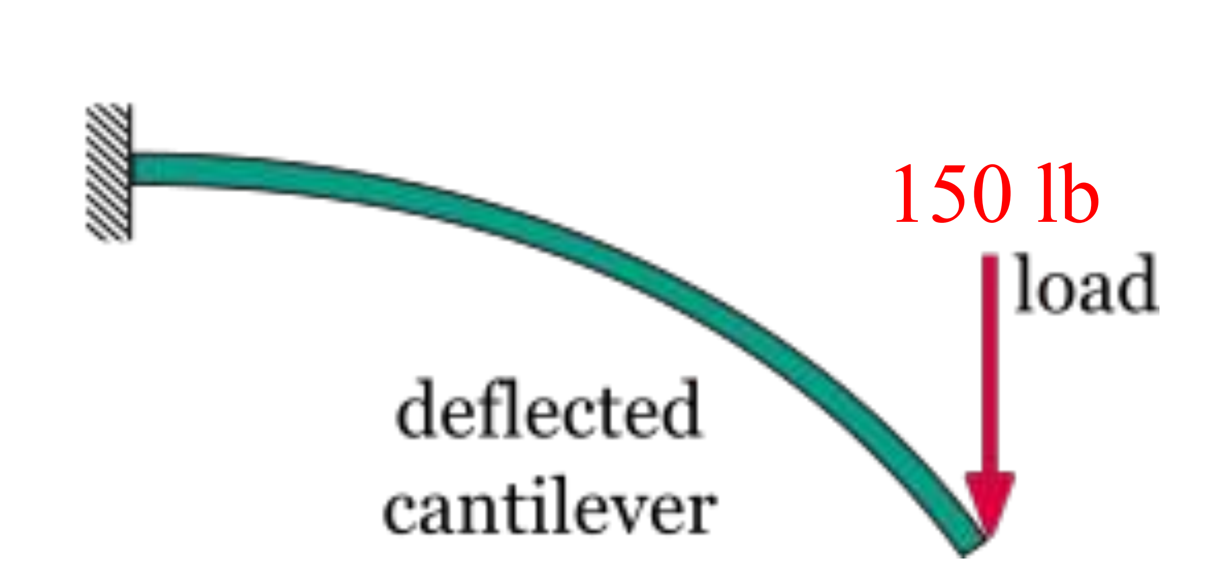


Figure 10: Deflected Cantilever [12]

Table 8: Deflection Results

Load Placement from Exterior Wall	Deflection (in.)
4’-0”	0.78
3’-9”	0.59
3’-6”	0.52

0.5 in.< Deflection<1.0 in. ✅

Modeling – 2D Structural Drawings

Structural Drawings: Competition Requirements

- Shear wall connection details
- Anchorage to the foundation
- Framing plans
- Plan view, elevations, and cross-sectional details
- Sheathing type and fastening schedule

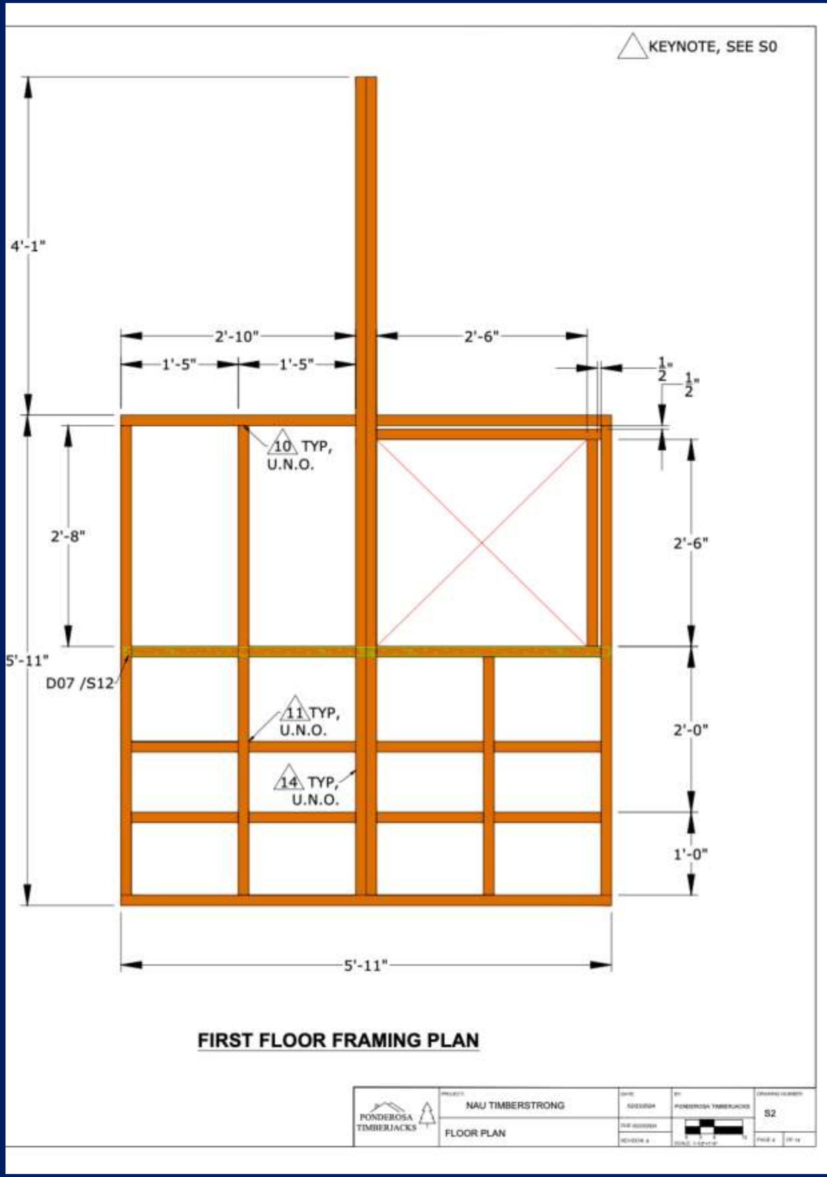


Figure 11: Floor Framing

Modeling – 2D Structural Drawings

22"x34" Construction Sheets:

1. Fastener Schedule
2. Anchorage to Foundation
3. Floor Plan
4. Roof Plan

5-6. Elevations

7-10. Framing and Sheathing Plans

11-12. Connector Placement

13. Details

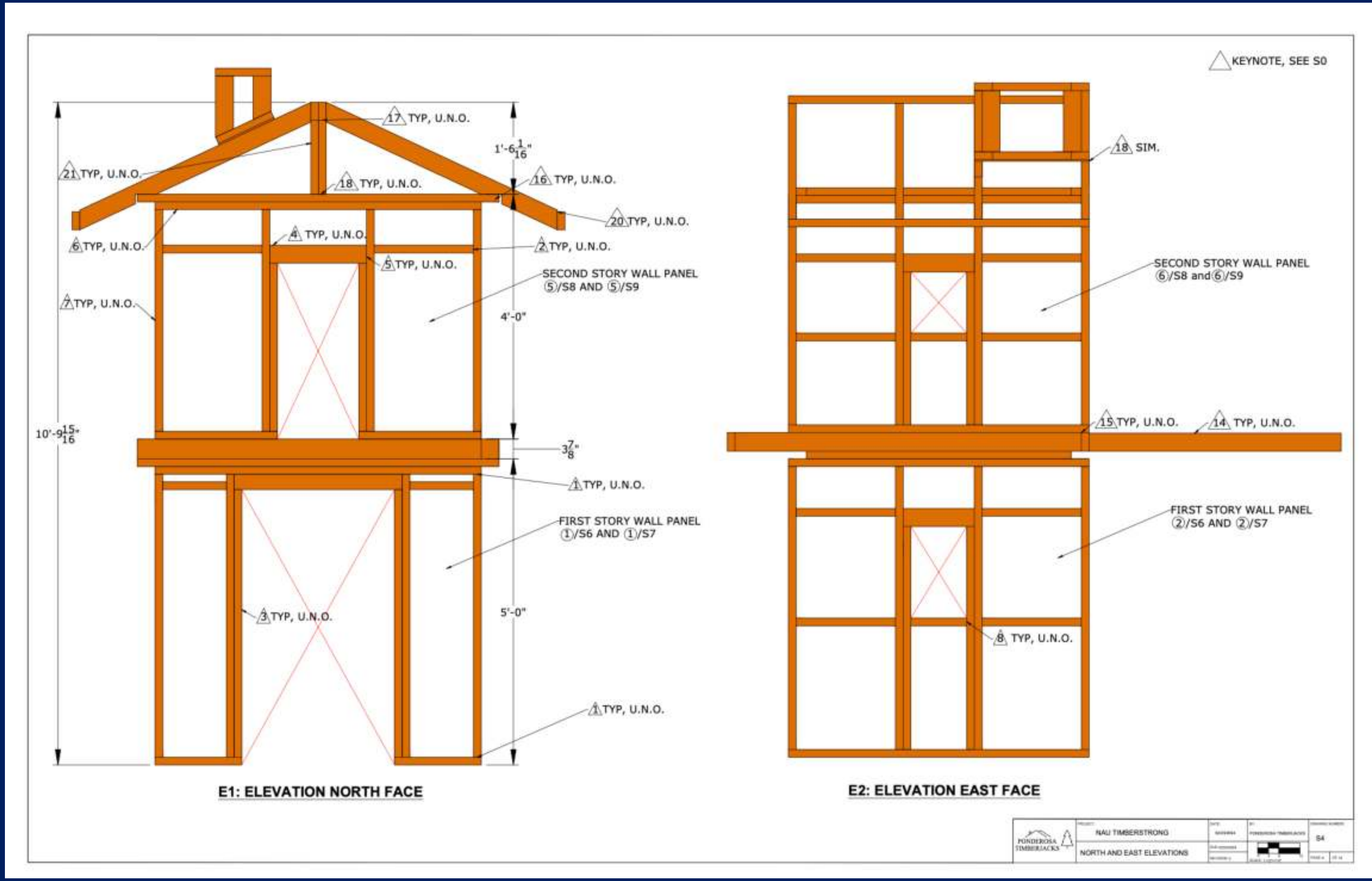


Figure 12: Elevation Drawings

Modeling – 3D BIM Model

Final Design:

- Log cabin-style architecture and aesthetics
- Roof ridge beams with gable shape and chimney
- Centered and stacked windows
- Balanced cantilever

3D BIM Showing:

- Elevation Views
- Connectors

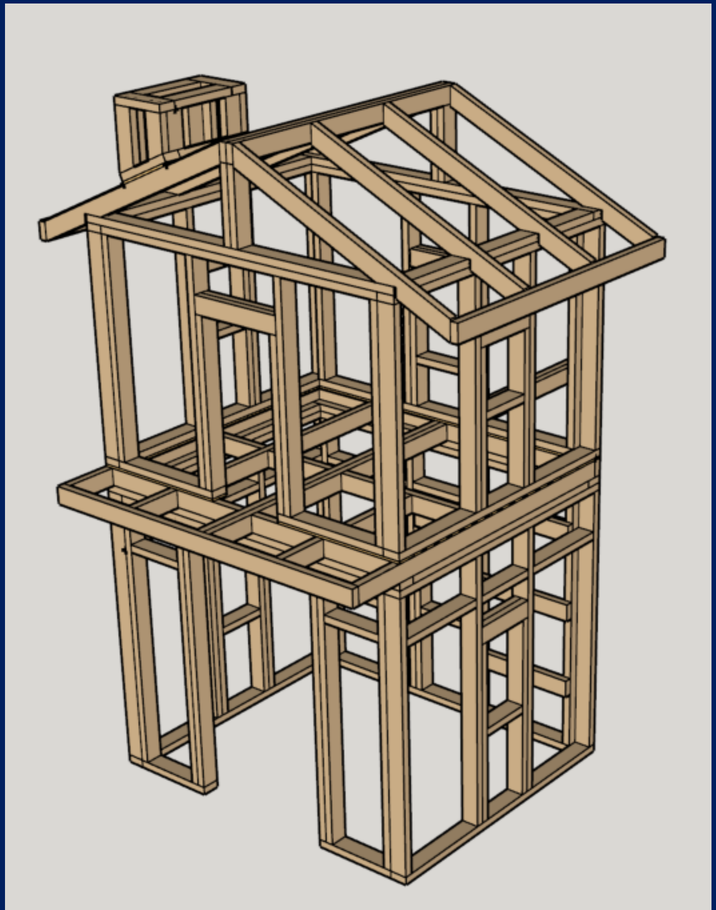


Figure 13: Revit Framing

Figure 14: Revit Model

https://youtube.com/shorts/IGWqpx4lVNs?feature=share

Construction – Materials

- Lumber: $813
- Connectors/Fasteners: $274
- Aesthetic Materials: $239

Total Structure Cost: $1,326

Figure 15: Material Movement [6]

Construction – Prefabrication

Prefabrication

- At NAU
- Cut lumber
- Frame wall panels and floor

Competition Rehearsal

- At NAU
- Practice construction
- Prepare supplies and materials

Figure 18: Rehearsal Build [8]

Figure 16: Prefabrication [7]

Figure 17: Prefabrication [1]

Figure 19: Rehearsal Build [8]

Competition

- Virtual presentation in March
- Panels staged prior to competition
- 90 minutes time limit
- Restricted to 20’ x 20’ area until finished
- Limited to battery powered drills

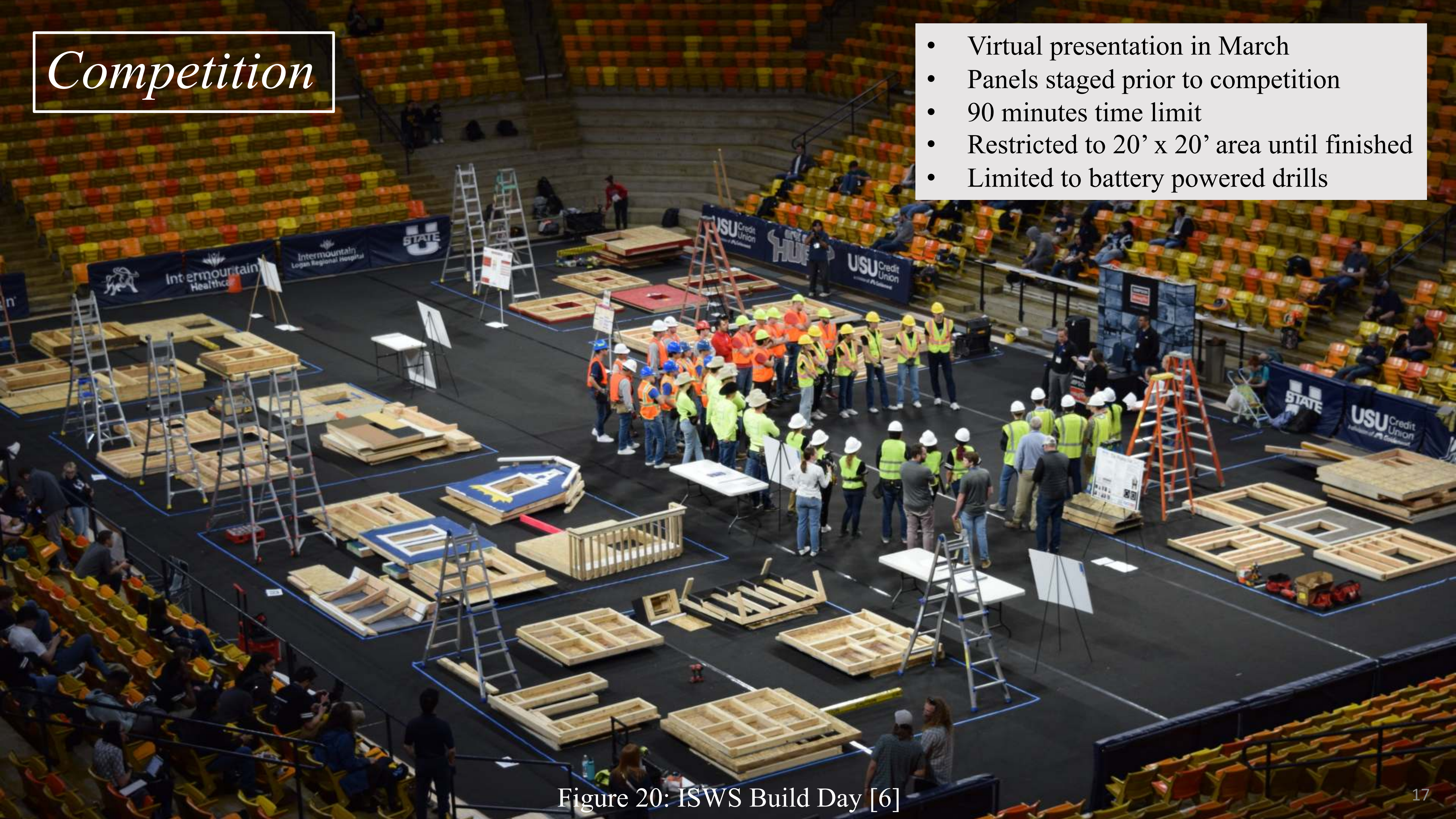
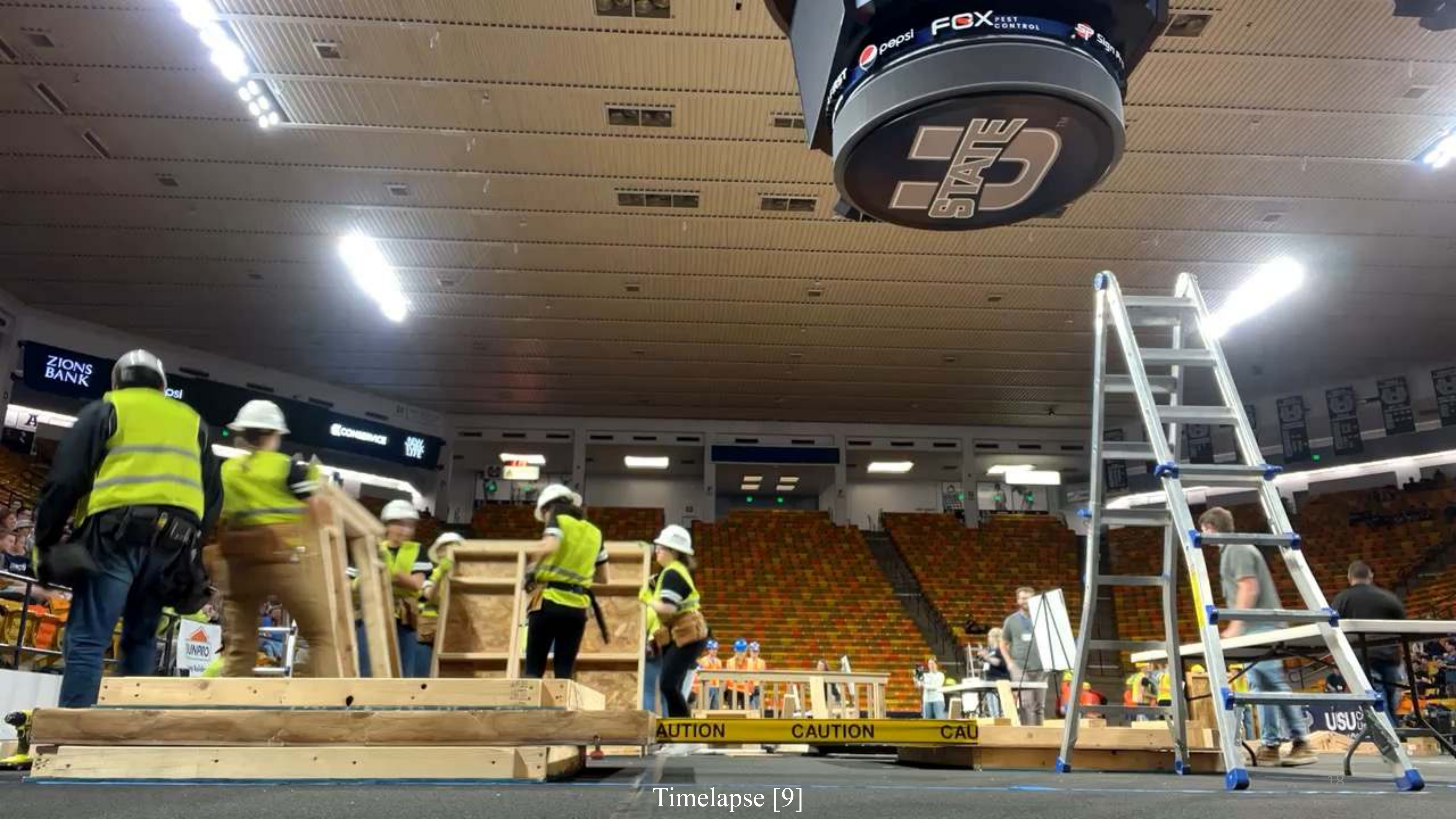


Figure 20: ISWS Build Day [6]



Timelapse [9]

Competition

Placed 2nd out of 7 teams

Measured deflection at 3’-9” = 0.58”
Predicted deflection at 3’-9” = 0.59”

Figure 21: Final Structure [6]

Figure 22: Deflection Testing [6]

Construction Lessons Learned

- Clarity on plan sets
- Dimensions that are helpful in the field
- Planning material amounts
- Working with suppliers

Figure 23: Construction Team [8]

Impacts

Figure 24: Timber House Framing [10]

Table 9: Impacts of Timber Use in Residential Houses

Social	Economic	Environmental
• Provides design versatility and aesthetic appeal • Vulnerable to moisture, damage, and insects	• Low initial material costs, labor costs, and construction time • High maintenance costs and insurance rates for homeowners	• Timber is a renewable resource/sustainable building material • Deforestation during harvesting and demolition waste is put in landfills

References

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[2] American Society of Civil Engineers, “TIMBERSTRONG DESIGN BUILD”, 2023.

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[5] "Figure 1," Research Gate, September 2018. [Online]. Available: https://www.researchgate.net/figure/Floor-diaphragm-A-summary-of-diaphragm-characteristics-can-be-listed-as-follows-transfer_fig3_328214443. [Accessed 12 February 2024].

[6] Megan Alexander, *Construction Photos,* Flagstaff and Logan, 2024.

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[11] “Wall Plate," Wikipedia, 11 November 2021. [Online]. Available: https://en.wikipedia.org/wiki/Wall_plate. [Accessed 1 May 2024].

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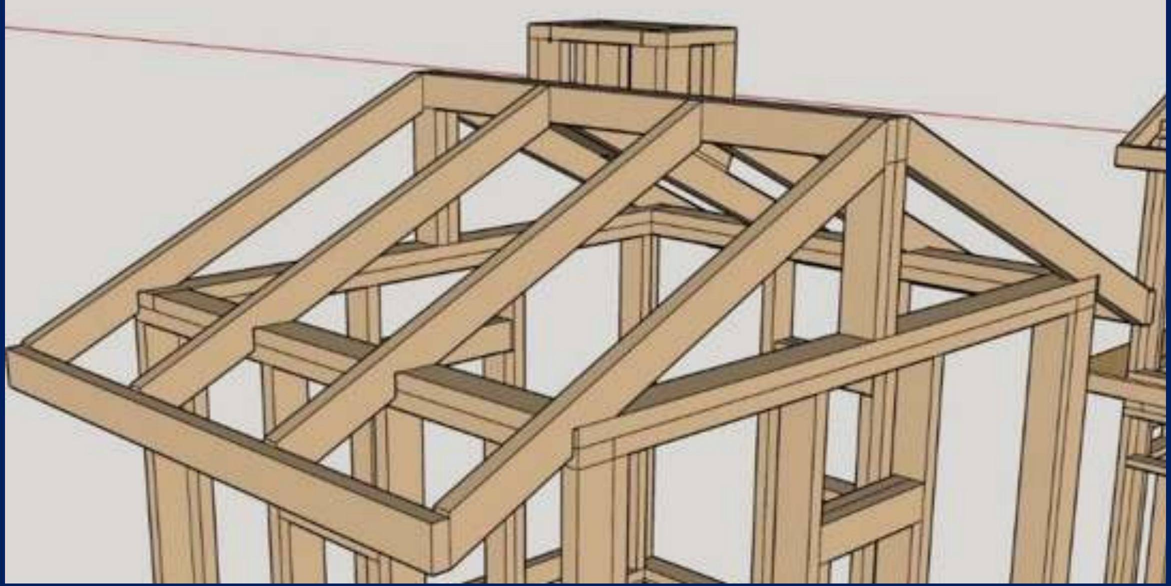
Questions?

Roof Design Results	
Design Aspect	**Design Result**
2x4 Member Size	All Framing Members
3/8” Sheathing	All Sheathing Pieces
6” Diaphragm Nail Spacing	All Diaphragm Edges
6D Diaphragm Nail Size	All Diaphragm Nailing
Rafter Tie Downs	SST H2.4ASS on each Rafter
Average Roof Diaphragm Factor of Safety	1.515

Floor Design Results	
Design Aspect	**Design Result**
2x4 Member Size	All Framing Members
Double 2x4 Member	Cantilever Beam
3/8” Sheathing	All Sheathing Pieces
6” Diaphragm Nail Spacing	All Diaphragm Edges and Beam along Opening
6D Diaphragm Nail Size	All Diaphragm Nailing
Strap on Beam along Opening	SST LSTA24
Average Floor Diaphragm Factor of Safety	1.572

Wall Design Results		
Design Aspect		**Design Result**
2x4 Member Size		All Framing Members
3/8” Sheathing		All Sheathing Pieces
Shear Wall Nail Spacing	6”	1st Story Front Wall 2nd Story Front Wall 2nd Story Sidewalls
	4”	1st Story Back Wall 2nd Story Back Wall 1st Story Sidewalls
6D Shear Wall Nail Size		All Shear Walls
Opening and Shear Wall Straps		SST LSTA24
Anchor Bolts		STB2-50234R25
Average Shear Wall Factor of Safety		1.568



Roof Framing Design

Rafter Design

Design for one interior rafter on the roof panel that includes the chimney. This design will be conservative (largest tributary and largest load), so the design of the interior rafters and the other half of the roof can be the same design.

Loads

$PL_{CH} := 17\ lbf$ — Dead load self weight of the chimney 2x4's and sheathing.

$PL_{CH} \div 2 = 8.5\ lbf$ — Half goes to interior rafter

$Trib_{int} := 19.167\ in$ — On-center spacing of the interior rafters

$w_{LR} := L_r \cdot Trib_{int} = 31.945\ plf$

$w_D := SH \cdot Trib_{int} + w_{stud} = 2.973\ plf$

Using ASD Load Combination 1.0D+1.0L

$w_{DandL} := 1.0\ w_D + 1.0 \cdot w_{LR} = 34.918\ plf$ — Distributed Load on the Exterior Rafter

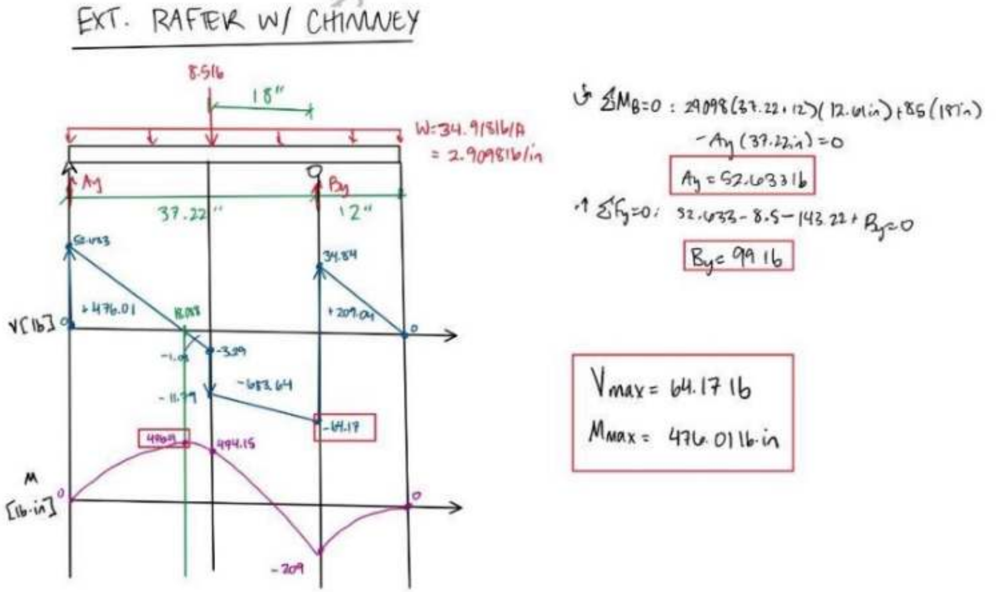
Solve For

$Rea_{1Raft} := 52.633\ lbf$ — Reaction of the rafter at the ridge beam

$Rea_{2Raft} := 99\ lbf$ — Reaction of the rafter at the top plate

$M_{max} := 476\ lbf \cdot in$ — Maximum moment

$V_{max} := 64.17\ lbf$ — Maximum shear



Flexure Design

$d := \sqrt{(6 \cdot M_{max}) \div (f_s \cdot b)} = 1.14\ in$ [NDS 3.3-2] $\text{if}(d \le 3.5\ in, \text{"Good"}, \text{"Bad"}) = \text{"Good"}$

Shear Design

$d := (3\ V_{max}) \div (2\ b \cdot f_v) = 0.372\ in$ [NDS 3.4.2] $\text{if}(d \le 3.5\ in, \text{"Good"}, \text{"Bad"}) = \text{"Good"}$

Roof MathCAD Example

Budget

Material Cost Estimate				
Description	Quantity	Unit	Unit Cost	Total
Lumber				
2x4-8ft Hem Fir	65	piece	$ 5.87	$ 382
2x4-10ft Hem Fir	2	piece	$ 7.45	$ 15
4x8ft-3/8 in OSB	14	sheet	$ 29.73	$ 416
			Lumber Subtotal	$ 813
Simpson Strong-Tie Connectors				
LSTA18 Light Strap Tie	12	strap	$ 1.26	$ 15
LSTA24 Light Strap Tie	9	strap	$ 1.68	$ 15
LSTA36 Light Strap Tie	4	strap	$ 3.05	$ 12
STB2-50234R25 Anchor Bolt (Box of 25)	1	box	$ 21.91	$ 22
H3 Hurricane Tie	4	piece	$ 4.49	$ 18
			Connector Subtotal	$ 64
Simpson Strong-Tie Fasteners				
Strong Drive CSV Construction Screw (Box of 240)	2	box	$ 21.32	$ 43
Strong Drive SDWS Framing Screw (Box of 150)	1	box	$ 40.55	$ 41
Strong Drive SDWS Framing Screw (Box of 250)	1	box	$ 62.88	$ 63
Strong Drive SD Connector Screw (Box of 100)	1	box	$ 13.98	$ 14
Strong Drive SD Connector Screw (Box of 500)	1	box	$ 49.64	$ 50
			Fastener Subtotal	$ 210
Aesthetic Materials				
Behr Exterior Paint	1	gallon	$ 30.98	$ 31
Staples	1	Pack	$ 9.99	$ 10
Wallpaper	4	Roll	$ 49.50	$ 198
			Aesthetic Subtotal	$ 239
			Total Cost of Materials	$ 1,326