NORTHERN ARIZONA UNIVERSITY

Bamboozle Engineering

CENE 486C – Capstone

Northern Arizona University

Bamboozle Engineering Project Report

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Bamboozle Engineering

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Acknowledgements

The Bamboozle Engineering design team would like to extend a pseical thanks to Professor Lar Reiboldt for the consistent guidance and display of professionalism throughout our project. The team would also like to thank Dr. Joshua Hewes, the team's Technical Advisor, for the technical guidance throughout the design process. Also, the team would like to thank Dr. Bero, our Client, for the positive and encouraging feedback over the last two semesters.

1.0 Project Understanding

This section identifies the purpose, background, technical considerations, challenges within the design, and the stakeholders for the Bamboo Bridge Capstone Project. Having a clear understanding of what the project entails will strengthen the team's knowledge and help establish a concise contract between the client and Bamboozle Engineering.

1.1 Project Purpose

Constructing a bridge of bamboo to allow safe passage for pedestrians and bicyclists is the purpose of this project. This project requires analysis and construction of a bridge that can withstand pedestrian live loads using bamboo as the main bridge design material. Therefore, the problem that will be addressed is the need for a low-impact bridge span, made only bamboo materials, which will carry pedestrian live loads in conjunction with its own self-weight.

1.2 Project Background

Many members of the Flagstaff community use the City of Flagstaff Urban Trail on a daily basis. The trail currently uses a treated wood bridge design, just off South Beullah Boulevard near the Interstate 40 overpass, to serve as a crossing point of the existing flood plain at this location. This project will address the need for a more aesthetic bridge design at this location, as per the client, Dr. Bridget Bero. The design of this new bridge will be made of bamboo, an eco-friendly material, which will serve as a replacement of the existing structure.

1.2.1 Project Location

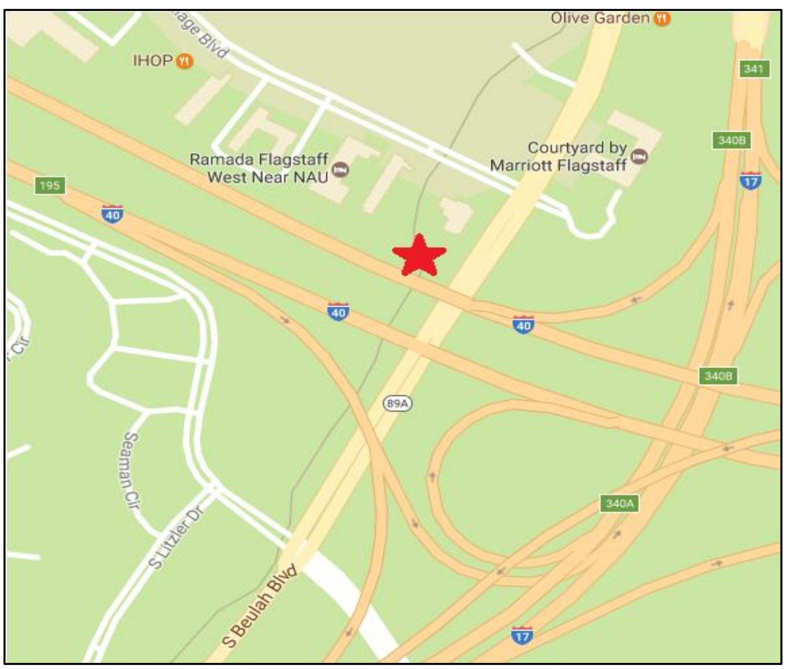

Figure 1: Site Map of Project Site, Google Maps

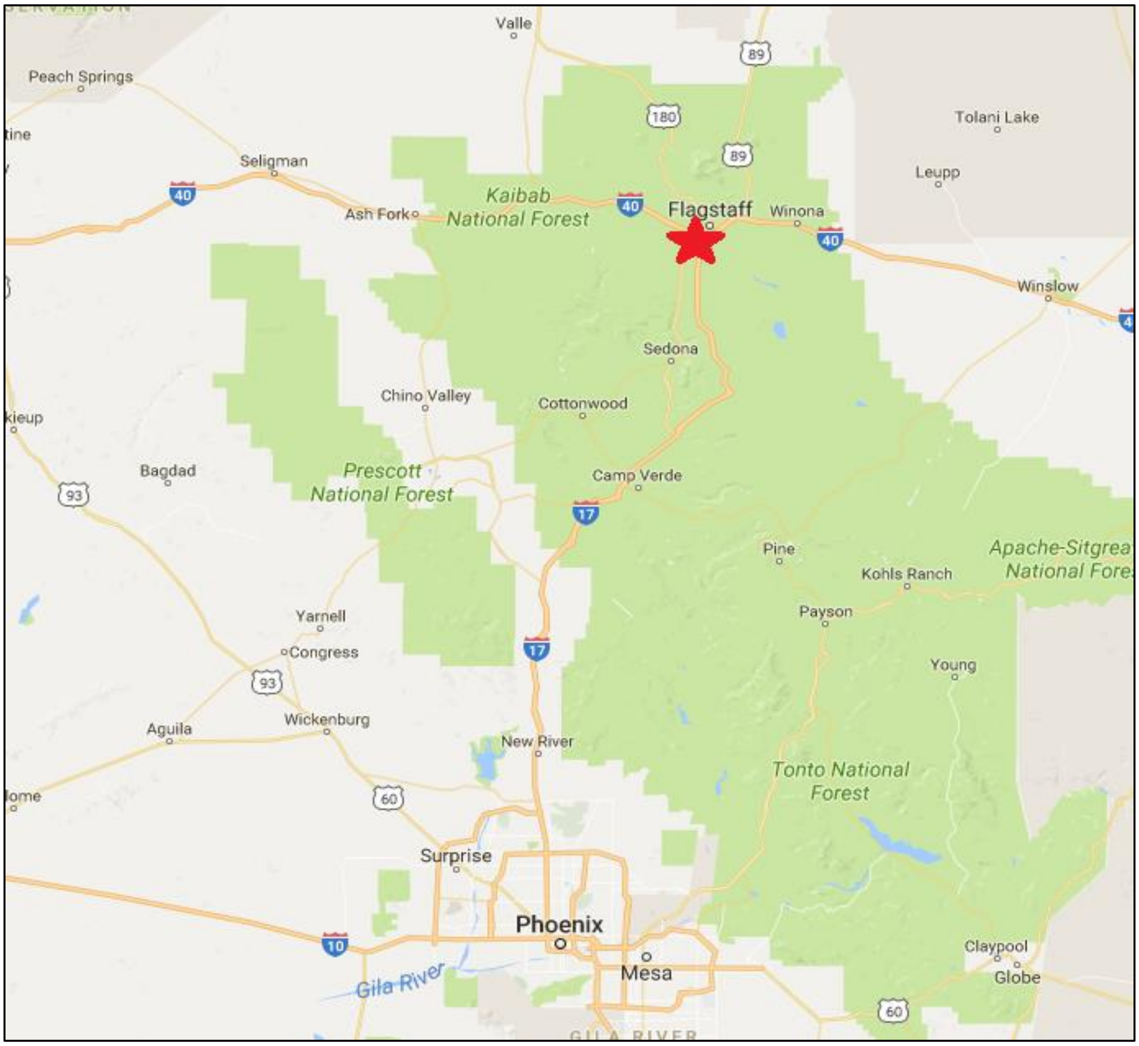

Figure 2: Vicinity Map of Project Location, Google Maps

1.2.2 Existing Structure

The existing structure at the project location is a standard pedestrian bridge made of treated lumber. The bridge currently joins two segments of the City of Flagstaff Urban Trail, and spans across a floodplain detention basin. Figure 3 below shows the existing structure as seen from S. Beulah Boulevard looking West.

Figure 3: View of Existing Structure from South Beulah Boulevard looking West

1.3 Technical Considerations

The development of civil engineering infrastructure is vital to the foundation of our modern day societies. More specifically, bridges and large infrastructure development depends heavily on steel and concrete materials throughout the design and construction processes. Bamboozle Engineering will use these typical materials as a starting point for comparative analysis, However, the project team expects to utilize bamboo to develop a structurally sound pedestrian bridge. In conjunction with these architecture types, the team will analyze bamboo material as structural components and connections in a lab test setting to optimize design for shear, buckling, bending, and strength. Computer software technologies such as Rapid Interactive Structural Analysis (RISA) and AutoCAD will be used to analyze design changes based on material differences, structural member design, and life expectancy of the structure [1]. In developing the design for this project, the team will work to construct the design and implement the structure for pedestrian use, minimizing design impact to surrounding environment.

1.4 Potential Challenges

Bamboozle Engineering will have to overcome a way to connect members of the bridge. The team will also have to physically construct a prototype bridge. With none of the team members being experienced in bridge building, this will be a huge challenge. In order to overcome the challenges, the team will have to seek guidance from professional engineers and other experienced workers in the field to succeed.

1.4.1 Technical Challenges

Of all the technical challenges the team will face, the boundary conditions and connections will be the toughest to overcome. The existing structure already has footings made of material that has yet to be determined, as specifications research from the previous design is currently being conducted. The presumed concrete footings will have to be analyzed in its current condition and incorporated into the bamboo design. With metal connections being an option, the engineering team will have to find out a way to efficiently connect members together while still remaining its structural integrity.

1.4.2 General Concerns

Using bamboo as a building material comes with many challenges. In the United States, it is a relatively new idea in the structural analysis world so there is not much research and laboratory testing on the idea. One of the key challenges the team will face is verifying the modulus of elasticity and rigidity in the laboratory. Bamboo has a natural 'joint' that could pose a serious challenge when determining the yield strength of the material. Depending on the properties of the varying cross-section, the minimum yield stress will have to be used when implementing it into the design.

1.5 Exclusions

1.5.1 Footings

Bamboozle Engineering will not be designing new footings for the bridge. This includes, but is not limited to, any geotechnical engineering analysis or Earthwork associated with manipulation of the pre-existing concrete footings.

1.5.2 Materials Testing if Time Permits

Most strength properties can be found online from reputable sources. Until it is found that further testing is needed Bamboozle Engineering will be excluding conducting our own material property testing.

1.5.3 Disclaimer

Anything not explicitly stated in scope will be excluded.

1.6 Stakeholders

As a team of future engineers looking to solve an issue our stakeholders and their concerns will be thoroughly examined. Those affected will include Dr. Bero, the users of our bridge, the city of Flagstaff, and Western civilization. Understanding the client needs of Dr. Bero will narrow our scope of work. The bridge we are focused on is located towards University Heights and Wal-Mart. Cyclists and pedestrians in the region are our primary users of the bridge. Our team will be building a scale model of that bridge. Ensuring our scale is secure, easily accessible, allows pedestrians and cyclists to cross safely, are the team's primary concerns. In addition, all stakeholders are affected by the success of the design. Further projects within the City of Flagstaff using bamboo as the primary material may arise based on the outcome of Bamboozle Engineering's bridge design. This can give further interests in bamboo being used as building material in the West, where it is less common. As a team we all stand to benefit from the success of our model bridge.

2.0 Testing and Analysis

The testing an analysis completed to design the Bamboo Bridge included the use of Microsoft Excel and RISA analysis tools. Microsoft Excel calculations were primarily used to compute deflections and bending stresses in each member. RISA analysis was used to develop a lateral bracing system to resist wind loading. The methods and procedures used within these tools are discussed in the following sections.

2.1 Methods and Procedures

In order to come up with an effective design, the method of analysis was the first thing to be determined. The two main ways of analyzing structures are to either design to the allowable stresses or to use load resistance factors (LRFD). In this project, allowable stress design was used but the governing factor in the final dimension-sizing ended up being dependent of deflections.

2.1.1 Equations and Formulas

Equation 1: Bending Stress in Members

$$\boldsymbol{\sigma_{bending} = \frac{My}{I}}$$

Where,

$\sigma_{bending}$ = Bending Stress (ksi)

M = Maximum Moment in Member ($kip - in$)

y = Distance From Centroid to Extreme Fibers (in)

I = Moment of Inertia of Cross-Section (in^4)

Equation 2: Deflection Calculation

$$\Delta = \frac{5\omega L^4}{384EI}$$

Where,

Δ = Deflection Mid-span (in)

ω = Distributed Load Seen by Member (kip/in)

L = Length of Member (ft)

E = Modulus of Elasticity of Material (ksi)

I = Moment of Inertia of Cross-Section (in^4)

2.1.2 Allowable Bending Stress Analysis

After determining the allowable bending stress that is spoken about in section 2.1.5, the cross-sections of the chosen members was determined by inputting commonly available dimension-sized lumber values into an excel spreadsheet to see what the actual stress in the member was. If the allowable bending stress was designed to, then the member sizing would have ended up being much smaller than the chosen sizes. Using Equation 1, the spreadsheet automatically calculated the bending stresses and a "check cell" identified if it exceeded the allowable value. The actual bending stress values can be seen in Table 1.

Table 1: Design Bending Stresses (ksi)

Allowable Bending Stress Check	12.8 ksi
Plank	0.160
Joist	1.363
Beam	2.276
Girder	0.999

2.1.3 Deflection Analysis

The deflection analysis is what ultimately determined the sizes of each member. If the members were designed to the allowable bending stress, then the midspan deflection would not meet city of flagstaff requirements. The City of Flagstaff adopted a specification from the American Industry of Timber Construction (AITC) that states the deflection of a beam cannot surpass "L/360" which is the clear span of any member divided by three hundred sixty. In Excel, the deflection of each member was calculated using Equation 2, which is derived as the midspan deflection of beams experiencing a uniform distributed load. After both values were determined, the actual deflections were compared to the limits and Excel output either a green cell (meets limit) or red cells (exceeds limit).

Table 2: Design Deflections vs. Deflection Limits

Allowable Deflection Check	L/360 (in)	Δ (in)
Plank	0.067	0.010
Joist	0.233	0.210
Beam	0.233	0.225
Girder	2.343	2.340

2.1.4 Lateral Bracing Analysis

The lateral bracing analysis was solely conducted using RISA software. Referring to Appendix B, one can see that only half of the lateral bracing rods are showed. Since only half of the rods experience tension, which is the axial force that resists lateral bending, then only half of the rods should be modeled. Once the rods were in place, the structure was ran to experience 0.16 kips per foot which was derived by a 40 psf load (Flagstaff Design Requirement) being distributed across the depth of the beam. Once the load was placed in the model, RISA output the axial forces in each member and the rods were designed to resist the maximum one.

2.1.5 Properties of Bamboo

The primary properties needed to conduct the analysis of the bridge were the allowable bending stress, modulus of elasticity and density of the material used in the design. In order to determine these values, background research was conducted and evaluated to find out if if it was reliable or not. Although the density used in design was determined through online sources, the density of bamboo from Lamboo Technologies matched up with those values. For allowable bending stress and Modulus of Elasticity, online source values were all taken into account and the conservative ones were used.

3.0 Design Alternatives

The design alternatives were developed by the project design team, keeping aesthetic appeal of the bridge at the forefront of decision making. The structural design of the bridge, the members that will endure loads and carry any weight applied to the bridge, was decided early on to be a beam design rather than a truss or cantilever. The variety for our design alternatives was made through the architectural design concepts, described in Section 3.2. These concepts were based on the concept of simplicity, while incorporating bamboo poles into the design. The architectural models were each modeled to be conjoined with the structural beam bridge design, so the differences between the design alternatives are through architectural presentation only.

3.1 Preliminary Analysis for Structural Design

With advice from our technical advisor, the team decided to keep the same structural design rather than three separate ones which was originally planned. To achieve variety in the design for the client, three separate architectural designs were developed.

3.2 Architectural Design Alternatives

Using the same structural design composed of laminated bamboo, the team determined it would be best to have the architectural appeal be constructed of raw bamboo. This section contains our three architectural design alternatives.

3.2.1 Identification of Three Architectural Design Alternatives

Alternative Design 'A' is a basic railing layout.

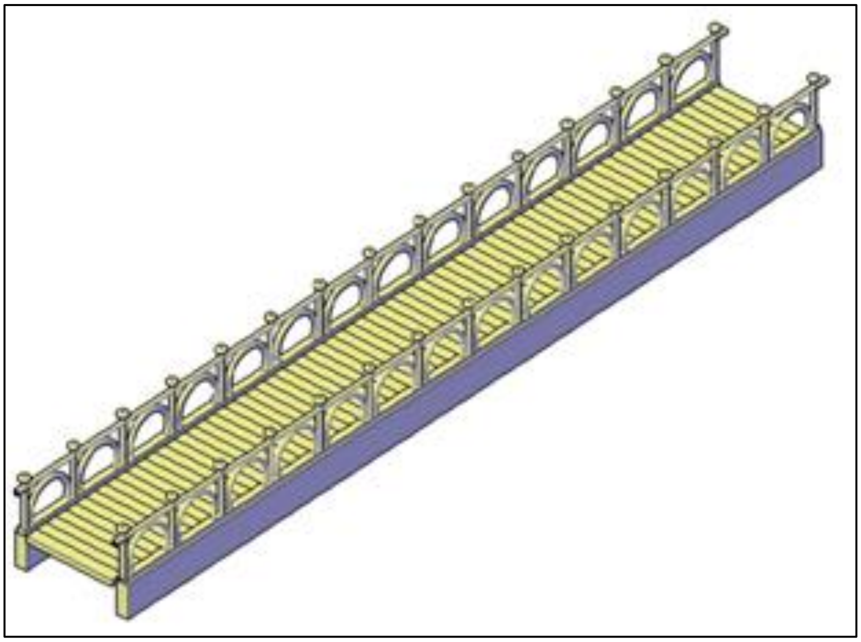

Figure 4: Design Alternative A, Isometric View

Alternative Design ‘B’ is an open dual arch design running parallel to the girders.

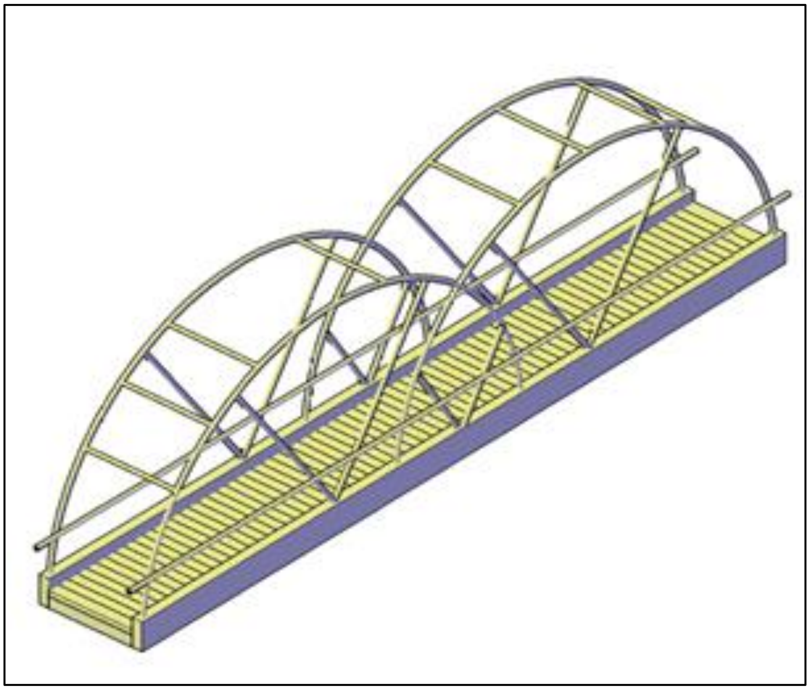

Figure 5: Design Alternative B, Isometric View

Alternative Design ‘C’ incorporates a series of smaller arches perpendicular to the girder forming a canopy over pedestrians crossing the bridge.

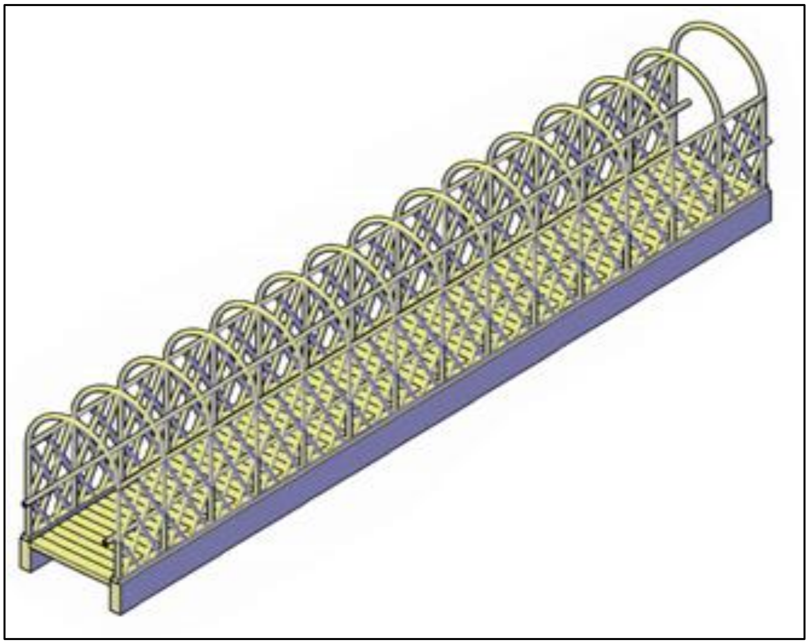

Figure 6: Design Alternative C

3.2.2 Design Alternatives Decision Matrix Components

The decision matrix for our architectural design alternatives includes the criteria of maintenance, cost, aesthetics, and constructability. The weights for each of these components and their individual rating scales are listed below.

1. Maintenance (20%)

    The scale for this design criteria is a 1-5 scale. Each of these rating values is listed below.
    1= Extensive maintenance required (monthly)
    2= Consistent maintenance required (every three months)
    3= Average maintenance required (three times per year)
    4= Infrequent maintenance required (twice per year)
    5= Maintenance is not an issue (once per year)

2. Cost (20%)

    The scale for this design criteria is a 1-5 scale. Each of these rating values is listed below.
    1= Cost is extremely high relative to other designs
    2= Cost is noticeably higher (10-20%) than any other alternative
    3= Cost is average an very close to other designs
    4= Cost is noticeably less (10-20%) than any other alternative
    5= Cost is extremely low relative to other designs

3. Aesthetics (40%)

    The scale for this design criteria is a 1-5 scale. Each of these rating values is listed below.
    1= The design is not appealing and does not fit surrounding environment
    2= The design is basic and not very unique
    3= The design is average and is aesthetically similar to existing structure
    4= The design heavily incorporates bamboo but is also distracting
    5= Raw bamboo is heavily incorporated in the design with strong aesthetic appeal

4. Constructability (20%)

    The scale for this design criteria is a 1-5 scale. Each of these rating values is listed below.
    1= Construction is difficult to implement in all aspects
    2= Construction is noticeably harder than any other alternatives
    3= Construction is average and similarly easy/difficult compared to other designs
    4= Construction is noticeably easier than other alternatives
    5= Construction is easy to implement in all aspects

4.0 Identification of Selected Design

The primary criteria for our selected design is predicated off of the decision matrix, shown in Section 4.1. The grades were strongly influenced by the opinion of our Client, Dr. Bero.

4.1 Decision Matrix and Justification of Selected Design Alternative

Table 3: Design Deflections vs. Deflection Limits

Criteria	Alternative (Raw Score)			Alternative (Weighted Score)		
	A	B	C	A	B	C
Maintenance (20%)	5	5	3	1	1	0.6
Cost (20%)	3	4	3	0.6	0.8	0.6
Aesthetics (40%)	2	5	4	0.8	2	1.6
Constructability (20%)	3	2	1	0.6	0.4	0.2
				3	4.2	3

4.2 Figure of Final Structural Design

Figure # shows the structural layout of the bridge without the architectural design. The individual members are also called out in Figure 7, below.

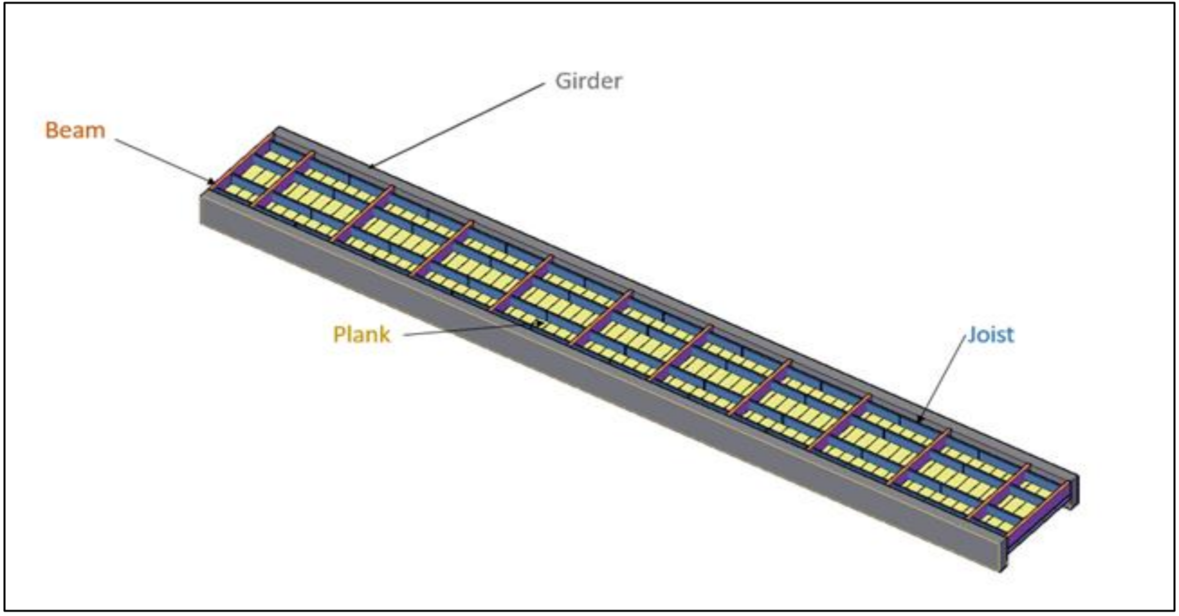

Figure 7: Bottom View of Final Selected Structural Design

4.3 Figure of Final Architectural Design

The figure below shows the final design chosen based upon it scoring the highest in our decision matrix.

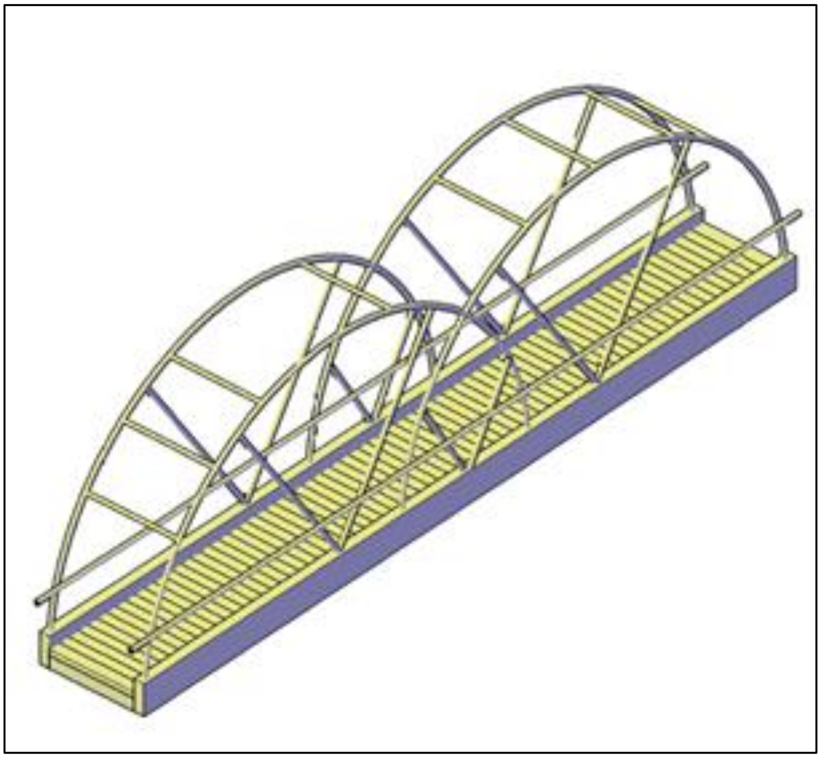

Figure 8: Isometric View of Final Selected Architectural Design

5.0 Final Design

The final design solution for our project, identified in Section 4, includes a structural design plan, an architectural design plan, and a lateral bracing design. These three components will be integrated as one structure and will serve the city of Flagstaff Urban Trail users as a structurally sound, aesthetic, and reliable part of the urban trail. The primary components of the final design are described in detail in Section 5.1 - 5.3.

5.1 Final Structural Design

The final structural design selected for this project was a simply supported beam bridge. This design was developed through hand calculations, which were coded into an excel design spreadsheet. The structural design member sizes are shown atop Page 13 in Table 4.

Table 4: Design Sizing of Each Structural Member

Member Attributes	B (in)	H (in)	I (in4)	S (in3)	A (ft2)	Y (in)
Plank	11.25	1.5	3.164	4.219	0.117	0.750
Joist	1.5	7.25	47.635	13.141	0.076	3.625
Beam	1.5	11.25	177.979	31.641	0.117	5.625
Girder	14	48	129024	5376	4.667	24

5.1.1 Final Structural Design Calculations

The Structural Design components was mainly calculated using Microsoft Excel Software. The overall length and width of the bridge were fixed values as they needed to conform to the existing footings. The rest of the dimensions were determined by meeting requirements such as bending stresses and deflections. Once those criteria were met, it was vital that the final dimensions were sizes that were available from the manufacturer chosen. The final dimensions can be seen in Table 4 above while the design spreadsheet can be seen in Appendix A.

5.2 Final Architectural Design

The final architectural design is an open concept that utilized raw pole bamboo as primary arches, and a piece of raw bamboo as a handrail. The use of arches and curvature contrasts the linearity of the structural design, comprised primarily of laminated bamboo.

5.2.1 Architectural Design Analysis

The raw bamboo and decking of the bridge were the two primary features the team focused on implementing into the bridge. The dual arch design was chosen by our client due to its airy feel and openness of the design. The decking of the bridge is the greatest exposed surface area and most susceptible to rain and snow. Due to these concerns the team went with a steel grating planks that better resist outdoor elements. This grating runs perpendicular to the joists they sit on. A spacer will be installed between the joists and grating to reduce the degradation of the joists. The beam and joist hanger connections being implemented are bare when they arrive. Therefore zinc coating and epoxy paint will be added for corrosion resistance. These details for are to increase the longevity of the bridge.

5.2.2 Final Design Connections

The final connections for attaching the beam into the girder will require a beam hanger. This hanger can be seen in figure 9.

2x12 Beam Hanger

Allowable Load (kips)	Design Load (kips)
4.9	3.43

Figure 9: Beam Hanger [7]

The joists will meet face-to-face longitudinally between the beams. Therefore the joist hanger shown in figure 10 will be used for making these connections.

2x8 Joist Hanger

Allowable Load (kips)	Design Load (kips)
1.68	0.85

Figure 10: Joist Hanger [7]

5.3 Final Lateral Bracing Design

The final lateral bracing design was developed in using RISA software by modeling the final structural floor plan as a truss with diagonal cross bracing for lateral support. The model output from this software can be seen in Appendix B. The maximum load found within the members of the lateral bracing support system was found using this model, described further in Section 5.3.1.

5.3.1 Lateral Bracing Design Calculations and Output

The lateral bracing system was design to a 40 pounds per square foot evenly distributed lateral load. This lateral load was multiplied by the depth of the girder design (4'), yielding a 160 pounds per foot distributed load across the length of the 70.3' bridge span. Once the model was run using RISA software, the calculated axial force within each member of the lateral bracing system was given. The model showed that the largest axial force, 0.783 kips, was seen in Member 20 and Member 21, shown in Table 5 below. These members are found to be near the midpoint of the span of the bridge. The design sizing of these members governed the rest of the other members, providing a uniform design size for each member within the lateral bracing system.

Table 5: Design Deflections vs. Deflection Limits

1	M20	max	.783
		min	.783
1	M21	max	.783
		min	.783

5.4 Impacts of Final Design Solution

The primary focus of our final design was analyzing bamboo as a structural supplement to traditional lumber. The impacts associated with implementing this form of material are listed and described in the following sections.

5.4.1 Economic Impacts

Bamboo is not a primary material for structural design in the United States. However, raising awareness of its advantages and uses with our project and similar designs could spark interests as a more viable alternative to traditional lumber. With an increase in structural bamboo manufacturing there would be a drop in bamboo prices. Also since the bamboo market is a competitor to material suppliers a decrease in the traditional lumber markets would be expected. However, at this time there are less financial profits for companies using bamboo in the U.S., but for projects located in Asian countries where bamboo is more prevalent it provides greater monetary incentives for using it as a structural material.

5.4.2 Social Impacts

Socially bamboo is widely accepted in many Asian countries and is slowly making its mark in American civilization. Implementing bamboo into our design and other projects in the United States will increase the Asian influence in America. Social connections between cultures are being made simple by using bamboo as structural supplement. With a new architectural design the bridge encourages people to use the Flagstaff Urban Trail System as well.

5.4.3 Environmental Impacts

From an environmental viewpoint bamboo offers many advantages. For projects similar to ours bamboo has little to no waste during the construction stage. Bamboo materials are recyclable and in Asian countries the scaffolding for construction also consists of bamboo [5]. Bamboo is fast growing and can be harvested much quicker than traditional trees used for lumber. The greatest bamboo export region in the world possesses the capability of producing 20 bamboo homes in the first nine months of the growing period [5]. With China and the United States at the top of the list for greatest pollution producing countries in the world bamboo offers a solution. Bamboo produces 35% more oxygen while also absorbing approximately 35% more carbon dioxide than most trees [6]. Bamboo is an excellent product to use for environmental purposes.

5.5 Final Scale Model Design

Figure 11: Team picture following completion of Scale Model Construction

6.0 Cost of Implementing Design

The final design solution required the analysis of project design costs and potential construction costs for implementation. Project engineering design costs are predicated off of hourly rates per position of a typical structural engineering design firm. These rates were used with our final Gantt chart and executed schedule. Our executed project design hours as of December 2017 were logged and compared to the projected hours for the project as of May 2017. The design team saw a 20%

decrease in the number of required hours to complete the project design. In conjunction with this analysis, a comparison of laminated bamboo lumber to typical Douglas Fir lumber was executed to provide the client with a complete analysis of potential building options. Based on a price takeoff for Laminated Bamboo from Lamboo Technologies (Phoenix, AZ), and our own typical lumber takeoff for Douglas Fir material, the team developed this analysis, described in Section 6.3.

6.1 Project Timeline (Gant Chart Original and Final)

The projected timeline for the project design was altered in several ways as the schedule was executed. The primary changes to the timeline were made to the following tasks: (i) existing bridge plan acquisitions, (ii) public survey, and (iii) RISA analysis. Each of these tasks were adjusted for the following respective reasons:

> (i) The existing bridge plans were assumed to be in the possession of the City of Flagstaff Multimodal Transportation Planner, Mark Ince. After an initial attempt to contact this individual, the design team made a follow up attempt ~6 weeks later. The design team was unable to make contact with this individual, and given the time constraints of the project, eliminated the acquisition of the existing bridge plans from the project schedule.
>
> (ii) The public survey was initially included on the design team schedule as a means to gauging public aesthetic sentiment for a pedestrian bridge in Flagstaff, Arizona. Due primarily to time constraints, the team was not able to initiate a public survey with enough time to gather extensive feedback. The public survey task was eliminated from the project schedule thereafter.
>
> (iii) RISA analysis was initially thought to be the primary tool for producing the structural design. After simplifying the model and using hand calculations, the team developed a design spreadsheet that was used to analyze the deflections and stresses in each structural member. Thus, RISA analysis was not necessary for this analysis. However, it must be noted that RISA analysis was still used for the lateral bracing structure. Reducing the amount of time analyzing our model with RISA significantly reduced the total hours during the design phase of our project.

These changes were made and reflected in our Final Gantt chart project timeline, shown in Appendix C.

6.2 Project Engineering Design Costs (Projected versus Actual)

The Engineering Staffing Table 6 below shows the projected design hours by task highlighted in blue, and the actual executed project design hours highlighted in white. The number of hours per project position per project task are shown. The total project hours per task versus the total executed hours per task are shown at the bottom of the table. The Staffing Summary Table 7 shows the total executed hours per position.

Table 6: Staffing Hours Breakdown per Task

STAFFING										
Position	Task 1 (hrs)		Task 2 (hrs)		Task 3 (hrs)		Task 4 (hrs)		Task 5 (hrs)	
Senior Engineer	10	6	20	10	80	50	10	15	30	25
Project Engineer	16	12	30	25	100	80	15	15	30	25
Project Manager	10	6	30	25	80	70	15	15	30	25
EIT	16	12	35	30	110	90	20	15	30	25
	52	36	115	90	370	290	60	60	120	100

Table 7: Staffing Summary Total Hours

STAFFING SUMMARY	
Position	Total Hours
Senior Engineer	150
Project Engineer	191
Project Manager	165
EIT	211

The engineering design costs for the project are calculated below in Table 8. The total projected hours by position and total projected costs are highlighted in blue. The total executed hours by position and total actual executed costs are highlighted in white. The estimated hours and design costs are based on May 2017 projected estimates. The final executed design hours and costs are based on the actual hours worked by each design team member. The hour and cost difference between May 2017 estimates and December 2017 executed was found to be a 20% and 22%, respectively. This cost difference is primarily due to the reduction in hours necessary to complete the structural design.

Table 8: Engineering Design Cost Analysis per Position

COST ANALYSIS					
Position	**Hourly Rate (USD)**	**Total Hours**		**Costs**	
Senior Engineer	$194.00	150	106	$29,100.00	$20,564.00
Project Engineer	$67.00	191	157	$12,797.00	$10,519.00
Project Manager	$90.00	165	141	$14,850.00	$12,690.00
EIT	$50.00	211	172	$10,550.00	$8,600.00
		717	**576**	**$67,297.00**	**$52,373.00**
		% Diff	**-20**	**% Diff**	**-22**

Table 9: Material Cost Comparison, Laminated Bamboo versus Douglas Fir

Material Price Comparison										
Supplier	**Lumber Material**	**Joist 2"x8"x8'**	**Quantity**	**Beam 2"x12"8'**	**Quantity**	**Girder 14"x48"x70.3'**	**Quantity**	**Total Cost**	% Diff
Home Depot	Douglas Fir	$8.26	40	$13.55	10	$8,973.75	2	$18,413.41	343%
LAMBOO	Bamboo	$72.50	40	$112.50	10	$38,763.00	2	$81,551.00	

6.3 Projected Construction Costs

The project material design costs for Laminated Bamboo are based on a price takeoff from Lamboo Technologies in Phoenix, Arizona. This price takeoff is listed in Appendix D. A material cost comparison between laminated bamboo lumber and Douglas Fir lumber is shown above in Table 9. The Douglas Fir lumber costs were found by using current market prices at the local Flagstaff Home Depot. As shown in Table 9 above, there is a significant increase in cost between using standard lumber and implementing laminated bamboo. The cost increase is a significant 343%.

Total material construction costs were developed to provide the client with an estimate of material costs should the project design be implemented/constructed. The total material construction costs includes all structural members as laminated bamboo lumber, all structural connections, all decking materials, and all lateral bracing connections. This cost does not include tie in connections to the existing footing. This cost does not include any labor or time required by the potential future design builder. The total material cost for this design, in adherence to the aforementioned exclusions, is $87,727.02, as shown in Table 10.

Table 10: Total Material Construction Costs

Total Material Construction Costs	
Lamboo Materials	$81,551.00
Decking Materials	$4,210.37
Strucutral Connection Materials	$1,040.31
Lateral Bracing Connections	$425.34
Total Costs	$87,227.02

6.4 Scale Model Construction Costs

The costs associated with the construction of the scale model are shown below in Table 11. These costs are strictly material costs from Michael's and Home Depot in Flagstaff, Arizona. The total material cost for the scale model was $130.89.

Table 11: Total Scale Model Material Construction Costs

Scale Model Materials Costs	
Home Depot	$38.85
Michaels	$92.04
Total Cost	**$130.89**

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Appendices

Appendix A

Material Properties	
Density (lb/ft^3)	42
MOE ($kips/in^2$)	1319
Allowable Bending Stress ($kips/in^2$)	12.8

Bridge Dimensions	
Length (ft)	70.3
$Width_{eff}$ (ft)	7
Width (ft)	7.95

Loading	
LL (lb/ft2)	75
SL (lb/ft2)	40

Trib Widths (ft)	
Slab	0.938
Joist	2

Deflection Limits (in)	
Plank	0.067
Joist	0.233
Beam	0.233
Girder	2.343

Member Attributes	B (in)	H (in)	I (in4)	S (in3)	A (ft2)	Y (in)
Plank	11.25	1.5	3.164	4.219	0.117	0.750
Joist	1.5	7.25	47.635	13.141	0.076	3.625
Beam	1.5	11.25	177.979	31.641	0.117	5.625
Girder	14	48	129024	5376	4.667	24

Lengths (ft)		(in)
Joist	7	84
Beam	7	84
Girder	70.3	843.6

Preferences	
# of Joists	4
# of Beams	10
# of Girders	2
Girder H:B	
B(in)	14
H[B(in)]	48

Plank Loading	
Self-Weight (lb/ft)	4.922
Live Load (lb/ft)	70.313
Snow Load (lb/ft)	37.500
Total Distributed Load (lb/ft)	112.734

Plank Analysis	
Max Moment (kip-in)	0.676
Max Bending Stress ($kips/in^2$)	0.160
Deflection (in)	0.010

Joist Loading	
Self-Weight (lb/ft)	3.172
Live Load (lb/ft)	150.000
Snow Load (lb/ft)	80.000
Plank Dead Load (lb/ft)	10.500
Total Distributed Load (lb/ft)	243.672

Joist Analysis	
Max Moment (kip-in)	17.910
Max Bending Stress ($kips/in^2$)	1.363
Deflection (in)	0.210

Beam Loading	
Self-Weight (lb/ft)	4.922
Live Distributed Load (lb/ft)	974.688
Total Distributed Load (lb/ft)	979.609

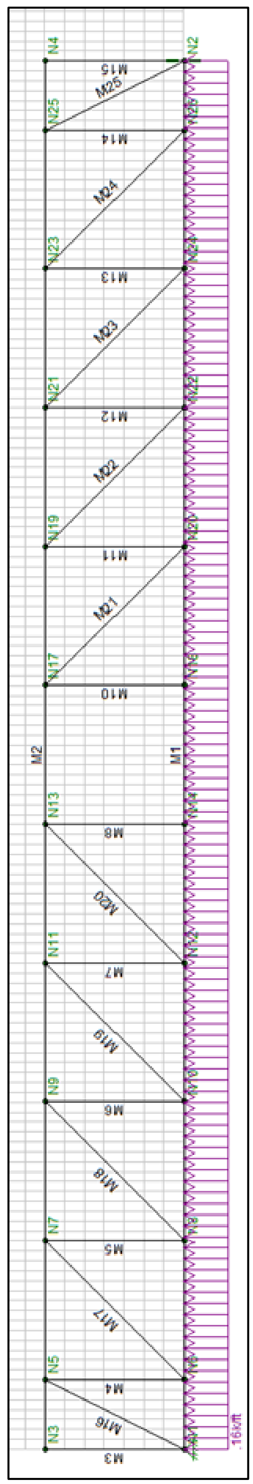
Beam Analysis	
Max Moment (kip-in)	72.001
Max Bending Stress ($kips/in^2$)	2.276
Deflection (in)	0.225

Legend
Exceeds Requirements
Meets Requirements
Calculated Cells
Input Cells

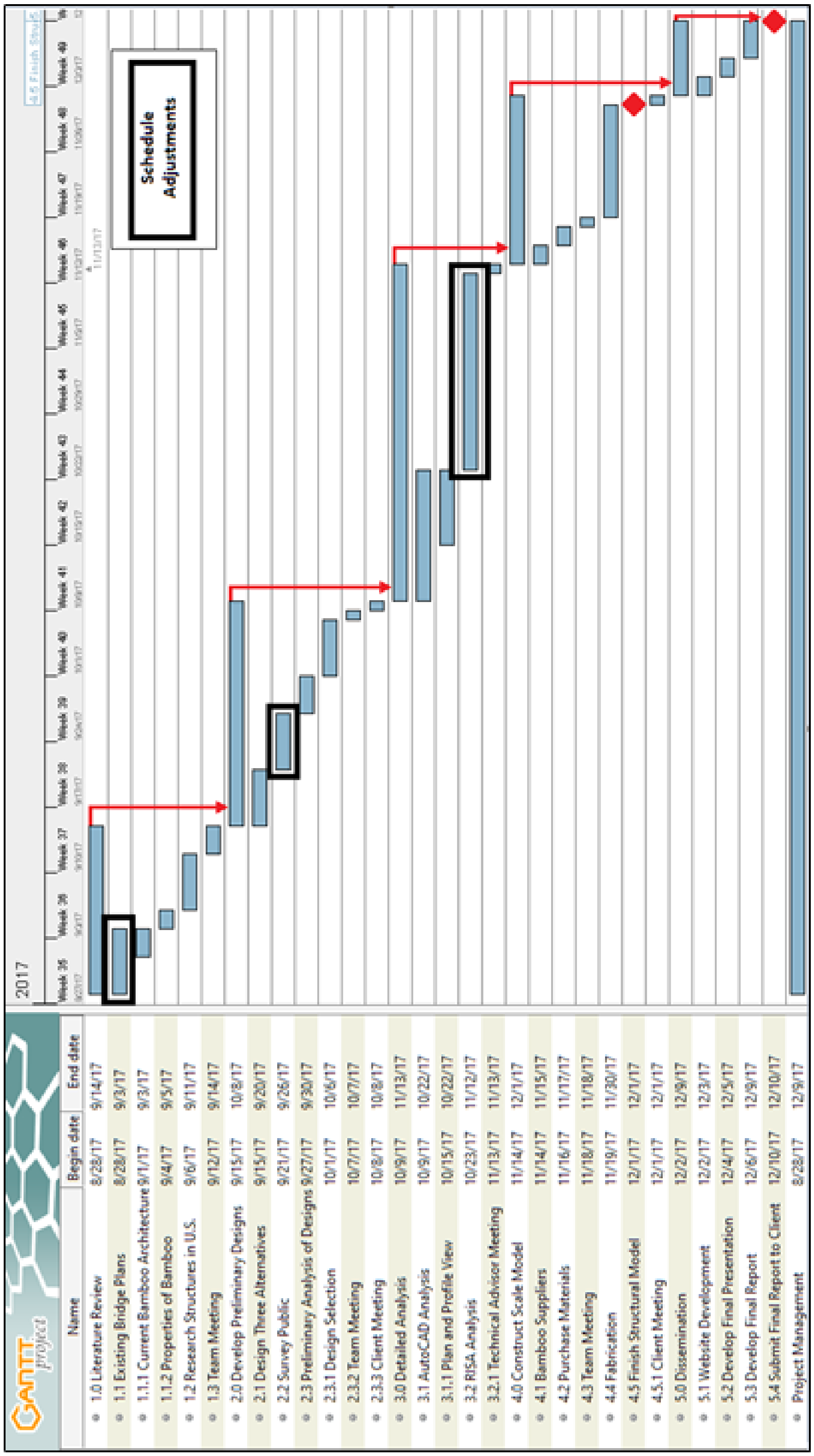
Girder Loading	
Self-Weight (lb/ft)	196.000
Live Distributed Load (lb/ft)	487.714
Hand-Rail Dead Load Limit (lb/ft)	41.000
Total Distributed Load (lb/ft)	724.714

Girder Analysis	
Max Moment (kip-in)	5372.406
Max Bending Stress ($kips/in^2$)	0.999
Deflection (in)	2.340

Appendix B



Appendix C


GANTT project
Name
Begin date
End date
1.0 Literature Review 8/28/17 9/14/17
1.1 Existing Bridge Plans 8/28/17 9/3/17
1.1.1 Current Bamboo Architecture 9/1/17 9/3/17
1.1.2 Properties of Bamboo 9/4/17 9/5/17
1.2 Research Structures in U.S. 9/6/17 9/11/17
1.3 Team Meeting 9/12/17 9/14/17
2.0 Develop Preliminary Designs 9/15/17 10/8/17
2.1 Design Three Alternatives 9/15/17 9/20/17
2.2 Survey Public 9/21/17 9/26/17
2.3 Preliminary Analysis of Designs 9/27/17 9/30/17
2.3.1 Design Selection 10/1/17 10/6/17
2.3.2 Team Meeting 10/7/17 10/7/17
2.3.3 Client Meeting 10/8/17 10/8/17
3.0 Detailed Analysis 10/9/17 11/13/17
3.1 AutoCAD Analysis 10/9/17 10/22/17
3.1.1 Plan and Profile View 10/15/17 10/22/17
3.2 RISA Analysis 10/23/17 11/12/17
3.2.1 Technical Advisor Meeting 11/13/17 11/13/17
4.0 Construct Scale Model 11/14/17 12/1/17
4.1 Bamboo Suppliers 11/14/17 11/15/17
4.2 Purchase Materials 11/16/17 11/17/17
4.3 Team Meeting 11/18/17 11/18/17
4.4 Fabrication 11/19/17 11/30/17
4.5 Finish Structural Model 12/1/17 12/1/17
4.5.1 Client Meeting 12/1/17 12/1/17
5.0 Dissemination 12/2/17 12/9/17
5.1 Website Development 12/2/17 12/3/17
5.2 Develop Final Presentation 12/4/17 12/5/17
5.3 Develop Final Report 12/6/17 12/9/17
5.4 Submit Final Report to Client 12/10/17 12/10/17
Project Management 8/28/17 12/9/17
2017
Schedule Adjustments

Appendix D

CONTACT:									JOB:	PAYMENT TERMS:		
Cainan Barnett cainanb@lamboo.us (866) 966-2999 Jeran Hammann jeran@lamboo.us (866) 966-2999 ext.20									STRUCTURAL COMPONENTS AND GIRDERS	50% DOWN 20% PRIOR TO SHIPMENT 30% DUE NET 15 DAYS AFTER SHIPMENT		
ITEM#:	QUANTITY:	UNIT OF MEASURE:	PRODUCT CODE:	FINISH COLOR:	LAYUP:	MATERIAL GRADE:	SIZE CODE:	PRODUCT SERIES:	PRODUCT DESCRIPTION:	UNIT PRICE:	UNIT OF MEASURE:	LINE TOTAL:
1	120	Pieces	VSP	TBD	Solid-Ply	Exterior	212	Lamboo® Elements™ Series	NOMINAL: 2x12x8' EXTERIOR GRADE UNFINISHED JOISTS	$112.50	per Piece	$13,500.00
2	12	Pieces	VSP	TBD	Solid-Ply	Exterior	CUSTOM	Lamboo® Elements™ Series	NOMINAL: 2x14x8' EXTERIOR GRADE UNFINISHED BEAMS AND SLABS	$151.15	per Piece	$1,813.80
3	2	Pieces	VSP	TBD	CUSTOM	Structural	CUSTOM	Lamboo® Structure™ Series	CUSTOM STRUCTURAL GIRDERS - 14" WIDTH 48" DEPTH 70.3' LENGTH UNFINISHED	$38,763.00	per Piece	$77,526.00
4	1	Shipment							FREIGHT CHARGES	$3,800.00	per Shipment	$3,800.00
5	1	Shipment							PACKAGING AND HANDLING	$500.00	per Shipment	$500.00

SUBTOTAL:	$97,139.80
SALES TAX:	$0.00
HANDLING CHARGE SALES TAX (7.25%):	$36.25
CREDIT CARD PROCESSING FEE: (3.5%)	$0.00
TOTAL:	$97,176.05

NOTES:

LEAD-TIME: 16 to 18 **WEEKS**

Typical lead-time will start the day after receipt of signed quote or customer purchase order along with payment per the "Payment Terms" section of the quote as stated above. NOTE: Lead-time does not include transit time to customer.

Materials: Will be provided as stated above.
Stain/Finish: All stained/finished materials will utilize a 2 coat system unless stated otherwise.
Freight Charges: Freight charge are provided based on estimated freight charges at time of quoting. All freight charges are considered "Good" unless the quote has expired.
Packaging and Handling: All packaging and handling charges are considered "Good" until quote has expired.

ADDITIONAL NOTES: