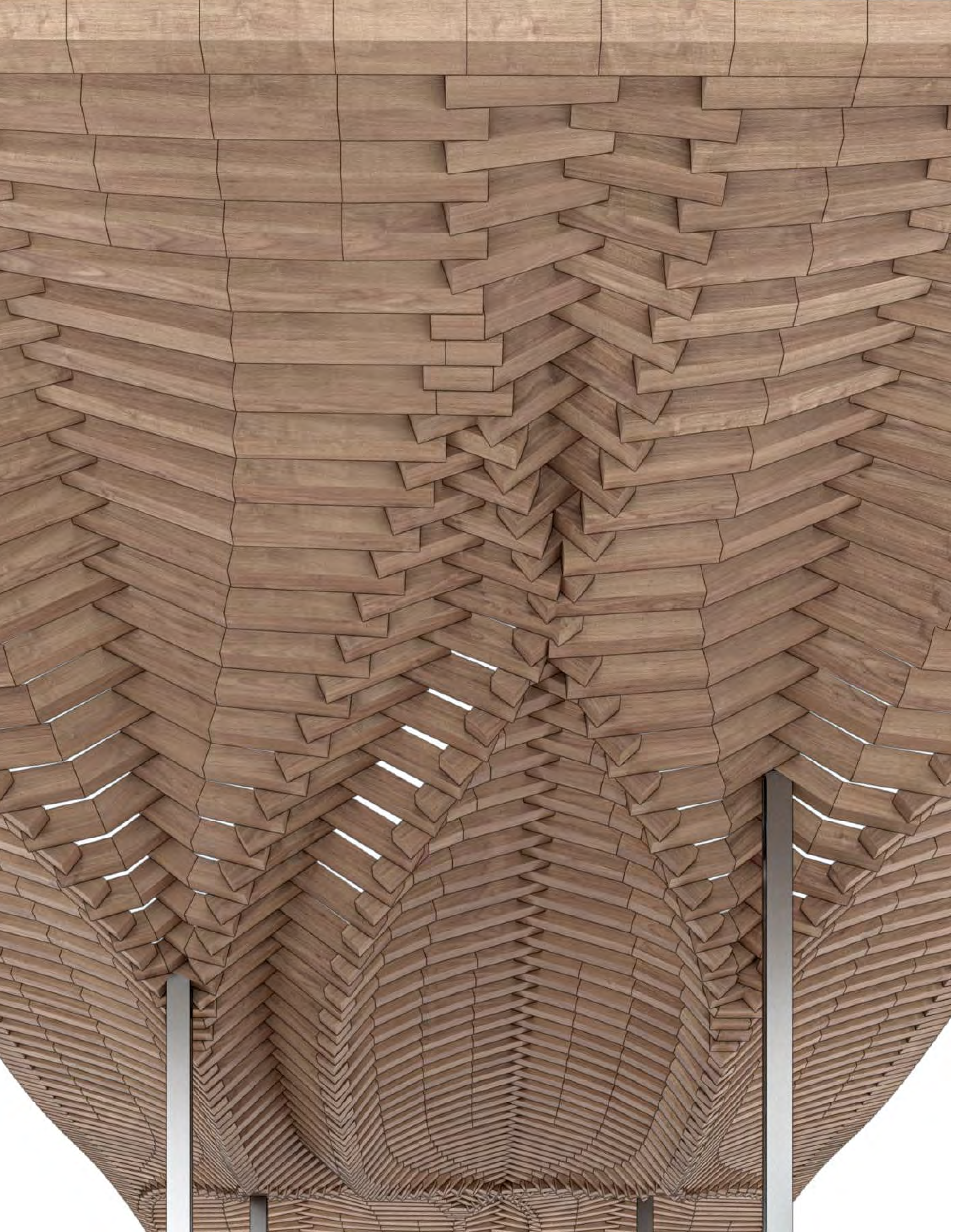
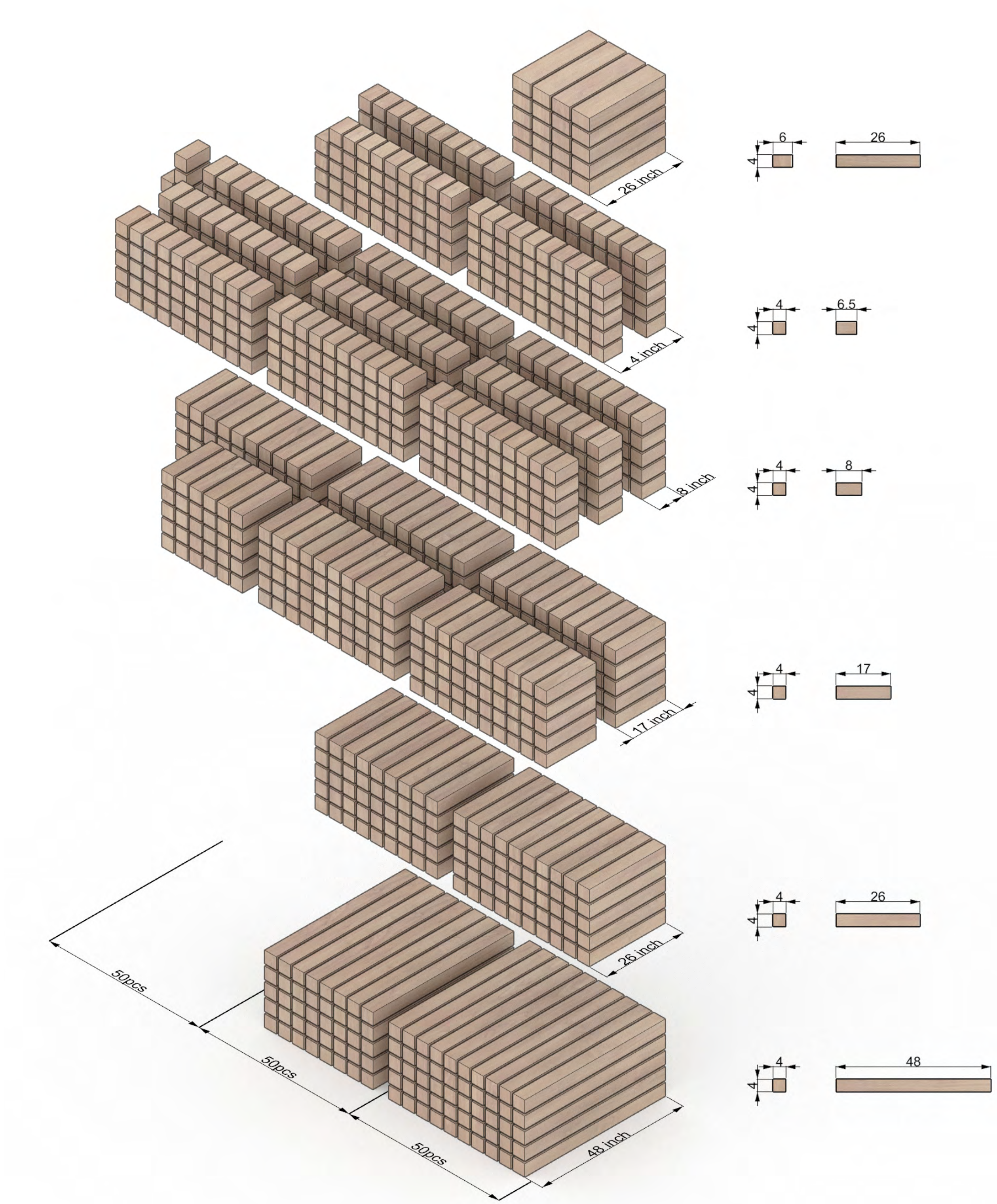


DOVE WAVE

Polyheral Structures Laboratory Proposal for
Inventory Constrained Design at Eventscape NY

PSL Weitzman SCHOOL OF DESIGN UNIVERSITY of PENNSYLVANIA EVENTSCAPE



Unit are in Inches

Introduction

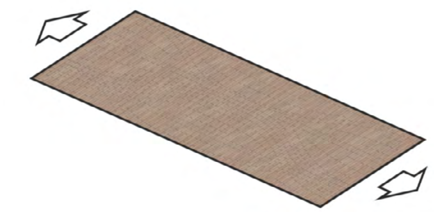
This proposal is Polyhedral Structures Laboratory's response to the inventory-constrained design call by Eventscape. This design research proposal intends to provide a solution to effectively use the existing black locust wood stock and turn it into a functional architectural system. In addition, we propose a methodology to minimize waste and preprocessing of the material and suggest a solution that can maximize its performance as a structural system or canopy. These objectives will be achieved using an intelligent structural geometry combined with an effective tectonic strategy using computational and structural design methods. The following sections will elaborate on various components of this proposal, including the concept, materialization, fabrication technology, structural analysis, and computational methods for minimizing waste.

Material Inventory

According to the provided chart, the majority of inventory has a 4" x4" section dimension that simplifies the design and construction process. There are also 20 pieces that have a 6" x4" section dimension, which we excluded from the overall design and construction given their few numbers.

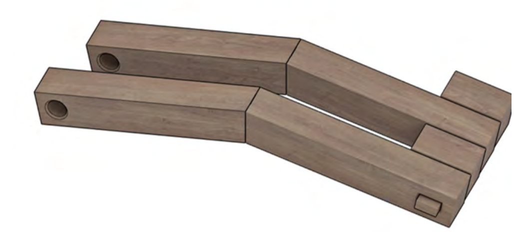
Design Objectives

We intend to design a canopy to be used as a performance stage for musicians or artists for different events at Eventscape NY. Thus the goals of the project can be summarized as follows: (a) designing a system that can span using the existing materials; (b) maximizing the use of the inventory material (c) minimizing the waste (d) proposing a simple while practical method of construction with minimal use of machine or secondary materials; (e) considering the disassembly and afterlife reusability of the system.



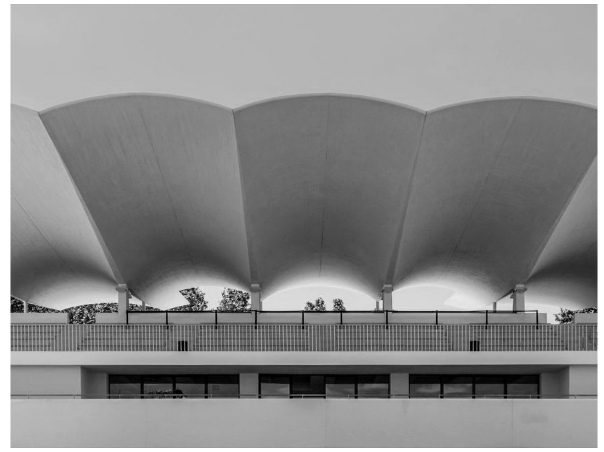
Acheiving long span with less material.

Minimal construction waste.

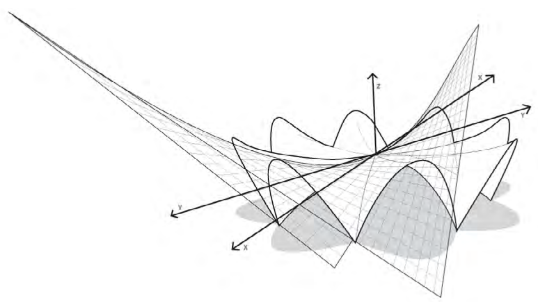


Usinfg simple tectonic method for the construction/ fabrication process.

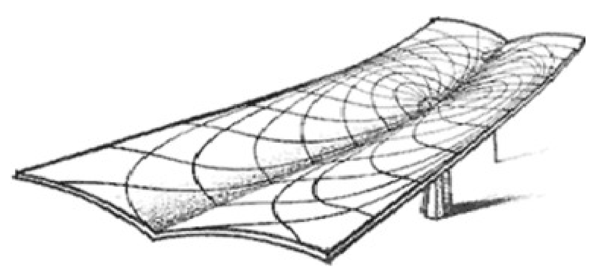
L'Oceanogràfic (Felix Candela)



La Zarzuela Racetrack (Eduardo Torroja)



Ruled Surface Geometry



Structural Creases

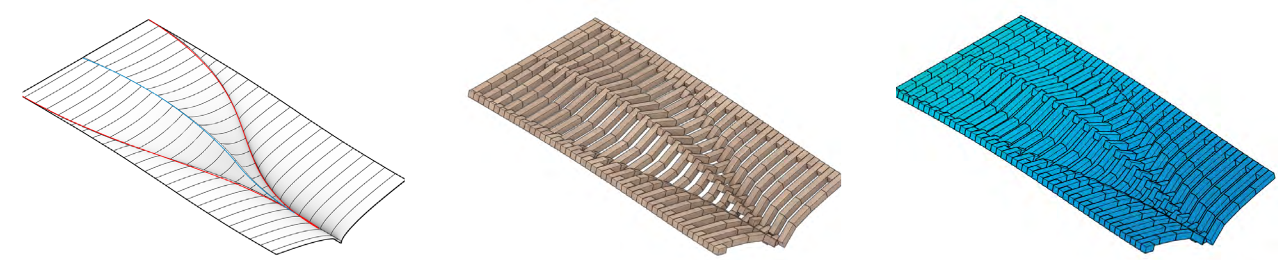
Motivations and Inspirations

Our design has been inspored by the works of legendray matser buiklders Felix Candela and Eduardo Torroja. Candella, in his L'Oceanogràfic building, emphasizes the use of ruled surface geometry in creating structural stiffness. The most important property of such systems is the anti-clastic geometry that creates positive and negative curvatures in two directions. Torroja, on the other hand, builds a thin shell cantilever structure for the roof of La Zarzuela Racetrack with a conspicuous crease or fold. The crease, in this case, works to increase the effective cross-section of the structure so the long cantilever of the roof will become possible. In our proposed structure, we combined the idea of a ruled surface with creases to take advantage of both systems. The ruled surface geometry gives stiffness to each segment, and the ridges and valleys increase the adequate depth of the sections.

Since the material inventory has linear quality, we propose to design linear beam elements that create curvature in the spanning direction, then dovetail these beam elements to make additional stiffness in the perpendicular direction. Furthermore, the ridges and valleys are optimized to minimize displacement by increasing the depth of the structure. Also, since the material is limited, these alternating beams allow for expanding the span of the design with a minium material.

Original Flat Profile

Ruled Surface Applied



Dovetailing Applied

0 13.2
displacement [cm]

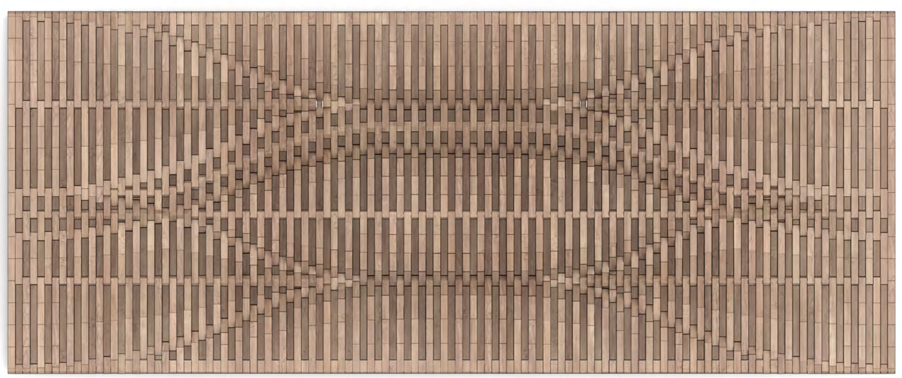
The design procedure starts with a flat surface, and the crease patterns as valleys and ridges are drawn on a flat configuration. Then the control points of the curves are moved in the z-direction, and the ruled surface is constructed between every ridge and valley. The ruled surface is then cut to make the cross-sectional curves as beams. Next, each beam curve is segmented into multiple straight-line segments to approximate the curvature. Each segment line could represent a timber member in this structure. Next, beams will dovetail with each other to create a structural system perpendicular to the span of the beams. The structural p[erfromance of each system is highlighted in each step.

13.3 ft

Front view

19.6 ft

15 ft



Top view

39.5 ft

Design

Our proposed structure consists of a spanning structure supported by four columns spaces 19.6 ft (6 m) from each other. The structure's total length is 39.5 ft (12 m) with a width of 15 ft (5 m). The structure will be served as a performance stage for musicians or artists in various events. With this proposal, we were able to utilize the stock material by 92% percent. The approach we choose in fabrication and construction requires minimum machinery and produces minimum waste. It also does not require a significant modification to the system.

Involvement of Technology

As explained in the previous sections, our design involves structural optimization and computational algorithm to utilize the wood stock efficiently. The construction process needed for this construction includes simple robotic milling, robotic trimming, and human assembly.

Robotic Trimming

The structure can be divided into main segments, with ridges and valleys resting on a column. Each segment is connected to the rest of the segments at its borders, ridges, and valleys. Each segment consists of linear beams that dovetail at the location of ridges and valleys of the surface. These linear elements are made of wood segments minimally trimmed at both ends. This process can be easily translated into a robotic-fabrication process consisting of an arm and a stationary saw blade in a working cell. The arm picks up each wood segment and pushes toward the stationary saw to trim the ends at the precise angle needed for the assembly. In the end, the arm will leave the part on a platform to be collected for the next step of the construction.

Robotic milling

Some parts of the structure need to be milled to receive round pegs connecting the dovetailed geometry. This milling process is also minimal and only leaves a vertical shaft within each wood segment to be connected to the next beam element in the structure. This milling is only required for members located at the borders or the ridges and valleys of the geometry.

Assembly of the beams

The members with trimmed ends can be put together in beam elements by a human, and the milled parts register precise locations where one beam dovetails with another beam at the borders or the ridges and valleys. Thus, the construction process becomes straightforward, and the system can control its precision by end members and the connected beams.

Consideration of secondary impacts

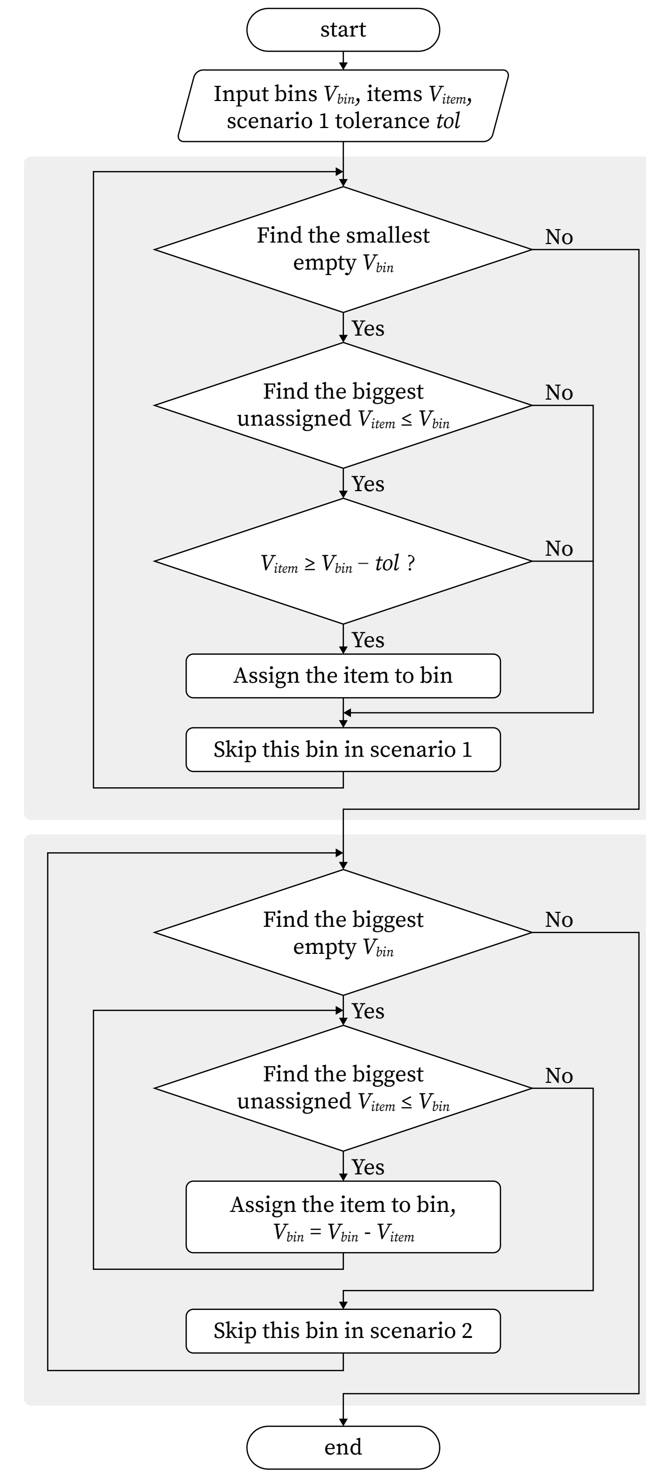
The structure and system of construction we propose can certainly have a second life. The structure can simply be cut in the midspan and rotated to be used as a separator or acoustic wall. The geometry is self-supporting also in its vertical configuration.
The structure's material can also be recycled and used for another project or design. Our construction method does not require 3d printing costume joints and the preprocessing of the construction materials is also very minimal. Thus it allows for upcycling the material for another project easily. In addition, simple off-the-shelf screws are used to connect the wood segments in the linear beam elements. In general, the design and fabrication have been developed to minimize the waste and machining time for the project. For that reason, only trimming at a particular angle is introduced, and milling is only needed for the border members and ridges and valleys where significant structural performance is required.

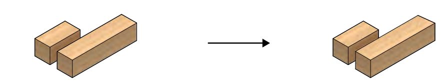

Idreess 70

Waste Reduction Algorithm

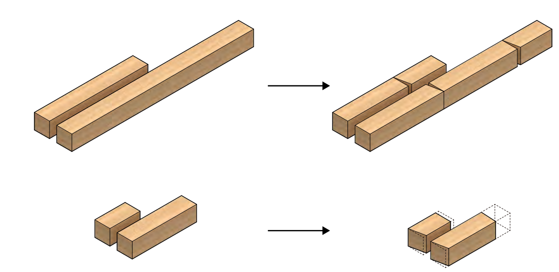
The project has been designed to maximize the use of 6.5 or 8-inch lengths elements. An effective strategy is needed to arrange the original timbers and cut them into the desired lengths. The method to maximize the use of the inventory with minimized waste is a form of "bin packing problem." I.e., different sizes of elements must be packed into a finite number of bins or containers. Usually, bins are one-dimensional entities, meaning the "size" is an addable quality such as weight, fluid volume, price, or length. In our case, we need to find the best timber length.

We refer to the timber inventory as "bins" and the desired segments for the straight elements of the beams as "items." To solve this problem, we use a two-step best-first search algorithm that finds the optimal solutions at each step, shown in the following flowchart.

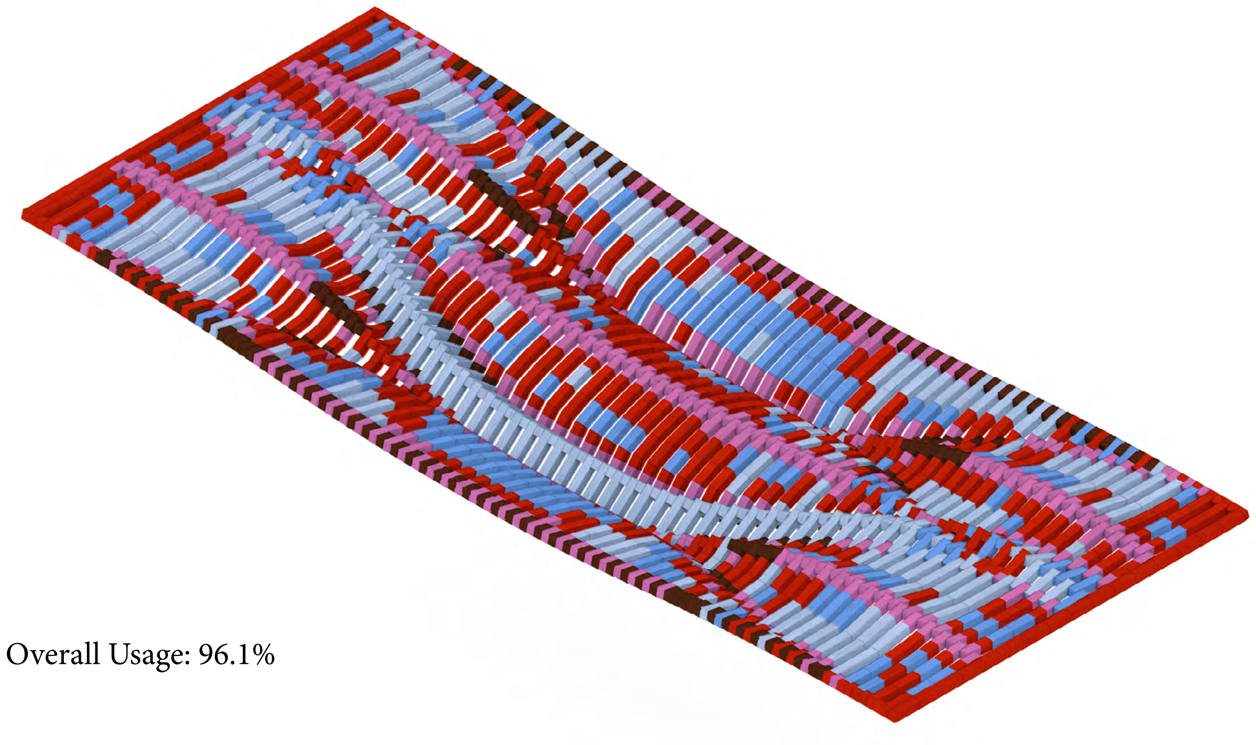




Scenario 1.
One item in one bin with remainder < *tol*



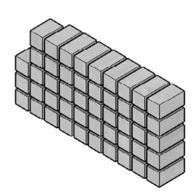
Scenario 2.
One or more items in one bin with a potentially large remainder



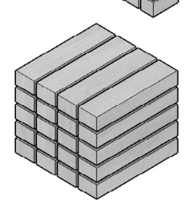
Overall Usage: 96.1%

Results

As a result, the algorithm successfully assigned 1652 desired segments for the beams into 1165 pieces of 4" x 4" wood elements from the inventory. Summing up the used length of parts, we have utilized 96% of the stock. Twenty-four short wood elements were not used and were kept at their original length. The algorithm is a time-efficient method with an excellent rate of inventory consumption. We can provide further details about the algorithm if needed.

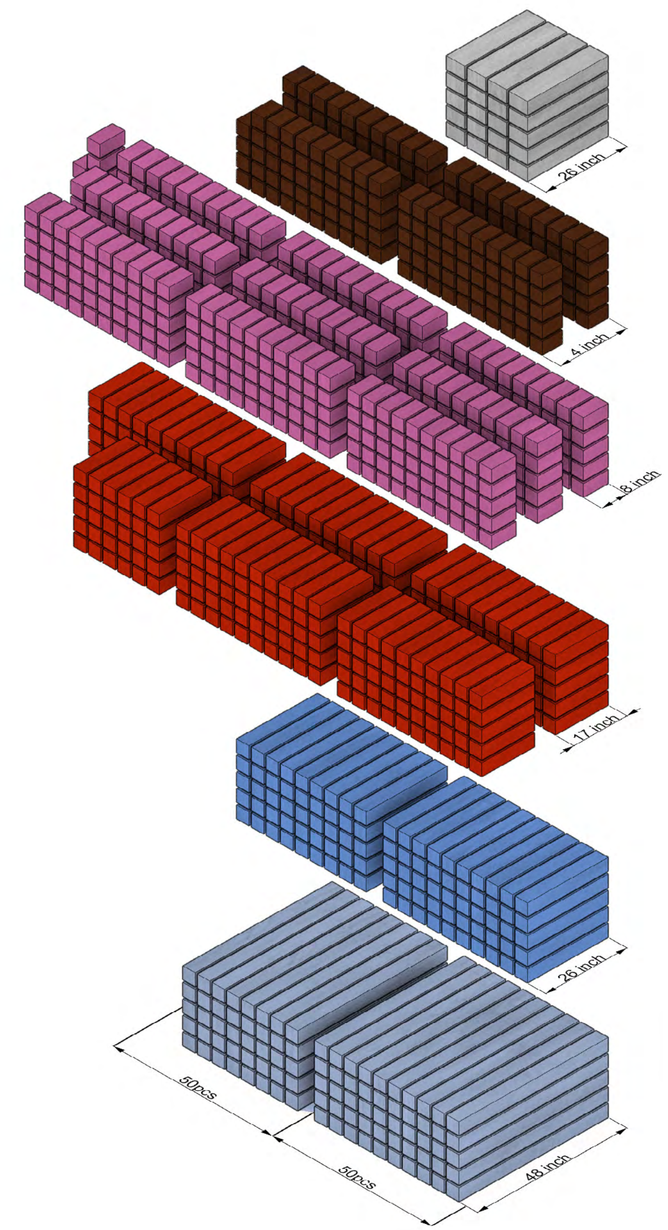


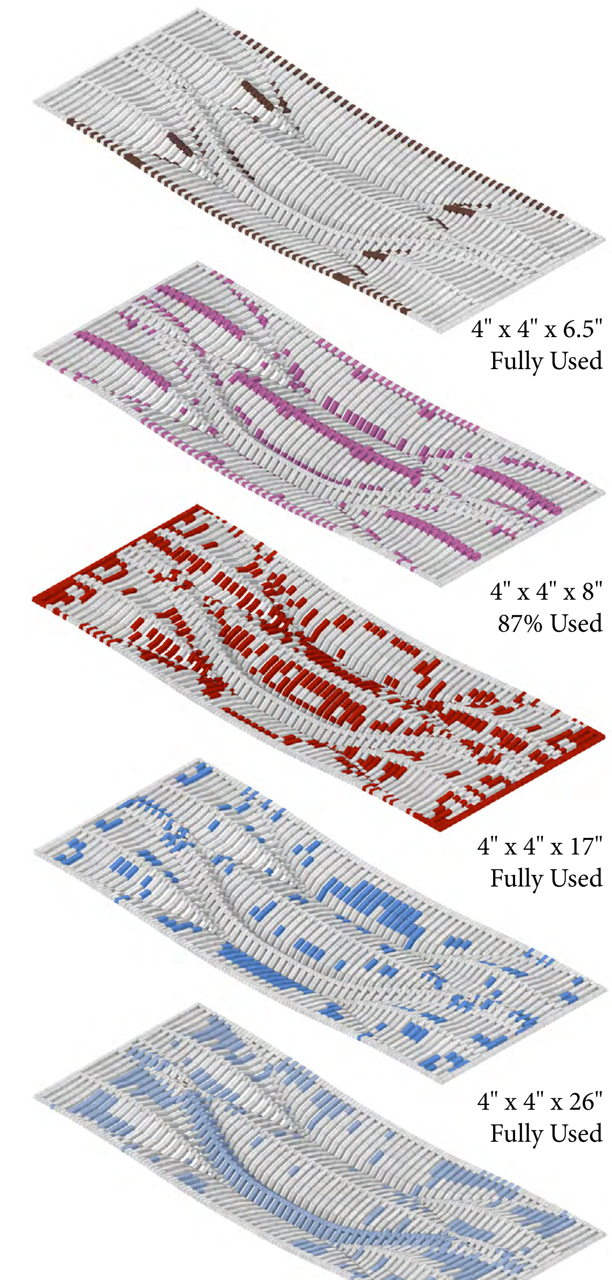
4" x 4" x 8"
13% Unused



4" x 6" x 26"
Unused

Mitered Waste
1.4% of Overall





4" x 4" x 6.5"
Fully Used

4" x 4" x 8"
87% Used

4" x 4" x 17"
Fully Used

4" x 4" x 26"
Fully Used

4" x 4" x 48"
Fully Used