MAKE / SHIFT

Algorithmic design for a circular material future

MIT SA+P
Digital Structures research group

Design Summary:

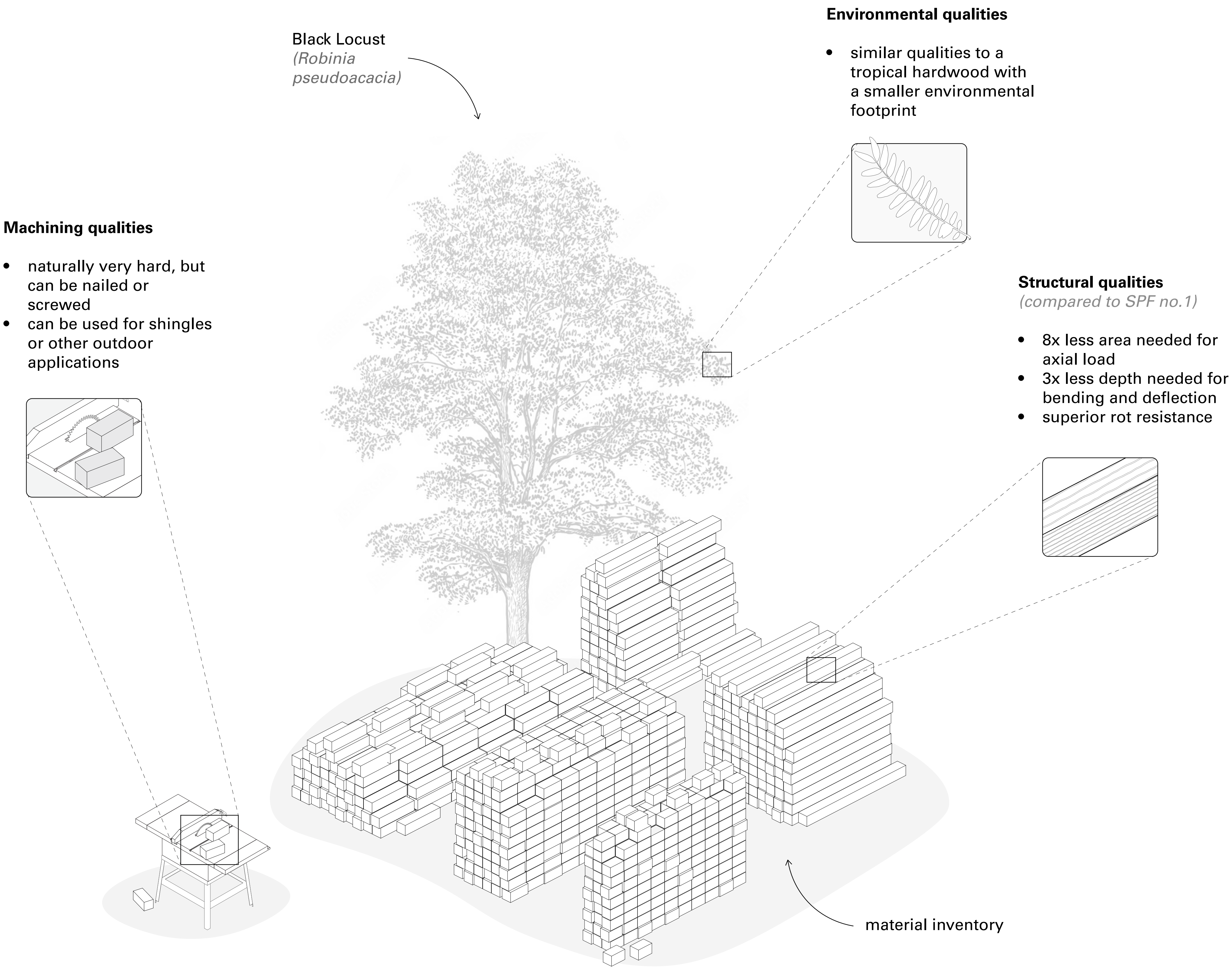
In a world of finite resources, it is increasingly important to give materials a second life. When building materials are reused, they are typically forced into conventional forms and assemblies, resulting in downcycling, damage, or underutilization. Design strategies with dimensional lumber rely on long pieces, complex joints, and don’t always use the elements optimally , often compressing them against their grain rather than along it. Instead of forcing unconventional building materials into status-quo forms and assemblies, Make/Shift proposes a system that takes advantage of the non-standard lengths of the recovered stock to defy orthogonal norms and create a structural system that embraces variability and flexibility, enclosing a space for storing second-life materials and hosting educational workshops.

To minimize waste and maximize the structural and spatial utility of the existing stock, the design process is preceded by the development of a cutting logic to extend the available inventory, creating thinner and lighter wood elements. The elements are cut along their length into smaller cross-sections, while the existing lengths are maintained to preserve the compressive strength of the material. This stretches the inventory from 1,400 elements to nearly 8,500.

The inventory is transformed into studs, battens, and shingles, allowing the originally homogeneous stock to serve diverse architectural purposes. To form the building structure and envelope, we break from the standards of conventional stick-framing: multi-part “stud” frames are nailed together and transformed into arches, battens are forced out of horizontal alignment due to the set lengths of the stock pieces, and shingles register the underlying variation on the exterior.

Walls become roofs, corners are rounded, and the resulting structure is characterized by natural variation, representing a design ethos for the circular economy that does not rely on standardized materials. With an expanded inventory comes a significant increase in ways to use these elements; to address the exploding number of options, we develop a computational sampling, assignment, and analysis methodology to effectively traverse, cull, and extract from the design space.

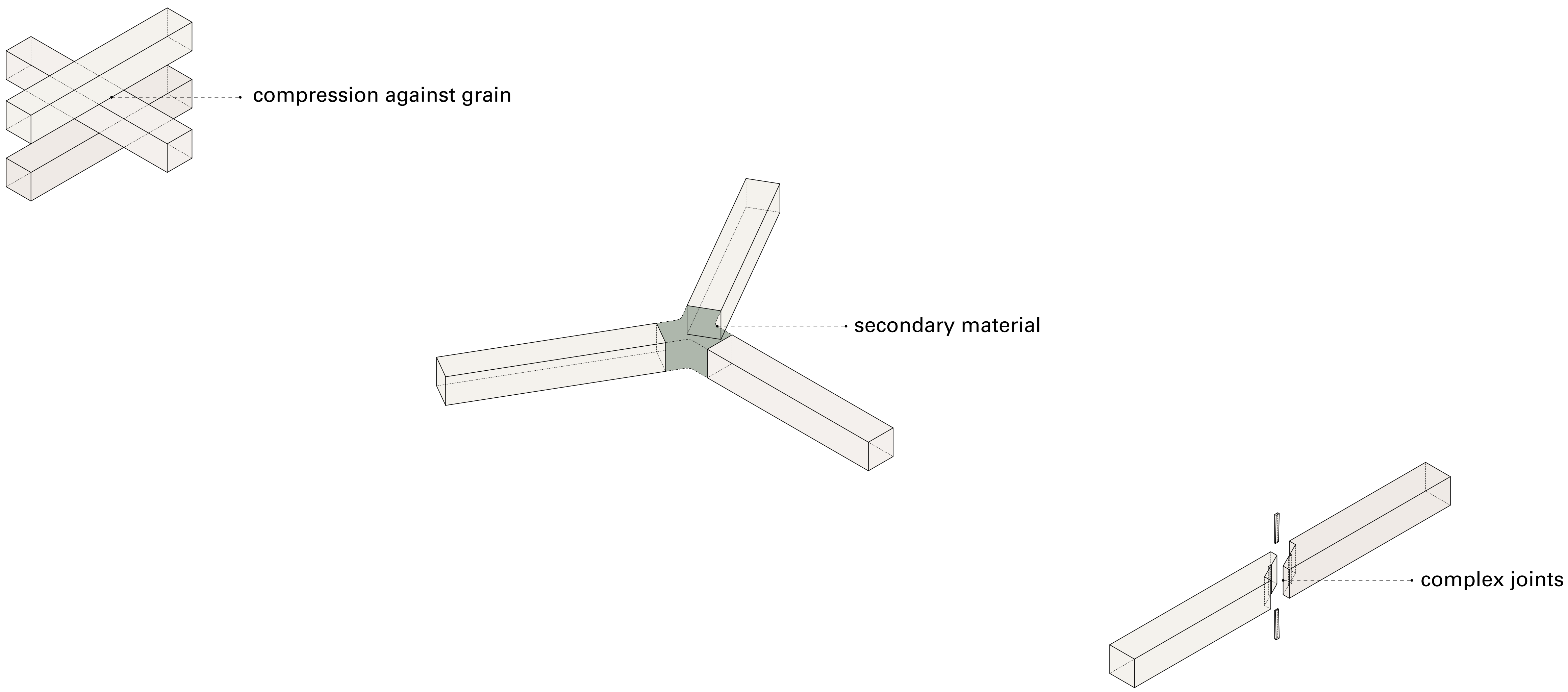
Through the nature of the design sampling process, any selected geometry is guaranteed to be structurally efficient for point loads acting at the joints of the frame. The assigned frames generate natural corrugation, stiffening the global structure as it curves in plan. A new design ethos for the circular economy also requires reversibility, materializing in simple moment connections that can be disassembled to allow the structure to be moved, repaired, and reconfigured.



Black Locust
(Robinia pseudoacacia)
Environmental qualities
• similar qualities to a tropical hardwood with a smaller environmental footprint
Machining qualities
• naturally very hard, but can be nailed or screwed
• can be used for shingles or other outdoor applications
Structural qualities
(compared to SPF no.1)
• 8x less area needed for axial load
• 3x less depth needed for bending and deflection
• superior rot resistance
material inventory

How can we develop a circular building workflow that leverages the superior durability of the black locust inventory while using computation to preserve its lengths and minimize waste?

In a world of finite resources, it is increasingly important to give materials a second life. When building materials are reused, they are typically forced into conventional forms and assemblies, resulting in downcycling, damage, or underutilization. Design strategies with dimensional lumber rely on long pieces, complex joints, or inefficient, perpendicular-to-grain loading orientations.



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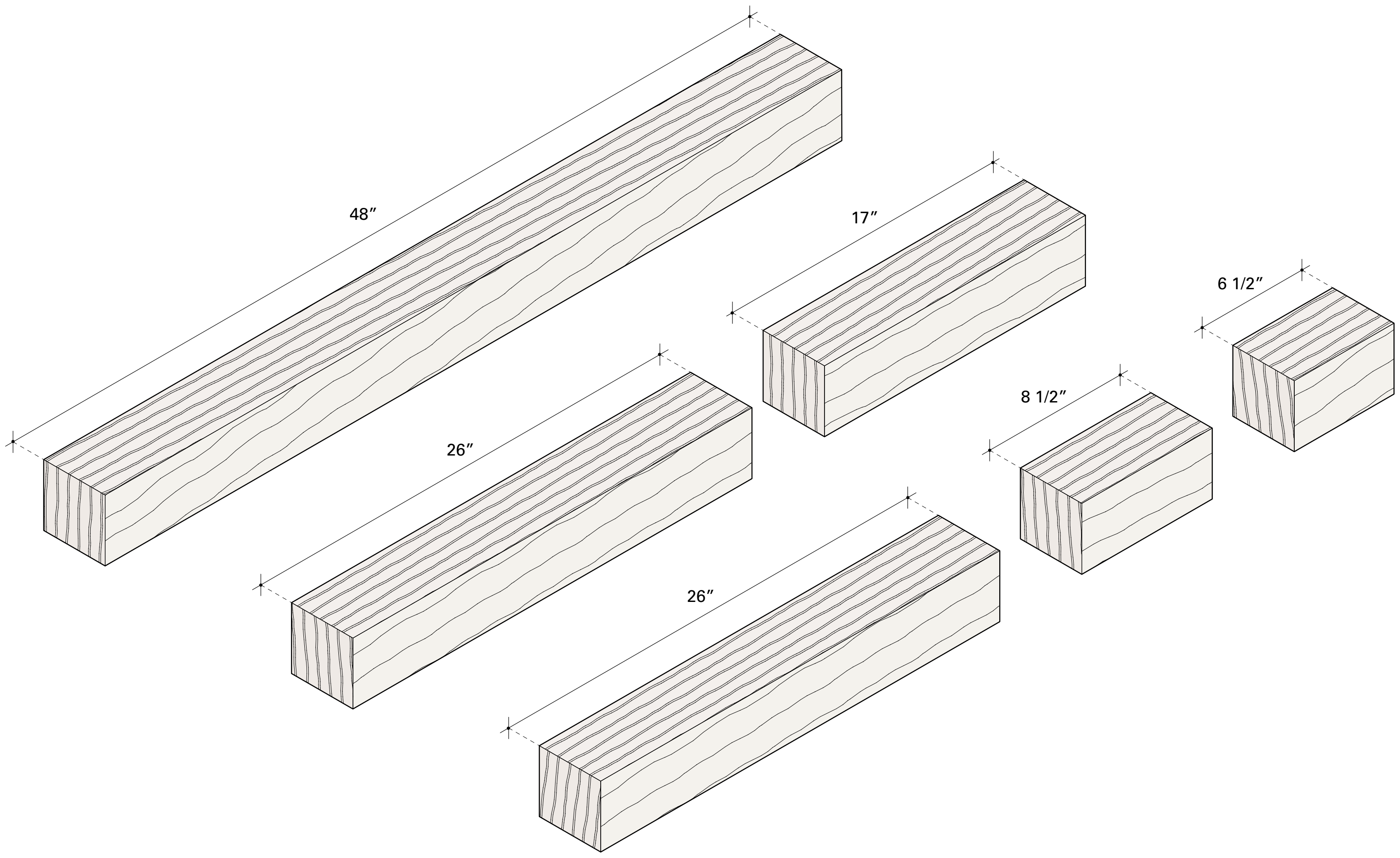

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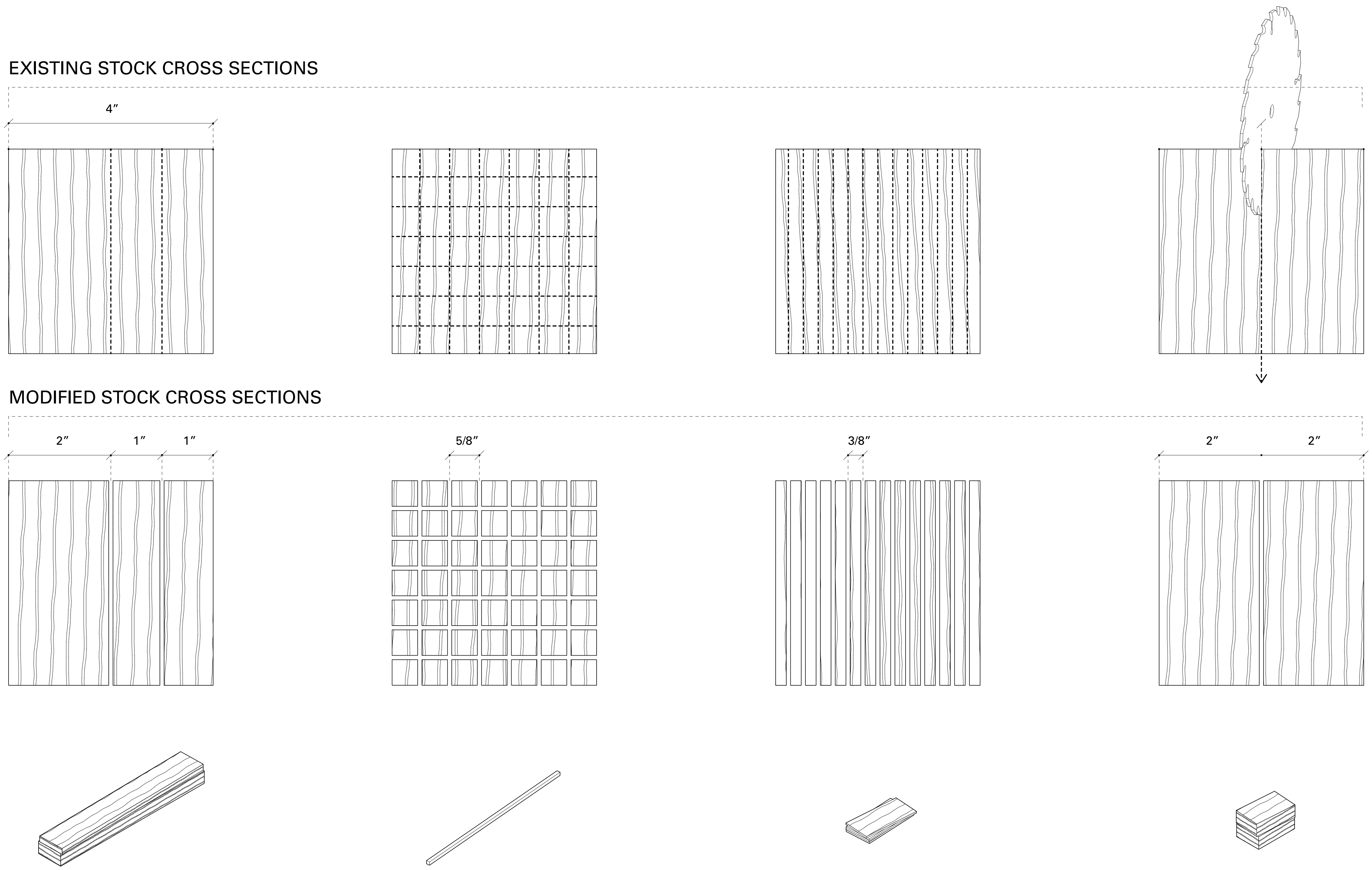

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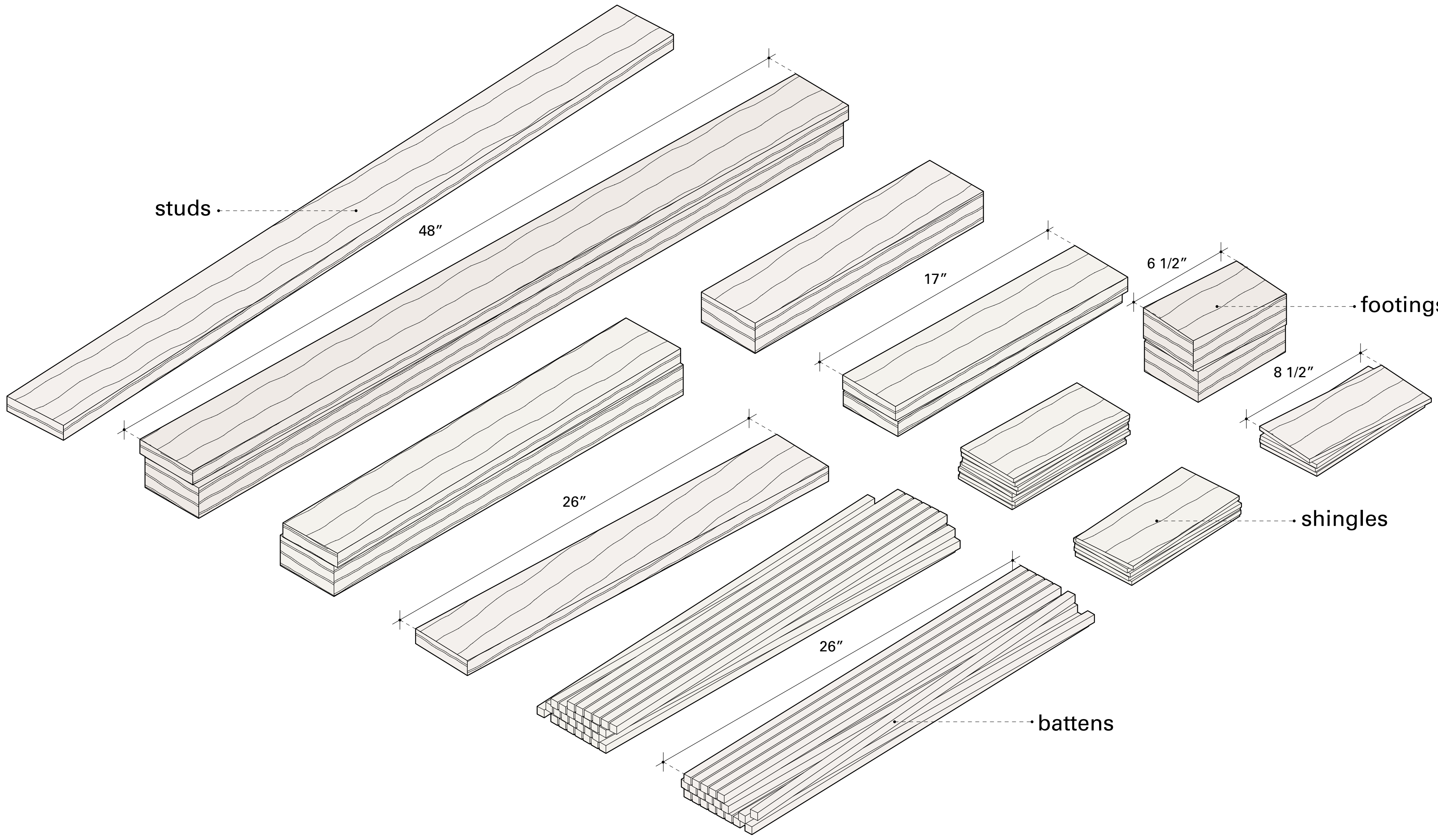
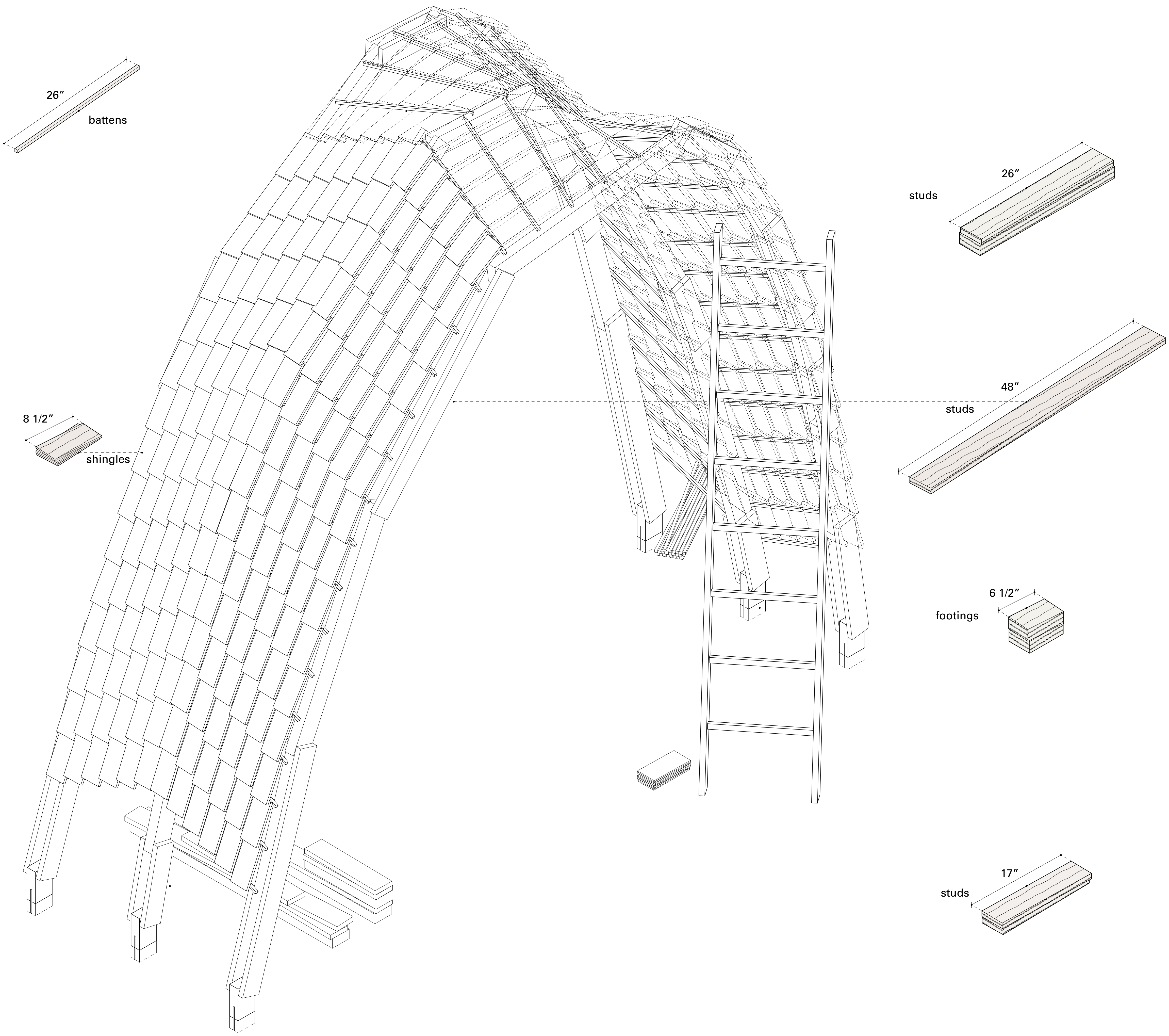
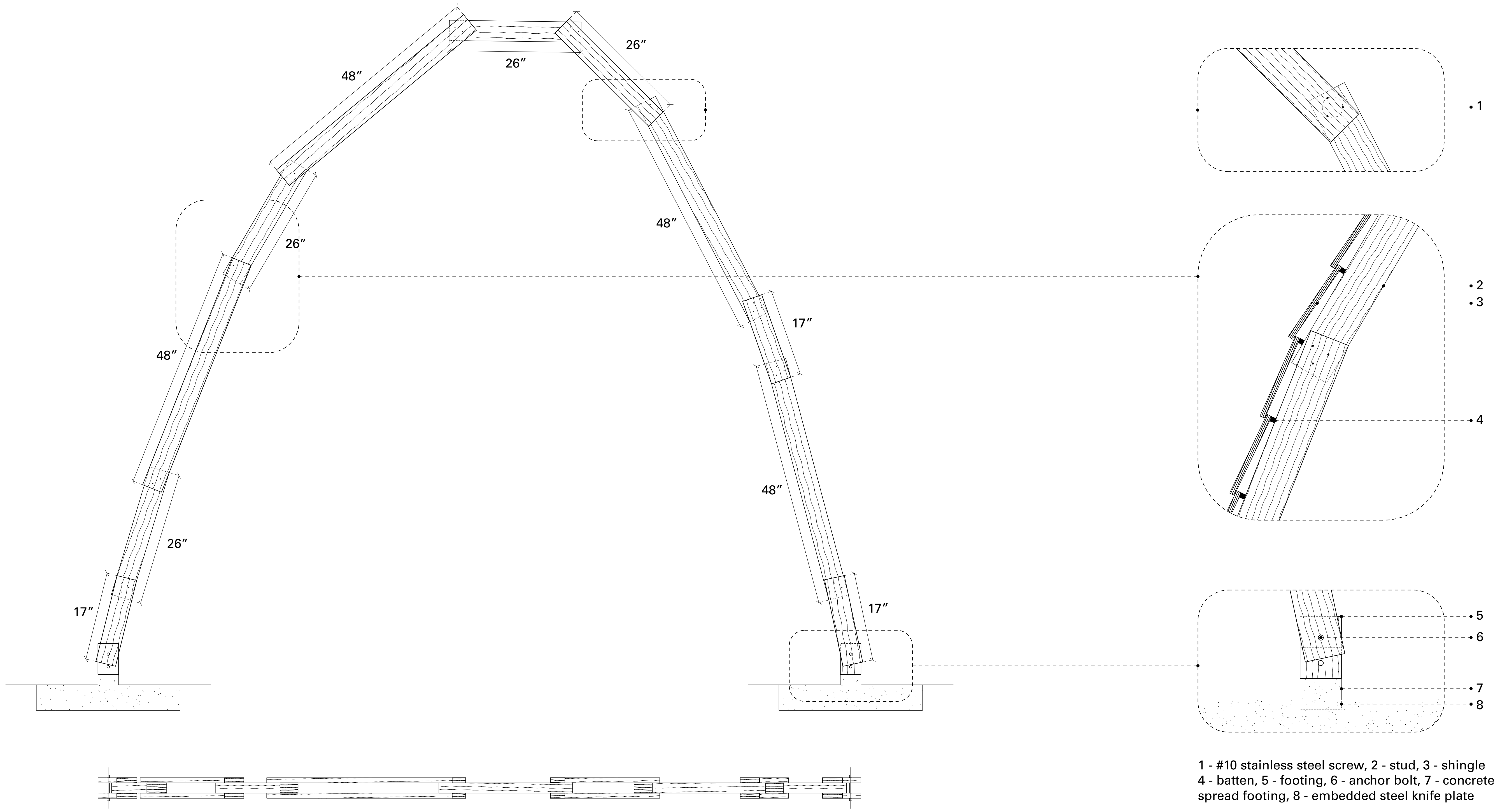


The inventory is transformed into studs, battens, and shingles, allowing the originally homogeneous stock to serve diverse architectural purposes.



Walls become roofs, corners are rounded, and the resulting structure is characterized by natural variation, representing a design ethos for the circular economy that does not rely on standardized materials.



1 - #10 stainless steel screw, 2 - stud, 3 - shingle 4 - batten, 5 - footing, 6 - anchor bolt, 7 - concrete spread footing, 8 - embedded steel knife plate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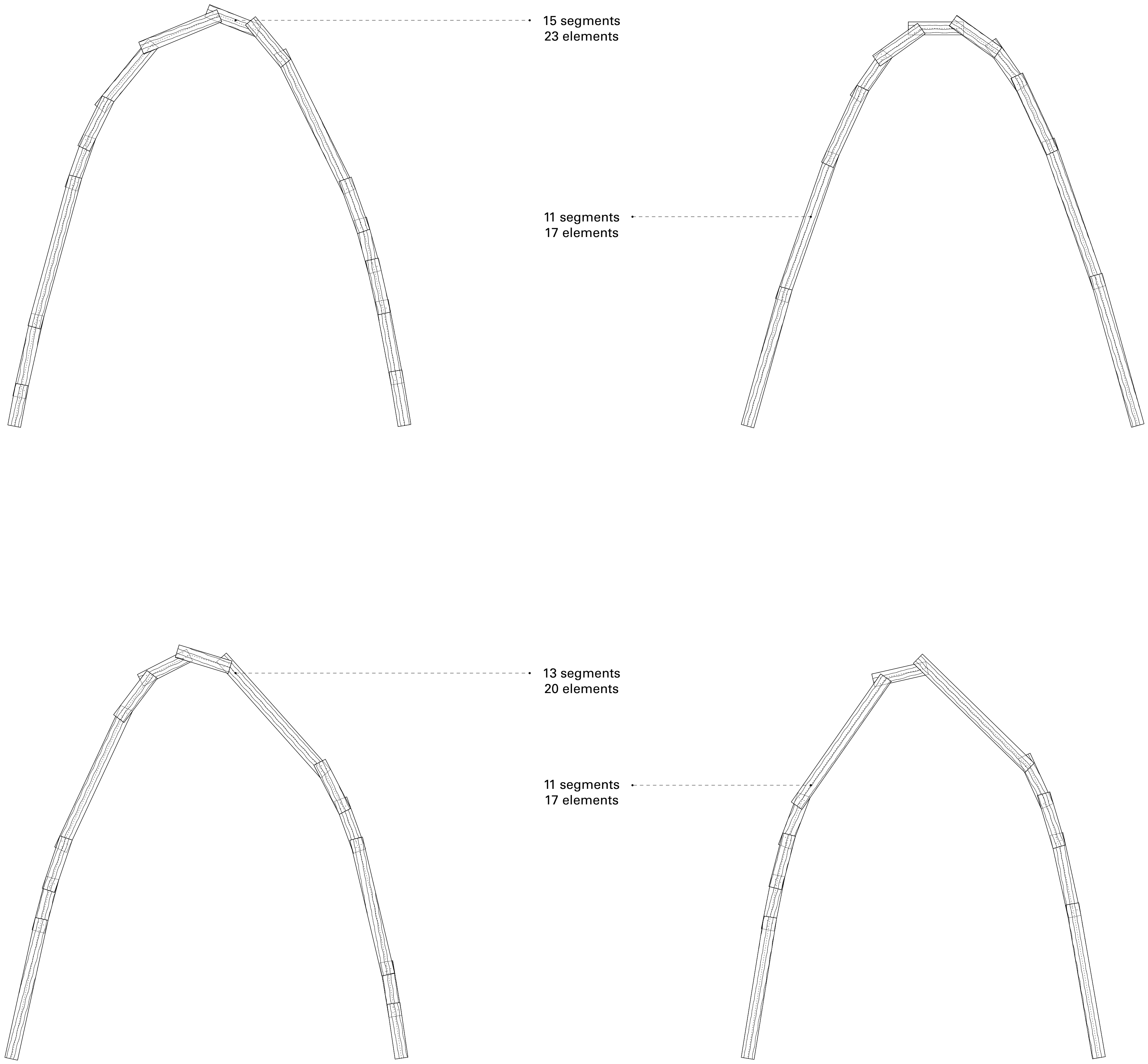
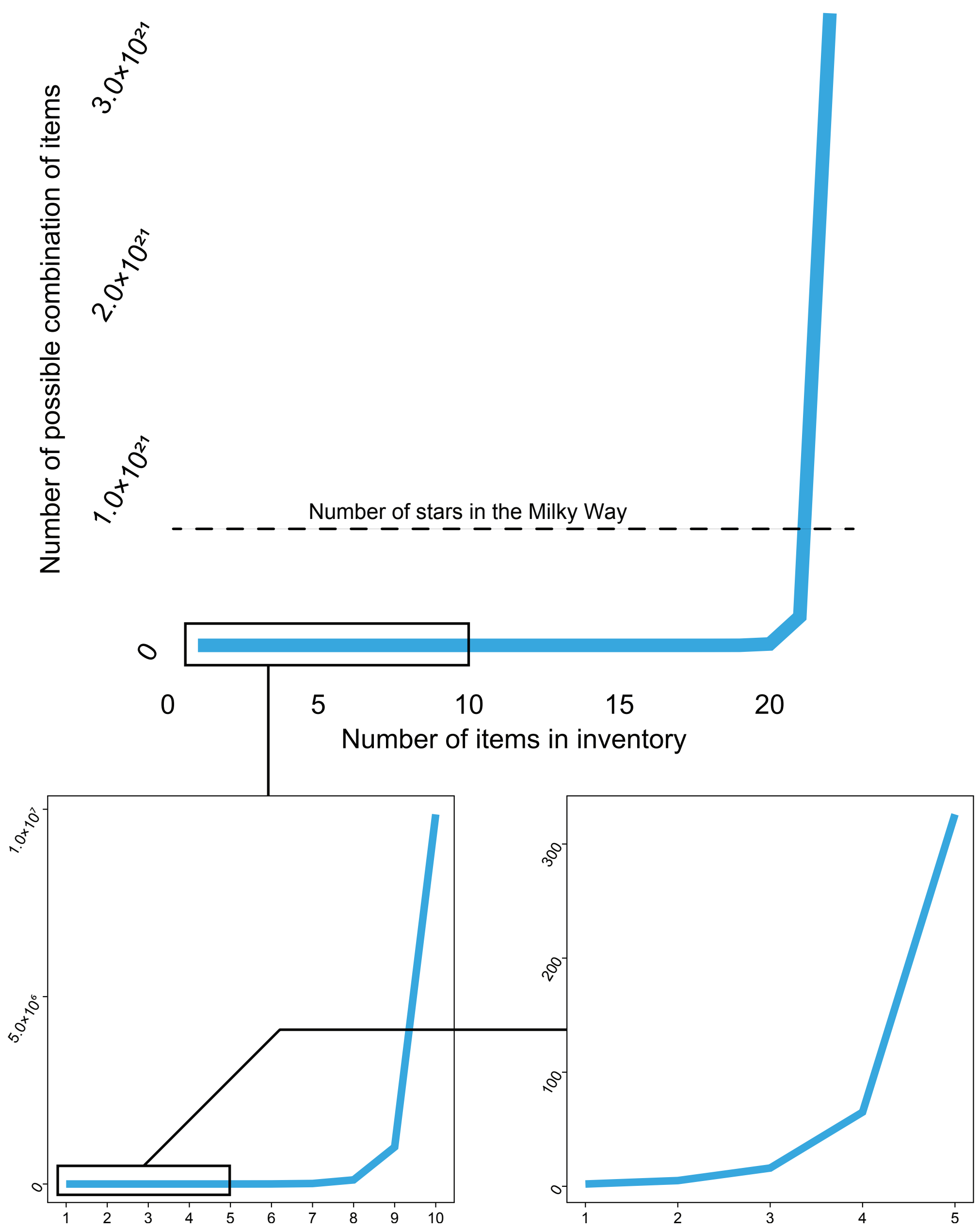
With an expanded inventory comes a significant increase in ways to use these elements; to address the exploding number of options, we develop a computational sampling, assignment, and analysis methodology to effectively traverse, cull, and extract from the design space.

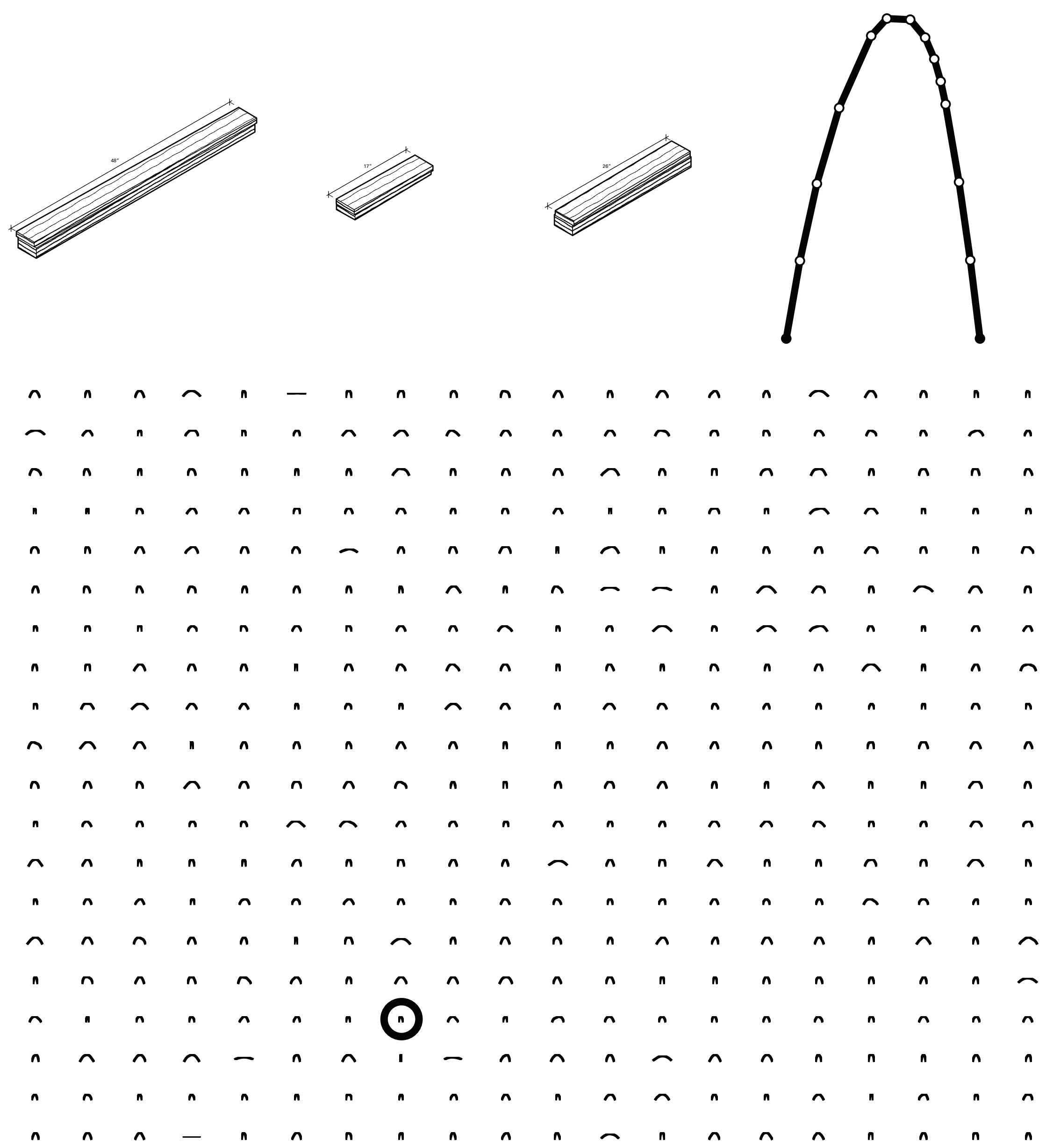


Make/Shift simultaneously takes advantage of both the extensive combinatorial design space and the finite set of individual geometries to computationally sample combinations that meet specific design criteria, narrowing the field to double pinned arches with zero cut-off waste.

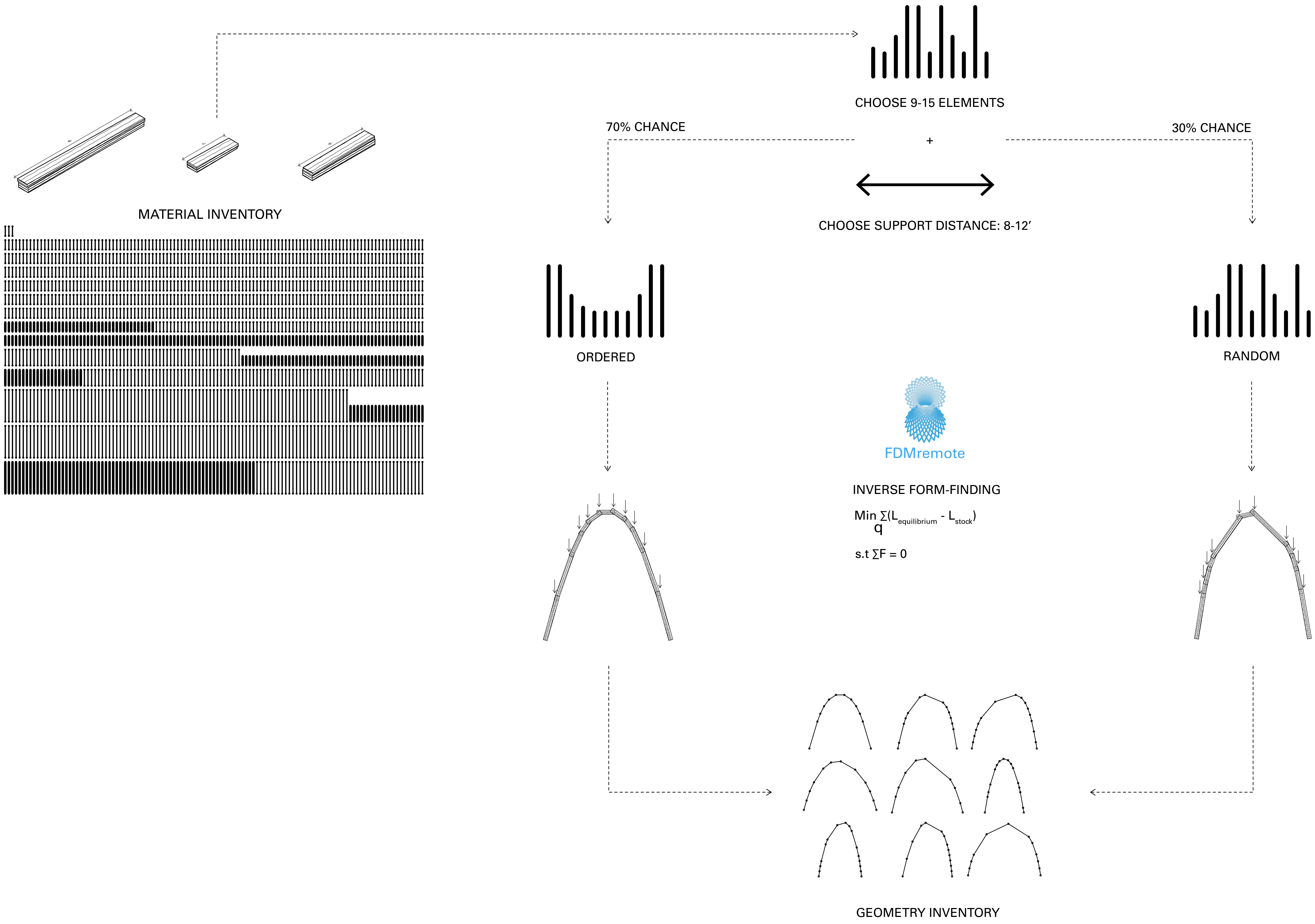
DESIGN SPACE SCALE



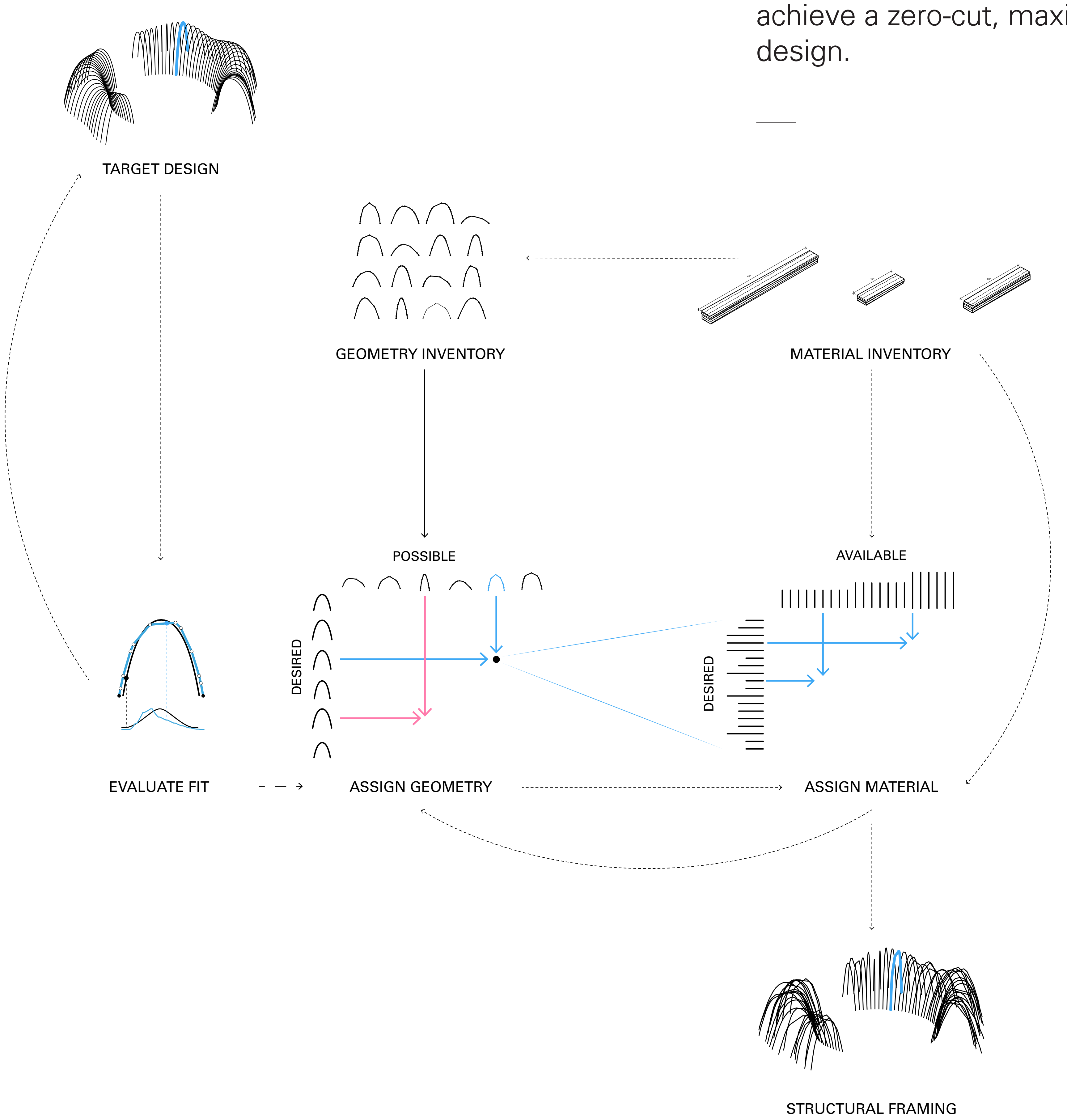
DESIGN SPACE EXPLORATION



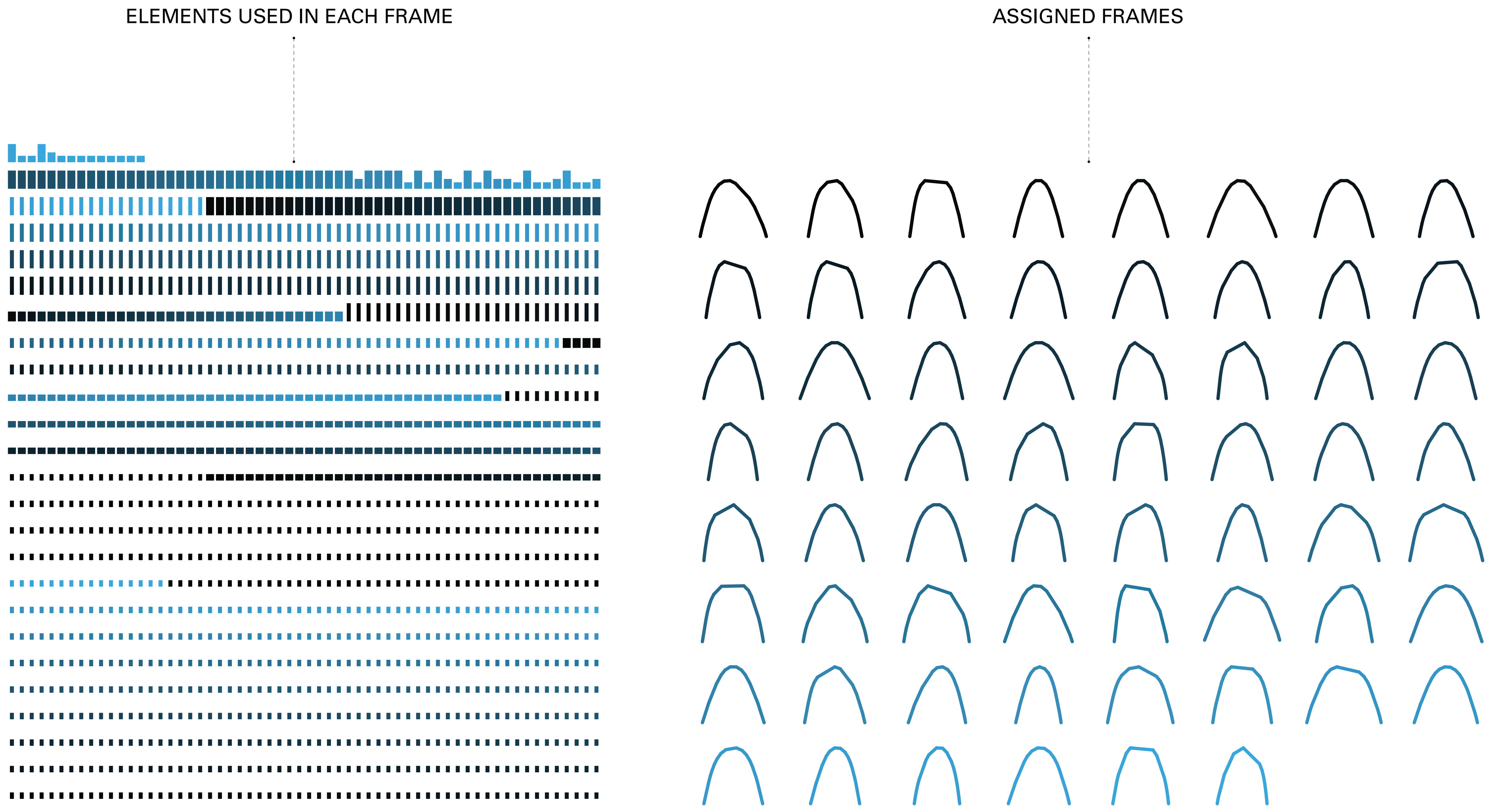
An inverse form-finding procedure is performed to determine an equilibrium geometry of a given set of inventory elements. This final geometry is added to the design candidate pool, an indexed list of possible framing geometries that can be built with the given inventory, is structurally feasible, and geometrically desirable.



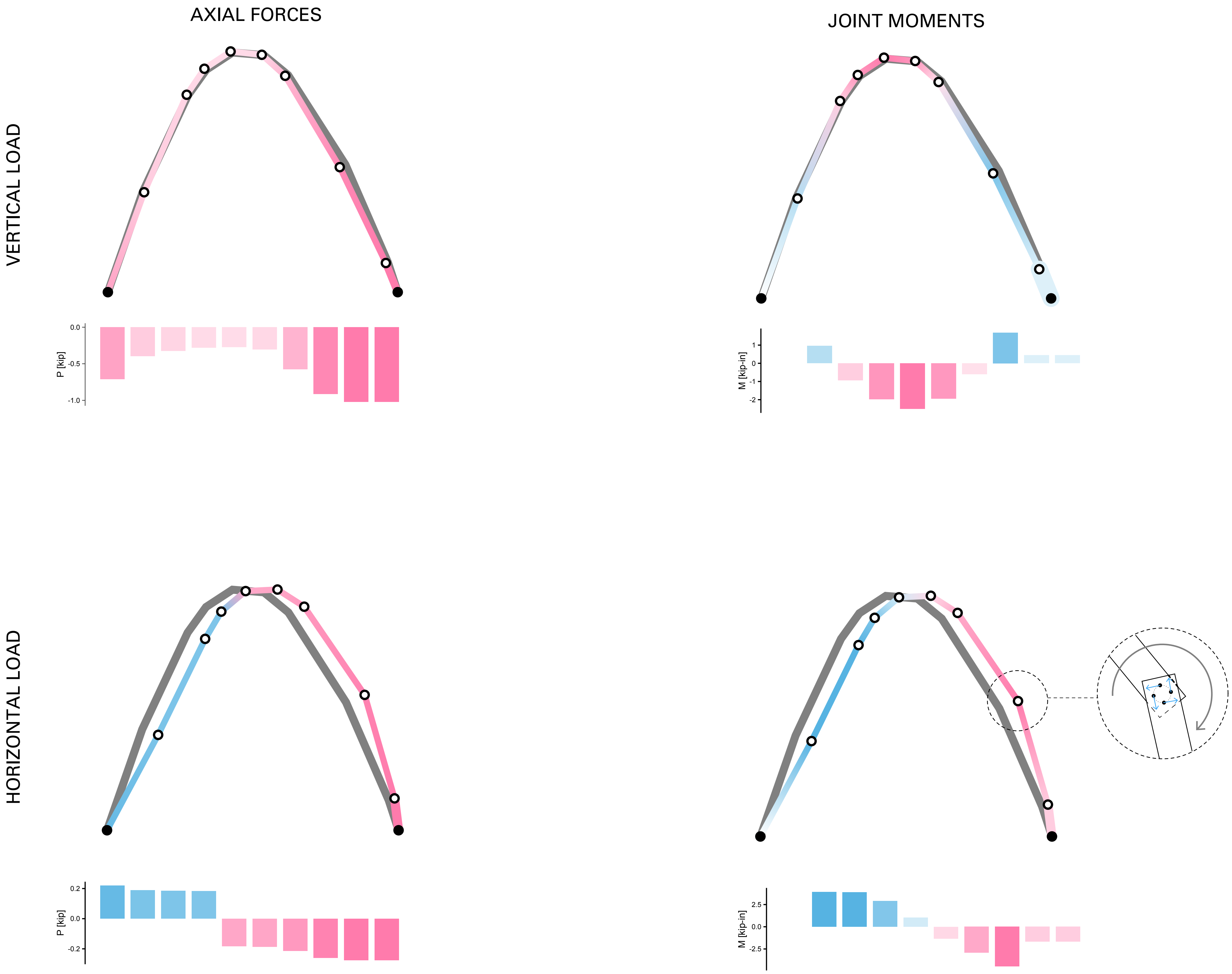
A design iteration starts by evaluating the geometric fit between all candidate frames in the geometric inventory and the target frames of the structure. Ranked by best fit, a random selection of the top performing candidates is then decomposed into its constituent elements; the entire collection of required stock of all assigned frames are compared to the available inventory. Target geometry, candidate selections, and inventory composition are all dynamically changed to achieve a zero-cut, maximum stock utilization design.



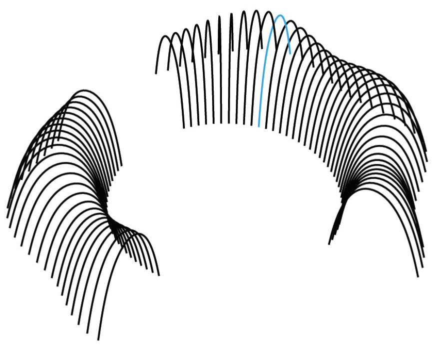
The design process consists of iterative sketching, inventory evaluation, and post-processing. Candidate geometries that best fit the target frames are collected and decomposed into linear segments. These segments are then compared to the available inventory stock; imperfect matches trigger a new round of computation with a new set of candidate geometries until a perfect match is found.

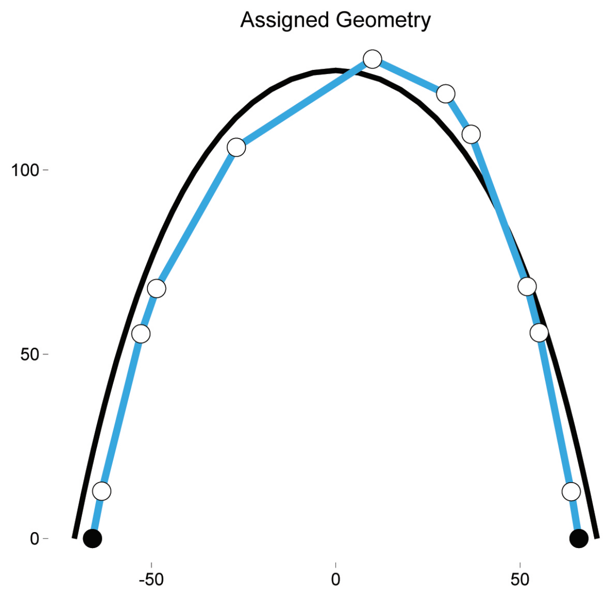


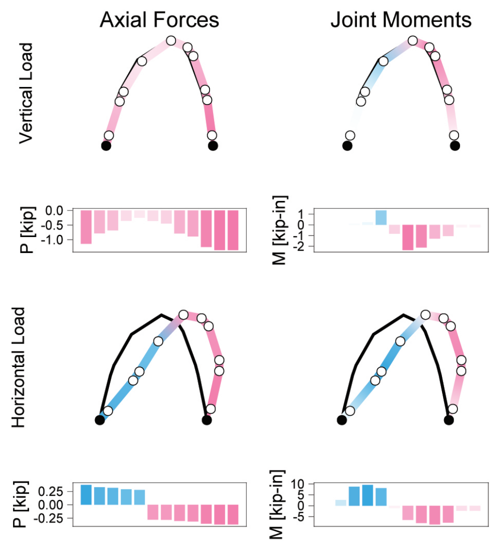
Through the nature of the design sampling process, any selected candidate geometry is guaranteed to be structurally efficient for point loads acting at the joints of the frame. Once a candidate is assigned to a target member, a more in-depth analysis is performed.



Two load cases are tested for each matched frame: a 100lbs/ft distributed gravity load and a 20lbs/ft distributed wind load on both the windward and leeward sides of the frame.





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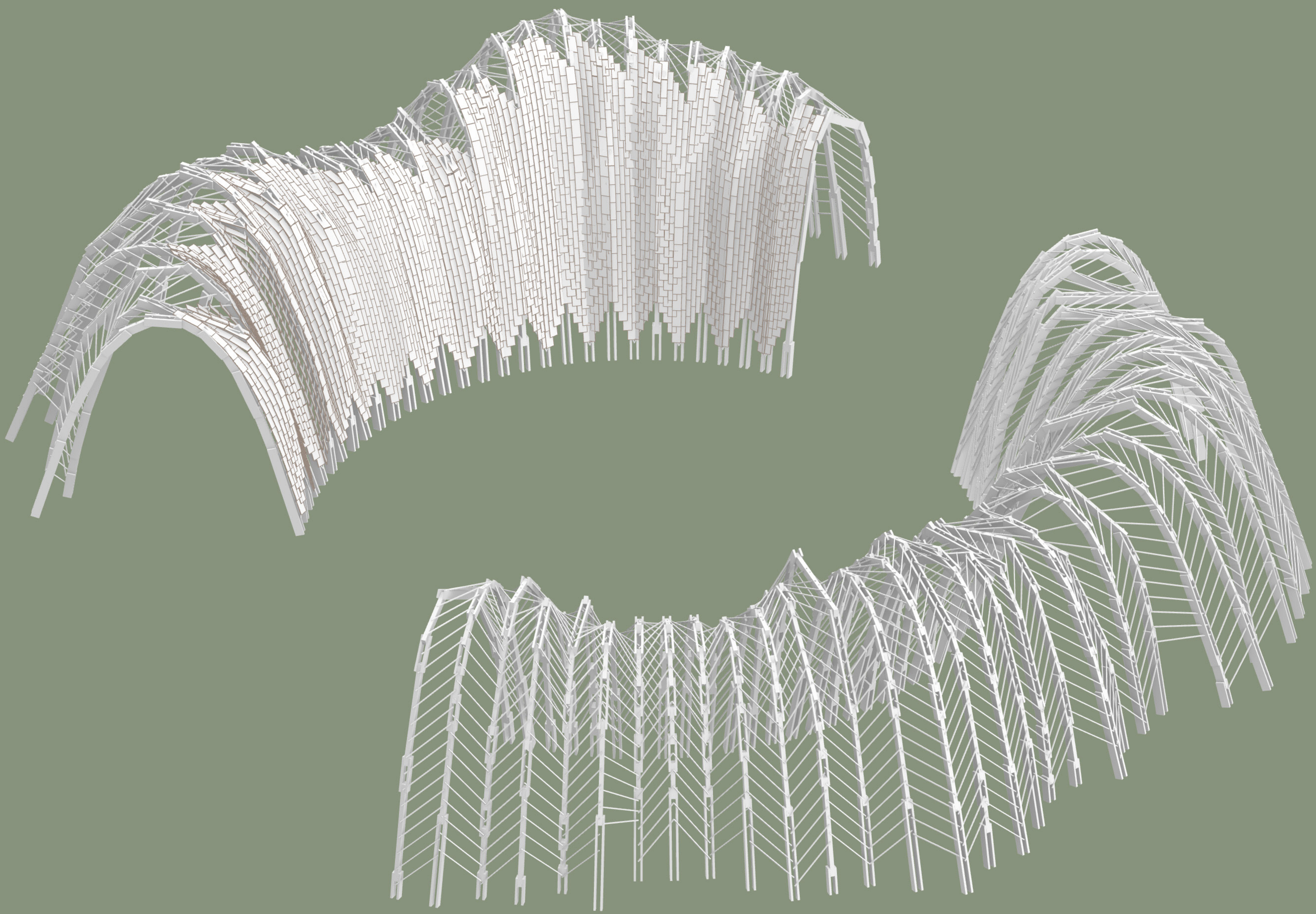
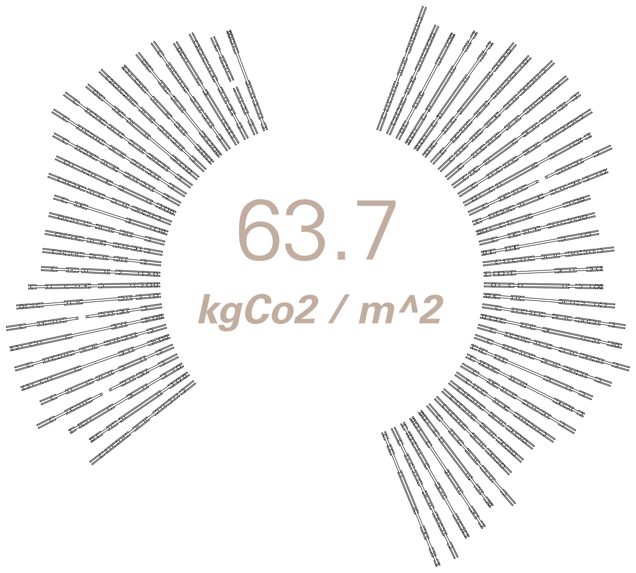
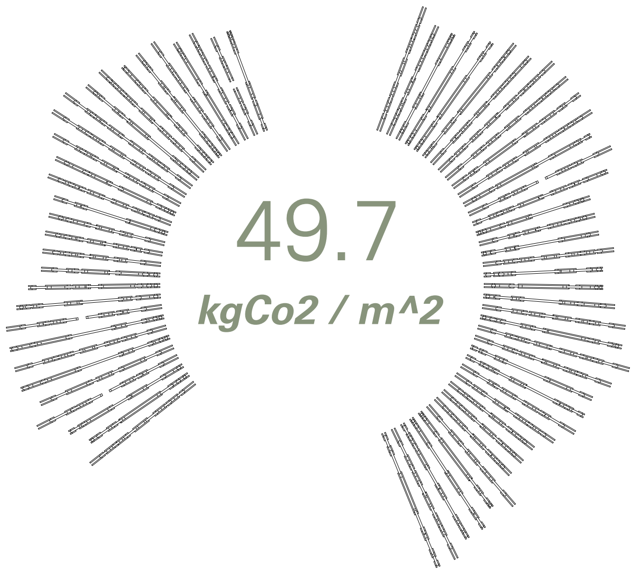


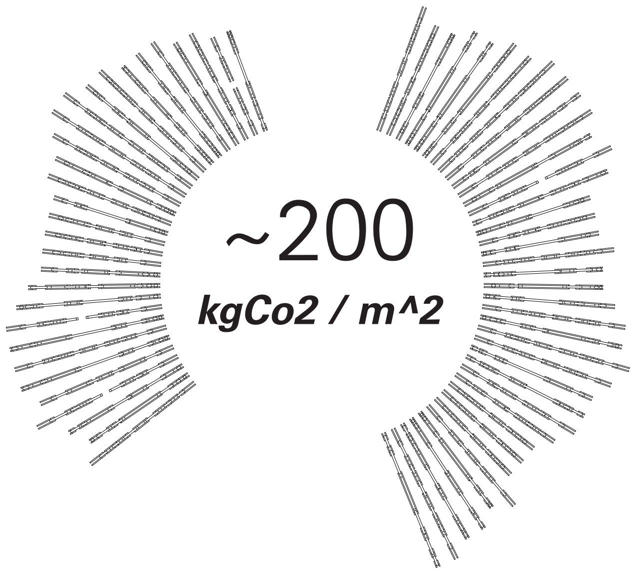
Embodied Carbon Of Make/Shift with ***new material stock***



Embodied Carbon of Make/Shift with the ***recovered materal stock***



Average Embodied Carbon of Timber Buildings (Hattan et al 2015)



The final step in the analysis was to understand how much embodied carbon was saved by using recovered wood stock. After conducting a cradle to gate life cycle analysis for all material quantities used in the structure, the salvaged wood structure was found to save approximately 8% of embodied carbon. A gate to grave analysis was also conducted to understand how much released carbon was mitigated by using the recovered stock and intercepting the waste stream to avoid burning.

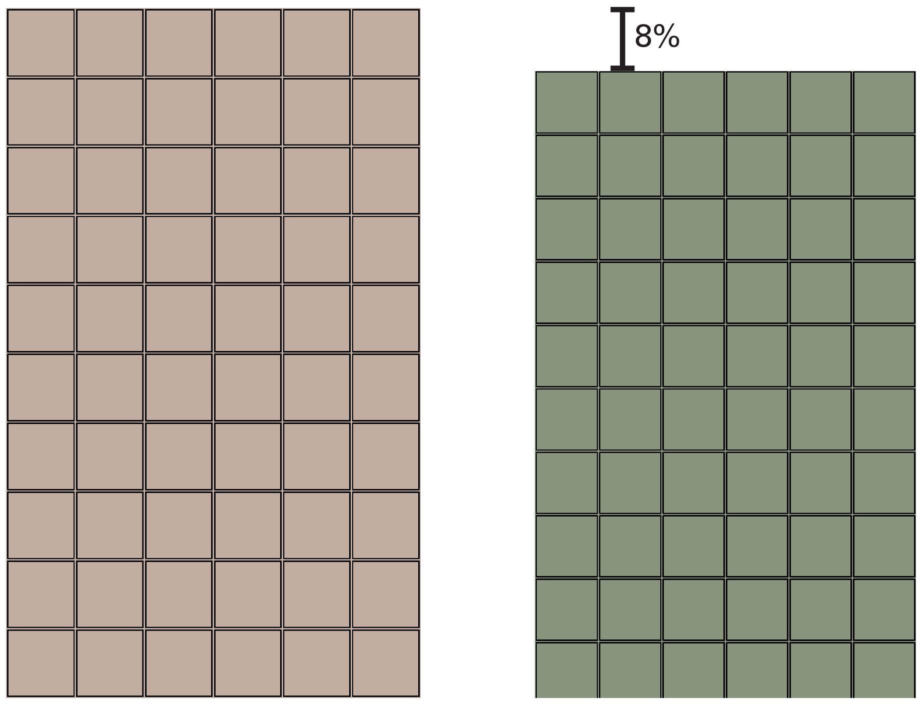
60.7
kgCo2/M^2

60.7 kgCo2/m^2 saved by avoiding burning of the waste stock in the gate to grave life cycle

95%

Increase in cradle-to-grave lifetime emissions if the stock been burned instead of reused

Embodied Carbon Savings From Using Recovered Stock



Project Team:

Juliana Berglund-Brown, SMBT
Inge Donovan, MArch
Kiley Feickert, PhD BT
Keith Lee, PhD BT
Jenna Schnitzler, MArch

Professor Caitlin Mueller, Digital Structures research group