Structural Optimization in Furniture Making
Trestle Table Documentation as a Parametric Process

Typology Evaluation through Finite Element Analysis
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A design process that cycles through iterative alternatives allows for incremental improvement. Within the constraining parameters of any given design space there exists a field of potential solutions. This project employs evolutionary algorithms to explore structural optimization at the furniture making scale. Digital models, hand calculations, and break testing are used to inform design decisions. Generative scripts are employed to make a series of parametrically related discrete members that form a field of formal possibilities. Input parameters are constrained to lie within the confines of the trestle table structural typology. A “rigged” finite element analysis model is leveraged to iteratively and adaptively test the goodness of fit (magnitude of member forces) of the specific solutions within the prescribed field. After exporting these results member sizes, shapes, and materials are selected through a more analogue process of quickly testing and documenting individual member utilisations. A design dialogue ensues between the material and the formal optimizations. Representative individual iterations are selected for validation through hand calculations and break testing. The results from this design method are then translated into a built interpretation of the trestle table. The interrelationship between the performative feedback of digital optimization tools and the process of making is explored. Opportunities, challenges, and pitfalls are documented and evaluated. The design results are compared with discrete examples of traditional trestle tables. These unselfconscious designs have been iteratively honed through the passage of generations. Vernacular response is evaluated as a repository of evolutionary optimization.
Testing the Design Space

Topostruct, a topological optimization tool, is used to preemptively visualize the force trajectories within the trestle end design space. To do so a two dimensional boundary curve and the external forces and restraints that act upon its edges are defined. Topostruct runs procedurally and determines the stress concentrations within the given field. Areas of least stress are culled and the procedure repeats. As the number of iterations increases, so does the clarity of the refined stress trajectories within the system.

This exploratory approach offers quick formal feedback.

Subtractive regions cause a redistribution of stress concentrations.
The Skeleton Table

The skeleton table model is an exploration of compounding geometric relationships resulting in complex yet cleanly resolved forms. This table uses simple “H” shaped trestle ends that are bridged with a curving stretcher. Struts are evenly distributed along the length of the stretcher. Every strut is of the same length but also meets flushly with the bottom plane of the table top. The graduated articulation is accomplished by varying the angle at which each individual strut meets the stretcher.

At each point along the stretcher where a strut is located the Z axis distance is measured to the plane of the table top. Using an arc cosine function with strut length and vertical distance as constants yields the angle of attack needed for each strut to cleanly meet the top plane. Once this logic is established in the model, a designer is free to fluidly explore the sculptural opportunities available within the structural type.

\[ \theta = \arccos \left( \frac{Z}{L} \right) \]

This system is modeled in mild (A36) steel with rigid joints. Two legs are restrained from planar X and Y translation.
Rigged Model Geometry
Strut Angle Offset

Distance to Top in Feet

Trestles
Stretcher
Strut
KARAMBA finite element model: deflected
**Trestle End**

The trestle end model tests a variety of two dimensional panel configurations. The upper spanning member of the panel is loaded laterally with a point load and vertically with an evenly distributed load. It is restrained at the ends of the lower spanning member. The end points of the bracing are adjustable but are restrained to the length of the spanning members. Excessive inputs are procedurally culled and return a zero value that places the braced ends at the center of the spanning member. The post members are free to translate along the spanning members but are restrained to remain normal.

The analysis is run with the braces defined by two separate cross sectional and material profiles. In the first two scenarios the braces are modeled as tension only steel cables with their ends released from transferring moment. Cable sets are explored that have either a static central post or an off center translating post. In the second set of scenarios the braces are modeled as wood members rigidly joined to the spanning elements. Again, in one scenario the post remains central and in the second the post is free to translate.

Deformed models are exported for their ease of visual interpretation. The evolutionary optimization seeks a reduction of global translation. Values of axial, moment, and shear force are accessible in this approach and can be evaluated in future applications as deemed appropriate.
Cable with Center Post

Brace with Center Post

Cable with Free Post

Brace with Free Post
Trestle End Definition

Rigged Model Geometry

KARAMBA FEA Model

Trestle End Deflection: Cables with Free Post
Rigged Model Geometry

Trestle End Unloaded: Geometric Range
Trestle End Deflected: Cables with Center Post
Trestle End Deflected: Braced with Center Post
Trestle End Deflected: Braced with Free Post
Trestle Table

After exploring the design space of the skeleton table and the trestle end, this design represents a return to a more strictly defined trestle table typology. The system consists of an upper spanning member that collects load; a lower spanning member that meets the ground; and a deconstructed vertical panel that bridges between the two. The trestle panel, a hallmark of traditional designs, has in this interpretation been split apart so as to locate material specifically in trajectories of force flow. When resisting lateral racking the deconstructed panels more readily form pure couples of tension and compression.

The supporting columns are connected with a short linkage used to increase the panel’s rigidity as well as to accept the table’s stretcher. The stretcher and the diaphragm of the table top work together to form a couple that resists longitudinal racking.

This design relies on breaking the architectural assumption that rigid joints cannot be developed in wood. When working at the furniture scale adequately rigid joints can economically be fashioned by designing joints that have adequate shoulder bearing areas.

This rigged model allows an individual to fluidly explore the design space found within the trestle table typology. By modeling discrete historical examples drawn from within the defined field, comparisons can be made between vernacular evolution and algorithmic optimization. The first is culturally impressed and unselfconscious. The second is digitally manifest and highly self-conscious. Both methods of furthering structural understanding are valid. Both methods rely on assumptions and intuition.

Ultimately they are each modes of gaining insight.
**Trestle Table**

See historic pairings

1. **Skinny + Thin**
2. **Skinny + Wide**
3. **Stocky + Low**
4. **Stocky + Wide**
5. **Skinny + Trim**
6. **Composite**
The results of this digital design process arrived at solutions similar to existing examples of traditional trestle tables. These unselfconscious designs have been iteratively honed through the passage of generations.

Generative scripts were employed to make a series of parametrically related analysis models whose output formed a field of formal possibilities. Input parameters were constrained to lie within the confines of the trestle table structural typology. The “rigged” finite element analysis model was leveraged to iteratively and adaptively test the goodness of fit (magnitude of member forces) of the specific solutions within the prescribed field.

Many of the traditional designs are not materially efficient. This is due to bearing area in joints driving the need for larger member sizes. Optimizations can have a variety of goals. It is challenging to establish a best fitness to test. Goodness can take many forms.

Vernacular response draws from a repository of evolutionary optimization. Many of the traditional designs are not materially efficient. This is due to bearing area in joints driving the need for larger member sizes. Optimizations can have a variety of goals. It is challenging to establish a best fitness to test. Goodness can take many forms.
Finite Element Analysis results are exported to design member sizes, shapes, and materials. This selection relies on a more analogue process of quickly testing and documenting individual member utilizations.

A design dialogue ensues between the material and the formal optimizations.

Simply supported members milled into small profiles were tested as a means of validating published elastic and rupture limits in wood of various species.

Bearing Area at the Joint and Global Deflection Prove to Govern

Topological Optimization: A procedural means of finding stress concentrations within a given design space

Density, Size, and Color indicate areas with high stress levels. These are the locations where structural material is needed.

Long Grain Separation Failure at Exposed Grain Tension Only Clean Traction/Compression Failure at Grain Transition

Finite Element Analysis results are exported to design member sizes, shapes, and materials. This section relies on a more analogue process of quickly testing and documenting individual member utilizations.

A design dialogue ensues between the material and the formal optimizations.
"There ain't no jointery without joints"

Glen Harcourt - master craftsman and founder of Steeprock Builders
1966-2006