Mass Timber Joinery Design for Digital Fabrication and De-constructability

Turner

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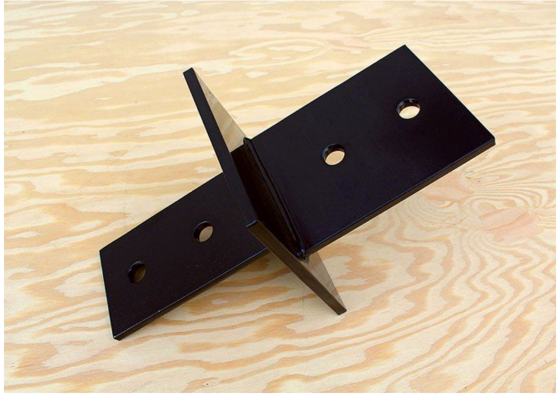
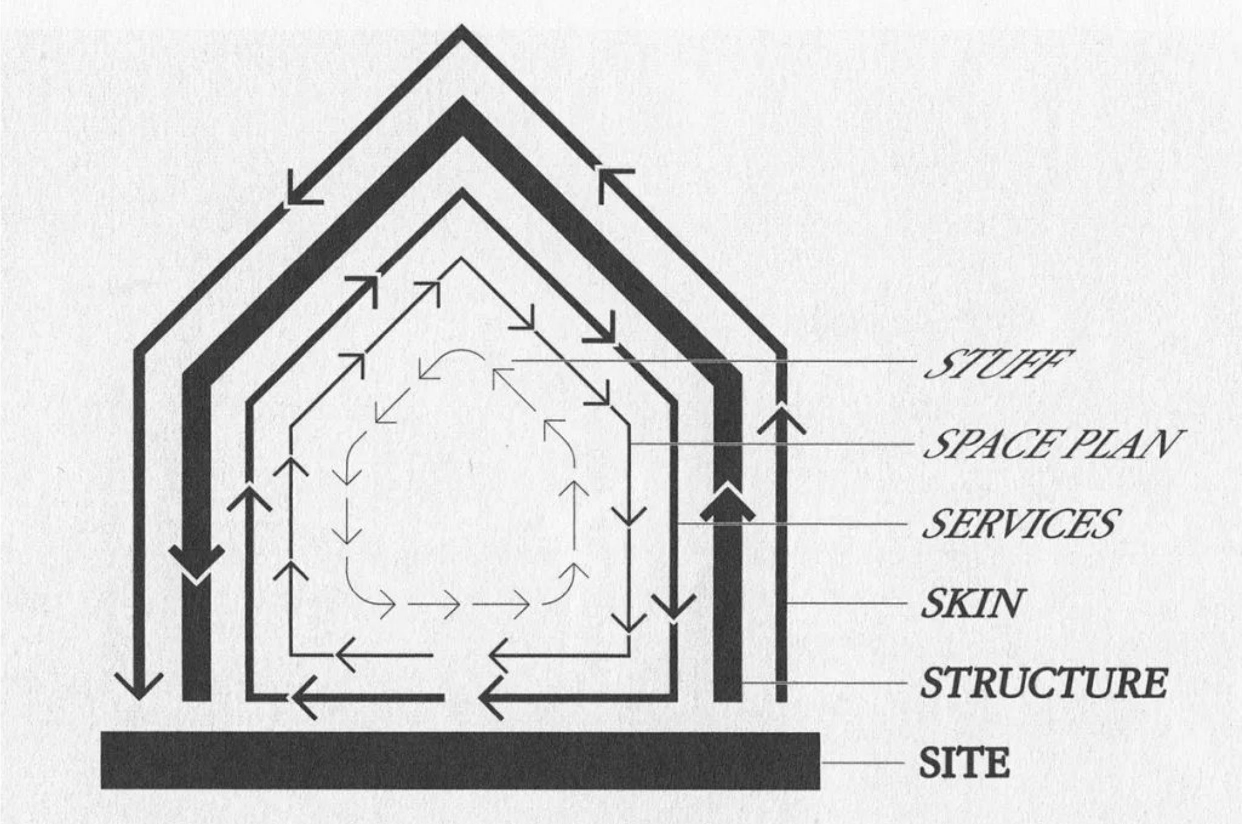
Research Overview | Current Mass Timber Practice

Research Overview | Mass Timber Connections



Research Overview | Shearing Layers



Stuff | Temporary

Space Plan | 5 - 20 years

Services | 7 - 15 years

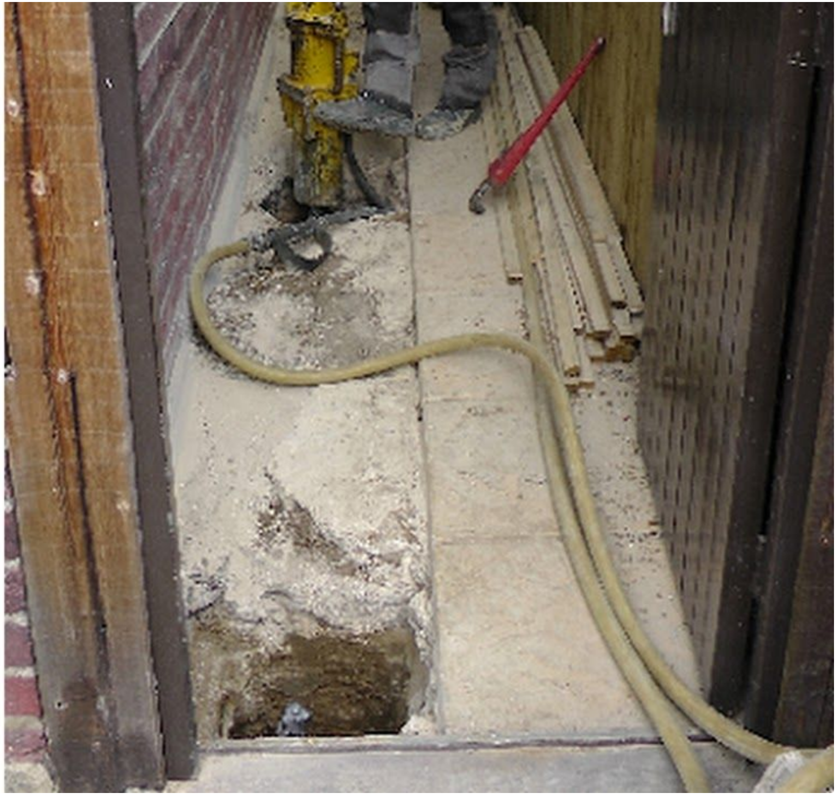
Skin | 15 - 30 years

Structure | 30 - 60 years

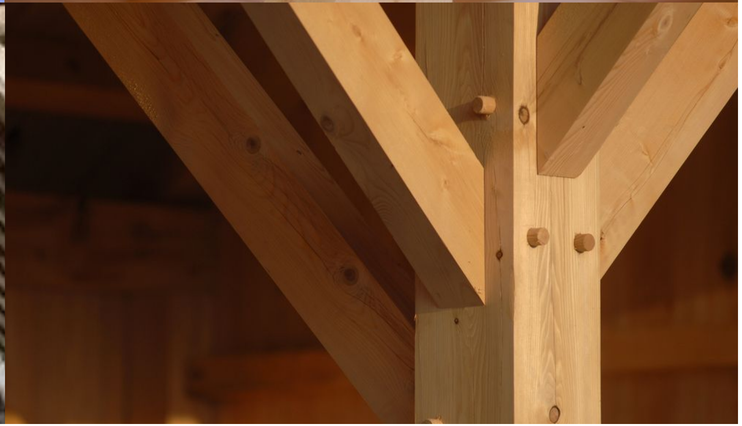
Site | Eternal

How Buildings Learn - Stewart Brand (1994)

Research Overview | Shearing Layers

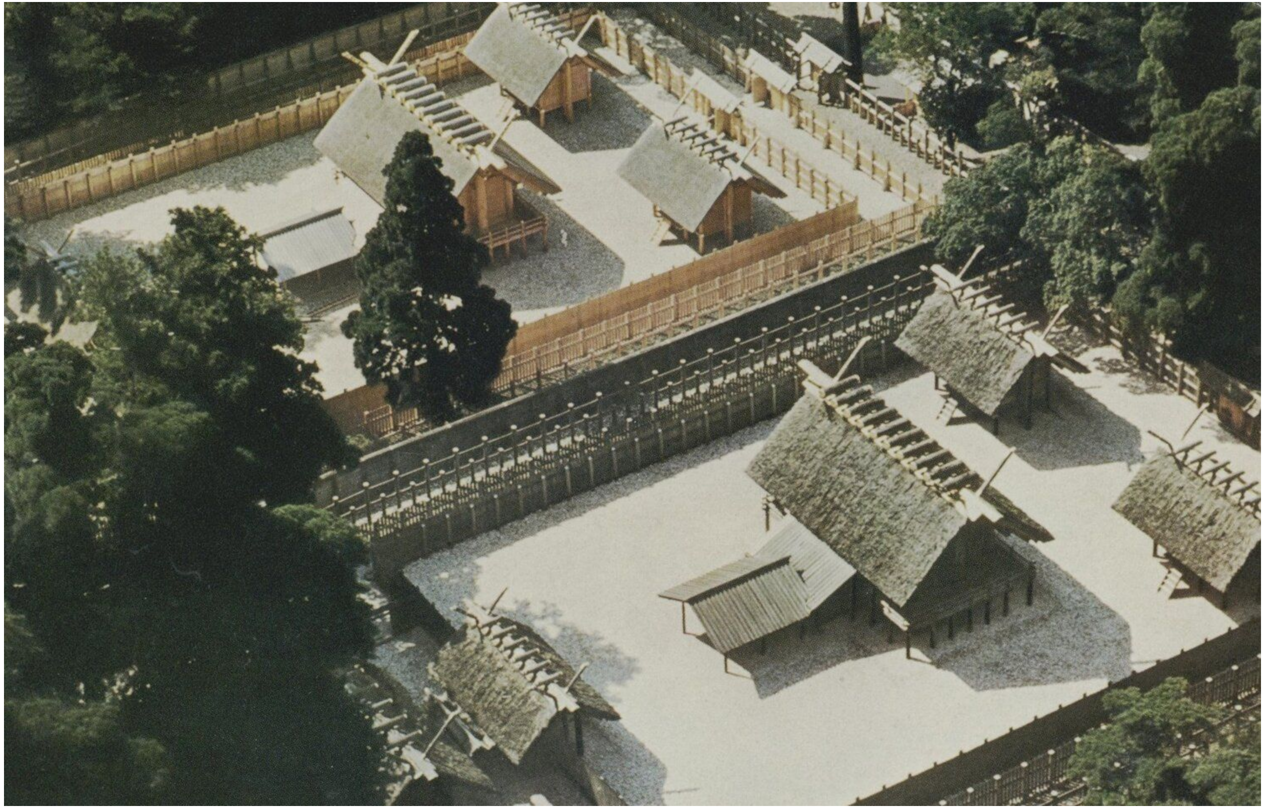


Solution | Deconstructible Joint



Research Overview | Deconstructability

- Japanese temples are built to be deconstructed.
    - Each element is inspected for damage and replaced
    - Allows most members to last significantly longer

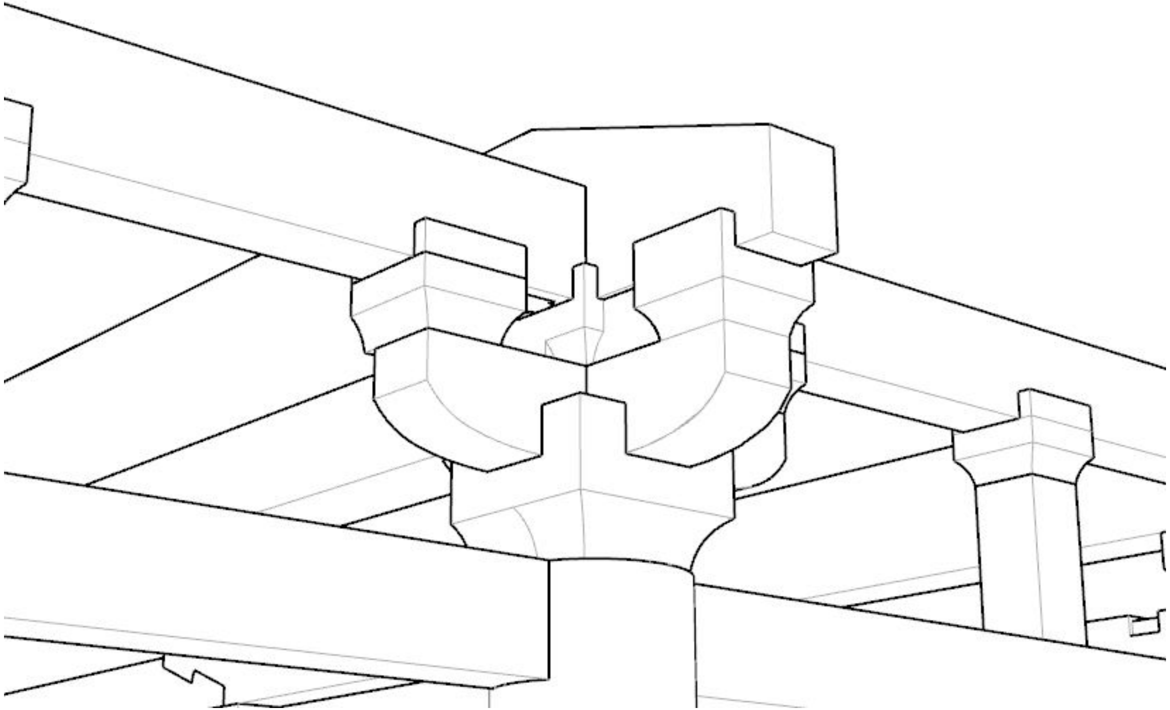


Ise Shrine - 1973

Research Questions

- How can Timber Joinery replace modern steel fasteners and what barriers are there to Timber Joinery in modern construction?

- How can digital computation and fabrication help resolve current issues with implementing timber joinery?



Research Goals

- Understand traditional timber joinery
- Digital fabrication tools for constructing traditional joints
- Digital Model for Post and Beam Timber Joinery
    - Tools to analyze stresses and fabrication issues
    - Deconstruction and Fabrication built into Design

Tsugite (2020)

Research Timeline

WINTER 2022

- Literature Review
- Case Study Fabrication
  - Small Scale
  - Large Scale
- Joinery Catalogue

SPRING 2022

- Component Catalogue
  - Common elements of joints
- Computational Joinery Tool
  - Based on Fabrication steps

SUMMER 2022

- Finite Element Analysis
- Fabrication Analysis tool for Computational Joint

FALL 2022

- Multi-objective Optimization
  - FEA
  - Fabrication
  - Embodied Carbon
  - Design for Deconstruction

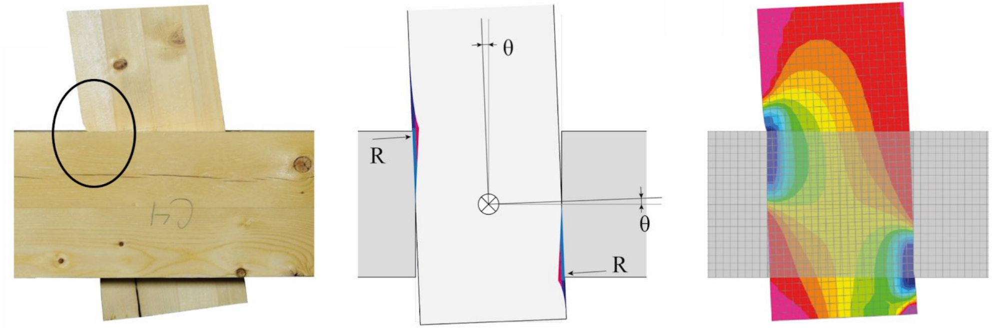
WINTER 2023

- Thesis Paper
- Compile Results and observations
- Consolidate tool as Rhino Plug-in

Research | Mechanical Properties

- Some research has shown that Finite Element Analysis of Joints are possible with modern computational techniques

- Focus on specific joint typologies or loading conditions.

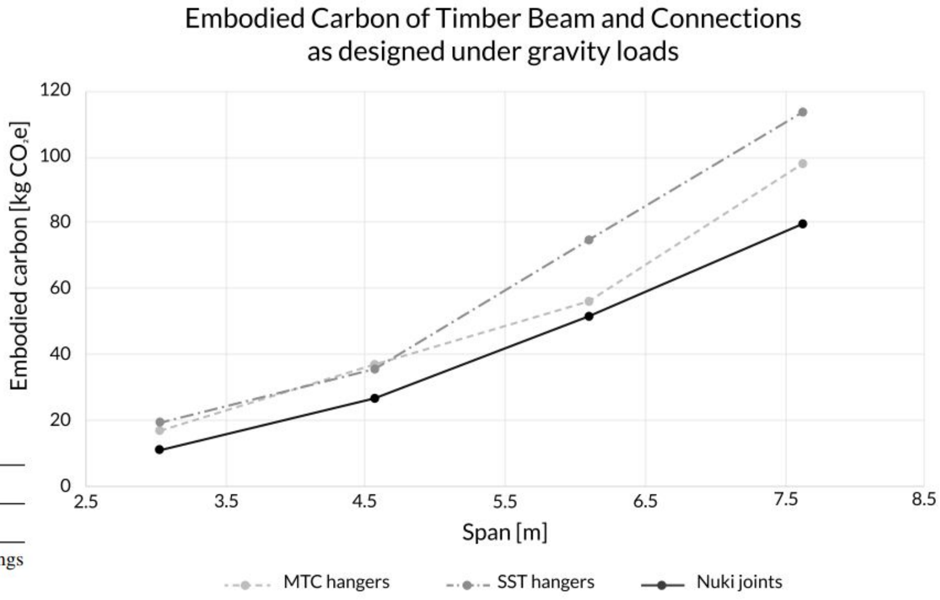


Julieta Moradei et al. (2018)

Demi Fang (2018)

Research | Embodied Carbon

- Timber Joinery can provide carbon savings to modern mechanical attachments for similar structural integrity

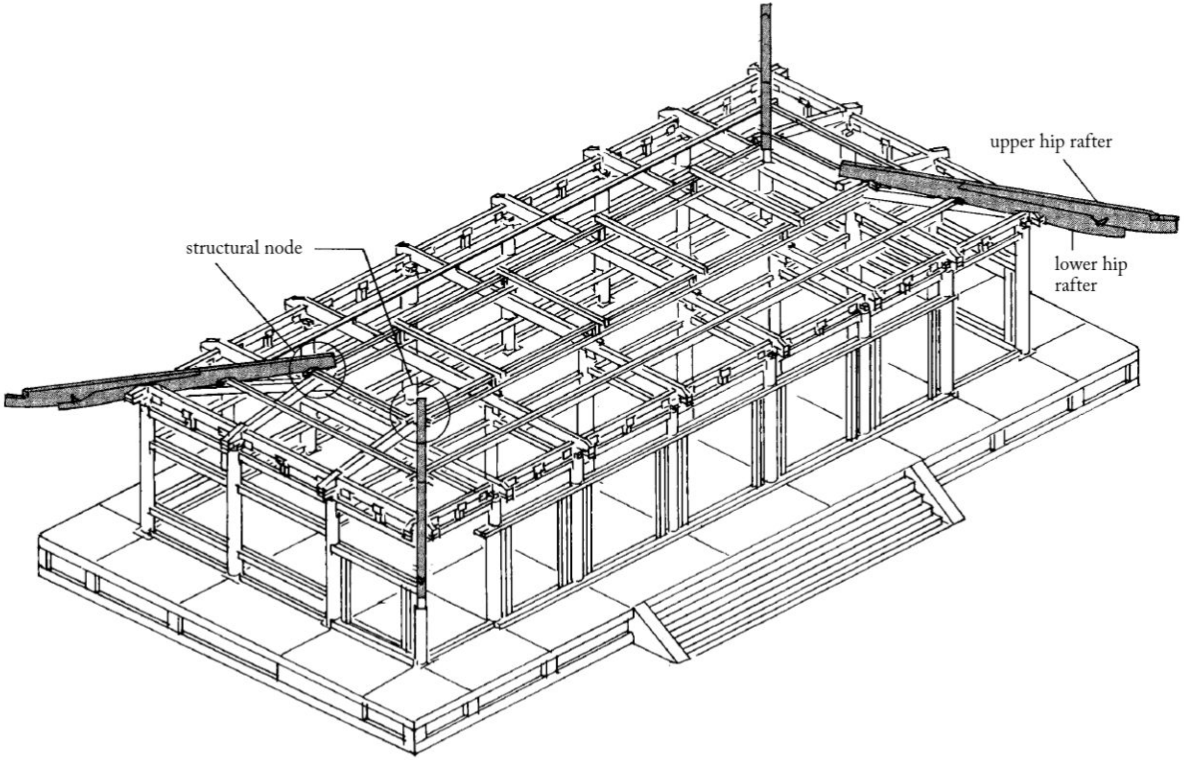


Embodied carbon savings achieved by switching connections				
	from MTC to Nuki		from SST to Nuki	
Span	Absolute values [kg CO_2e]	Percent savings	Absolute values [kg CO_2e]	Percent savings
3.05 m (10 ft)	17.1 to 11.7	32%	19.4 to 11.7	40%
4.58 m (15 ft)	37.3 to 26.4	29%	35.8 to 26.4	26%
6.10 m (20 ft)	55.2 to 51.1	7%	74.6 to 51.1	31%
7.63 m (25 ft)	91.2 to 79.1	13%	113 to 79.1	30%

Demi Fang (2021)

Japanese Joinery Case Study

- Genjo Sanzo-in Picture Hall in the Yakushiji Complex
- Construct a model at different scales to better understand traditional joinery and how to apply modern fabrication techniques to them.



The Genius of Japanese Carpentry - Abby Brown (2013)

Fabrication of Case Study

- Fabricating traditional japanese joinery with digital fabrication techniques
    - 3-axis CNC mill
    - Laser Cutter
    - 3D printer

Case Study | Small Scale

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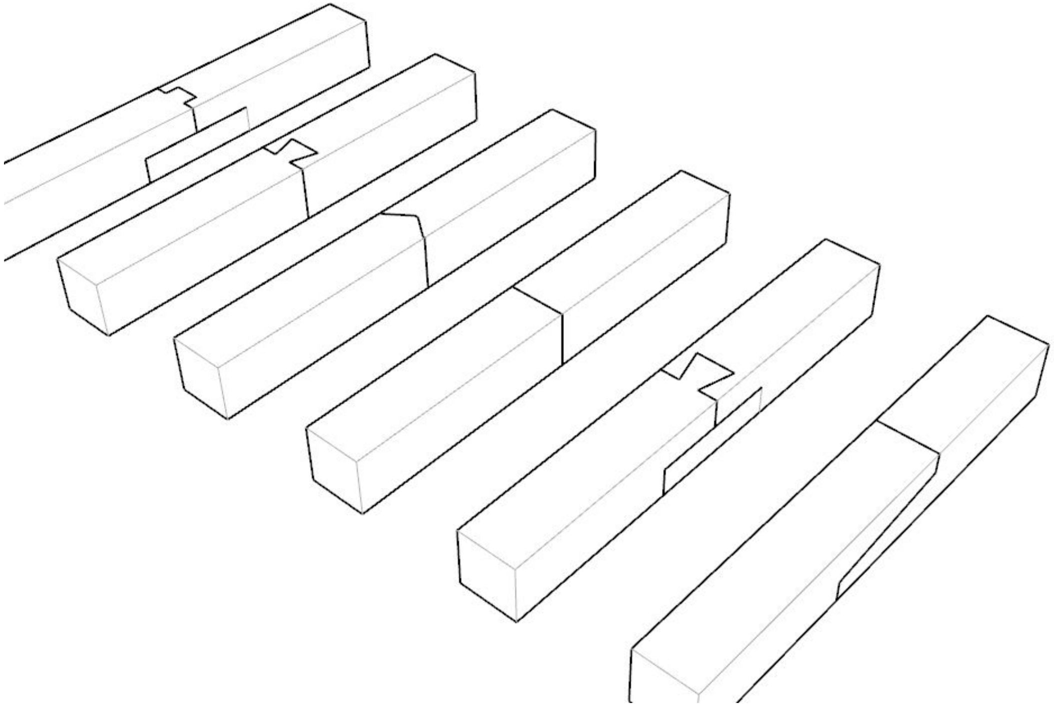
Joinery Catalogue

- Taxonomy of different families of joints
  - Compression, Tension, and Bending stress
  - Dynamic Lateral Loads
  - Finite Element Analysis
  - Comparing values in cost, embodied carbon, etc.

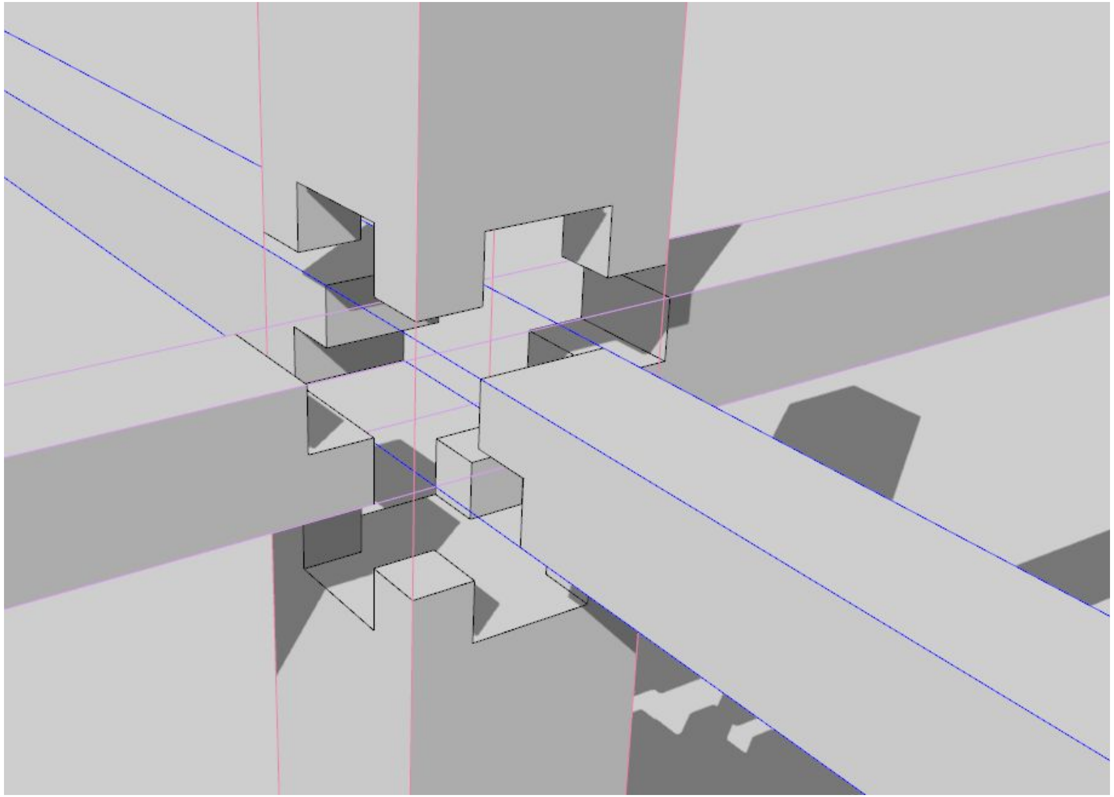


Joinery Catalogue | components

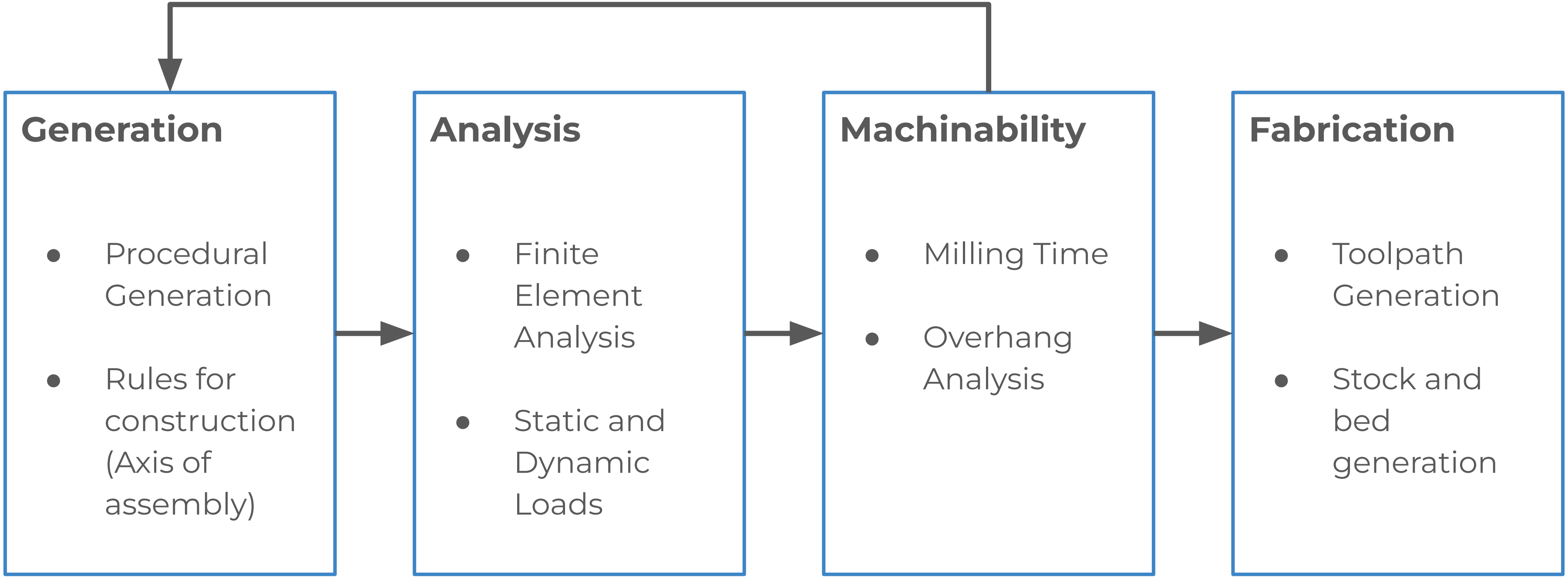
Name	Assumed Ends	Profile Axis	Push Pull Axis	Restricted Movement	Movement Axis	Millable	Comments	Through Cut	Typical Sides
Scarf	X/-X	Z (Rotated around Y axis	X	Slides along the plane Restricts: perp+ No Restrictions: perp-	Z+, X-,Y+, Y-	TRUE	Plane Joint: Similar to Lap Joints and Butt Joints but is at an angle	TRUE	SIDE
Miter	X/-Y	Y (Rotated around Z axis	Z	Slides along the plane Restricts: perp+ No Restrictions: perp-	Z+, Z-, X-, Y+	TRUE	Plane Joint: Similar to Scarf Joints but used on corners. Always bisects the two	TRUE	TOP
Lap	X/-X	Z	X	Slides along the plane Restricts: perp+ No Restrictions: perp-	Z+, X-, Y+, Y-	TRUE	Plane Joint:	TRUE	SIDE
Butt	X/-X	Z	X	Slides along the plane Restricts: perp+ No Restrictions: perp-	Z+, Z-, X-, Y+, Y-	TRUE	Plane Joint:	TRUE	NONE
Mortise and Tenon	X/Y	Z	X	Slides perp to profile plane Restricts along profile	Y-, X+	TRUE	Tenon Joint:	FALSE	END
Stub Tenon (|)	X/-X	Y	X	Slides perp to profile plane Restricts along Profile Axis	X+, Z+, Z-	TRUE	Tenon Joint:	TRUE	TOP
Stub Tenon (||)	X/-X	Y	X	Slides perp to profile plane Restricts along Profile Axis Nonrestricted: + push pull axis	X+, Z+, Z-	TRUE	Tenon Joint:	TRUE	TOP
Stub Tenon (L)	X/-X					FALSE	Tenon Joint:	FALSE	END
Stub Tenon (Half-Blind)	X/-X	Y	X	NR: + perp to profile plane R: along Profile Axis R: - perp to profile plane NR: + push pull axis	X+, Z+, Z-	TRUE	Tenon Joint:	FALSE	END
Stub Tenon (+)	X/-X					FALSE	Tenon Joint:	FALSE	END

Computational Joint | Multi-Component Joint Tool

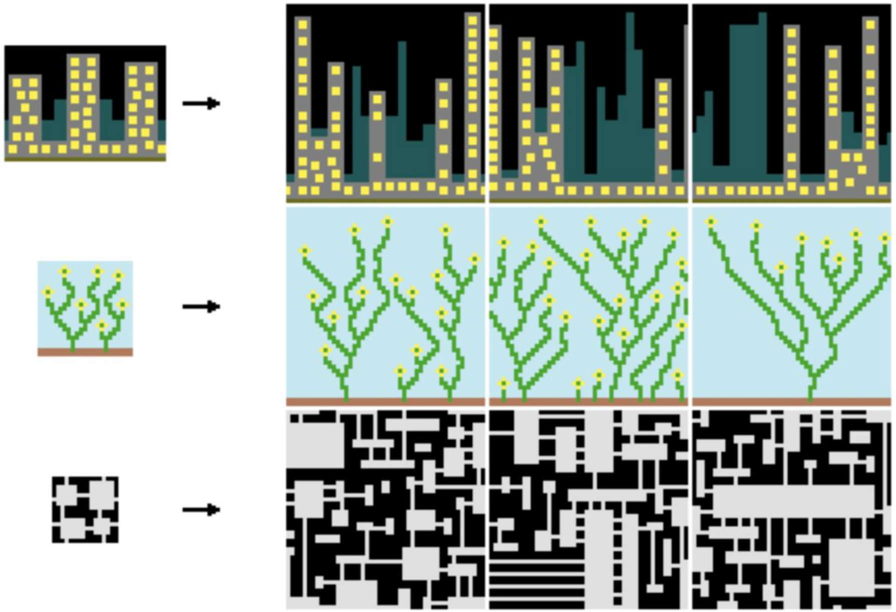
- Generation tool
- Capabilities of using any post and beam configuration
- Create and combine joint components

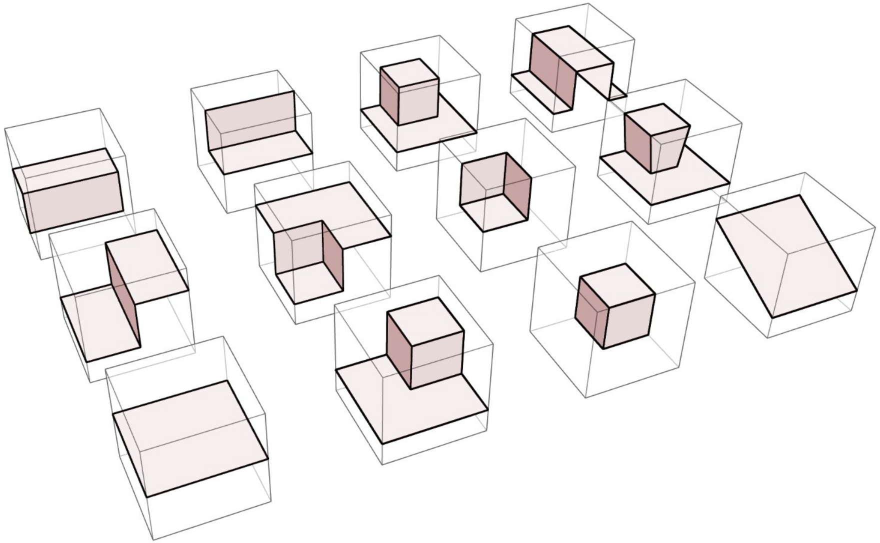


Framework


Generation
Procedural Generation
Rules for construction (Axis of assembly)
Analysis
Finite Element Analysis
Static and Dynamic Loads
Machinability
Milling Time
Overhang Analysis
Fabrication
Toolpath Generation
Stock and bed generation

Generation | User Guided Generation

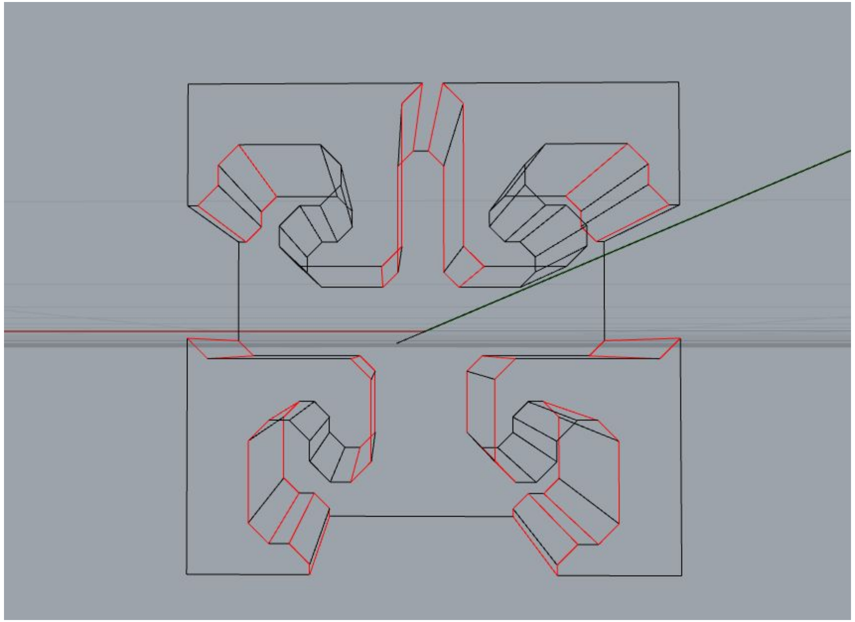




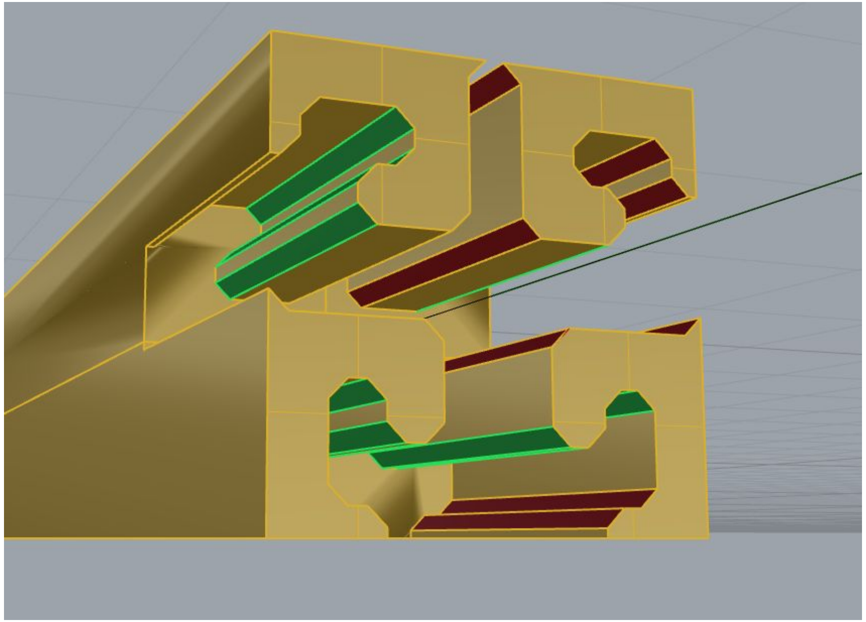
Machinability | Current Work

Opportunities to quantify and determine millability

- Overhang Analysis



- Mill Direction Analysis



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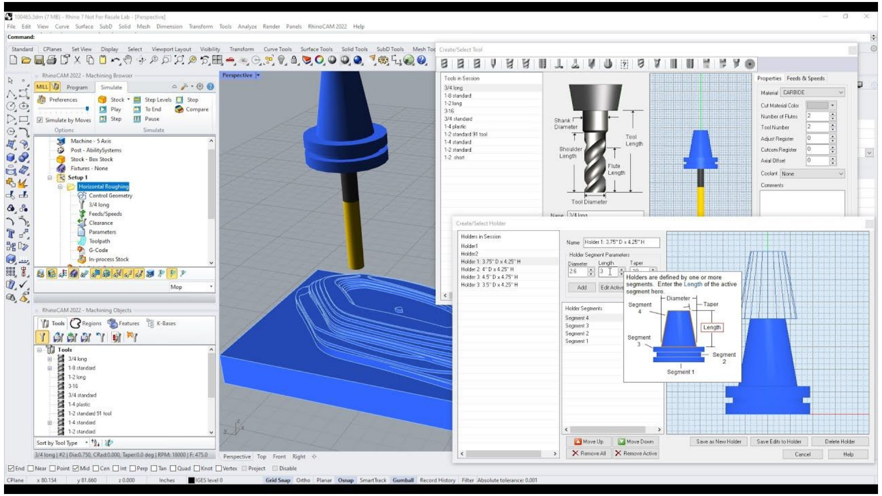
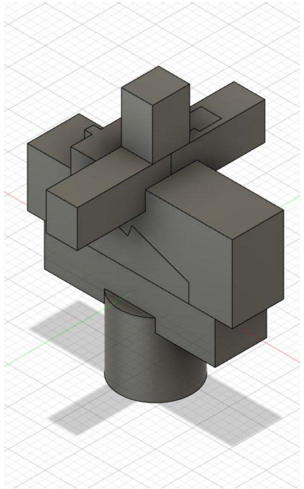
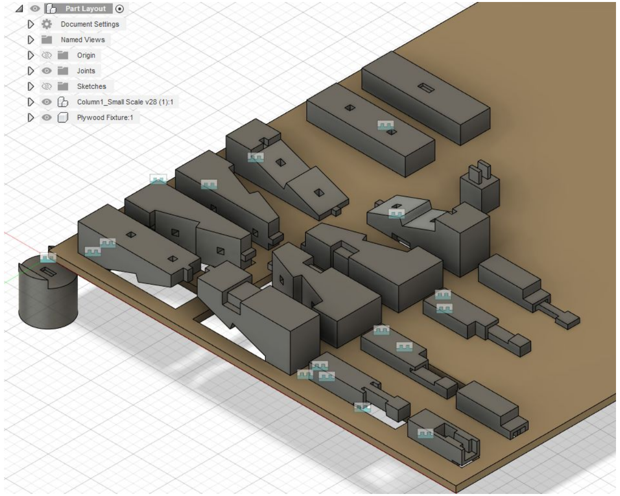
Future Research | Fabrication

- Milling Automation





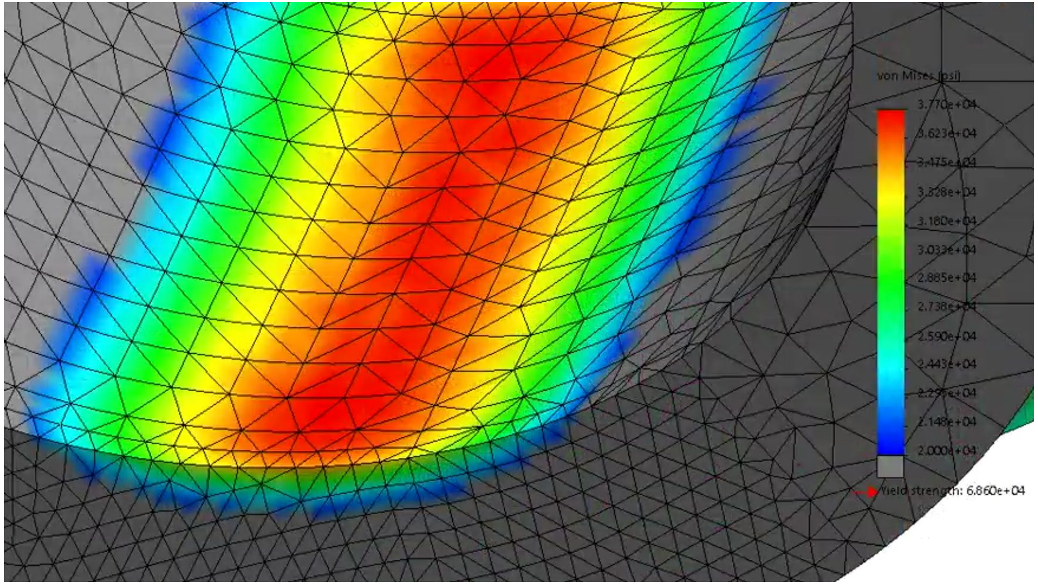


RhinoCAM® MecSoft

python™

Future Research | Analysis

- Finite Element Analysis
- Anisotropic Materials
- Multi-part simulations



Ansys

python™