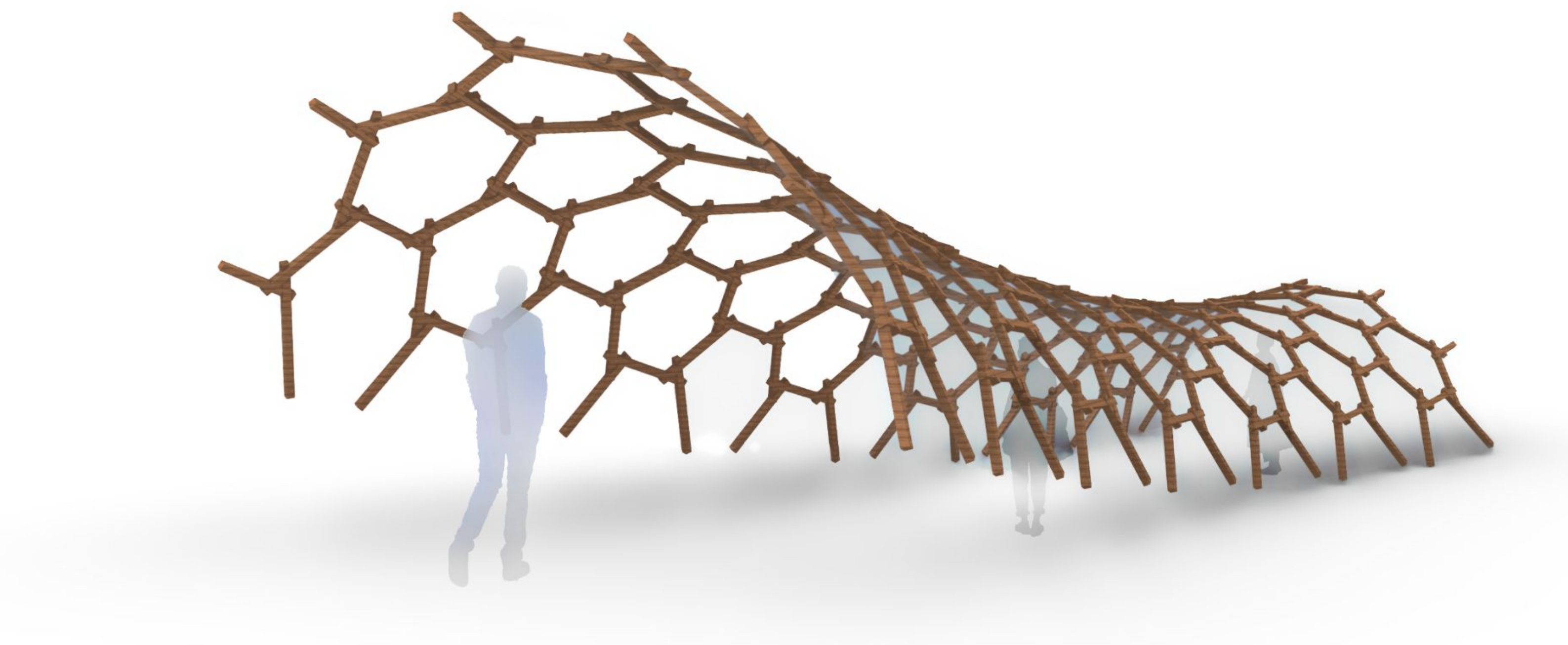
Reciprocal Frame Fabrication

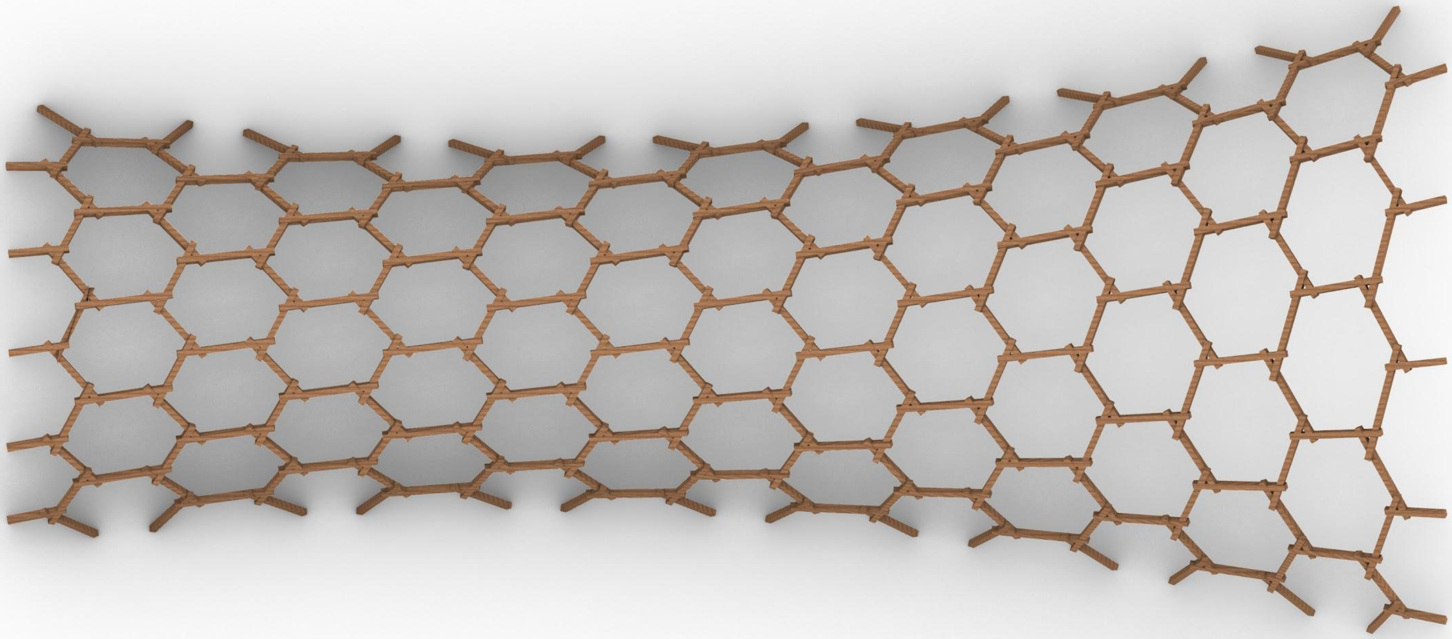
Robotic Milling and Path Planning

Harrison Hildebrandt



Project Brief

For those familiar with the subject, robotically fabricated timber construction often invokes images of plywood structures with sophisticated finger joints or laminated furniture milled in complex curves that would be difficult to achieve without the use of 5 or more axes. What is not so evident is the use of higher degrees of freedom CNC machines when fabricating beam or stick timber structures. We wanted to investigate how robotic milling could be used to fabricate morphologies out of discrete elements and how it could increase the achievable complexity for the joint. After conducting some research we discovered that there are precedents for using a robot arm to mill individual elements, especially in the area of reciprocal frames. Reciprocal frames are self supporting structures made out of three or more overlapping beams and with no additional central support. While initially we wanted to develop our own joints and member distribution logic, we ended up utilizing a well developed Y-type 3 valence connection.

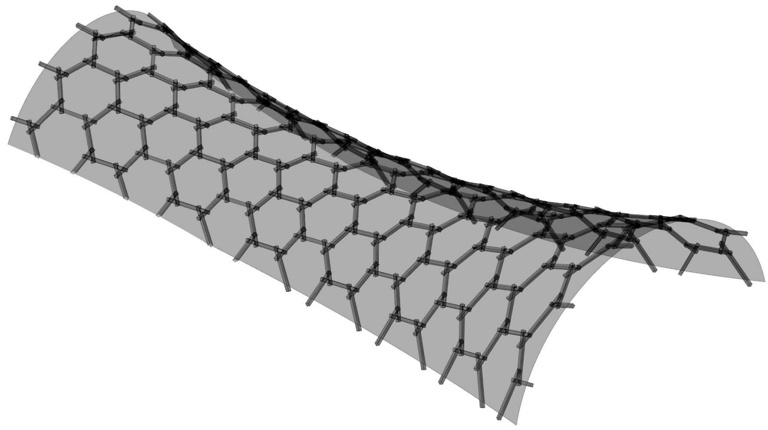


Primary Goals

1. Parametrically generate reciprocal frame model from geometric input
2. Automatically organize, orient, and label individual members
3. Generate toolpaths for milling 5-axis lap joints
4. Generate toolpaths for milling end conditions of members
5. Incorporate flip cut through fixture design and toolpath generation
6. Provide accurate simulation with all components included

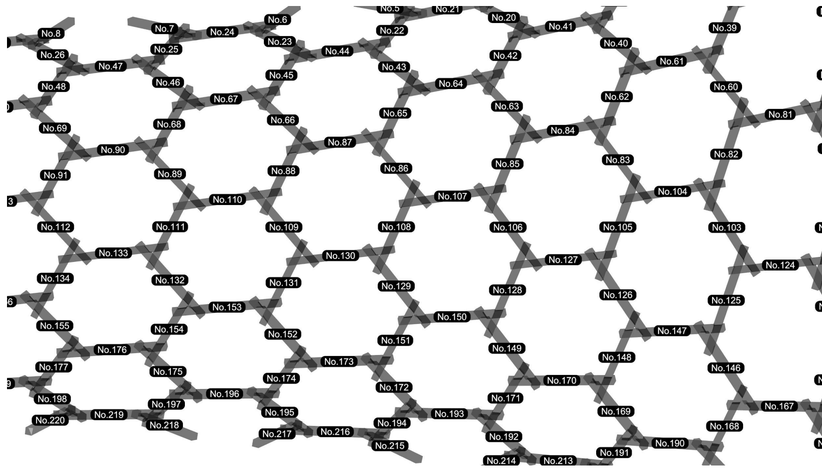
Geometry Generation

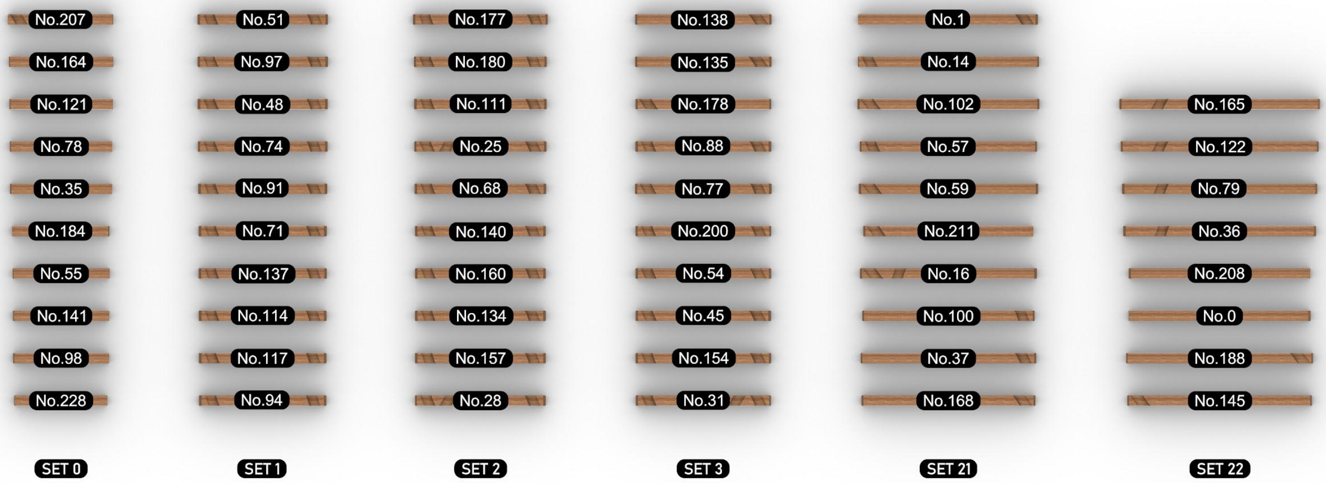
The global design method of the structure was developed using primarily the plug-in NGon, referencing examples provided by its creator Petras Vestartas. It takes an input surface and creates a reciprocal frame structure based on different constraints such as member cross-section, valency number, and interaction angle.



Member Organization

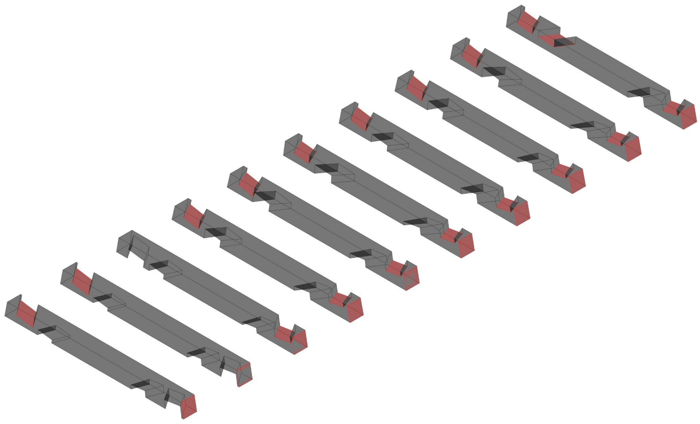
The members are then sorted by size, moved and oriented to the WorldXY plane, and split into groups of ten (the max number that the fabrication fixture can hold at once).





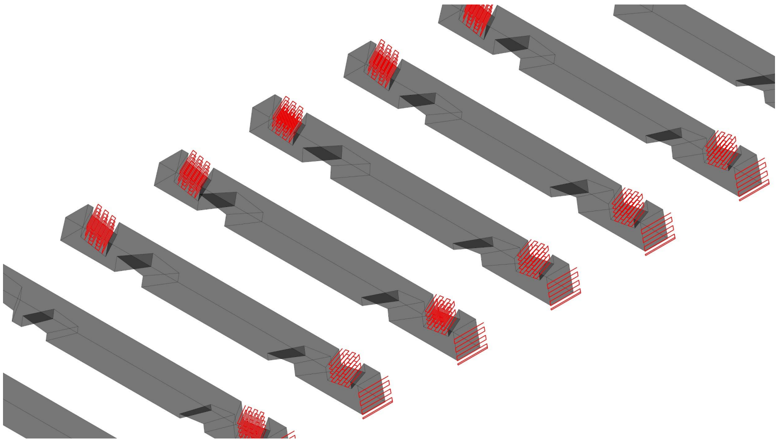
Face Selection

In order to automatically generate the correct milling paths, the system needed to automatically selected the correct faces to be milled. It also needed to categorize them as as either edge surfaces or joint surfaces, whether they were on the nearside or far side of the milling setup, and whether they were on the top or bottom (flip cut) of the member.

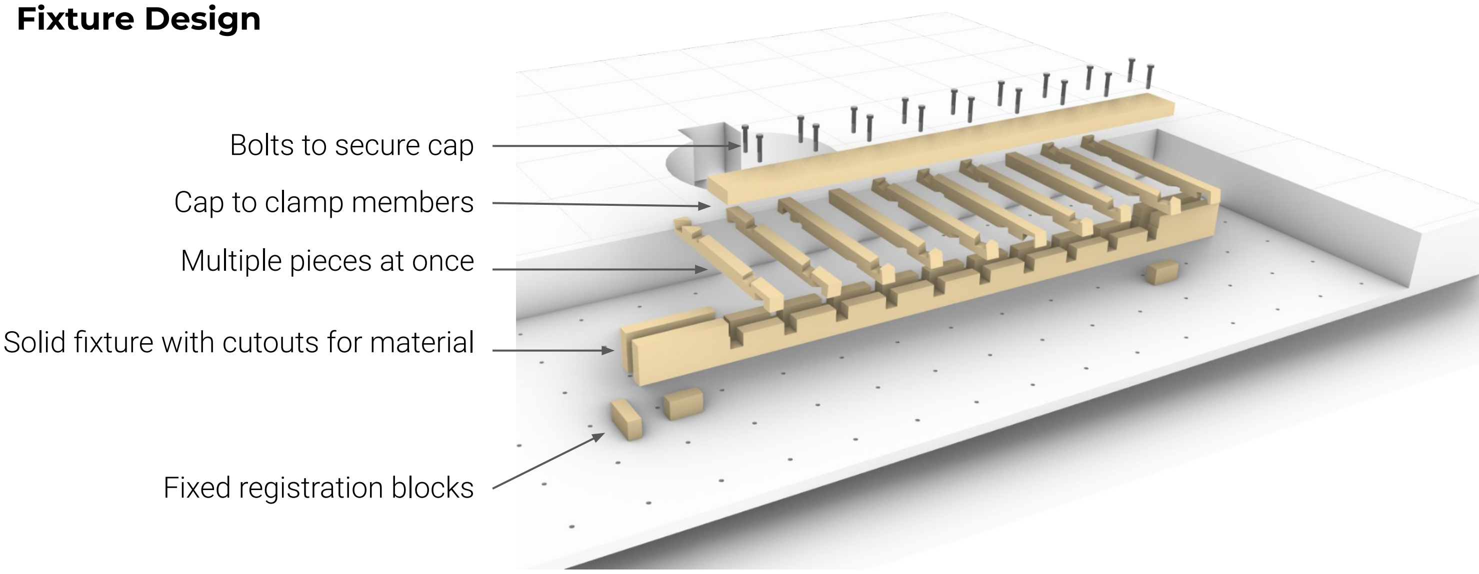


Contour and Toolpath Generation

Next the system generates the toolpaths based on the different surfaces and the tool diameter. The lap joint surfaces needed to be end milled (meaning the surface is cut by the end of the tool) while the edge surfaces needed to be profile milled (meaning the surface is cut by the side of the tool). As a result, the toolpaths were created in two different ways. Either with their normal vector parallel to the surface (edge) or perpendicular (lap joint).

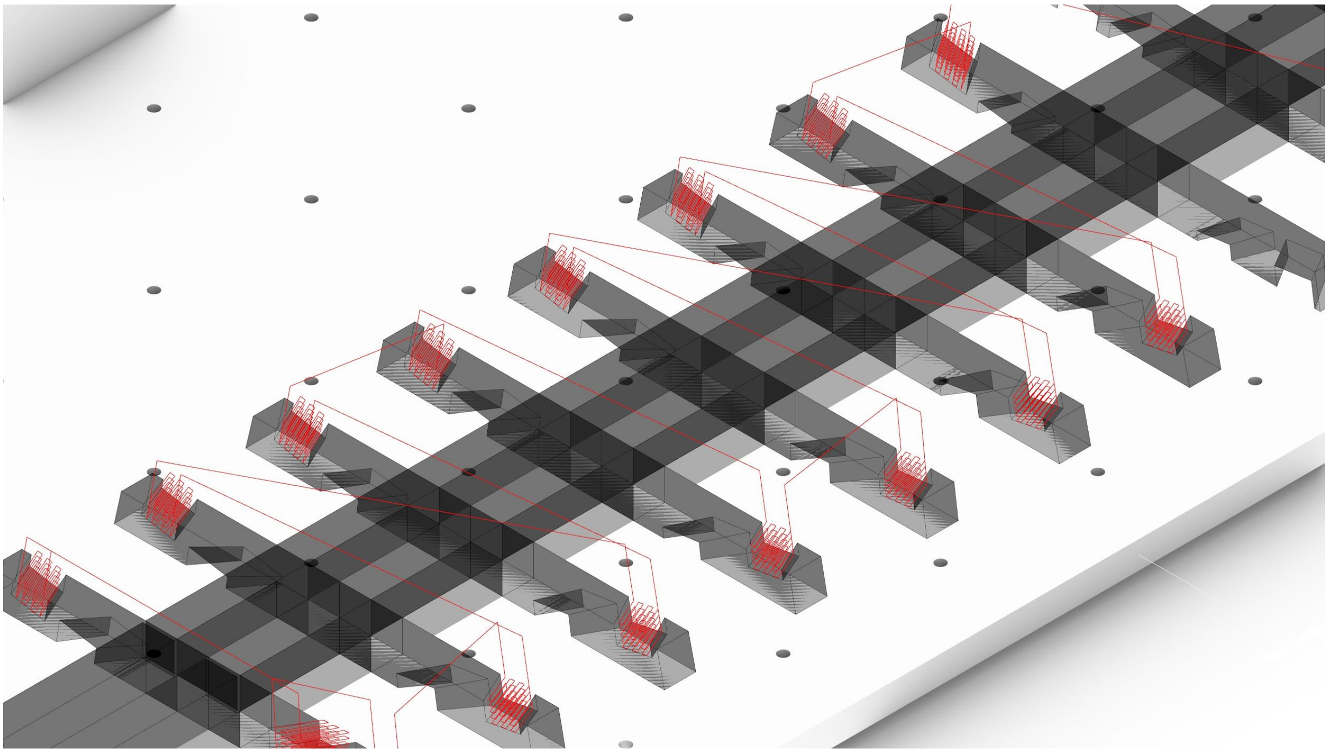


Fixture Design

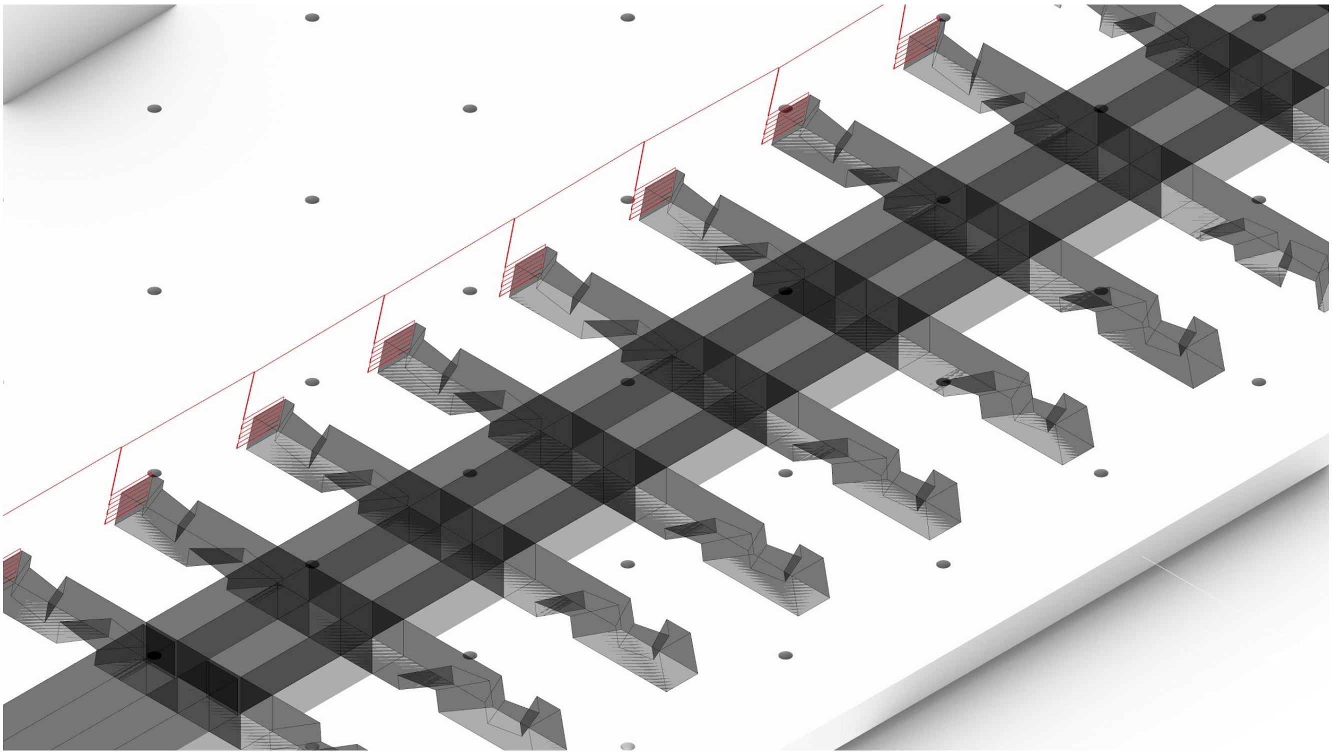


Leads and Links

Once the geometry and toolpaths were oriented to the robot and fixture setup, the finishing touches were added to the toolpaths. This included all of the auxiliary moves by the robot, its approach and retreat moves, the clearance moves, and the moves connecting the individual toolpaths.

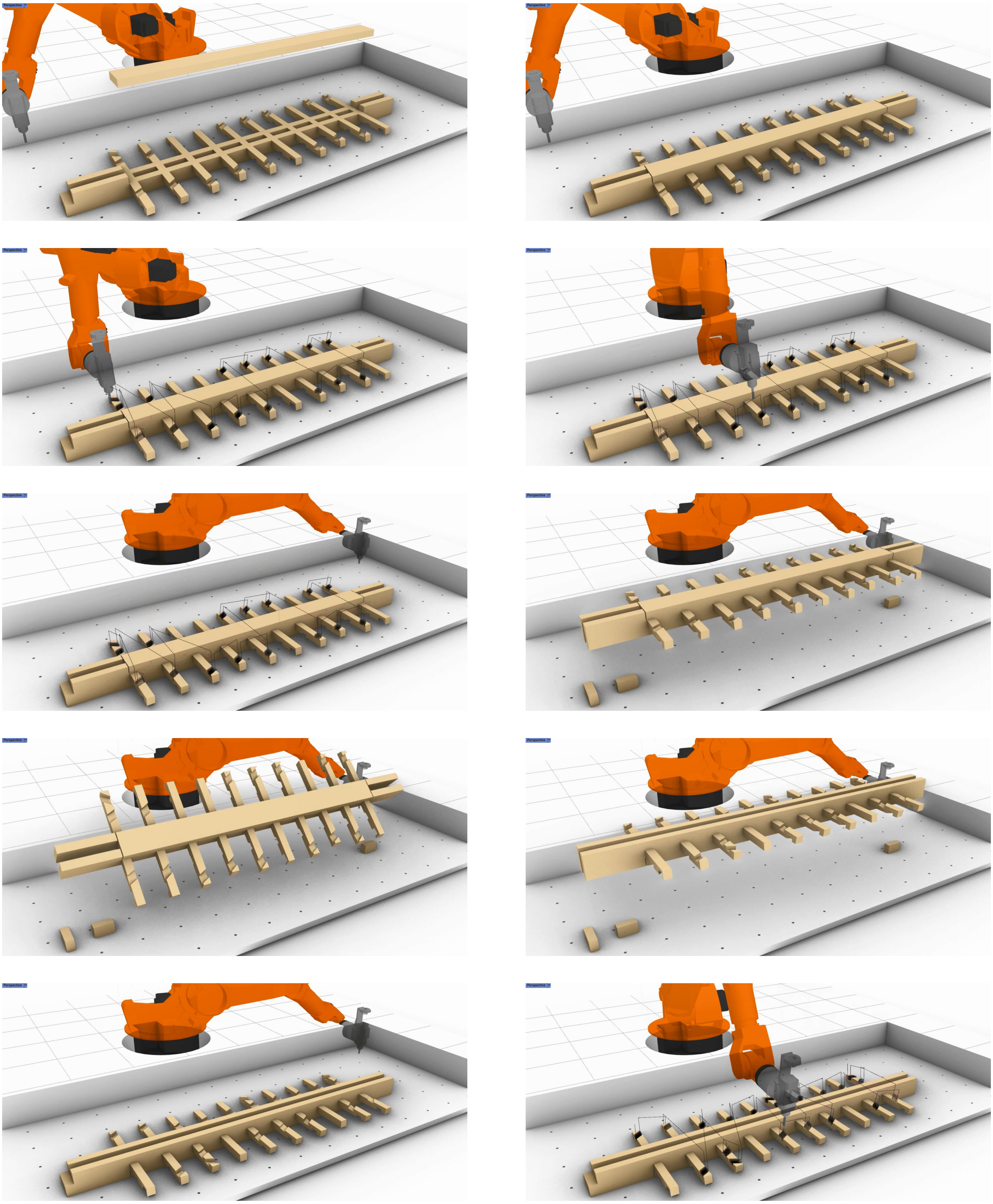


Lap joint toolpaths with leads and links



End surface toolpaths with leads and links

Full Sequence



Full fabrication sequence of lap joint milling with flip cut

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References

1. https://www.food4rhino.com/en/app/ngon