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Advanced Timber Plate Structural Design

# Joinery Generation and Fabrication

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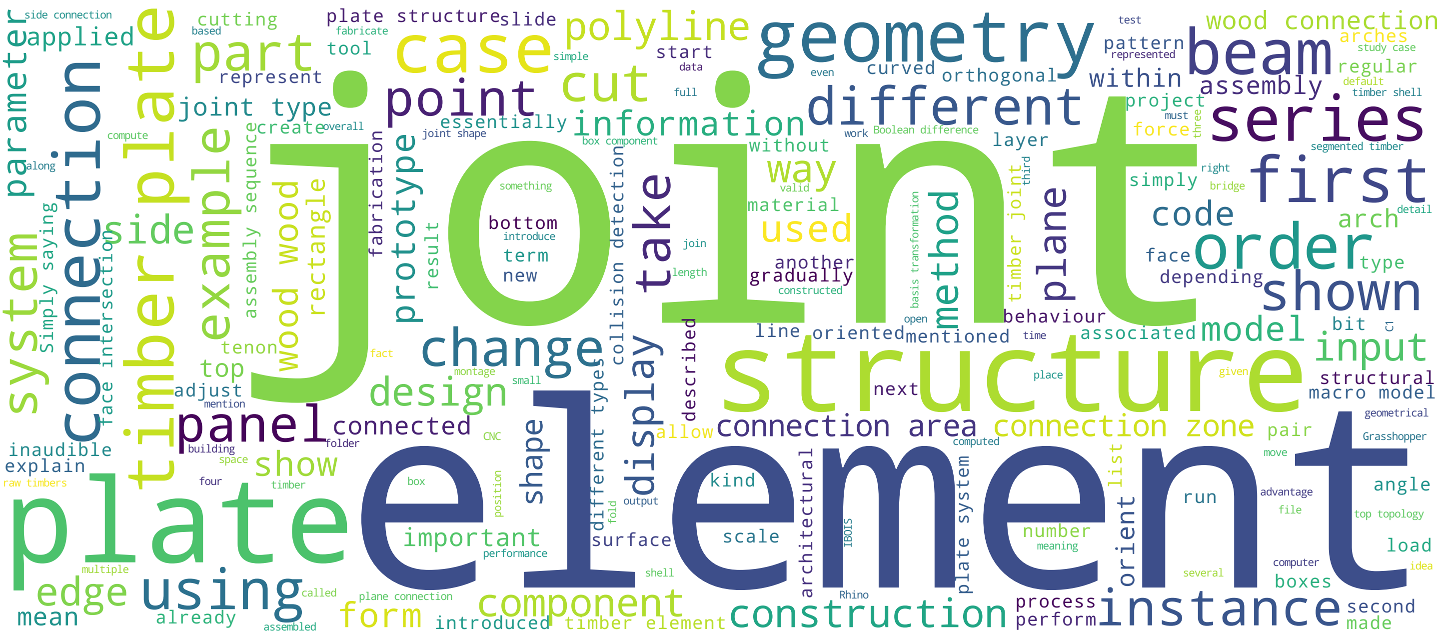
- Geometry Generation
  - Selection of Study Cases
  - Joint Types
  - Joinery Generation for Timber Plates
- Conclusion and Fabrication
  - 2D Nesting
  - CNC Fabrication




Search MOOC

Video

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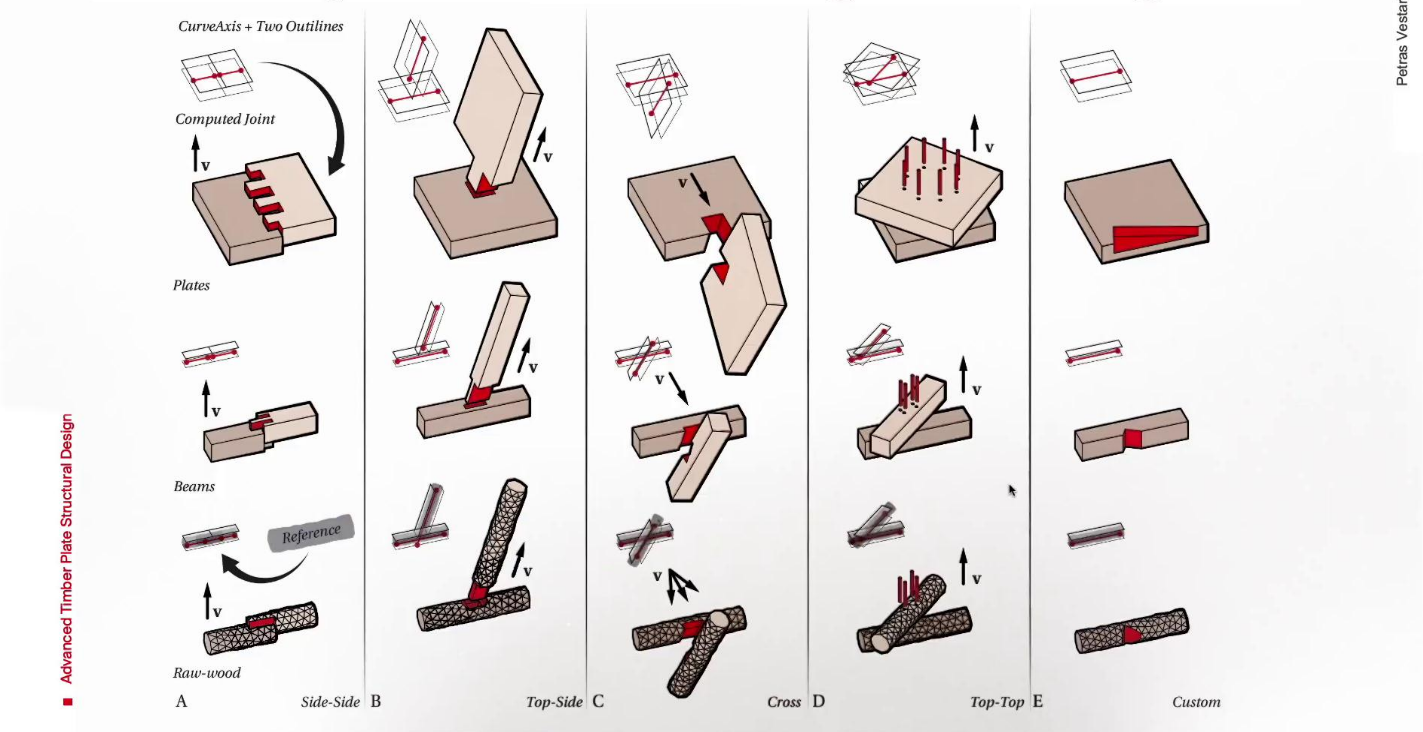
# Joinery Solver – From Regular to Irregular



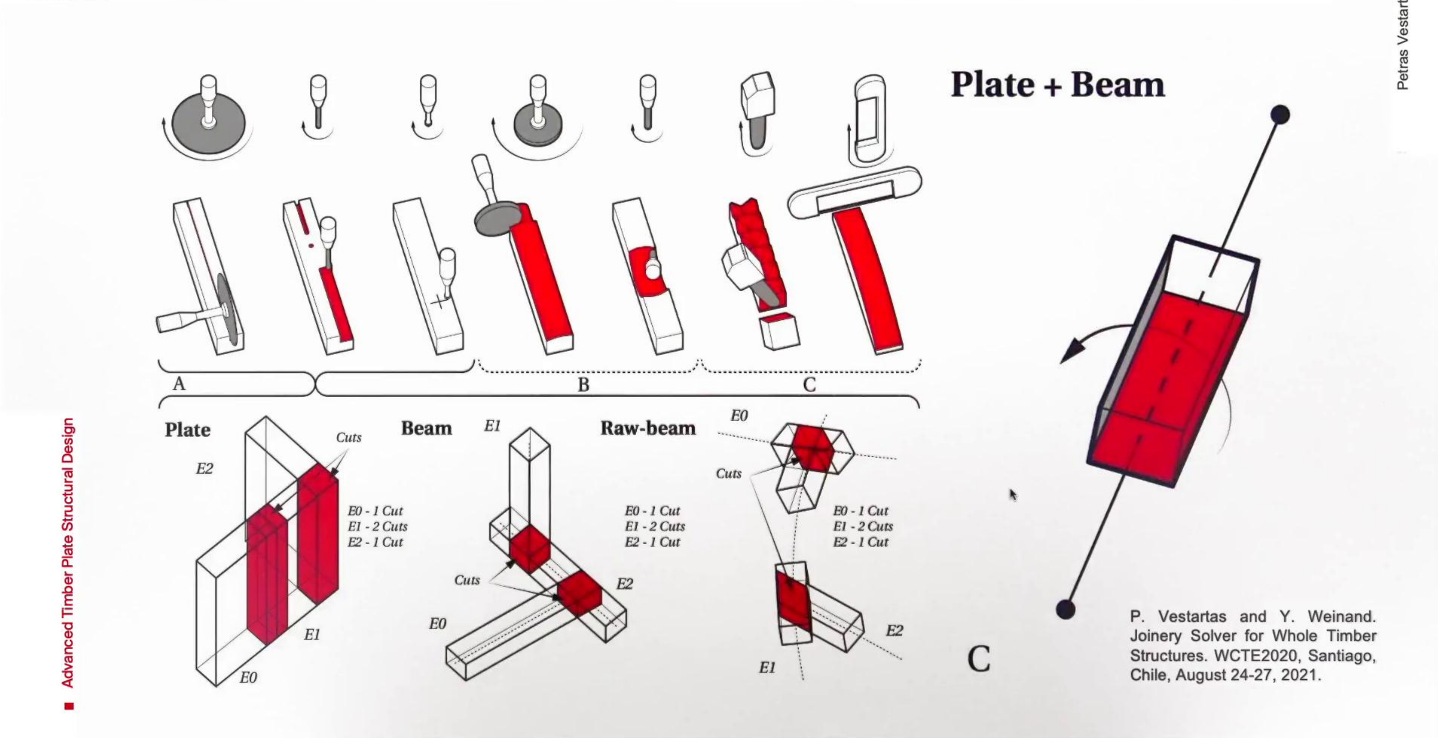

In this chapter, we are going to describe the Joinery generation methods, for the timber plates, beams and raw timbers, regarding the digital fabrication and Joinery generation. There are essentially three parts in the introduction, which is a theoretical part. Then we go more into a geometrical generation. Then inside the conclusion and fabrication, we're going to show the 2D nesting method, and the CNC fabrication. Let's start from the first theoretical part. It is really important to mention that this method is applicable for timber plates, for beams, and also raw timbers, in different types of joints and different subtypes of categories of these joints, and why this idea is valid.

Notes

Summary

0m 04s

# Element – Minimal Model is a List of Joints

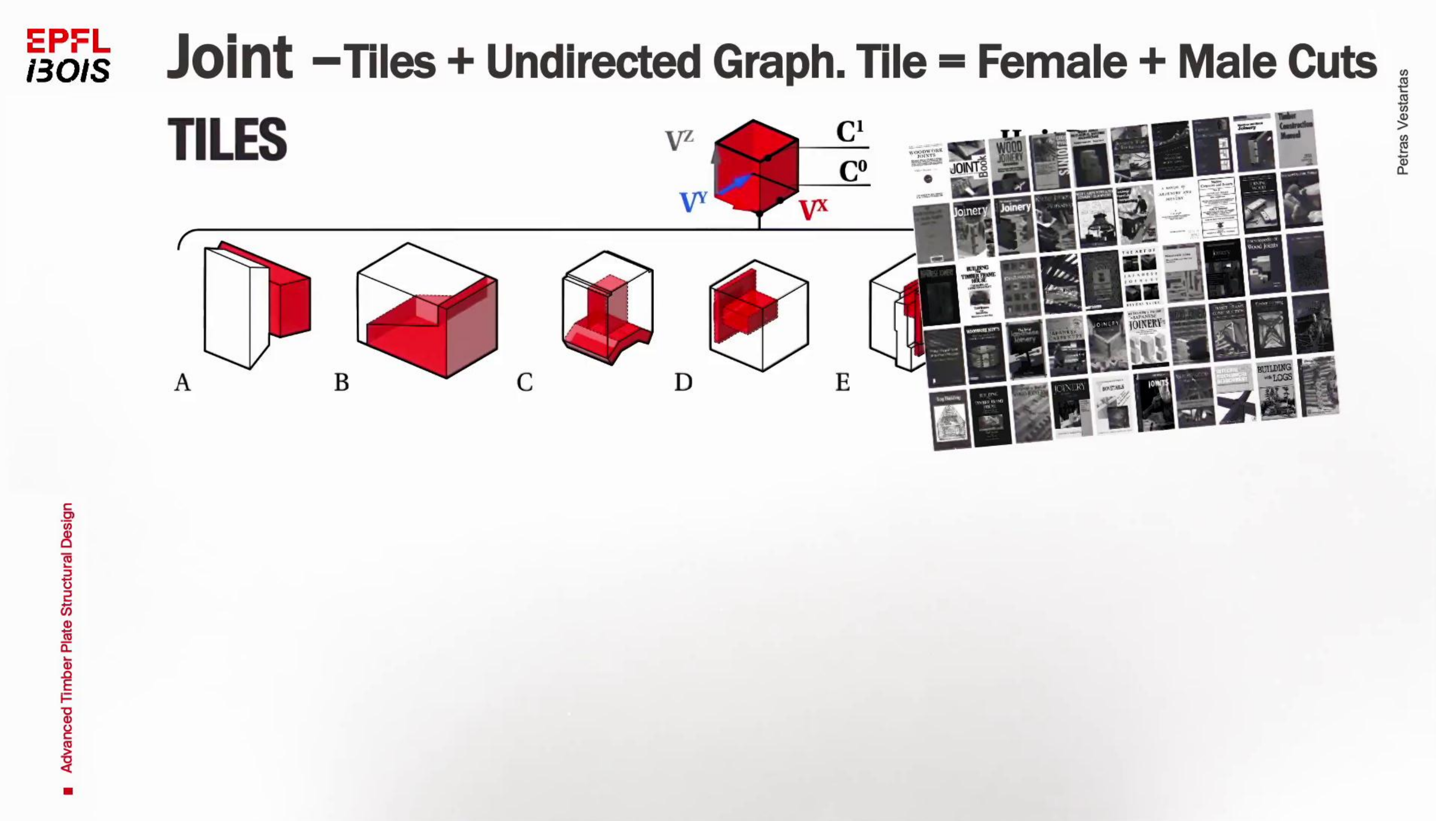



This idea is valid, is because we start describing joints, not from the description of the joint shape, but we start from what you can actually fabricate using a series of digital tools. It means that in the connection zone, we have limited set or specific set of cutting types or cutting joints that we can use that are mostly inscribed into rectilinear shapes. Then what is timber element? We showed what is the joint type, and now what is the timber element? The timber element in terms of the plate, can be described as a pair of polylines, and a beam can be represented as an axis system in a series of planes. In this proposed method I'm trying to bridge both systems to get advantage from beams and plates and represent that in one continuous code.

Notes

Summary

1m 01s

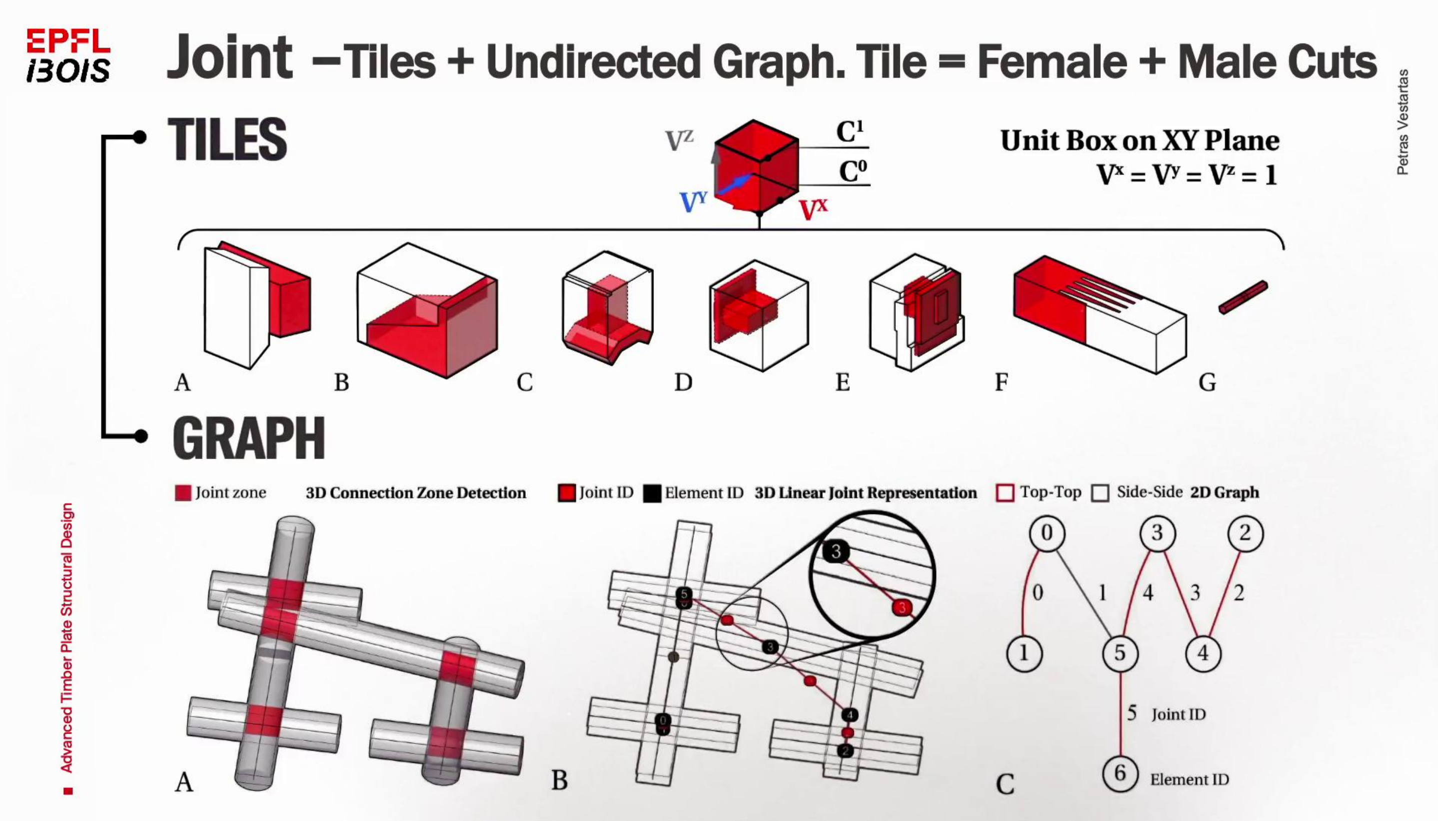



When we go deeper into the joint description, we need to get into historical documents, how these joints were described. The joints were described as a series of positive and negative parts, or part A and part B are shown in white and red. Mostly they are shown or inscribed into a orthogonal or box systems.

Notes

Summary

1m 56s



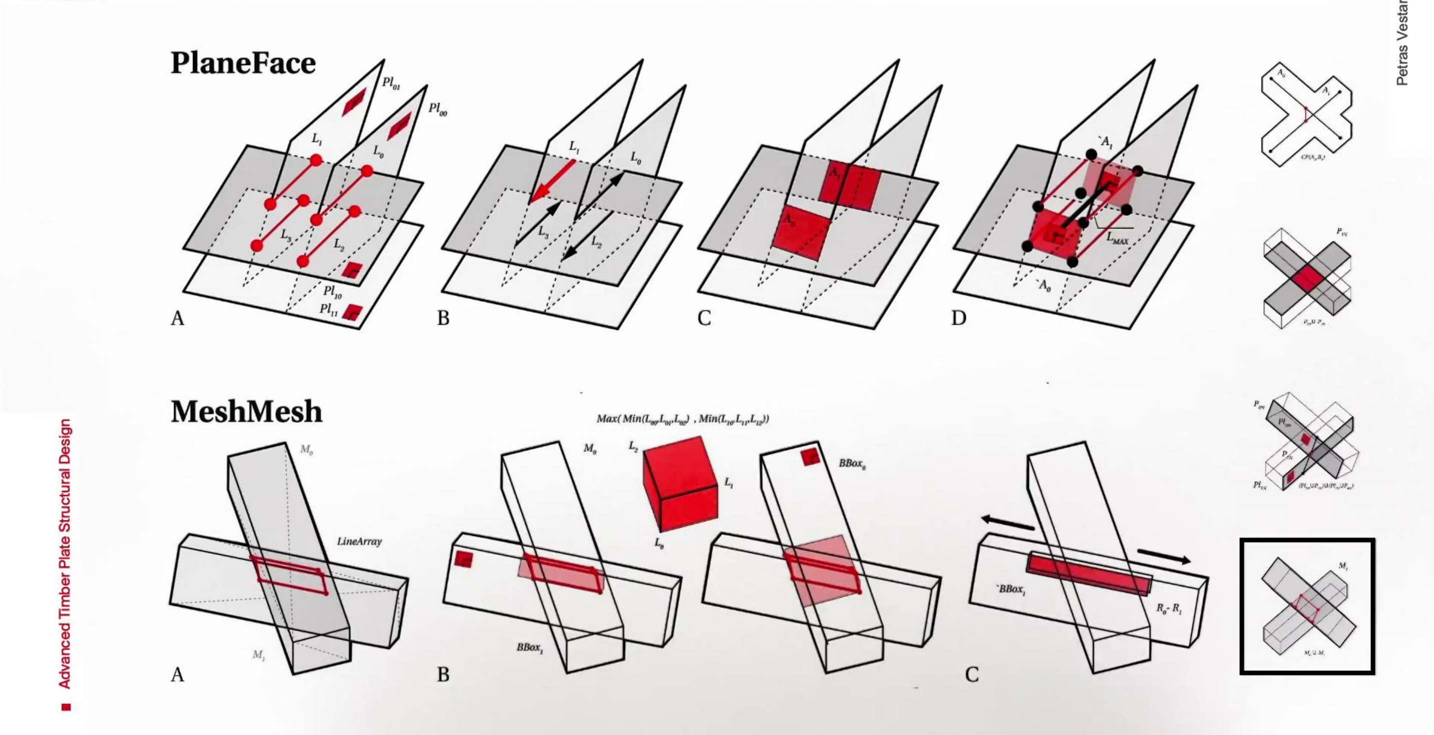

One of the authors was William Farham that explains that a timber joint is an element composed from female and male elements. You can actually see that joint the moment you fabricate, but within the element, you cannot actually draw it easily. Then, in order to represent these geometry descriptions in computer, you need to track additional information that is called graph. In this case, elements are connected top to top, or bottom to bottom, or shown in the red colour, or side to side shown in the grey colour.

Notes

Summary

2m 22s

# Search – Connection Detection

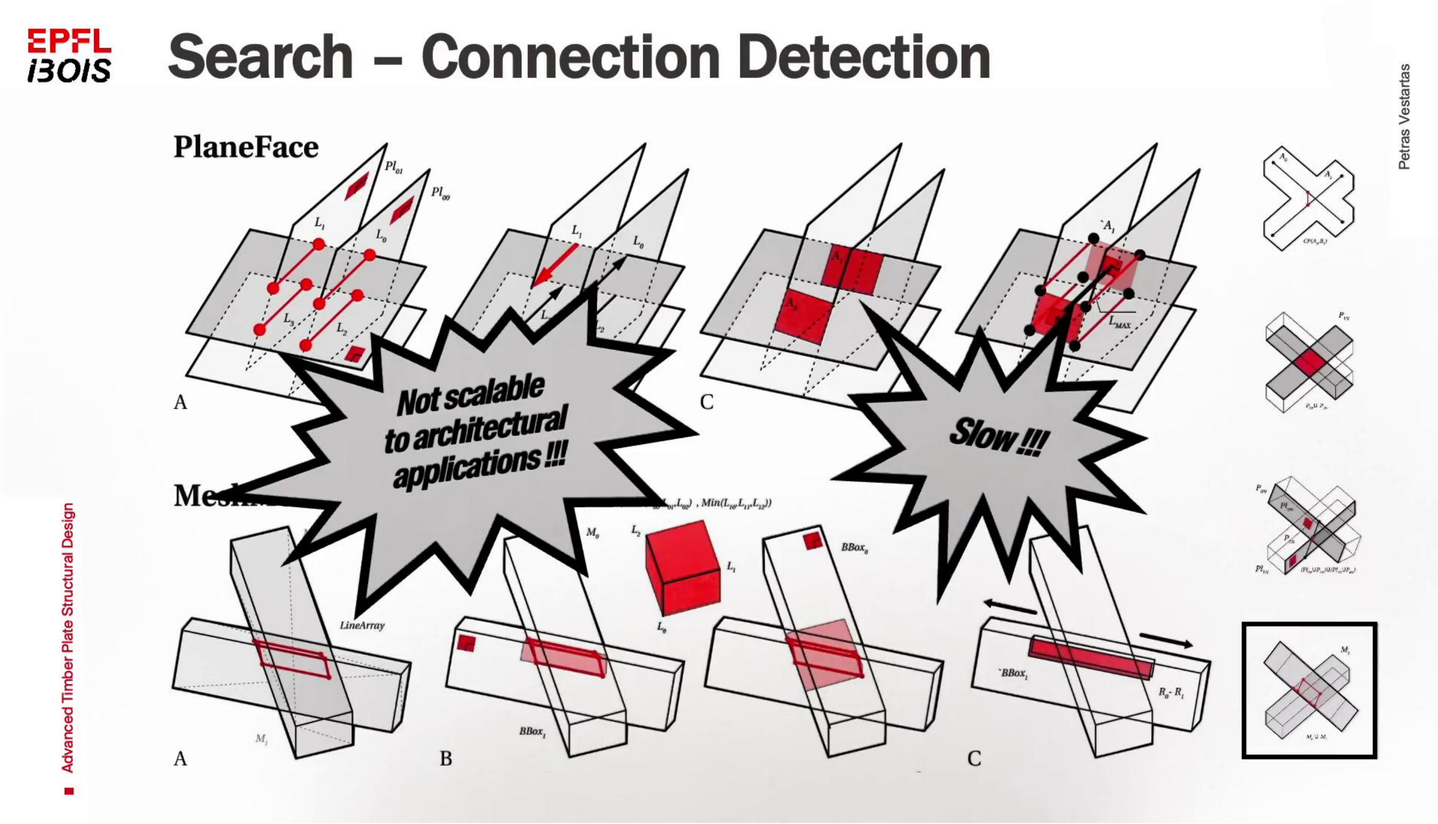



Then you need to actually find those areas where there are potential joints, and you can perform using the curve to curve intersection, face-to-face intersection, a plane to face intersection, or mesh to mesh intersection. The problem is that those methods are super slow.

Notes

Summary

3m 07s



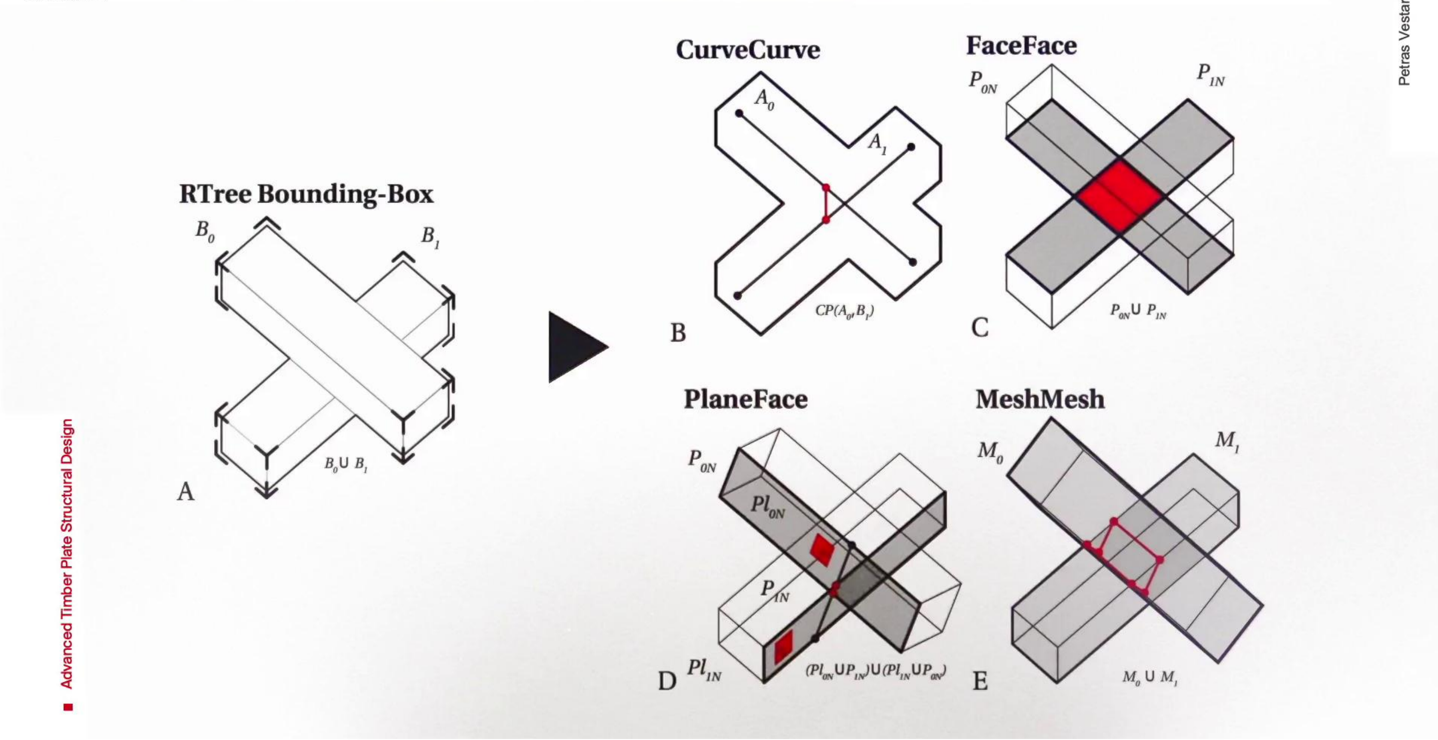

Therefore they are not really scalable to something that can be a structure, a pavilion, a real building. Simply takes too much time to compute.

Notes

Summary

3m 27s

# Search – Connection Detection



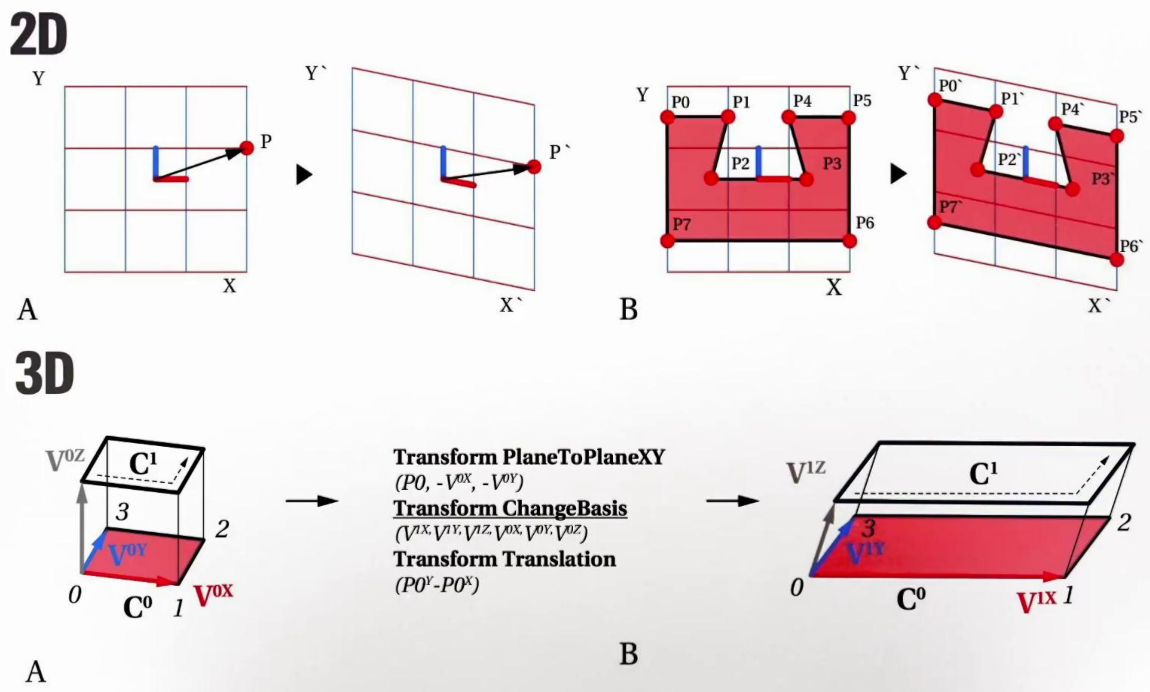

This way I'm proposing collision detection method that essentially says that, element B0 and B1 can be intersected using the bounding-box alignment, and only then you perform those slower methods.

Notes

Summary

3m 38s

# Tile – Change-of-basis Transformation

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The other part that is extremely important is how you orient a join that is drawn by hand in 2D into a 3D space. For this, I'm using the simple change of basis transformation method. Where you can see on your screen that there is a point that is a red point on one coordinate system that is orthogonal, and then you can actually move that point to another coordinate system that is not orthogonal. This operation is called change of basis transformation. A more closer example to timber joints, you can see adoptive connection, and that can be oriented to another coordinated system by simply transferring group of points. Since we are mostly working in rectilinear manner, we can use a pair of rectangles C0 and C1, and using free vectors we can orient that to another connection area that is not orthogonal but it transfers essentially the joint shape.

Notes

Summary

3m 54s

# Tile – Change-of-basis Transformation

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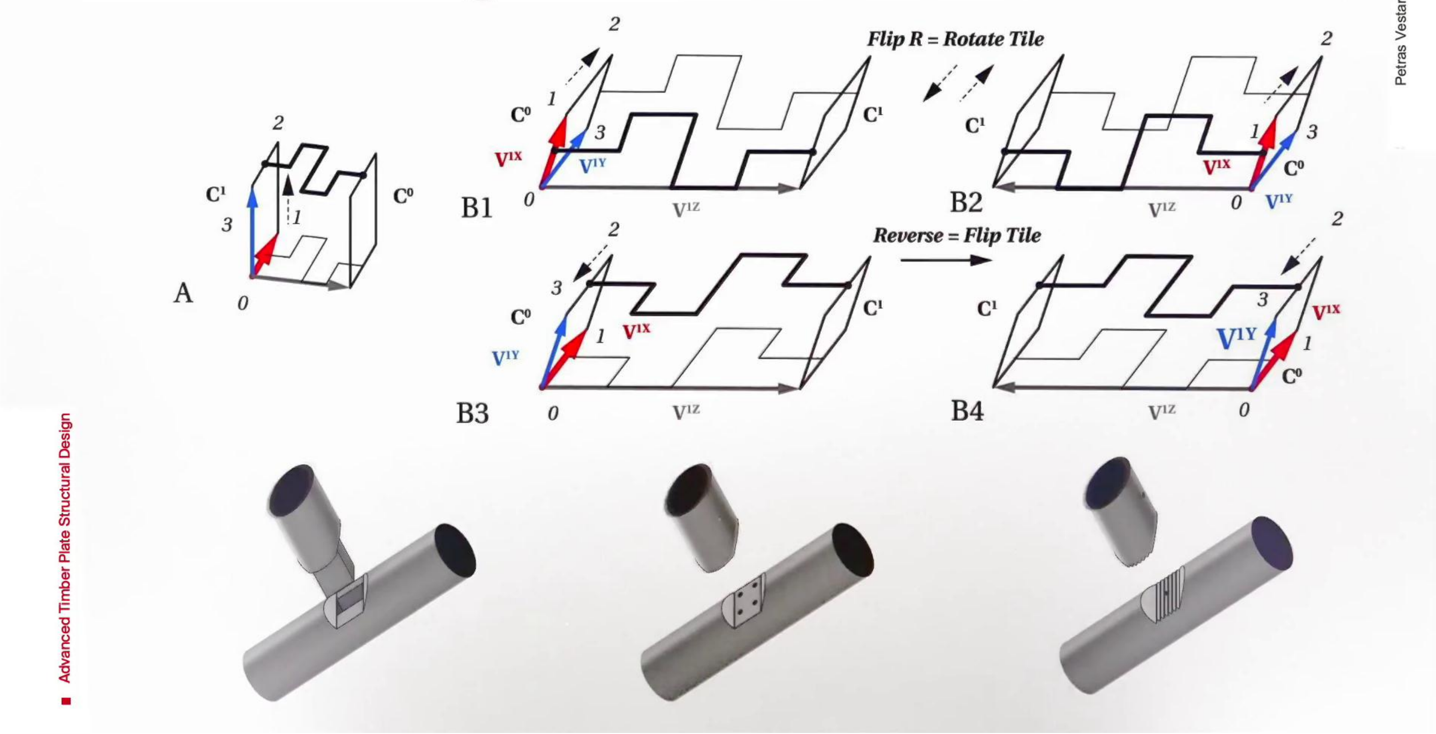


The joint shape is marked in this figure colour, for instance, that is inscribed between C0 and C1, and that can be oriented to different connection zones. It is important that you take into account the way these grey rectangles are constructed because you can have a rotated joint in a wrong position and so on, so you need to track these changes. Finally, you get this result of different types of joints, but the the key process is the change of basis transformation.

Notes

Summary

5m 02s

# Boolean Methods – Digital Cuts

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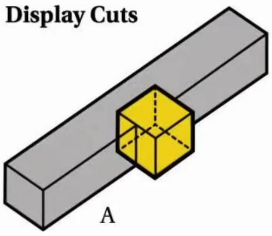


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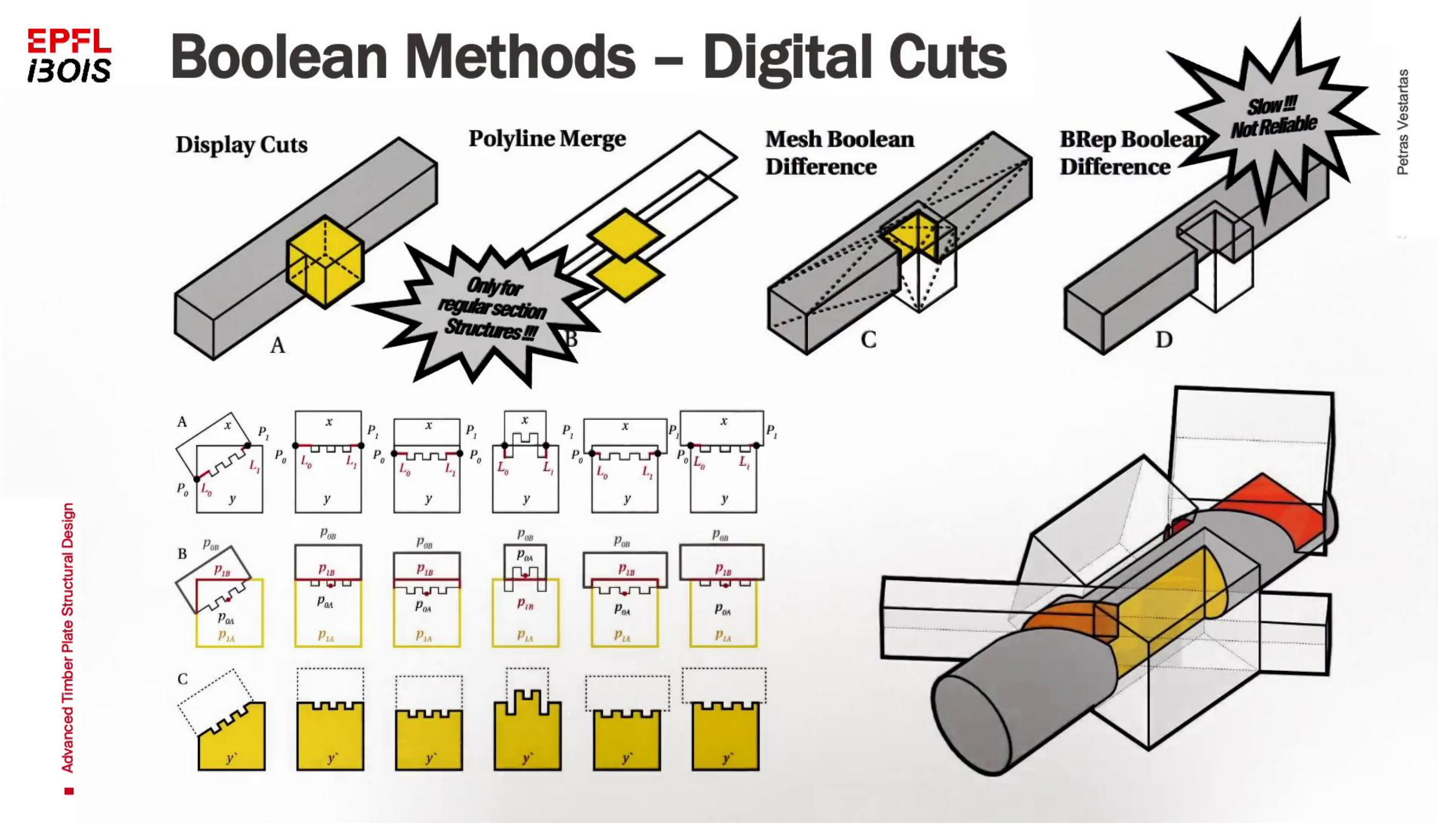
Then you need to actually cut the joint in the digital space. For sure you can display the joint as it is without any cutting procedure, so this is like a real-time process.

Notes

Summary

5m 34s




For plates, you can cut the joint on exact edge from a series of polylines. This is also relatively fast, but it's only applicable to regular rectangular structures or rectangular planner plate systems. What happens for the beams and for let's say regular elements, you need to perform either mesh, boolean or BRep boolean difference. For this, actually, there was no reliable fast method in existing CAD applications. That's for this code. You're going to employ the CAD SQL library that is helping to cut joints from different configurations in fast and reliable manner.

Notes

Summary

5m 46s

# Side-side Topology

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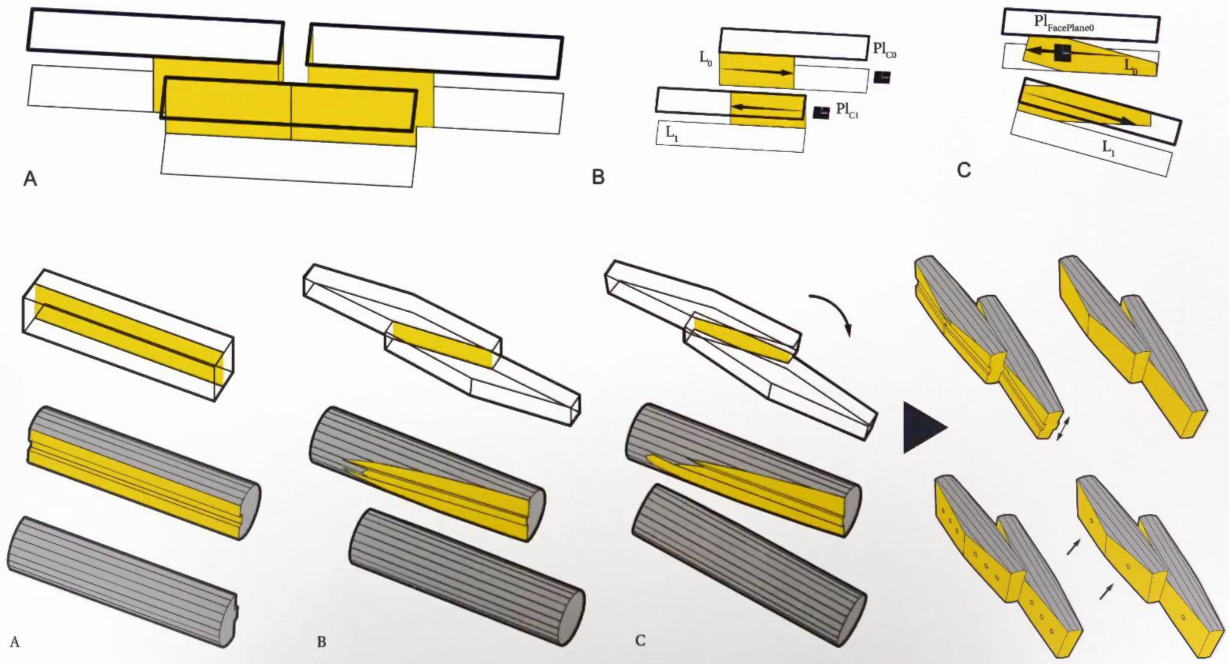


Then we're going to introduce a bit more detailed description of what the joints are and how they are found, but the first one is the side-side connection. Simply saying that between those two rectangles, you can identify the connection areas marked in yellow, and you can either detect the connections in the parallel case, or rotated case. In the way those elements are rotated, there can be actually different joinery descriptions. If you want to find some cut regular object you simply attach that element to regular objects, and you perform simply the Boolean different methods. You can then display this geometry in your computer.

Notes

Summary

6m 40s

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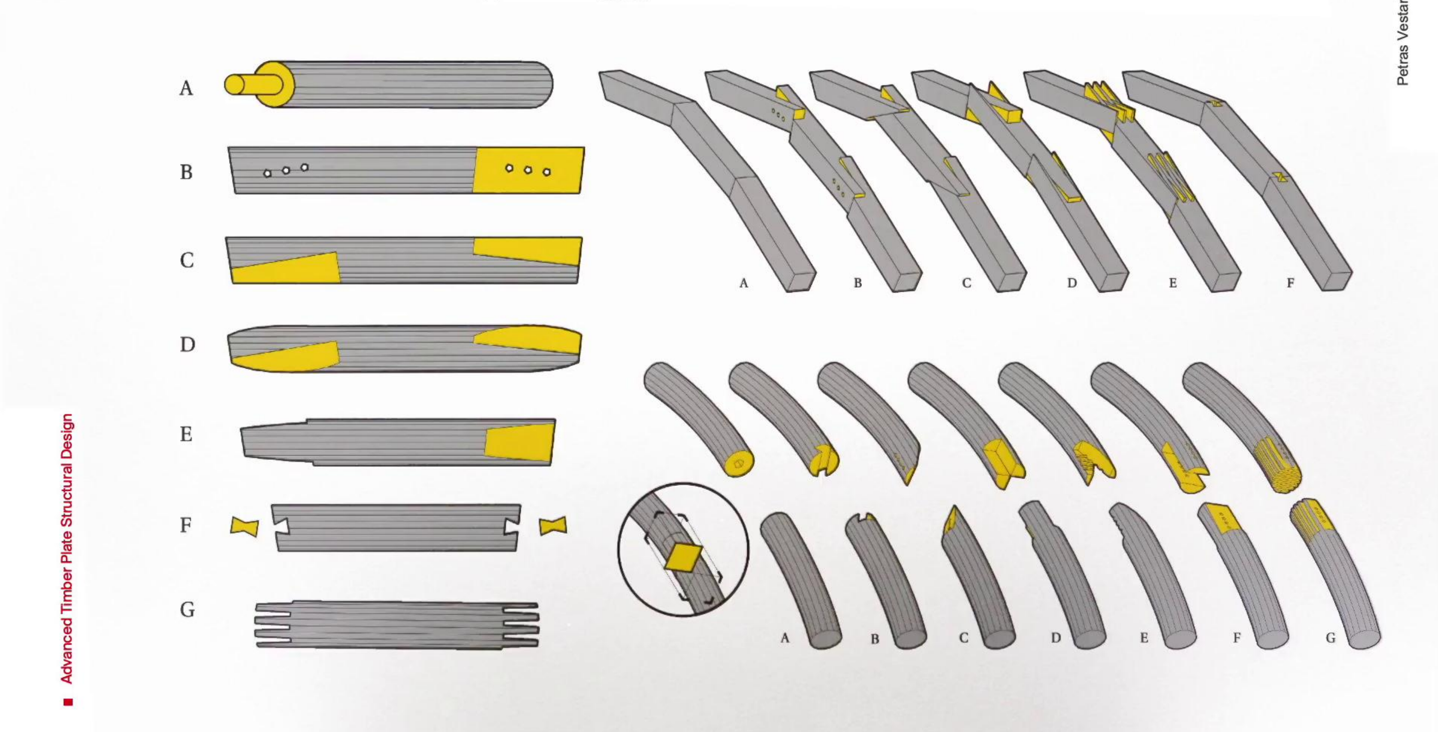
# Side-side Topology

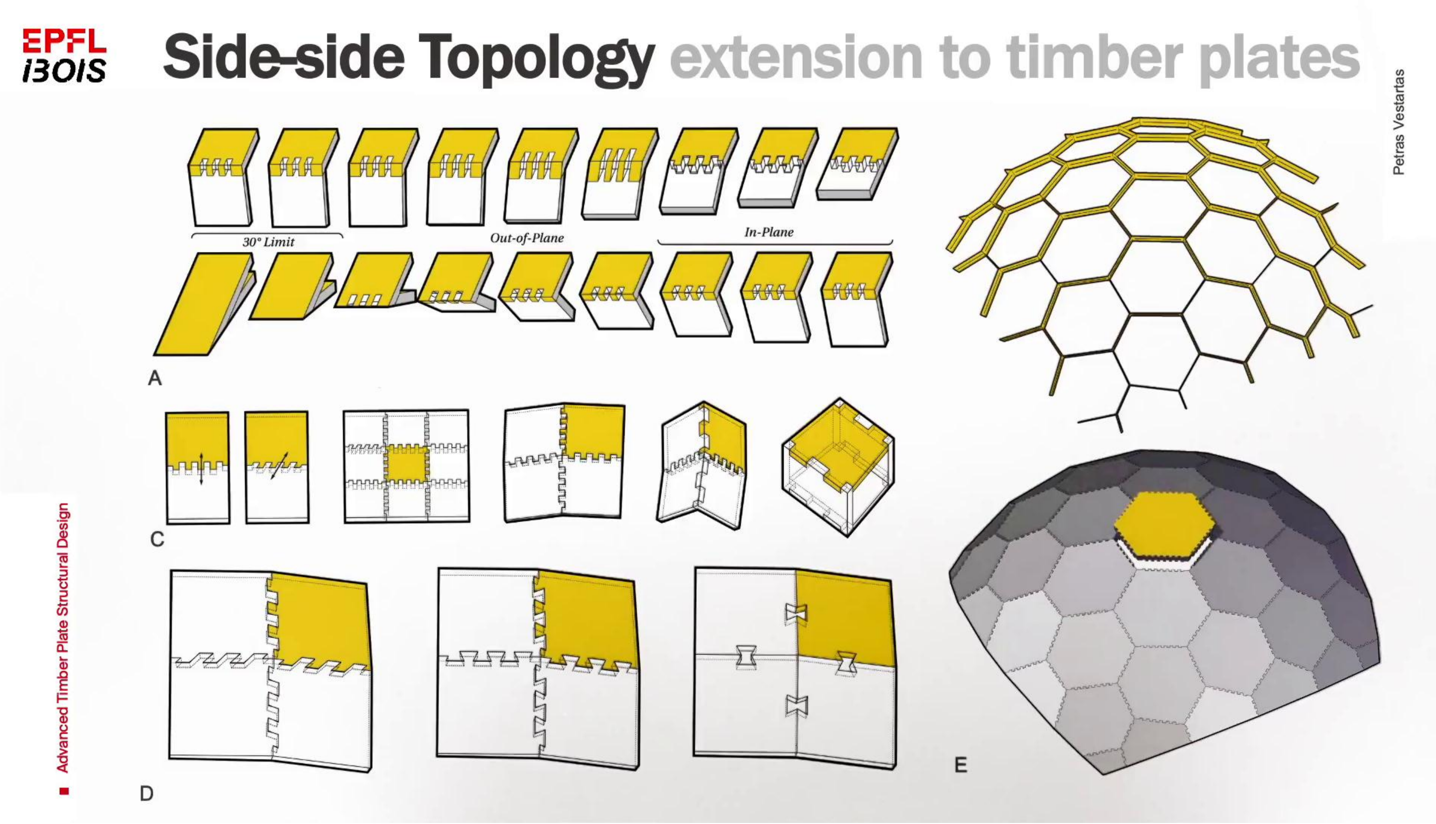



Also, you can apply these joints for short-end connections in round, rectangular or curved, crooked manner. As you can see here in the connection zones, the collision detection simply finds the connection area as a rectilinear object, and then it's cut out from regular or regular shape.

Notes

Summary

7m 26s



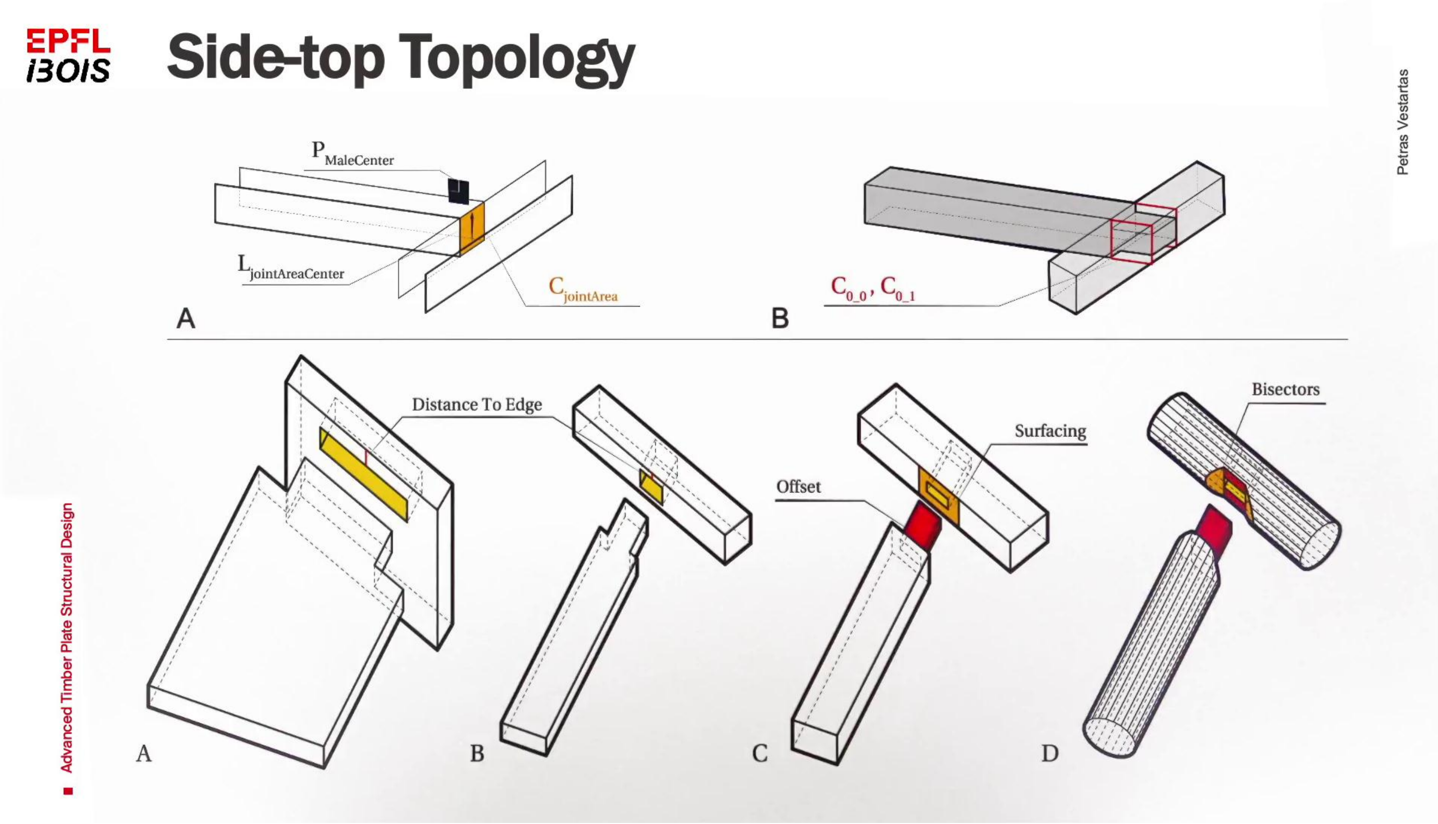

The key point was really to have a bridge between beams and plates. In this case, you can actually see that the joints were introduced depending also on the angle of the plate. You can see that there're in-plane connections, and there are out-of-plane connections. The code considers therefore the degree limit, which is a limit of maximum fabrication angle you can have on CNC or robotic arms. It also adjust itself depending on the length of the edge. Also adjust itself depending on the user given insertion direction, as was mentioned actually before, and the segmented timber shell. You can have different types of joints. In this case, there is a simple miter joint, then you have dovetail joints or butterfly joints. So you can simply change the shape of the joint while the the key collision detection method is staying the same. Afterwards you can scale the full solution based on the face-to-face intersection, down to the actual joint description when you cut out positive and negative parts from the plates.

Notes

Summary

7m 52s

# Side-top Topology

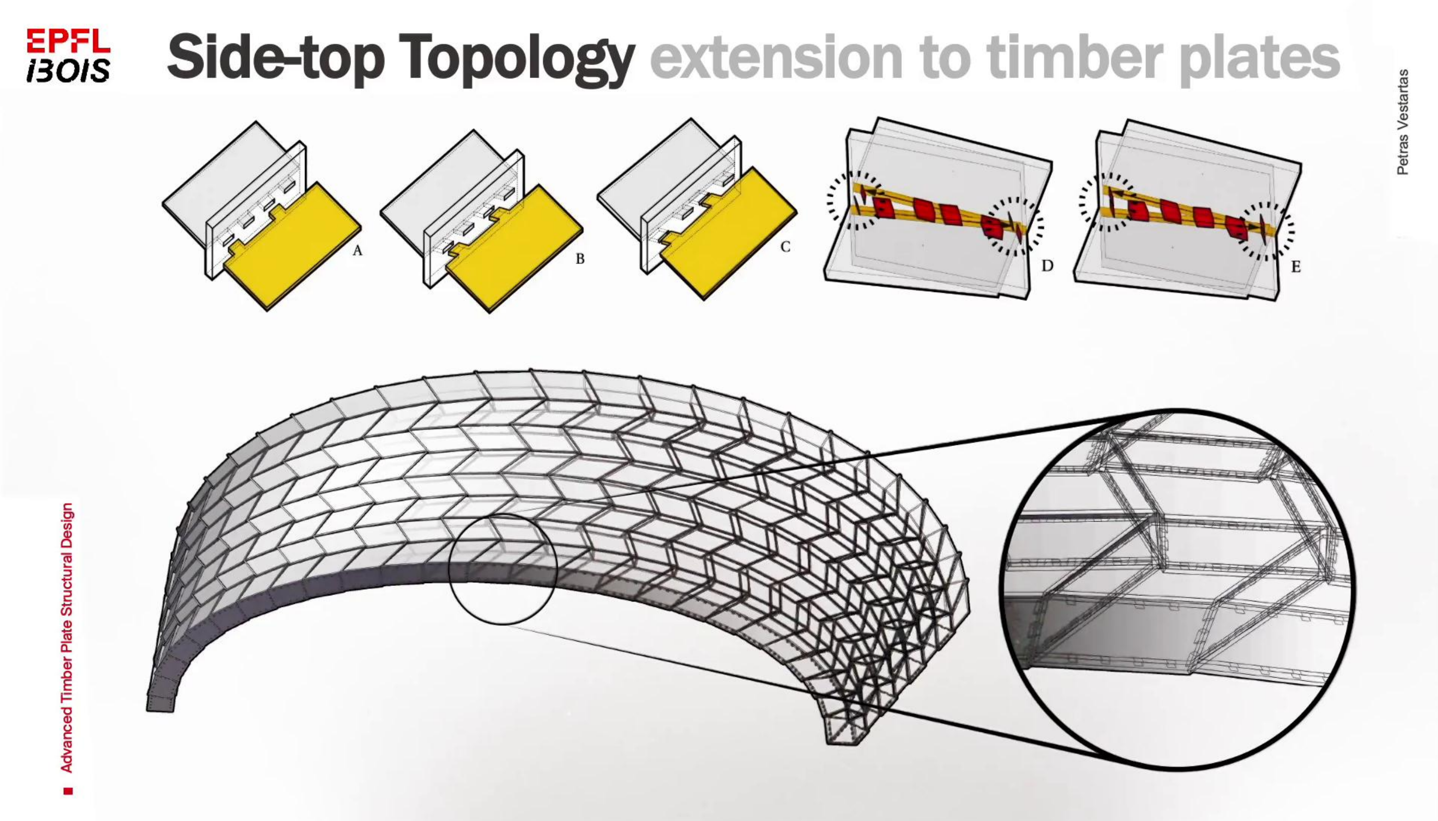



Then comes another topology that I'm going to show is a side-top topology. Simply saying the two elements are connected in a T shape, so you intersect a rectangle that is marked as a joint zone between those two rectangles. The top and bottom outlines, between another rectangle that is a side of a plate. Then you actually orient the connection element like a joint of these two rectangles, and then you can perform Boolean difference in order to display that geometry. Finally, you can see that the difference are really subtle between plates and joints. But you have to consider the connection zones. For instance, you can change joint type. If you're using a plate, you simply use a free point polyline. Then gradually, if you go to the beams, you have to have more connection areas. That's why you need to change the subcategory of the joint type. Then gradually, if there is a round shape, you can actually introduce another type in order to have more connection zones.

Notes

Summary

9m 05s

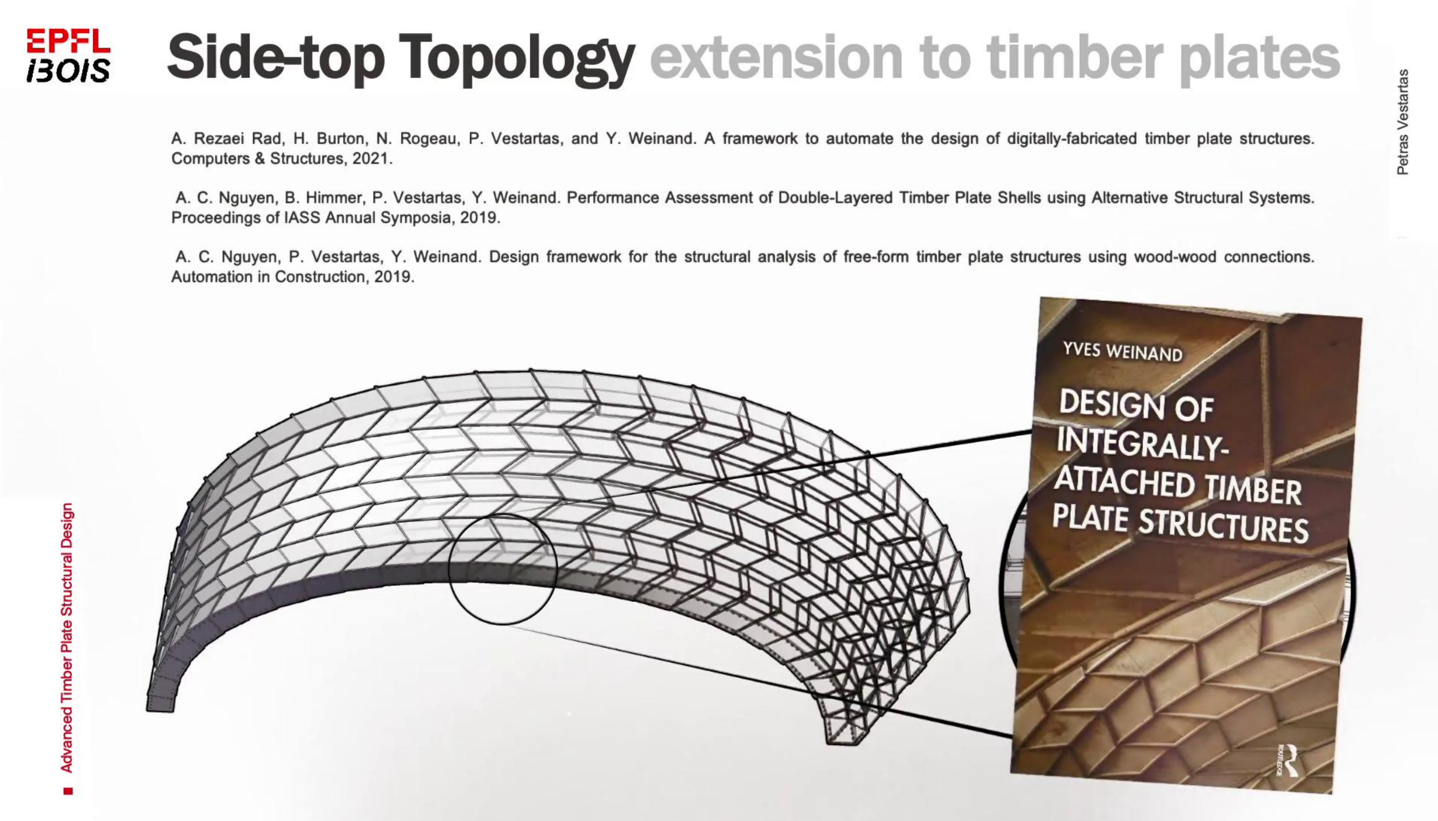



As you can see here the side-top topology were applied to a segment of temperature. As was mentioned before, this subtlety of free one-end joint, where you need to align those tenons to have a uniform alignment. Then you can get the actual connections for these arches of the one-end structure. But the basic principle still remains the same locally. First you can see the connection areas marked in orange, so you detect side-to-top topology, and also side-to-side connections marked in yellow. Then you assign joints on each edge and between each rectangular elements, you orient the joint. Then you perform a polyline Boolean difference in order to display, and fabricate the geometry. This was also scaled to to the full arch, as was shown before.

Notes

Summary

10m 18s



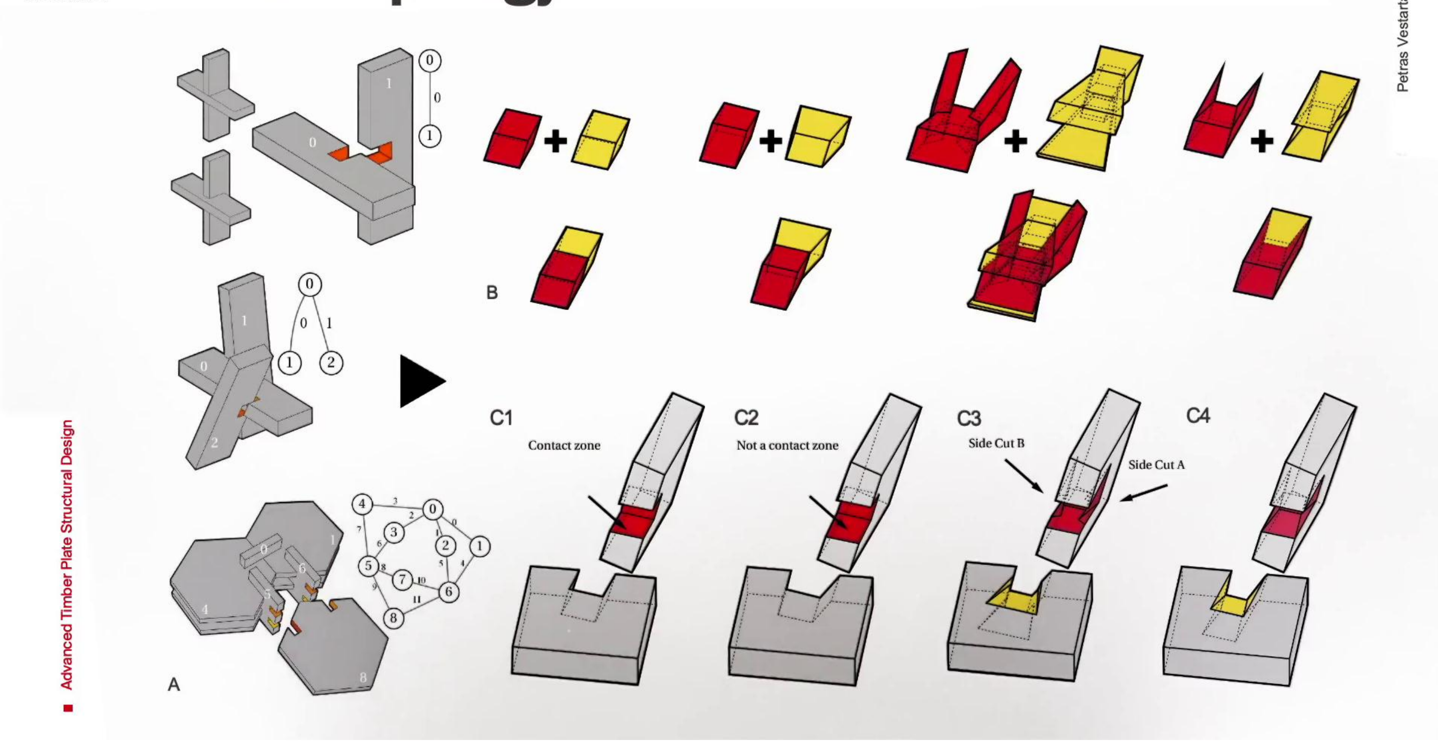

It was published in multiple research papers and also in the book, that was essentially a key part of this lecture.

Notes

Summary

11m 17s

# Cross Topology



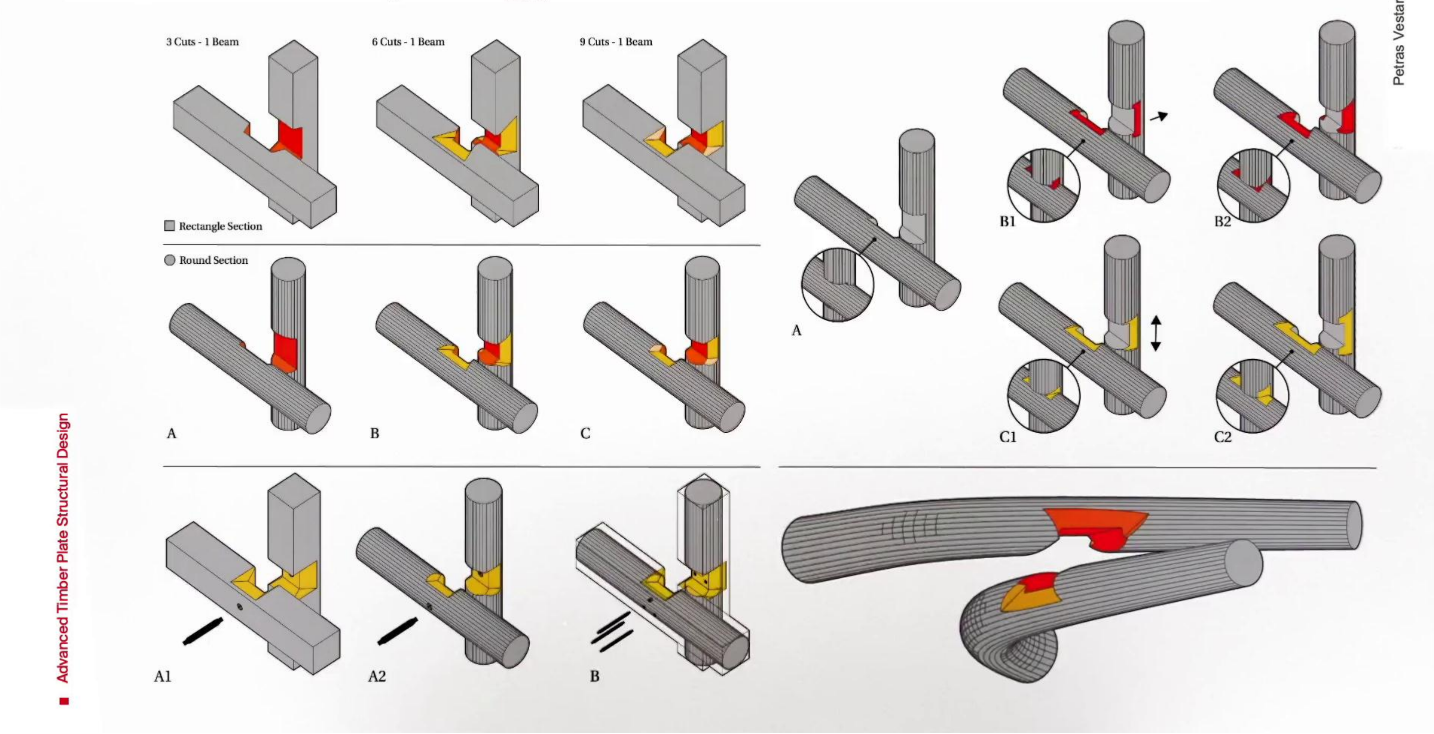

Then there is a third and last topology I'm going to show today. It is a cross topology simply saying that there is half of the intersection that is removed from element 1 and element 0, orthogonal or angle case. You can actually have different subtypes. For instance, the first subtype is actually removing the elements, in a way the intersection looks like. But then you can actually attach additional elements, to introduce conical joint. And what does it mean? It means that you can have additional side cuts if you have beams that are not regular, they're curved, they're raw timbers. If you're using plates, you simply can use C1 and C2.

Notes

Summary

11m 27s

# Cross Topology

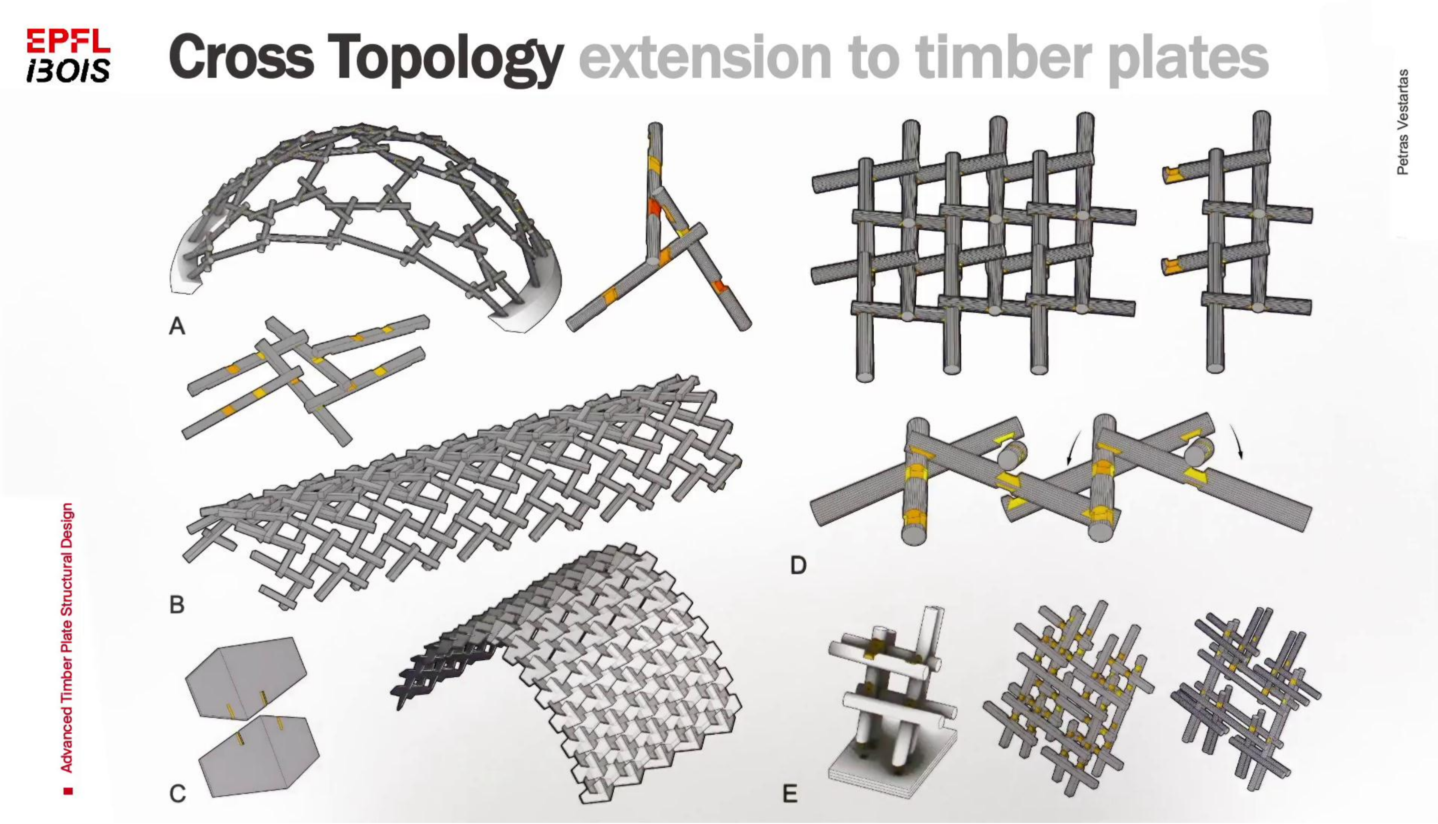



To give a bit more explanation what it means, depending on an angle, you need to have more freedom of insertion. That's why you like to cut from all different sides. If you have round or rectangular manner, using additional connectors, using additional properties of the joints. So this kind of simple cross connection can be more complicated depending on the assembly sequence we have. If it is orthogonal system or curved system you might need those additional cuts. You see here that it adjusts itself based on different angles, based on different curvature, and also different section values and so on.

Notes

Summary

12m 14s




It is important to mention that these joints were tested on existing study cases. For instance, [inaudible 00:13:04] system in round sections. Then there is a roof system based on a rectangular sections, and finally a plate system that was a past EWA project, and a few other examples in round section as well, exploring the reciprocal topology.

Notes

Summary

12m 56s

# Added Value

- Joinery generation based on a fast collision detection
- Graph methods for constructing an assembly graph
- Collection of joints from multiple projects that makes the algorithm richer
- Fabrication-aware joinery
- Applicability to regular timber objects and irregular raw timber
- Novel method for Mesh Boolean operations

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In order to recap the full presentation, I'm going to to explain or reunion and the points that we have talked about. The first point is that the joints were found using a collision-based method. So no additional mesh data structure. We use just simply by intersecting a series of elements you can find connections between elements and close to a real-time manner. Then graphs were introduced in order to keep or to record which element is connected to which one. Finally, there was also the collision of joins from multiple projects. A collection of those from multiple projects were extremely important to develop the code because you need to have real cases and you need to make assumption of real cases. That's why they were study cases on each topology of of joint. Majority of joints were actually tested physically. They are fabricated and they were actually applied to both regular and irregular structures, meaning there is regular plates or beams in rectangular sections and raw numbers. Finally, Mesh Boolean method from Siegel was implemented into rhino application that you can run this methods reliably and fastly. In the next lectures, we are going to take a look more into the actual examples. We are going to continue working on the rhino and grasshopper exploring different joint types, topologies, essentially for timber-plate systems.

Notes

Summary

13m 25s