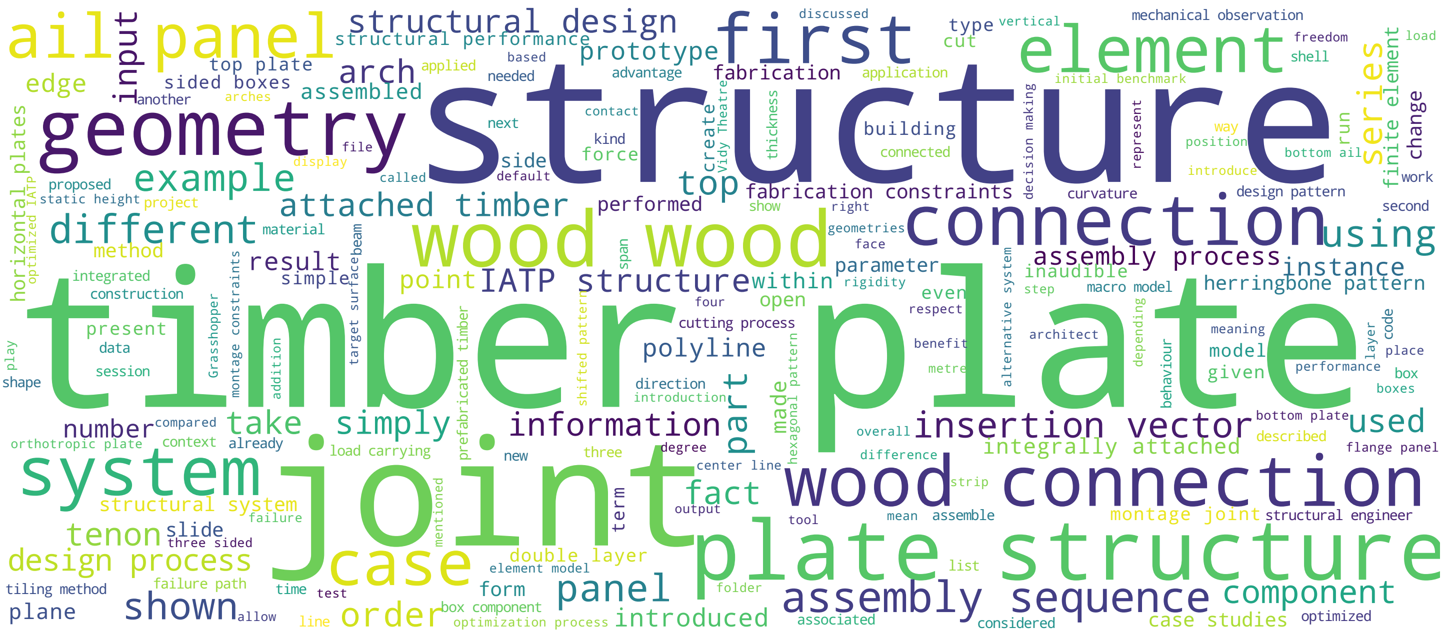
EPFL
IBOIS

Yves Weinand

Prefabricated Timber Plates

With precurved geometry



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Video

EPFL

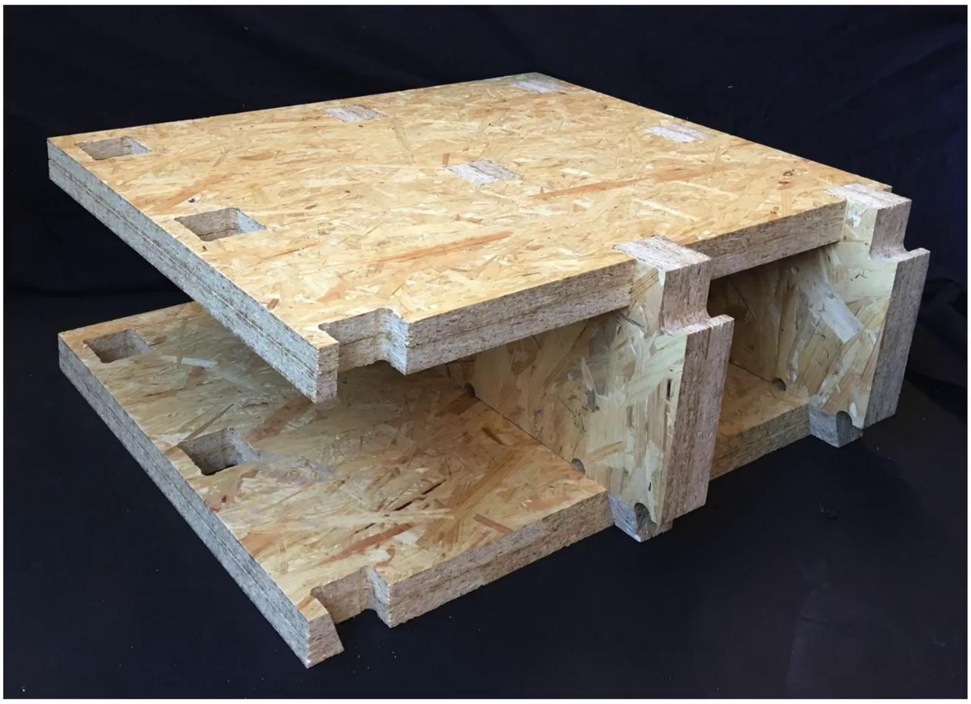
I would like to present two examples of optimization in timber plate structures. The first one concerns a prefabricated timber plates with curved geometry, and the second one, an optimized design pattern and force flow for free-form timber plates. The performance of the timber plate structures, realized by physical experiments, indicates that the overall structural behavior is controlled by the wood-wood connections and the architectural pattern. Within this context, it was realized that the design pattern used as the arrangement of the IATP structures leads first to systematic structural failure. This I presented earlier, where a continuous failure path was observed during the experimental test of the medium-scale prototype. The adopted tiling method and the associated assembly logic dictated that some wood-wood connections carry loads much more than other connections. Accordingly, the failure in those connections leads to the failure of the entire system, while other connections do not significantly contribute to the load carrying mechanism. It is within this context that there is a need to optimize the design pattern with respect to structural performance and force-form mechanism.

Notes

Summary

0m 04s

Prefabricated Timber Plates



Form and force can be optimally combined and many benefits can come out from the optimization process. Instead of fabricating wood-wood connections with bigger dimensions or instead of using additional connectors such as screws or nails, the structural performance can be considerably improved by changing the assembly pattern. We will now present two case studies which exemplifies this. Prefabricated Timber Plates with curve geometry. We have seen how the continuous investigation of global and local interconnecting geometries of timber fold structures can lead to various results and many technical and aesthetic solutions.

Notes

Summary

1m 35s

Prefabricated Timber Plates

The optimization process of the eight presented case studies is performed through continuous adaption, essentially reacting to fabrication constraints. Those fabrication constraints are generally expressed in geometrical terms, or performed through geometrical modifications. The geometry of folds, for instance, has to be adapted, as shown, with repercussions also on global form considerations within the process. One could conclude that fabrication constraints became the most important parameter of the optimization process regarding the design of interconnected timber plate structures.

Notes

Summary

2m 25s

Prefabricated Timber Plates

Yves Weinand

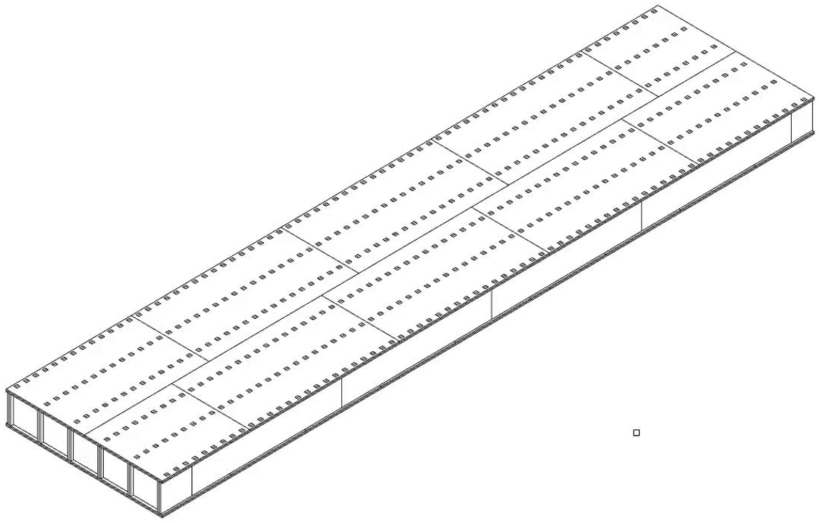
Advanced Timber Plate Structural Design

Material constraints also run into considerations. Available dimensions of timber plate panels have to be considered while processing the nesting outlet.

Notes

Summary

3m 10s



In terms of waste management, it is crucial to optimize the interaction between early formal decisions and the global scale of the structure and its repercussions locally, as far as the geometries of connections came into play. The quality of the nesting process directly conditions the quantity of not used material.

Notes

Summary

3m 24s

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Montage constraints also played a significant role in developing large-scale structures such as the Vidy Theatre and the Annen Project since montage joints must be discussed and determinated within a given logistic frame. We are not discussing the connections of the overall wooden structure to its basement, which in many cases stay as logistically classical, [inaudible 00:04:15] connected where the foundations are made out of concrete. The wooden structure is boarded onto it by means of steel plates and bolts. In the case of the Vidy Theatre, the contracting company tends clearly to define 33 independent prefabricated pieces. This decision led to two different wood-wood connections that were not initially part of the parametric model.

Notes

Summary

3m 47s

Prefabricated Timber Plates

One could argue that those later in the design process added connections of another kind are less pure and express another tectonic. Moreover, the assembly process itself differs also for those newly added connections. So both criteria appear to alter the initial, full coherence of the system and weakens it in part. In the case of the Annen structure, montage joints within the structure had to be avoided altogether. Each arch is mounted horizontally as a whole, pivoted and lifted vertically towards its final position. One could say that a montage joint needed to be avoided given the primary assembly sequence of the so-called knitted structure, and that the geometrical topology of that montage joint would turn out to be complicated to be executed, would need the addition of other kinds of connectors, and harm the coherence of the primary assembly logistic hardly.

Notes

Summary

4m 40s

To conclude, fabrication constraints and montage constraints essentially dominate the design process, the execution logistics, and the results. The underlying parametric model masters and includes all constraints and allows us to adapt and include essential geometrical choices. So how could structural design decision-making processes be integrated into the workflow, which has been illustrated beforehand? All presented case studies included also their mechanical analysis. Mechanical models have been defined and data flow has been described to facilitate finite element models and micro models conceptions as a newly defined way for mechanical characterizations of folded timber plate structures and the integrated connections. But those mechanical tools and models were implemented afterward. The main geometrical decisions were already taken when the mechanical observation started to flow in. We did not break the current iterative rearm, which divides design process into separate categories or phases. Here, the structural engineer jumps in at a later stage.

Notes

Summary

5m 50s

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Prefabricated Timber Plates

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Advanced Timber Plate Structural Design

Choose one of the significant motivations regarding these presentations and the videos in total is to illustrate that structural design investigations, within the context of the structural design of interconnected timber plate structures, have not been adequately addressed or explored yet. The decision-making processes, as described here, have not considered mechanical observations at first. How would an early input of mechanical observations improve and optimize geometrical choices that need to be implemented into the parametric master model? How would those mechanical constraints help to define geometrical border conditions and [inaudible 00:08:08] with fabrication and montage constraints, which on their side would require geometric adaptions of another kind? It is fascinating to see how an architectural synthesis is needed in every construction project, and how the architect needs to play into balance multiple contradictories and competing criteria, to see how he then deducts the most powerful concept out of those by a maximum consideration of each of them. But what about the engineering approach and the mechanical or structural design synthesis of timber plate structures using wood-wood connections?

Notes

Summary

7m 18s

We do not intend here to open a discussion on the interaction between form and structure. We do not intend to analyze how the architect and the structural engineer have to divide the competence applied to both form and structure. But we would like to open a window onto the structural design process, which would move mechanical decision-making upstream and within the basic geometric choices which underly the design of the project. Timber plate structures allow for structural design choices that might be newly integrated in a holistic manner, looking at the global picture and result. The down-to-earth chain during which the structural engineer is rebuked at a later stage to make it happen could be replaced by the primary participation of the engineer. We present two case studies respecting the described workflow by adding mechanical observations at an early stage. We have been designing a shelter structure, which has been explained earlier, with regular orthotropic plate structures. Here, a prefabricate timber plates with pre-curved geometry and pre-camber effect will be explained. We explored in detail prefabricated timber plates with standard geometry.

Notes

Summary

8m 49s

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Prefabricated Timber Plates

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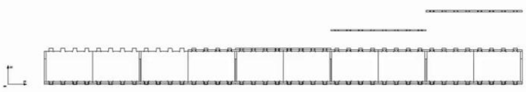
Advanced Timber Plate Structural Design



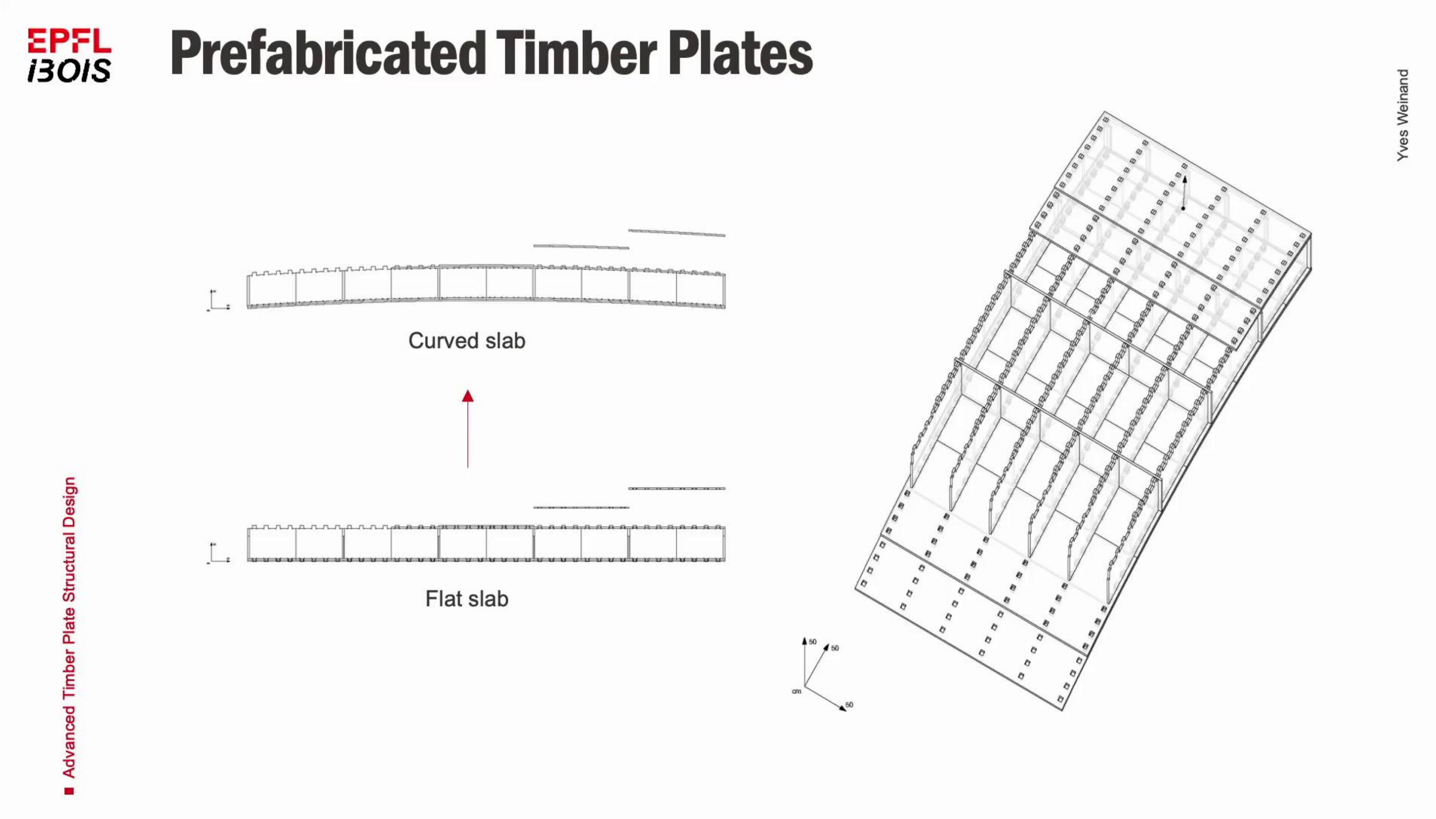
Flat slab

The double-layered orthotropic plate structure, its static height and span, the double-layer geometry and assembly of ails and flanges made out of OSB panels. The number and the geometrical contours of tenants were all related to its primary purpose. Propose a simple and recyclable [inaudible 00:10:36] structure of a new kind. In this case, it spans over 10 metre. The final dimensioning criteria for such structures are always deflections. In this case, we need to limit deflections under permanent [inaudible 00:10:48] loads at the serviceability limit state, ELS. [inaudible 00:10:55] and all dimensioning procedure allows for a fast and accurate dimensioning of these orthotropic plate structures, taking into consideration the semirigid behavior of its connections and panel disposal. [inaudible 00:11:09] we can determine the exact static deflection under such loads. Pre-camber, a beam structure, is a classical tool used to limit deflections. As the fabrication and assembly process defines major border conditions for such a structure, the pre-cambered result could be achieved by reframing the geometry of the cutting process and the sequences of the montage of each part of the system.

Notes

Summary

10m 17s

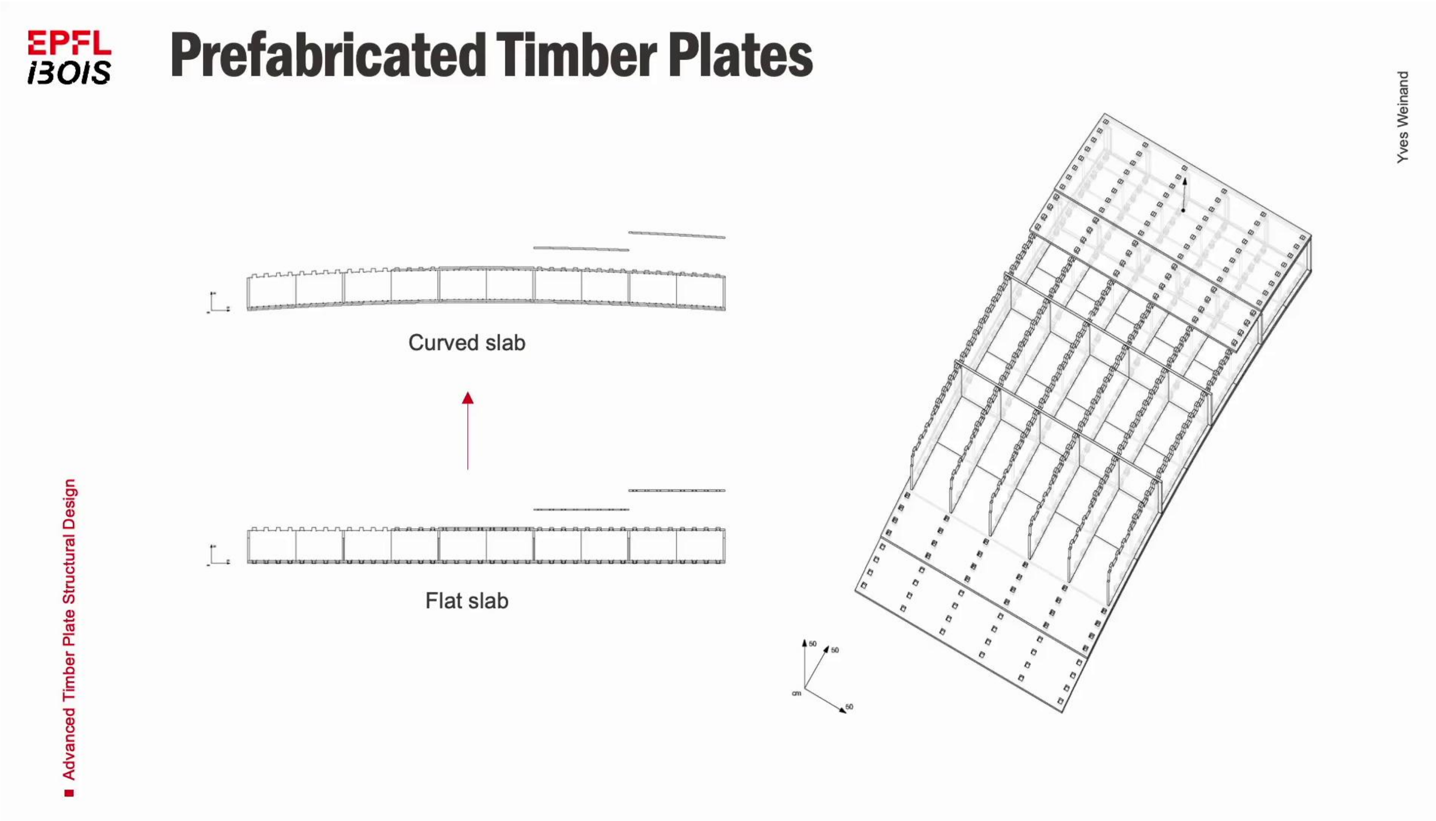


In this case, as a first type, we proposed to phrase out a curved shape for all panels used as flanges in the system. The applied shape reproduces a curvature that corresponds to a ratio of 95 millimetre over 10 metre. All panels are integrated into the system while flipped upwards, so the curvature is reversed and opposes the upcoming deflections under permanent [inaudible 00:12:05]. To introduce the ails panels and fix them onto the curved shape flange panels, we propose a second step to actively bend those ail panels by imposing the same curvature. In fact, the ail panels need to be held in that specific curved position, be then positioned on the top and the bottom of the flange panels. Still holding the imposed curvature, the ail panels need then, in a third step, to move, using a simple translation into its final position. But how do those geometrical decisions affect the assembly process and the shape of each 10? The reference project uses exclusively rectangular and orthotropic geometries for its main form as a rationalized construction system for standardized architecture. Wood-wood connections, such as tenants and rules are all phrased out in respect of the same rectangular geometrical frame.

Notes

Summary

11m 37s

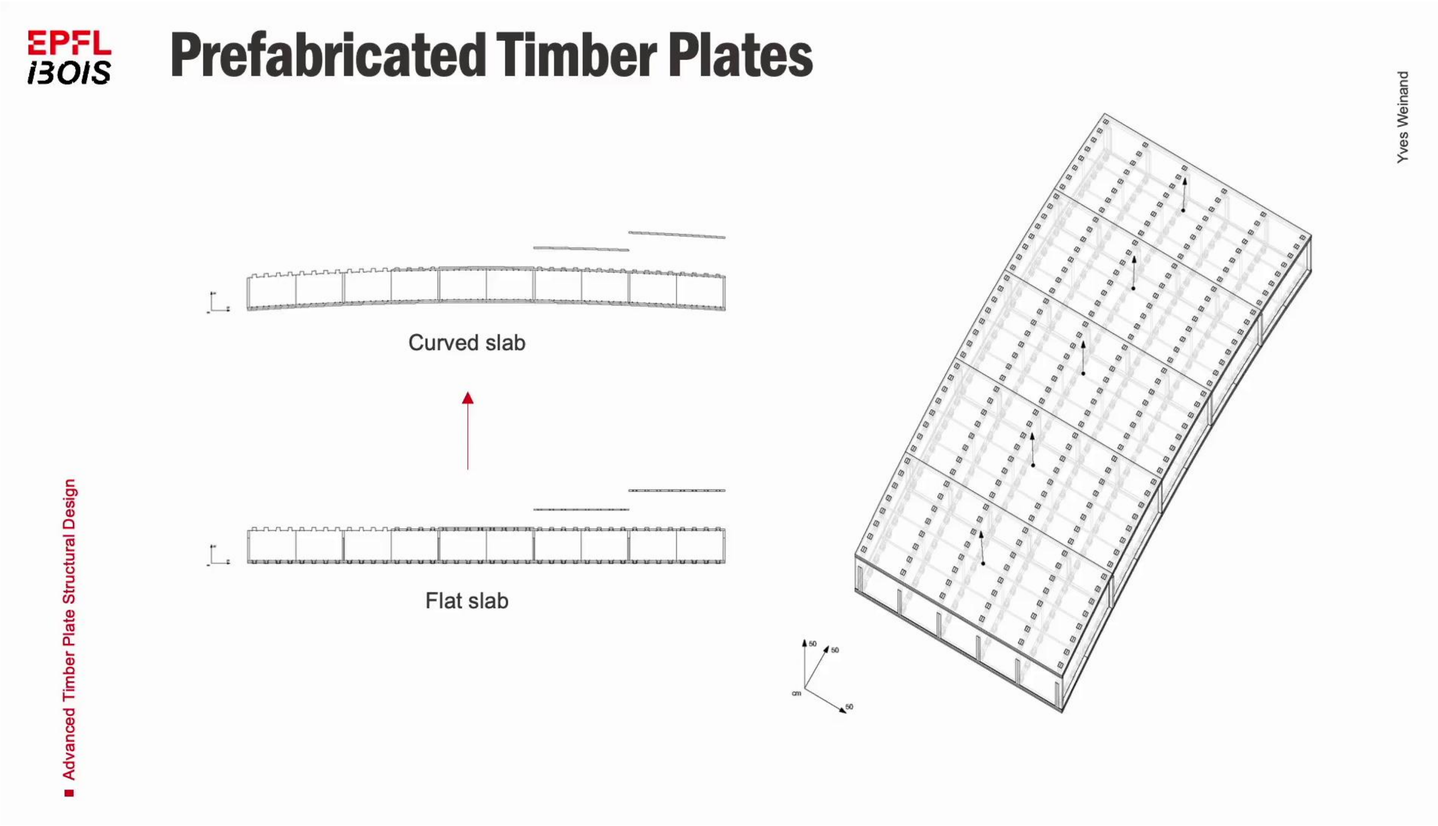


Single exceptions are mesh holes directly related to the cutting process. That mesh holes will also appear in this present proposal. When we observe the geometry, we recognize conically-shaped tenon linked to the top ail. The conic shape comes from the need to facilitate the assembly process. The insertion vector is singular and vertical. For the present case, we still have a vertical insertion vector to assemble the actively banned ail panels with the pre-shaped curved flange panel. The tenon itself can still be slight off conical shape. Still, the vertical center line of each tenon needs now to be parallel to the vertical insertion vector of the overall system. [inaudible 00:13:54] the center line of each tenon will be no more perpendicular to the curved center line of the curved-shaped [inaudible 00:14:01]. This has two main consequences. The shape of each tenon will be asymmetrical, and the shape of each tenon will be different. The described development concerns the assembly process for the top ail panel. By observing the failure, we see that the conic shape has not been reproduced at the bottom to assemble the bottom ail. Here, a distinct notch-shaped connection has been produced for each layer of the two ail panels.

Notes

Summary

13m 04s

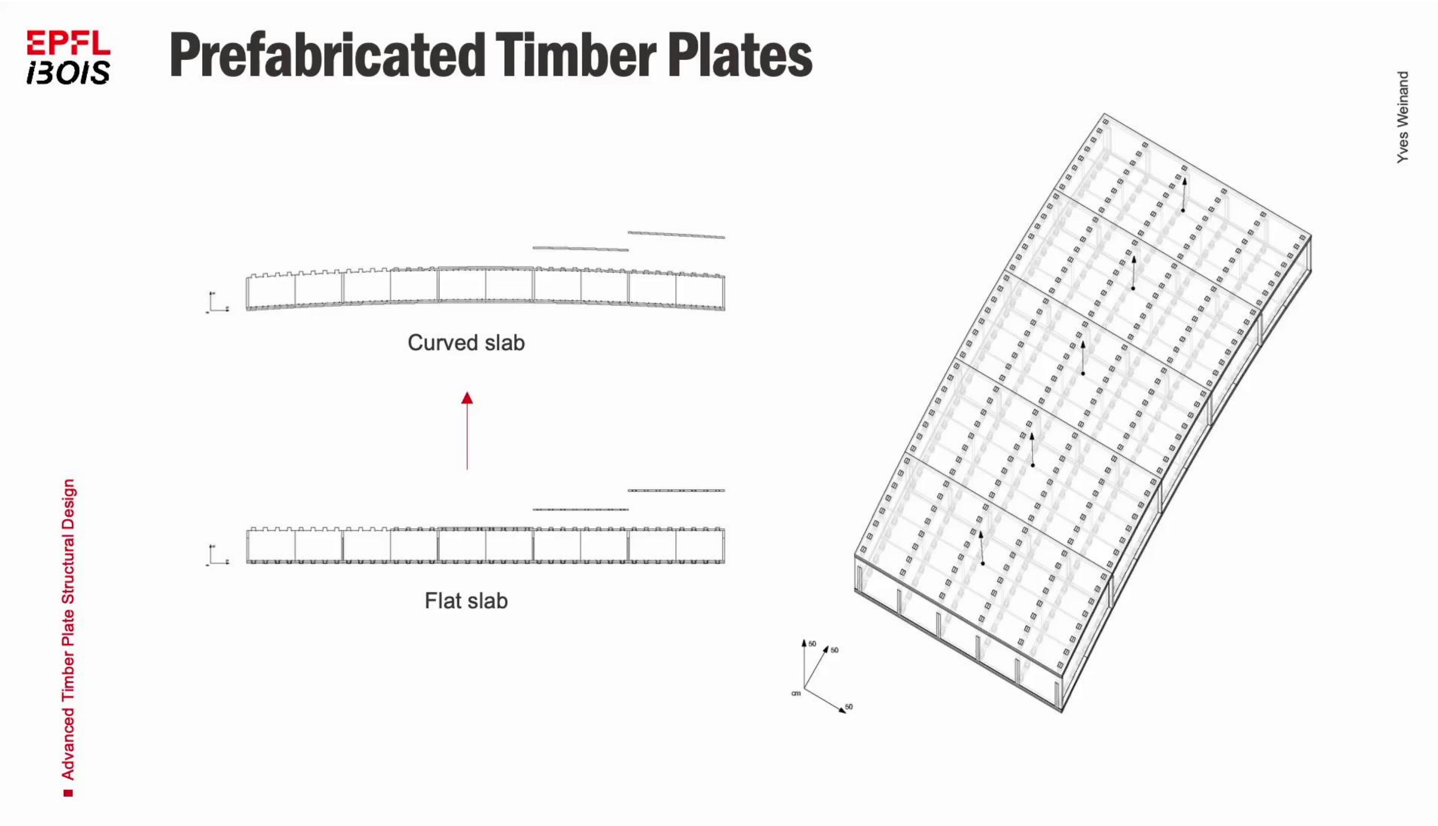


Those notches are needed to hold the bottom ail panels upwards, resisting gravity. In contrast to the top part, where both ail panels are introduced simultaneously, by translation, the bottom ail panels need to be introduced one by one. In the present discussed case, both actively bend ail panels must be held in their curved position and assembled one by one. The consequences of this demands equally for revision of each notch shape since its rectangle position is not more respected. The notch itself will undergo minor geometrical adaptions. Still, those adaptions need to be coded, nested, and finally cut. Once those geometrical observations are understood and integrated into the fabrication process, we end up producing a very efficient mechanical system. As mentioned before, the system will probably balance deflections [inaudible 00:15:37] while finding a perfectly horizontal proposition. Creep could even be considered by increasing the value of the static deflections by a given creep factor and apply those additional deflections to the chosen pre-cambered curvature. Notably, we achieve a system with an augmented mechanical capacity without additional production costs, by simply manipulating its geometrical configuration.

Notes

Summary

14m 32s

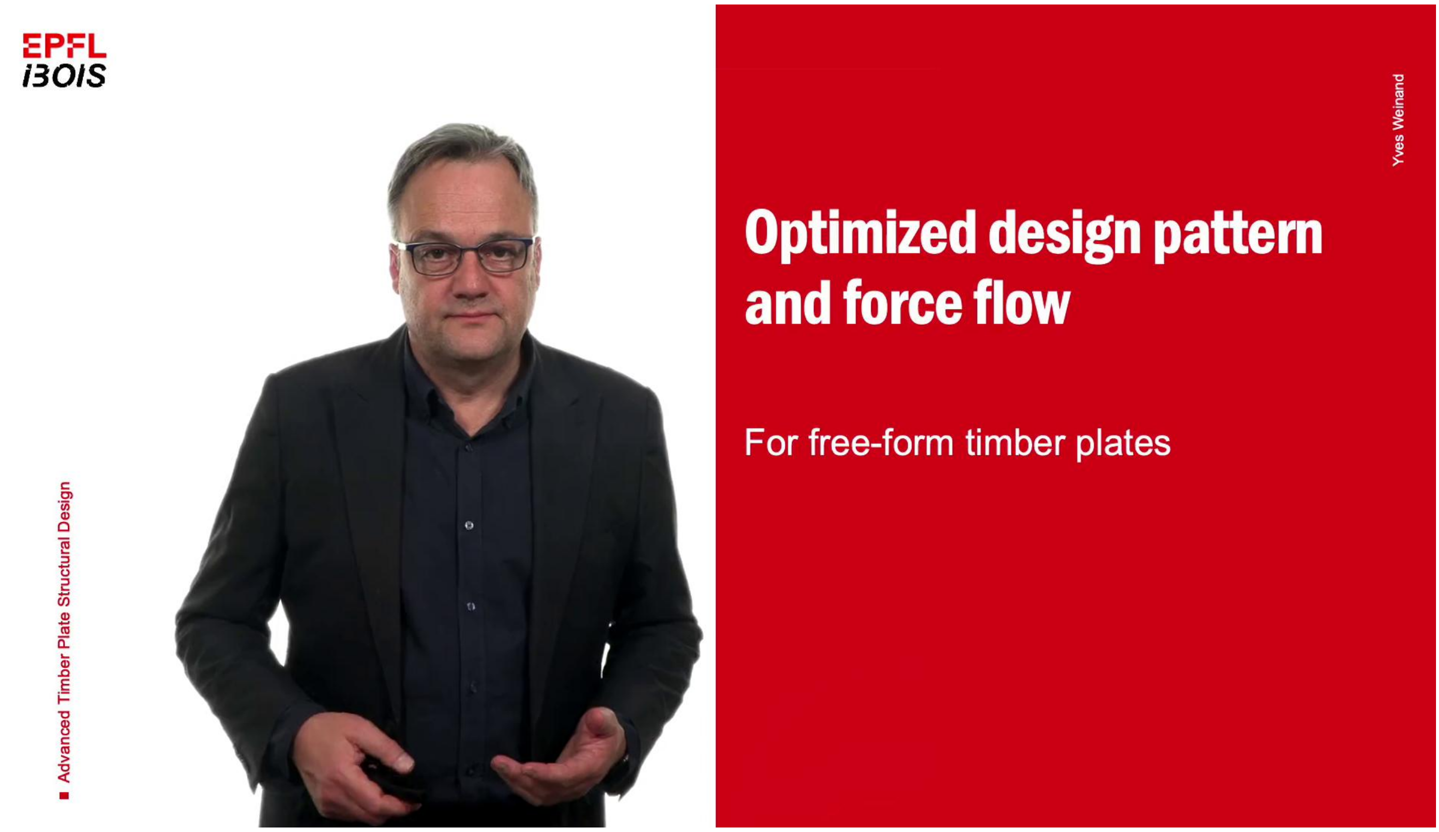


The amount of material is the same, the coding stays almost similar, as does the cutting process. In addition to achieving our initial goal, we also benefit from the following side effect. The very moment we relax the actively bent ail panels, those panels will tend to relocate into their initial horizontal position. By doing so, they will add a snap-fit effect on each knot or tenon, which will benefit the rigidity of each connection and the whole system.

Notes

Summary

16m 05s



Second case study concerns the design optimization in double-layer, double-curved, free-from [inaudible 00:16:50] attached timber plate structures. The optimization is performed by introducing contact.

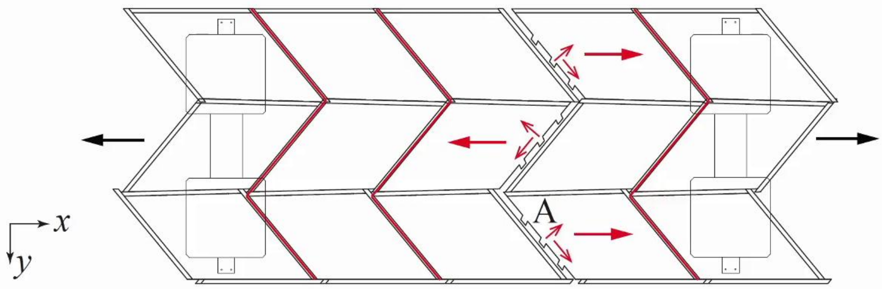
Notes

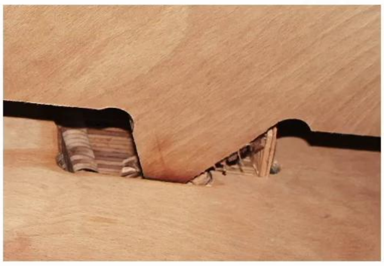
Summary

16m 40s

Optimized design pattern and force flow

Yves Weinand





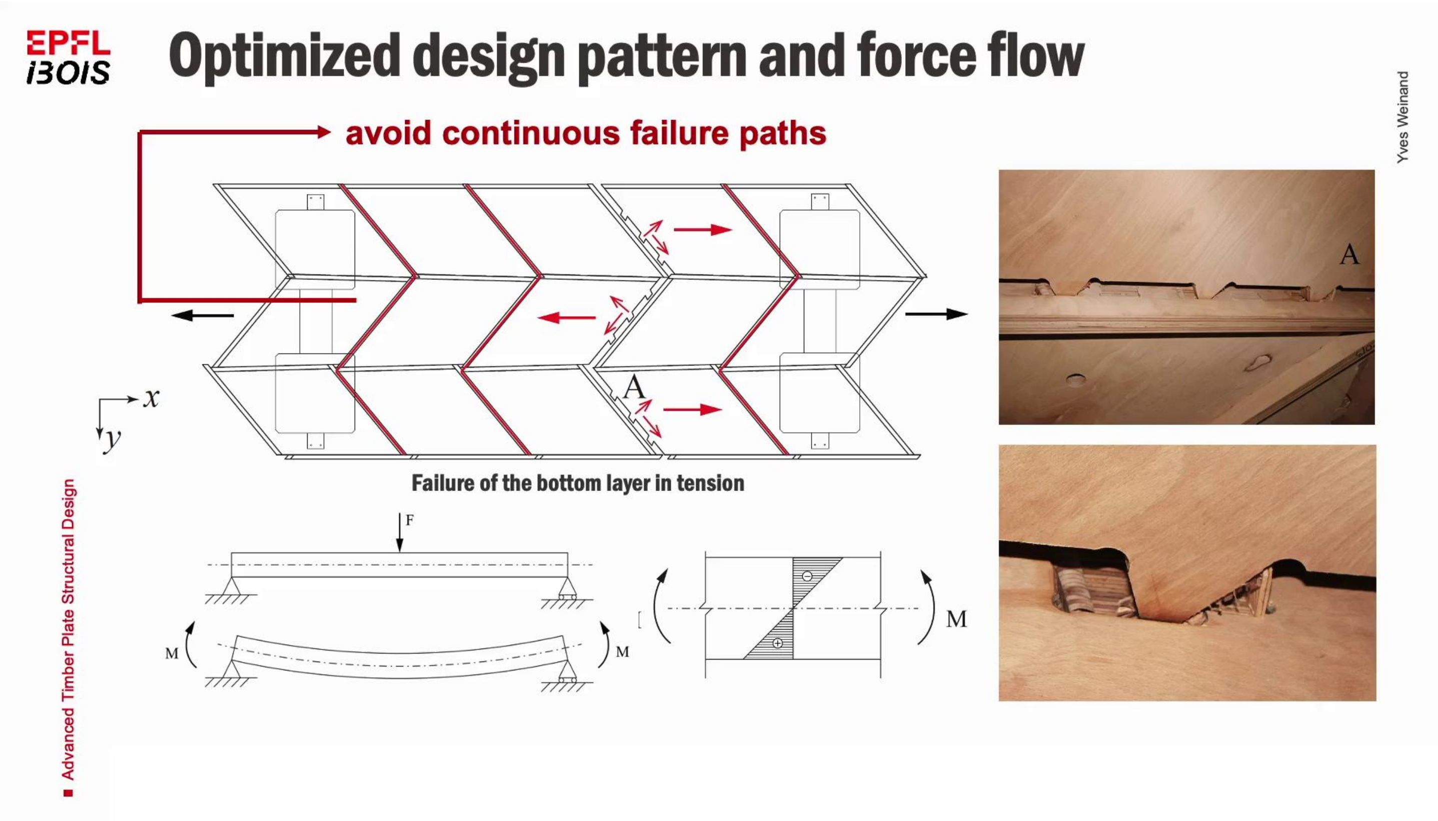
■ Advanced Timber Plate Structural Design

The design optimization starts with probing into a new assembly method while satisfying the geometric tessellation of IATP structures. In other words, while timber plates keep their original topology and essentially remain quadrilateral, a new tiling method is introduced to direct forces in a way that equally distributes stress on wood-wood connections. As a result, the overall appearance and global architectural design of the model are kept while the structure performance is enhanced. The structural behavior improvement is reflected in the relatively uniform distribution of loads to the wood-wood connections, and the fact that the failure path recognized in the first benchmark is blocked. Here, a new assembly corresponding to the double-layer IATP structure is introduced, and its structural performance is compared with the initial benchmark. The performance of the optimized and initial prototypes is compared in terms of the structural displacement and the load-deformation curve of the midspan for each structure. Design alternatives have been imagined. Similar architectural design and geometry generation methodology used in the initial benchmark is adapted for the optimized IATP structure.

Notes

Summary

16m 57s



As such, a similar surface segmentation process was used and the optimized structure consists of top, bottom, cross longitudinal, and cross transfer plates, as already shown. Moreover, the adaption of the optimized tiling method ensures that the target surface assumed at the very beginning of the design process remains intact. However, the difference between the optimized and the initially designed benchmark is that the parallelogram herringbone pattern used for the initial benchmark is shifted. This shift puts the top plates of a strip in between the connection line of the top plates. This shift puts the top plates of a strip in between the connection line of the top plates of the neighboring strip. This shifting pattern was mainly designed due to the fact that the escape path, the failure pattern, was appearing at the stretched bottom layer of the structure even if geometrically [inaudible 00:19:28] is blocking the assembly sequence. In fact, the failure path appeared during loading testing and contradicted the initial assumption of the block graph. Geometrically, the structure is blocked due to the connections, but joints themselves brick along one vector per escape path. Consequently, further studies were carried out to understand the application of the alternative structural system.

Notes

Summary

18m 24s

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Optimized design pattern and force flow

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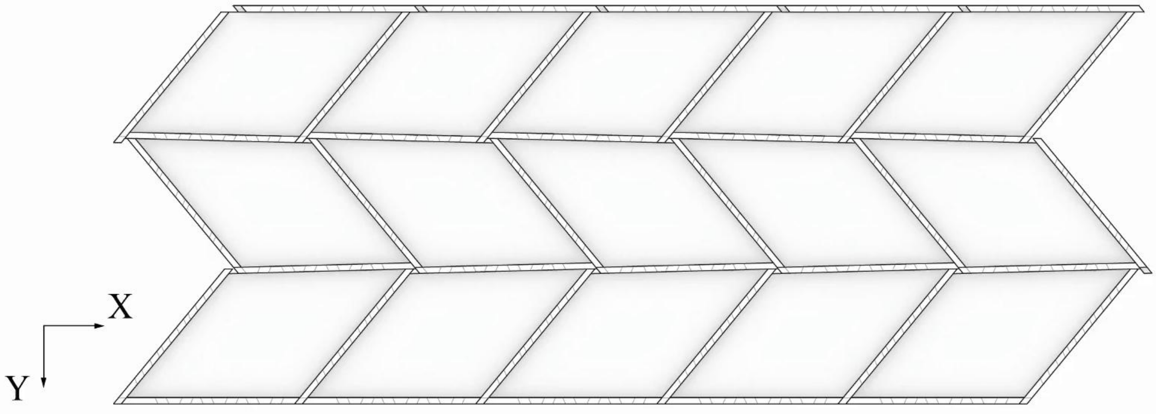


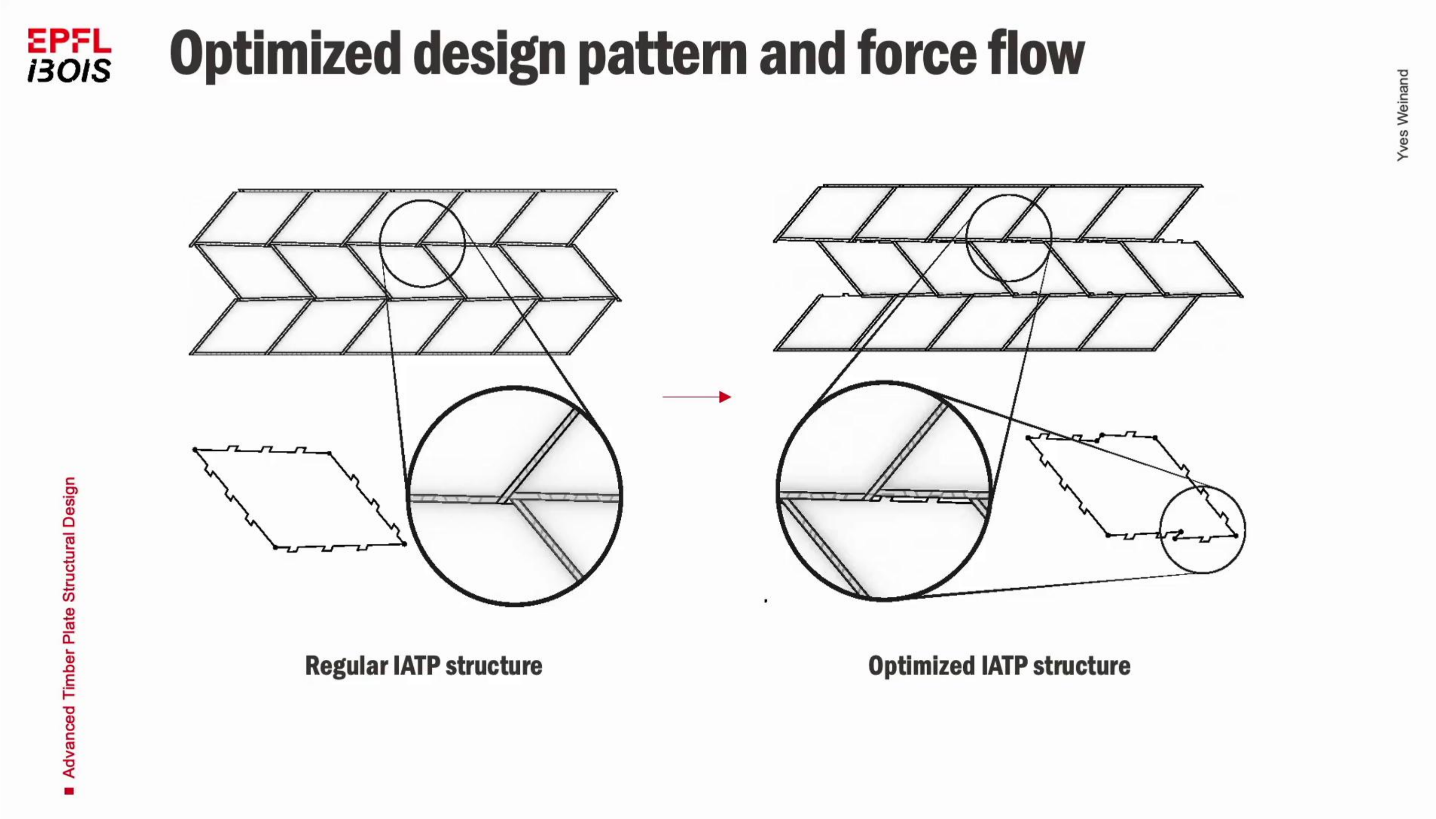
Advanced Timber Plate Structural Design

The reference structural system, which uses the initial herringbone pattern, is illustrated. Each shell is composed of an assembly of hexahedral shaped boxes in the system, each made of two vertical and two horizontal plates. The latter forms the top and bottom layers of the structure. This structured system has been widely investigated. Neighboring horizontal plates are connected with one degree of freedom, through tenant wood-wood connections. So the cross plates, which are themselves assembled with [inaudible 00:20:29] joints. Each box shares its vertical panels with neighboring boxes. Boxes are individually formed. Afterwards, each box component is inserted along the insertion vector defined by the direction of the remaining degree of freedom of the connections.

Notes

Summary

19m 53s

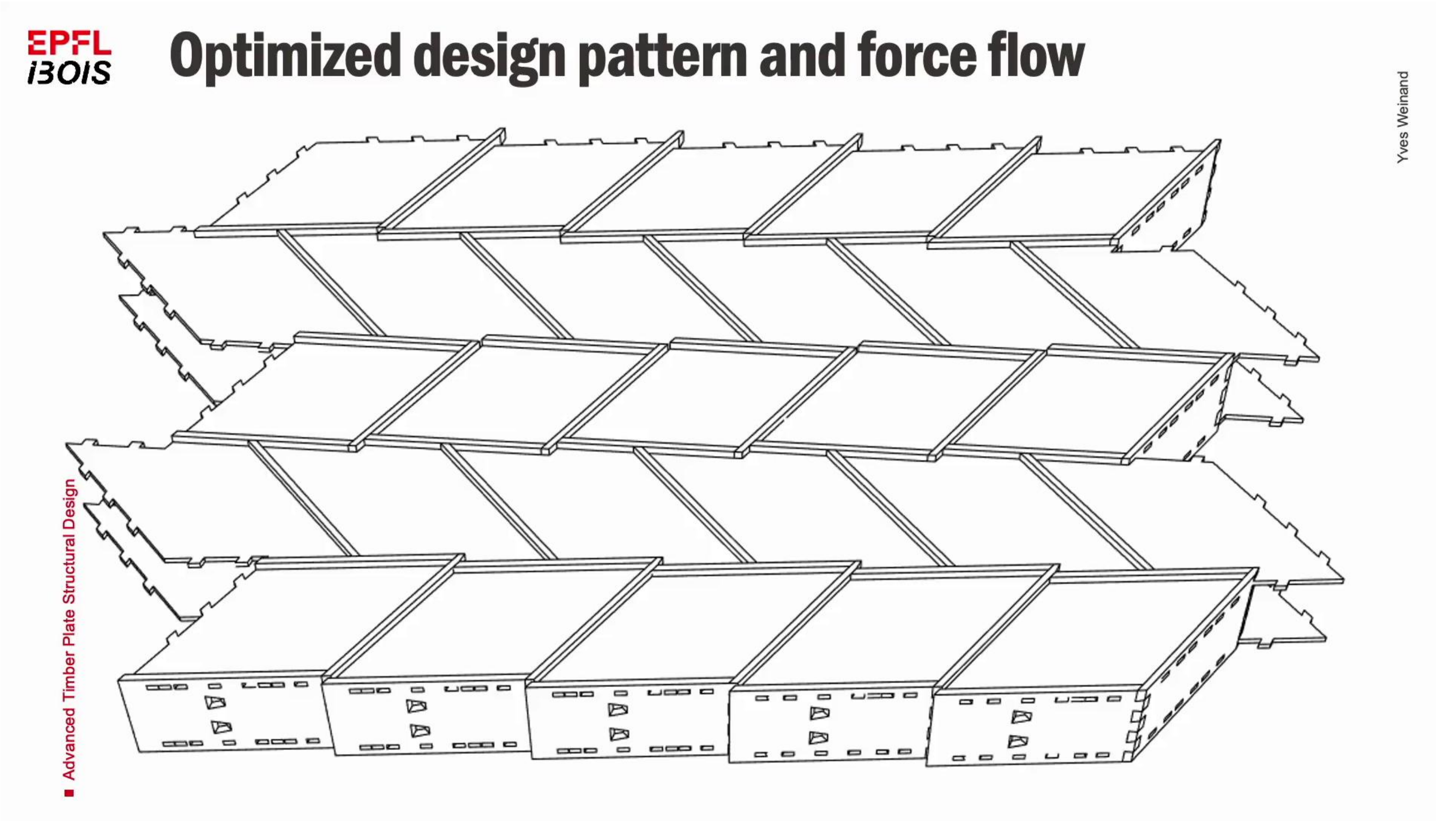


As an alternative system, a hexagonal pattern is proposed where continuous [inaudible 00:20:53] are interrupted including the assembly sequence of individual components.

Notes

Summary

20m 48s

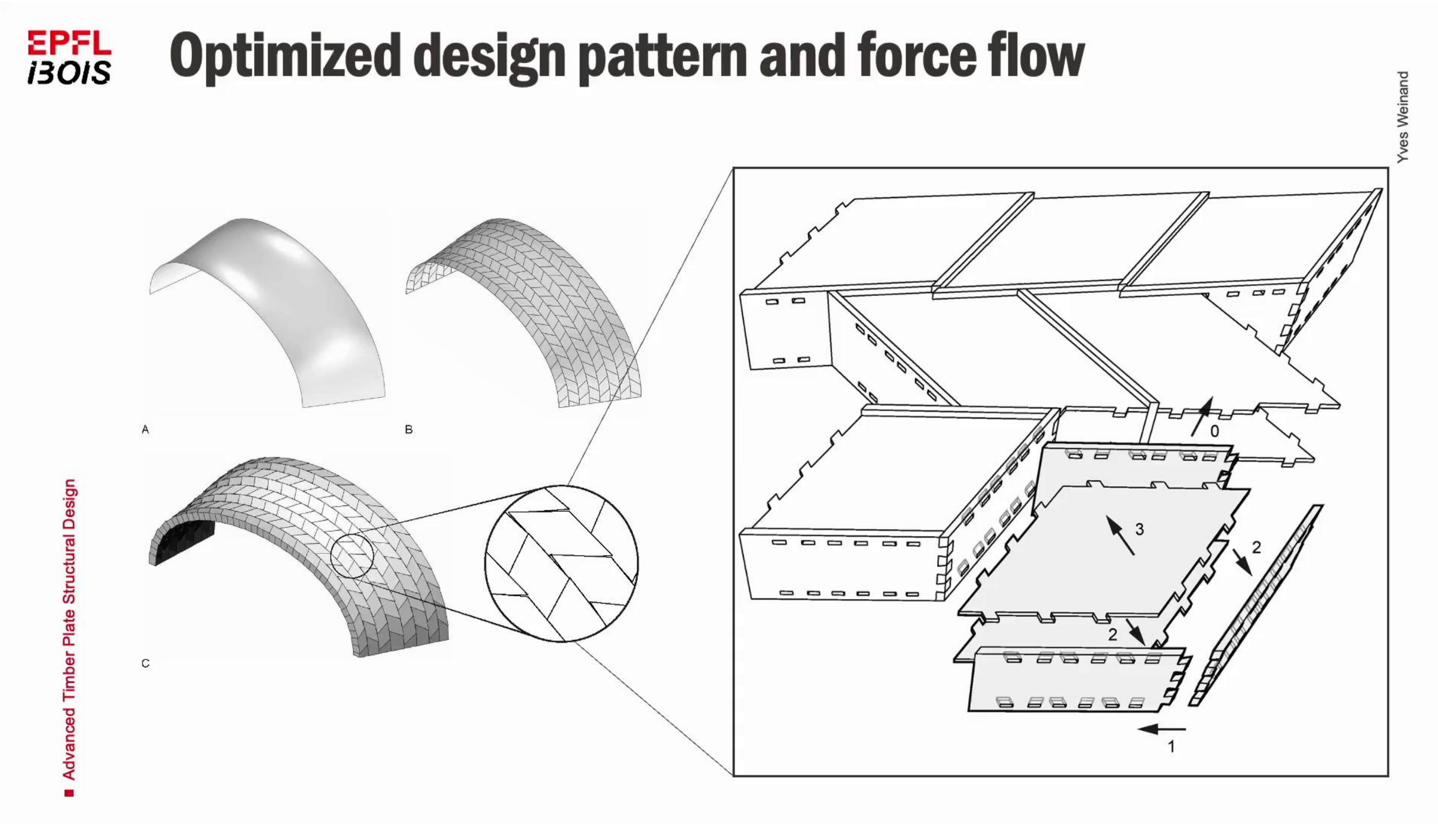


The shape of the hexagon graphically resembles the same quad elements and gains an advantage for considering structural performance versus the build project. The geometry shown here shifted herringbone pattern and contact zones. A hexagonal tesellation was applied to the same double curved surface. In this study, both structured systems were investigated regarding mesh, discretization, timber plate generation, assembly sequence, and engineering calculations. The shifted hexagonal pattern was investigated to challenge the problems and count out in the initial system.

Notes

Summary

21m 00s



The geometrical constraints used for the reference system are kept where the target surface and the static height between the top and the bottom plates remain the same. The architectural [inaudible 00:21:57] stays identical. The hexagonal pattern results in a shifted pattern where the long edge of a box meets with two adjacent components instead of one, as shown here. Due to the planarization and thickness of the plates, each top and bottom plate obtains an additional edge. The shape of horizontal plates was modified to enable the assembly sequence without collision.

Notes

Summary

21m 45s

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Optimized design pattern and force flow

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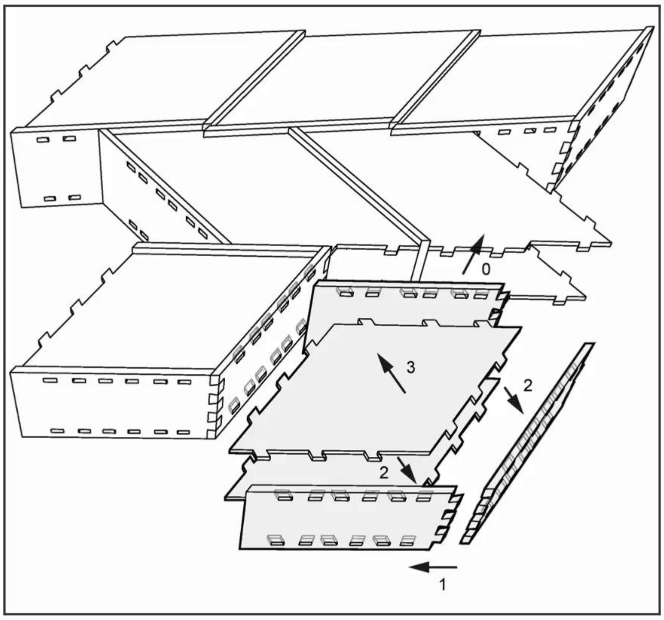
Advanced Timber Plate Structural Design



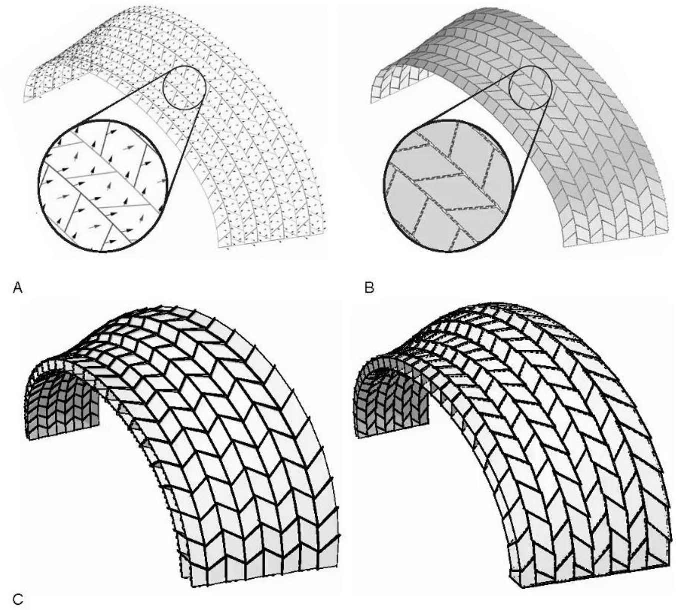
Overall, the main design change is transforming the quadrilaterals used in the herringbone pattern to nonconvex octagons. The resulting geometry of the shifted herringbone pattern modifies the assembly sequence of the system, as is shown in those figures. One possible solution is to assemble quadrilateral and nonconvex octagonal shape plates by adding additional side plates, depending on even or odd row. Those four-sided boxes are assembled in the same manner as in the initial construction system. After one row of those boxes is placed, the second row of boxes, consisting of three-sided boxes, is positioned. Vertical plates are then inserted along the assembly vector, directed by [inaudible 00:23:17]. The same process is repeated for subsequent rows. Consequently, the proposed assembly sequence requires more steps and is therefore more complicated than the initial assembly sequence. The introduction of nonconvex octagonal shape plates with the [inaudible 00:23:36] patterns has the advantage of providing zones of abutment of the horizontal plates in the structural system, as it is shown here.

Notes

Summary

22m 24s

Optimized design pattern and force flow



As discussed before, the shape of the plates has to be modified for abutment angles better, less than tenant angles Alpha, defined by the insertion vector, V, and unique for each edge of the plates to ensure the insertion. The kink in the hexagonal plate cannot block the insertion. Therefore, a small gap is introduced. For abutment angles that are larger than tenant angles Alpha, no modification of the plate shape was required to see the difference between angles. Therefore, the contact zone remained the full area of the abutment, as shown here. According to the assembly sequence illustrated in the insertion vector of the vertical plate is identical to the insertion vectors of the horizontal plates, which will be three-sided boxes and forming those three-sided boxes.

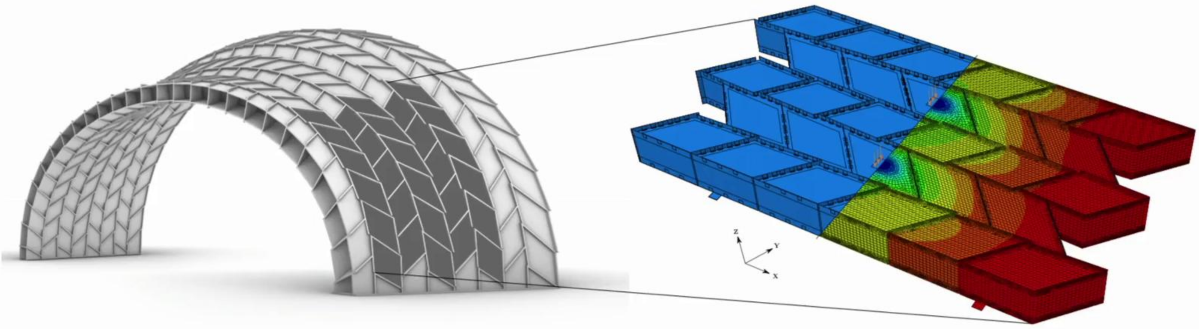
Notes

Summary

23m 48s

Optimized design pattern and force flow

Aryan Rezaei Rad



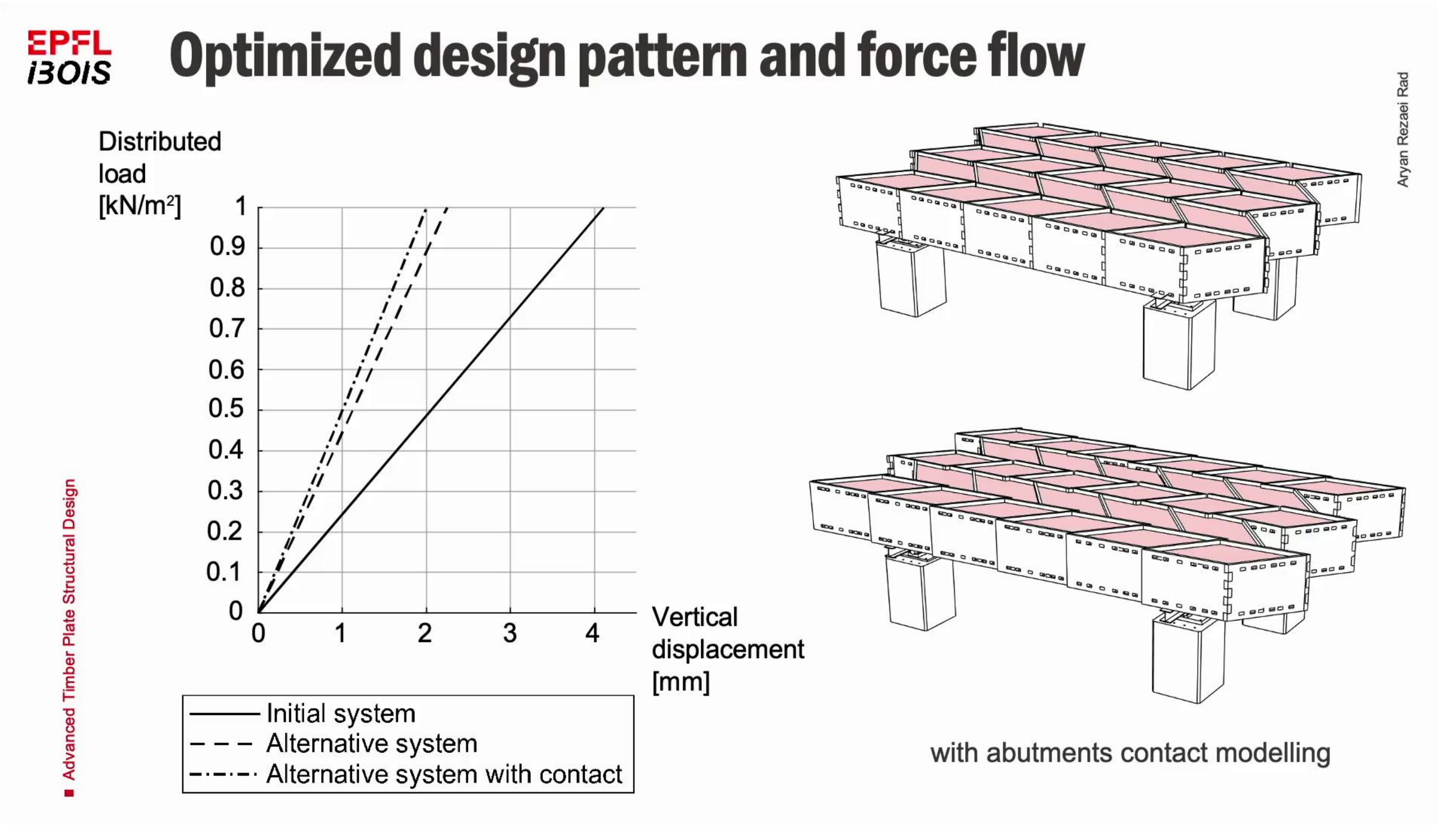
Advanced Timber Plate Structural Design

Given the introduction to the optimized integrally attached timber plate structures that was extensively discussed in this session, in the rest of the session, I'm going to talk about simulation methods and specifically finite element methods in order to simulate such structures.

Notes

Summary

24m 38s

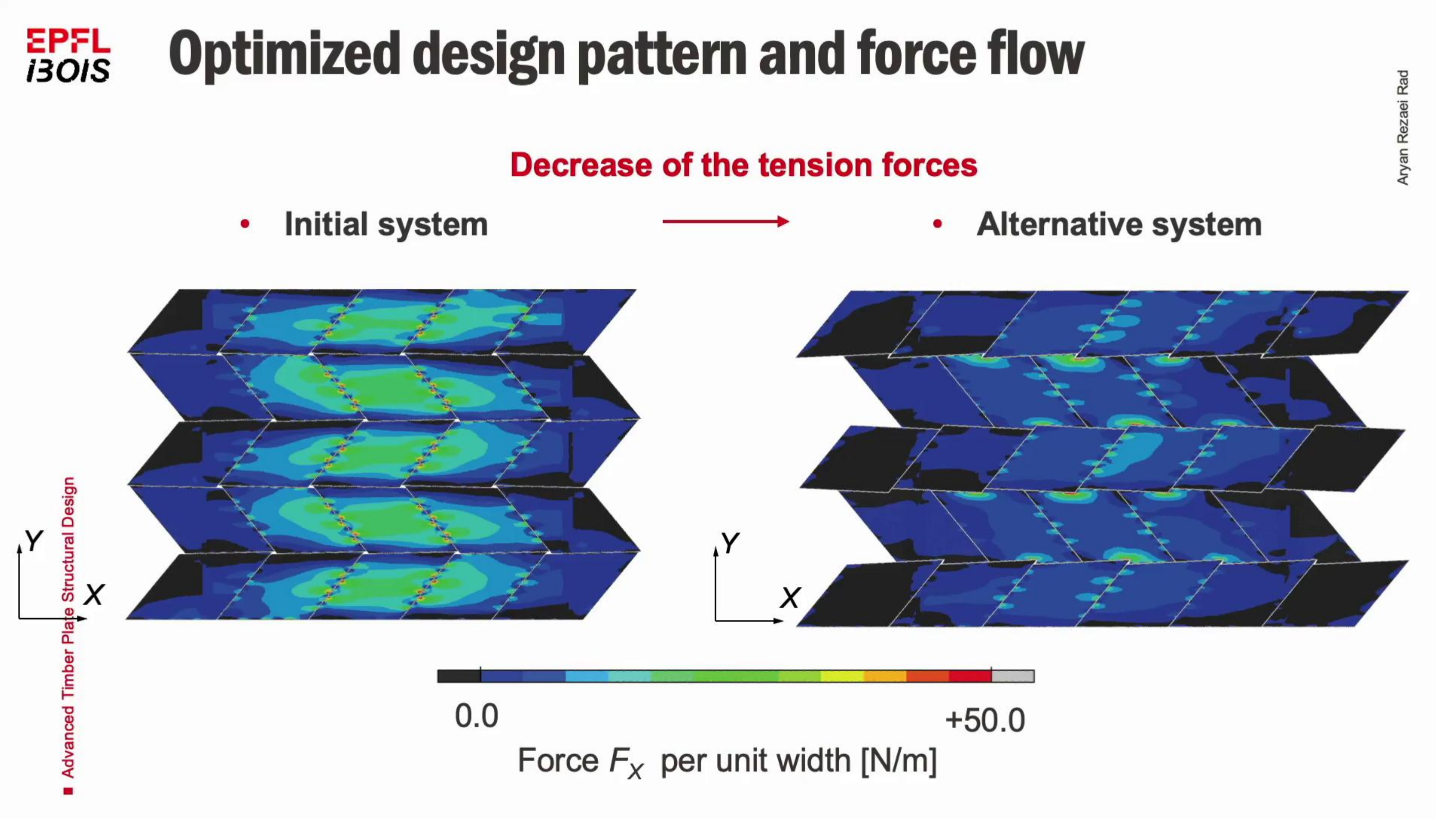


So given the initial prototype that we discussed about before, which is a regular integrally attached timber plate structures, and the new one, which is talking about a shifted pattern of integrally attached timber plates that you see in this slide, the results of the finite element model for both the initial system and the alternative system indicates that the optimized IATP structures demonstrate superior performance, meaning that by providing the contact between different timber plates, as well as shifting the pattern, the integrally attached timber plate structures can demonstrate a better performance and the reliable load-transferring mechanisms.

Notes

Summary

24m 58s



As you see here in this slide, in the very initial model, we had only tangent compression resistance of wood-wood connections playing the major role in the load-carrying capacity of our structural systems. However, in the alternative system, which is an optimized IATP structure, with this shifted pattern, we are activating another kinematics, which is specifically the shear behavior and the contact between timber plates as an additional sources of resistance or load-carrying capacity.

Notes

Summary

25m 46s