CARAPACKS

Pavillon Design
SoSe23

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Prof. i. Vertr. Dr. Ing. Jonas Schikore
Prof. Dr. Christina Jeschke
David Ott

Abstract

Carapacks is the result of a design-build project that took place over multiple semesters at the Architecture Faculty of Biberach University. The team led by Simon Vorhammer, Dr. Jonas Schikore, Dr. Christina Jeschke, and David Ott developed a concept for implementing arbitrarily curved freeform surfaces as double-shell interlocking systems. The uniqueness of the hexagonal system lies in the fact that all components are free of curvature and torsion, and they possess perpendicular cut edges. This ensures efficient and cost-effective manufacturing using 2.5-axis CNC laser or water jet cutting technology.

The assembly process is straightforward and can be carried out by skilled amateurs without the need for heavy machinery. Labels and positions are embedded into the components, allowing the geometrically unique panels to be effortlessly assembled without the need for blueprints, similar to solving a puzzle. The planarity allows for space-saving stacking. For instance, all the individual parts of the construction study shown below can fit into the trunks of two station wagons.

The digital parametric model makes it possible to define various input parameters such as overall shape, degree of enclosure, shell thickness, and segment size. This enables the almost instantaneous generation of manufacturing-ready kits for a wide range of initial geometries.

To test the interlocking mechanism, a 1:1 scale pavilion was erected on the university campus during this summer, using 592 wooden elements. After a duration of approximately six weeks, it will be dismantled and reassembled elsewhere on the campus next year.

The system is not limited to wooden pavilions but could also be applied to roofs and facades. Material durability can be ensured by selecting wood for outdoor use or employing other weather-resistant sheet-like materials as well as wood treatments. Water resistance could be achieved through an additional, externally situated transparent cover, such as ETFE.

Concept, Planning, and Manufacturing

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Prof. Dr. Christina Jeschke
David Ott

Assembly

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Jürgen Pröll
Fabienne Neuf
Katy Guth
Kira Kortländer
Yusuf Cosgun
Lara Wingenfeld
Florian Gärtner
Berkay Mutlu

Mit freundlicher Unterstützung von

Ackermann GmbH · FAUST LINOLEUM · MAURER Holzwerkstoffe

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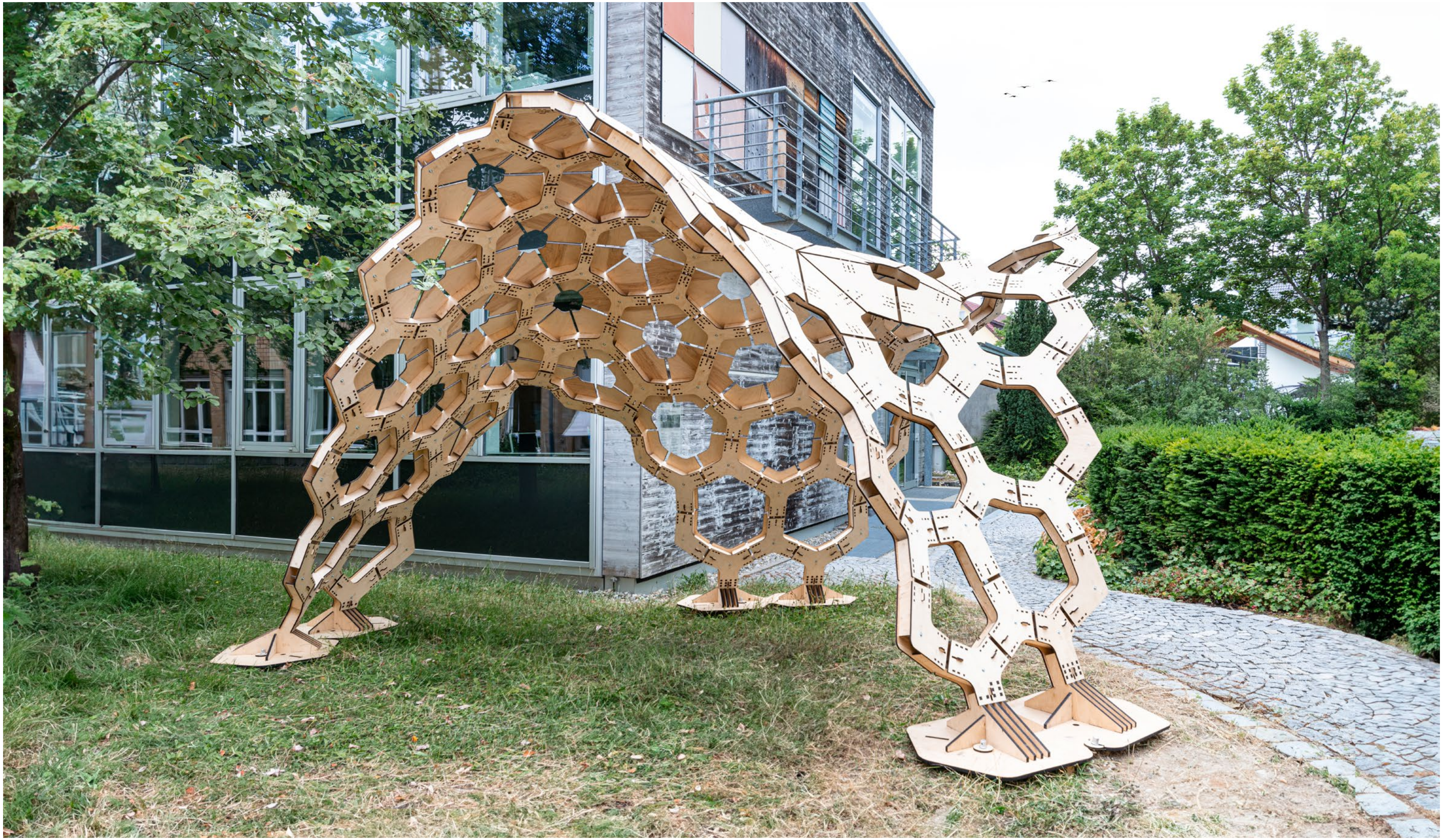
Prof. Dr. Christina Jeschke
David Ott



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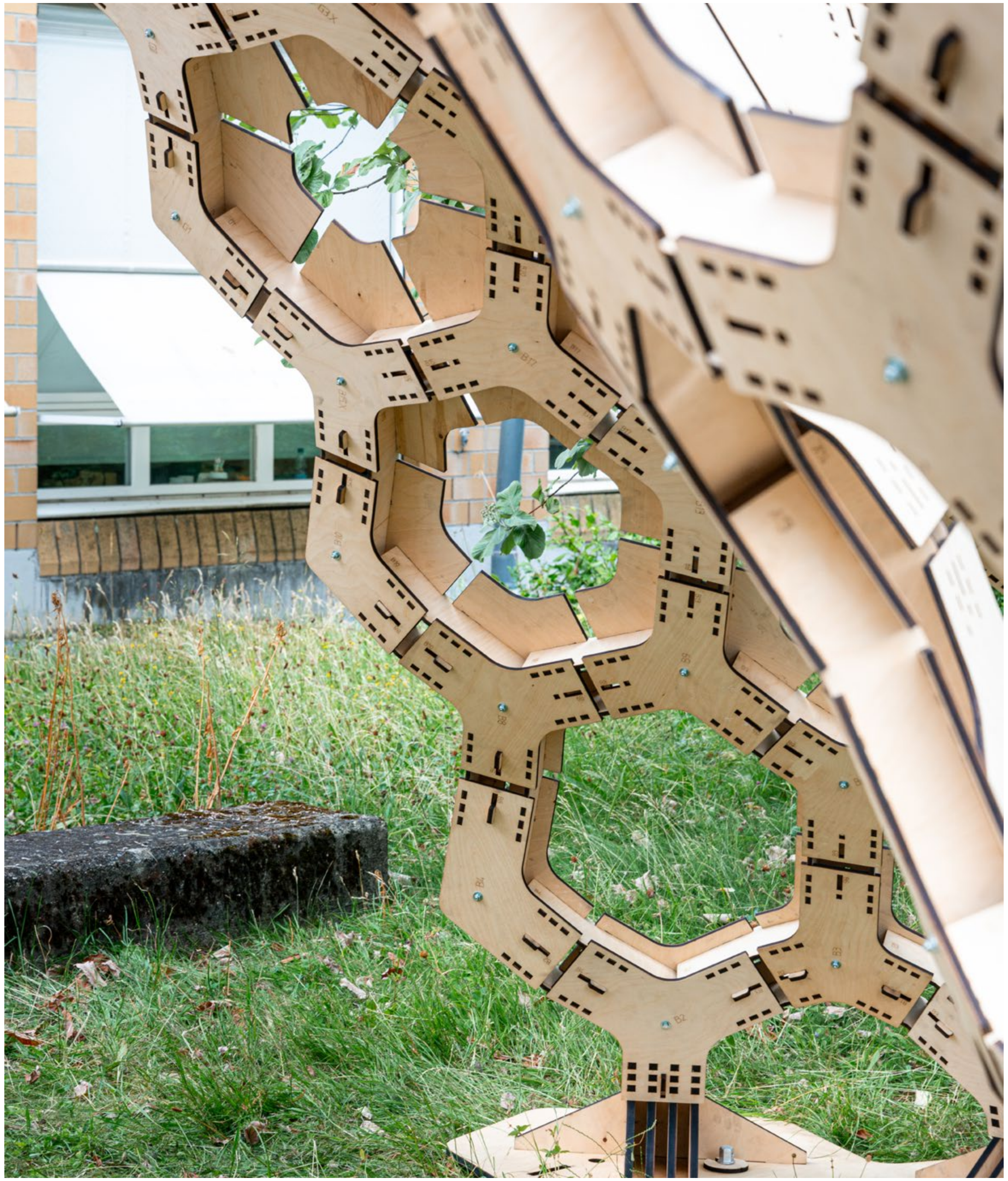
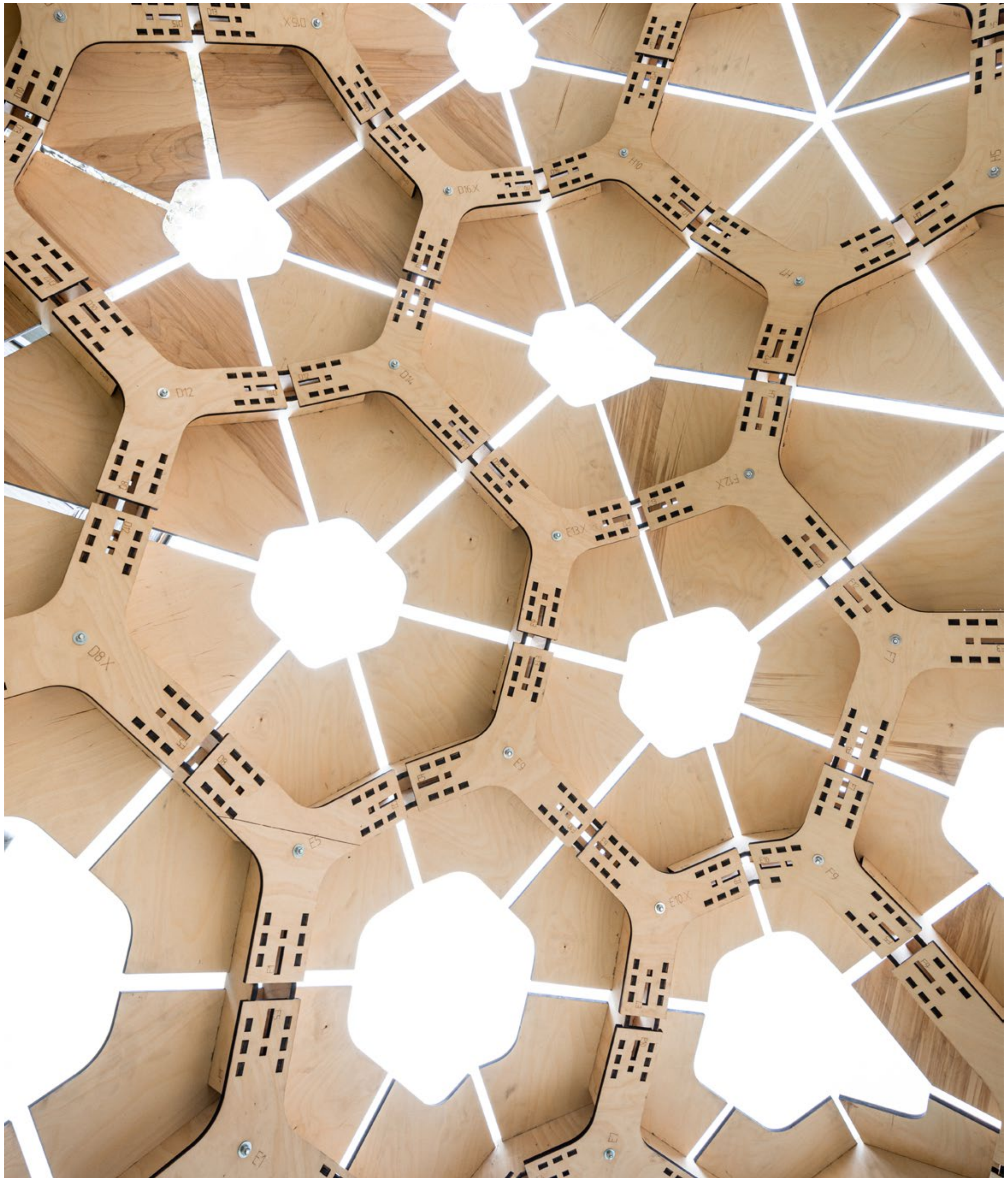




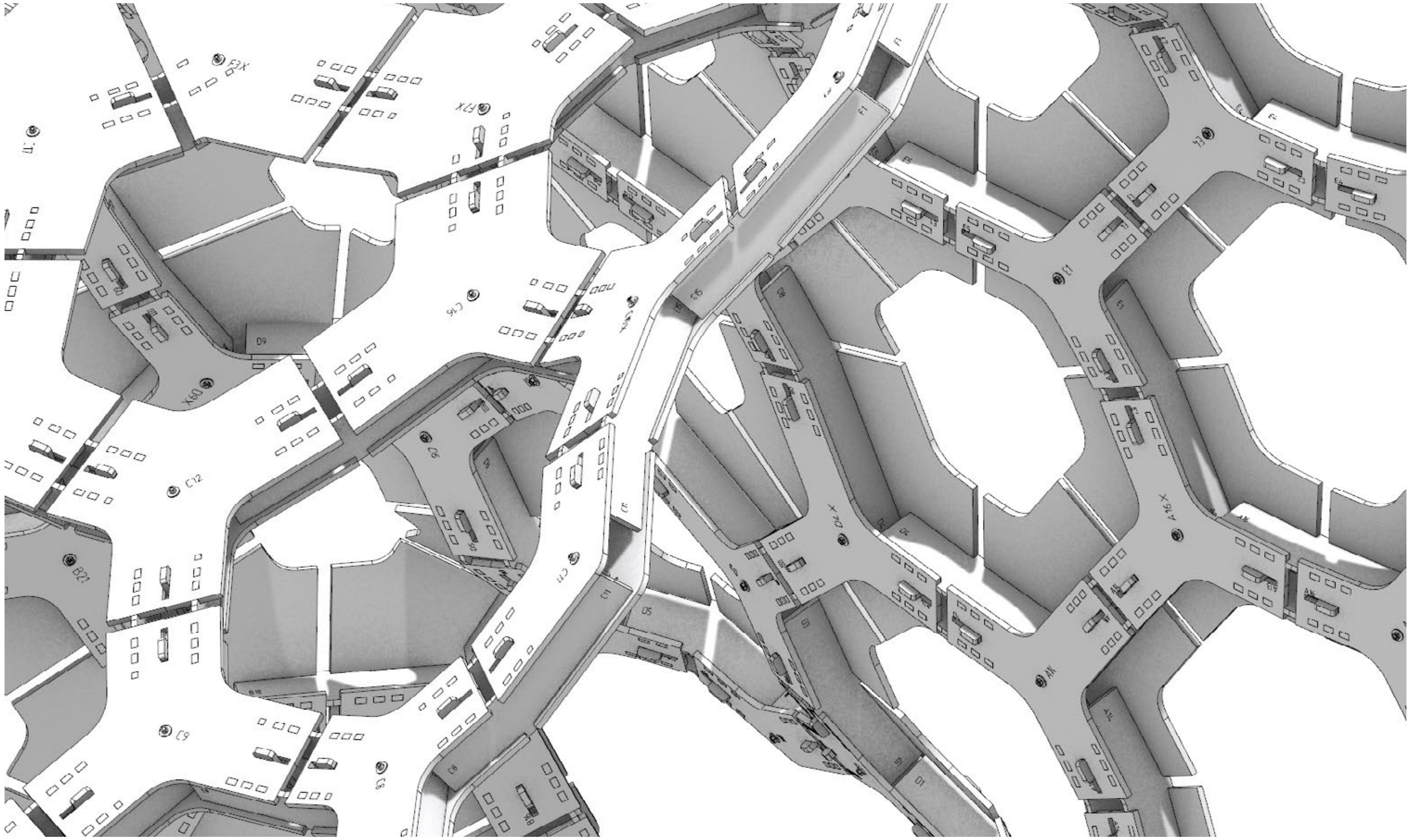

B9
B9
B8

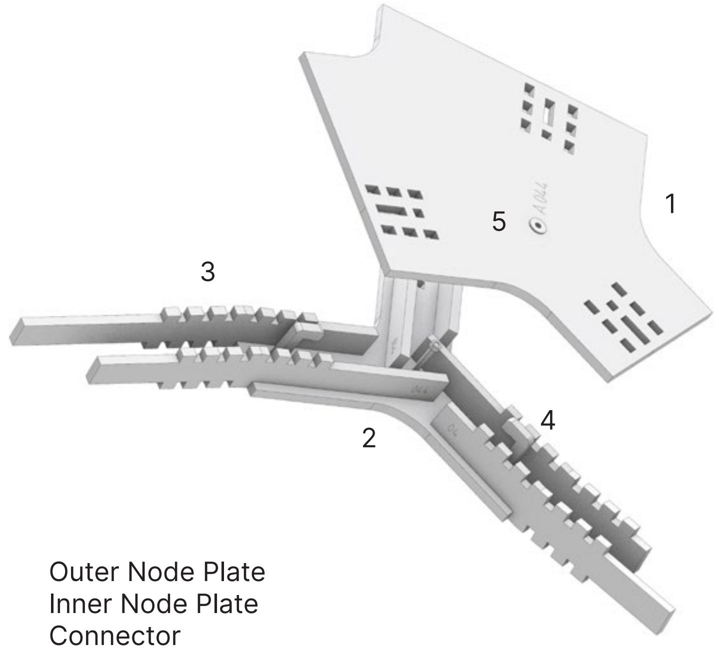

B19
B19
B19


D3
D4

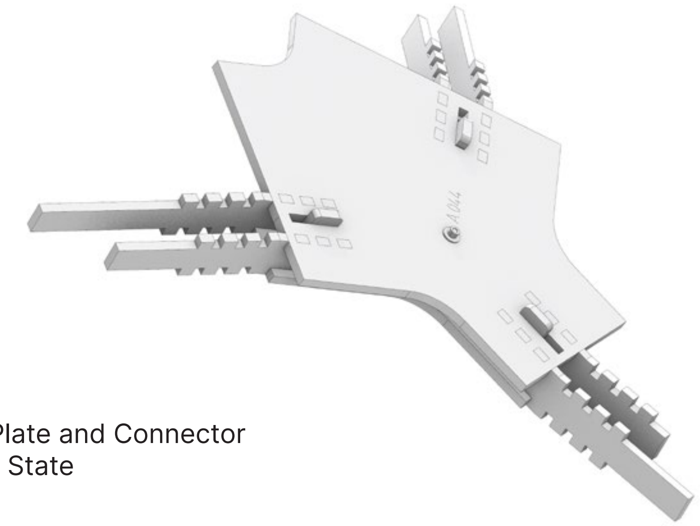

A17
A15
A15

Connection System

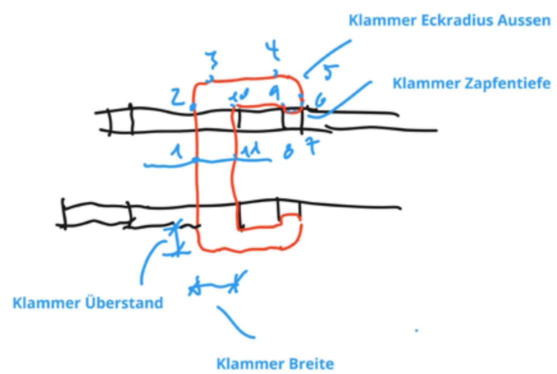




1 Outer Node Plate
2 Inner Node Plate
3 Connector
4 Clip
5 Screw

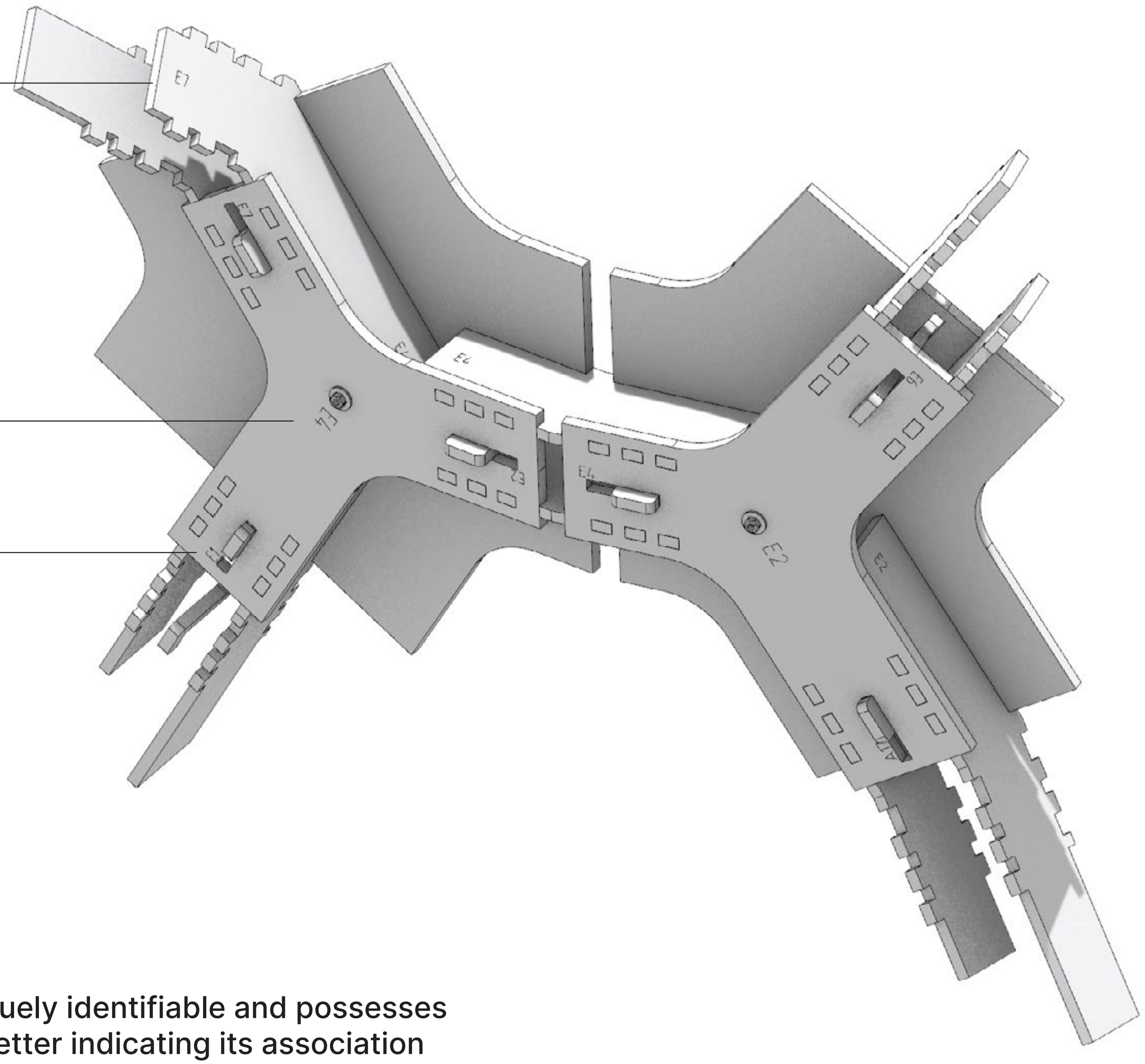


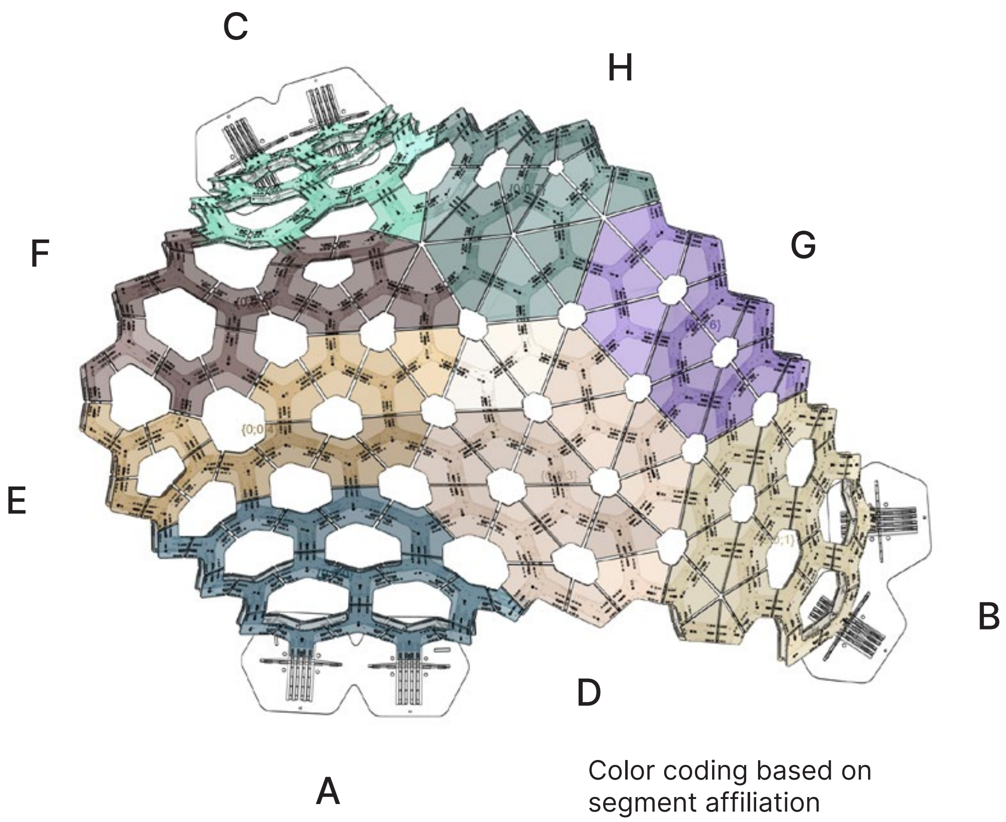
Node Plate and Connector
Closed State



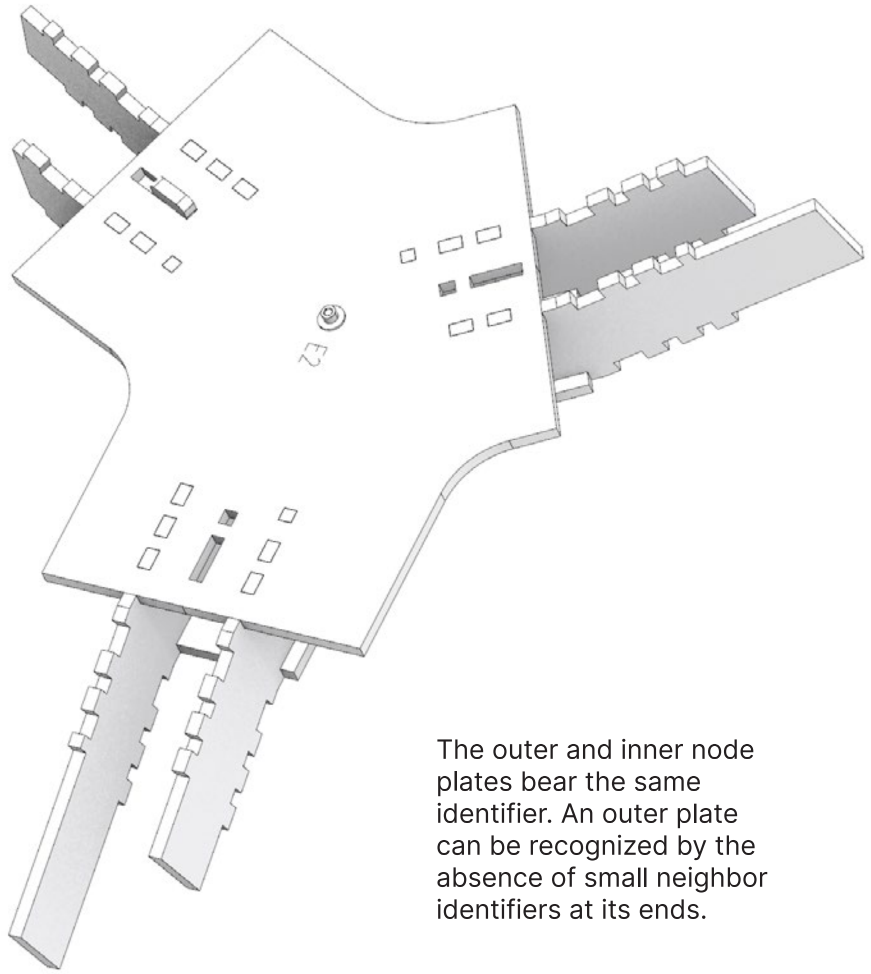
The digital freeform surface is initially divided into trilateral cells. The subsequent construction involves star-shaped node plates both above and below the surface, representing the sub-surfaces of these planar cells. These node plates are connected to each other through special connectors that accommodate angular changes perpendicular to the plane of the surface, ensuring a robust, load-bearing connection. Fixation and stabilization of this connection are achieved through a central screw, which tightly presses the two node plates together, while additional wooden clips are used to minimize undesired deformation of the node plate legs.

Naming system





Color coding based on segment affiliation

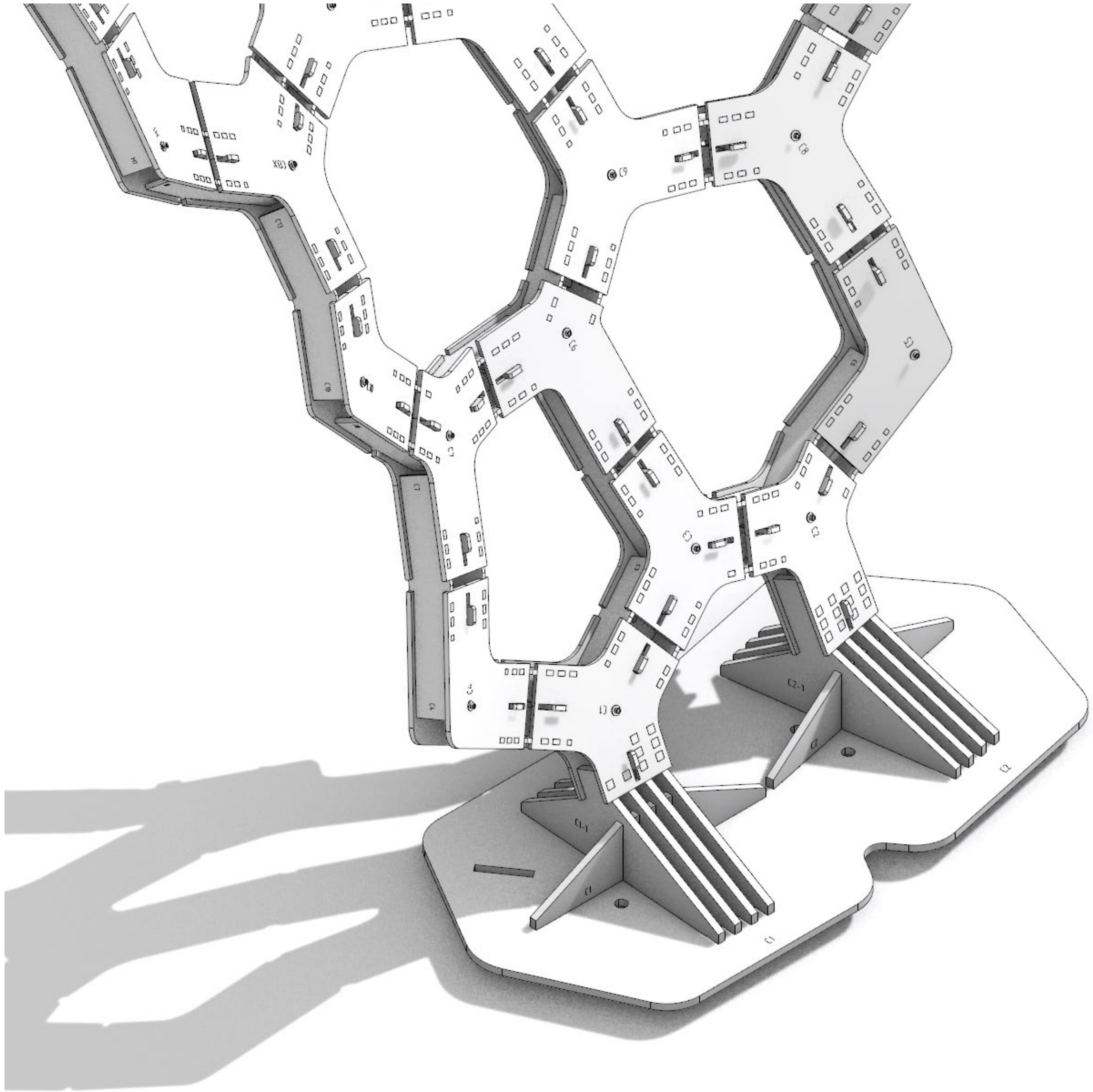


Each node plate is uniquely identifiable and possesses a label consisting of a letter indicating its association with a specific segment. A trailing number assigns the plate a consecutive number based on its vertical position in ascending order. The inner node plates have the identifiers of neighboring node plates at their ends, enabling an association without the need for separate lists or plans. The connectors also bear the identifiers of their corresponding node plates.

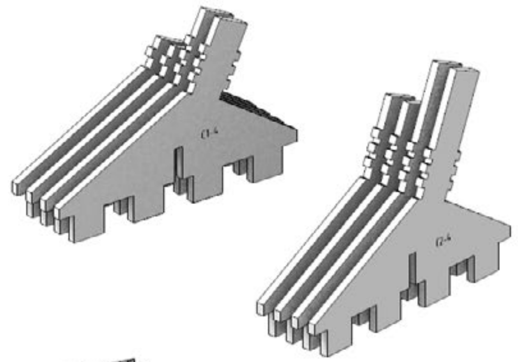
Furthermore, a primary identifier is extended by adding an "X" to label node plates situated at the edge of a segment. These plates are only inserted during the connection process of pre-assembled segments.

The outer and inner node plates bear the same identifier. An outer plate can be recognized by the absence of small neighbor identifiers at its ends.

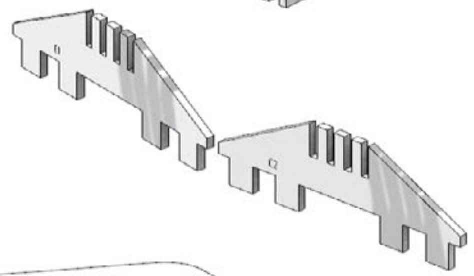
Supports



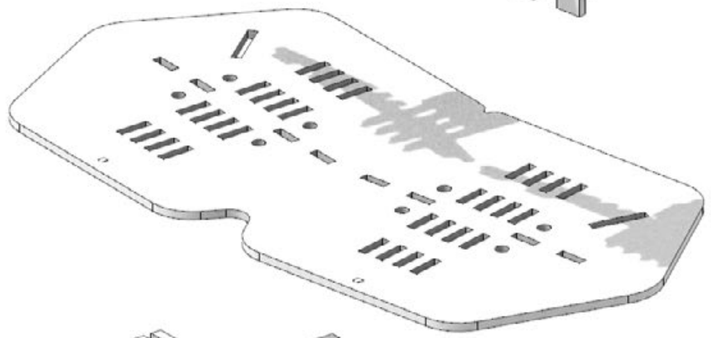
Support connectors



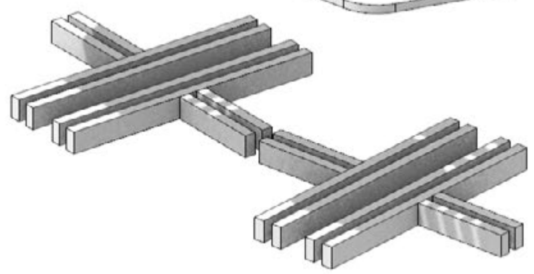
Support cross connectors



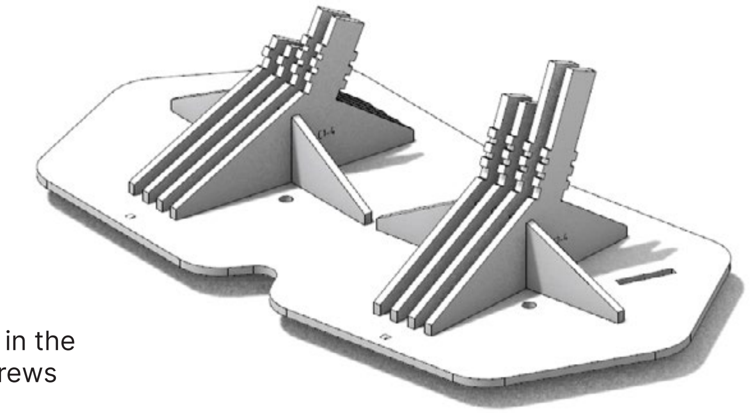
Support plate



Hardwood profiles

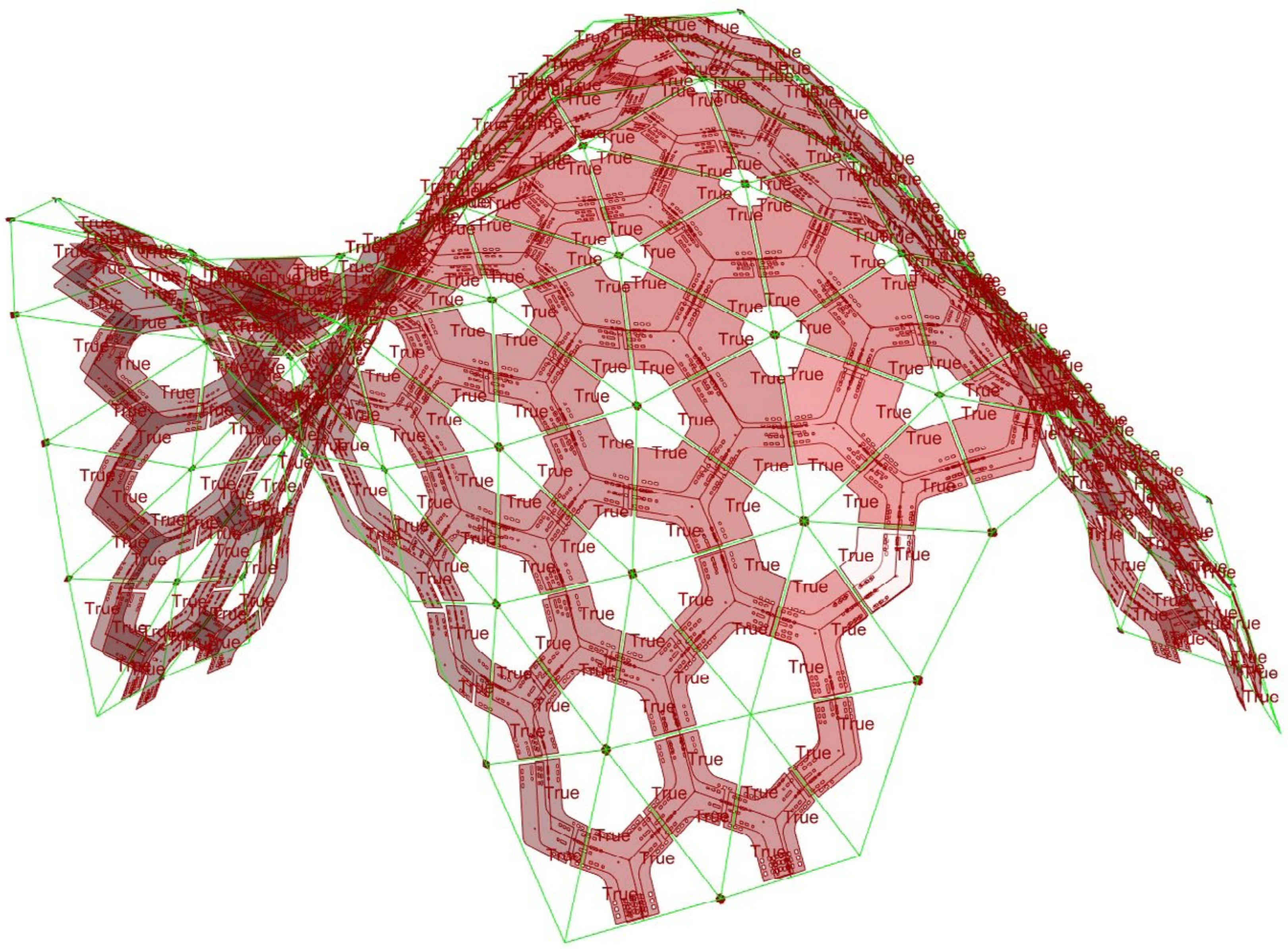


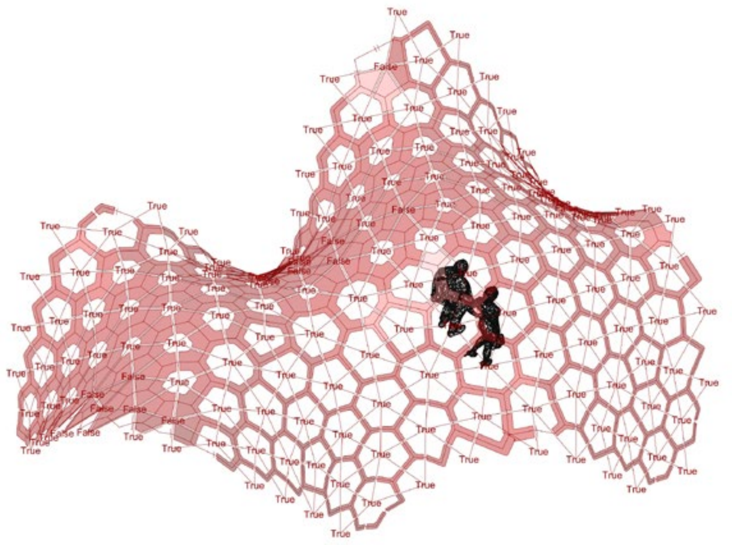
Assembled
support



Drill holes for anchoring in the
ground using ground screws

Parametric
Model

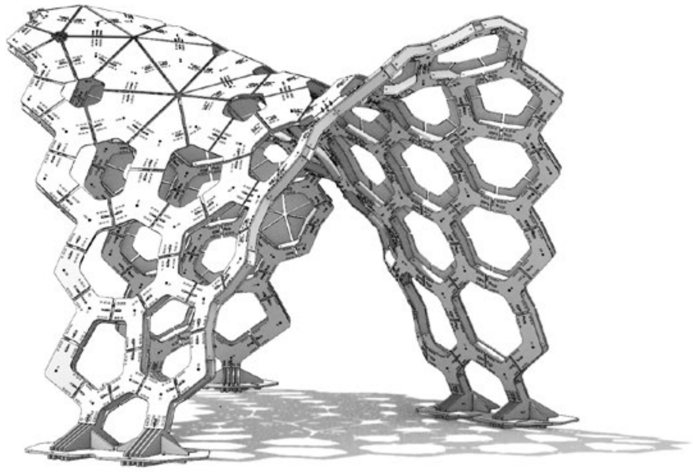




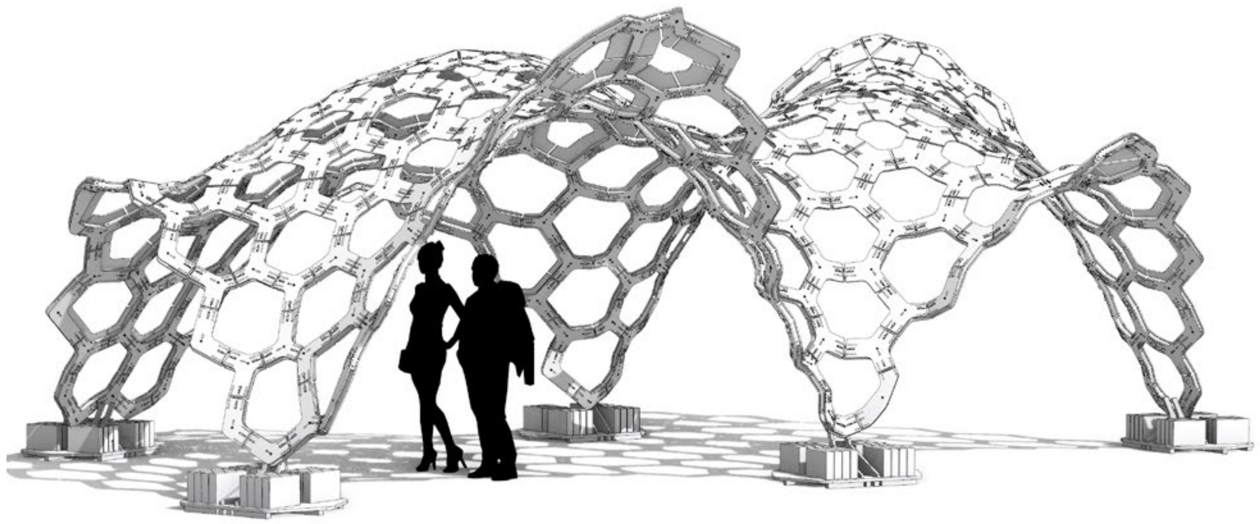
For the planning, a parametric model was created. Each change in a parameter leads to the automatic generation of a precise 3D model, eliminating the need for manual modeling. The freeform surface plays a special role among a total of 45 input parameters, which collectively define the shape of all parts.

The illustration depicts the result on a larger freeform surface with altered parameters for the opening of the elements.

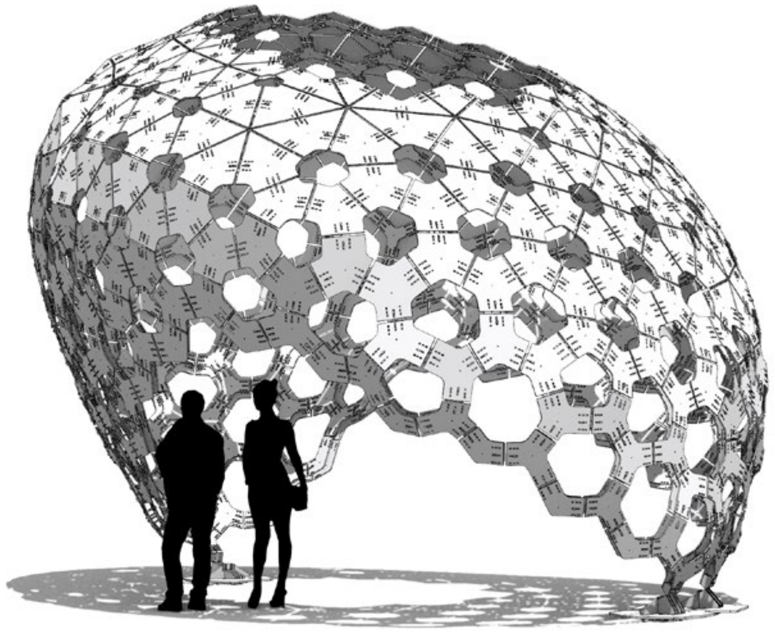
Variants



01 Number of parts: 592
Weight: 152 kg



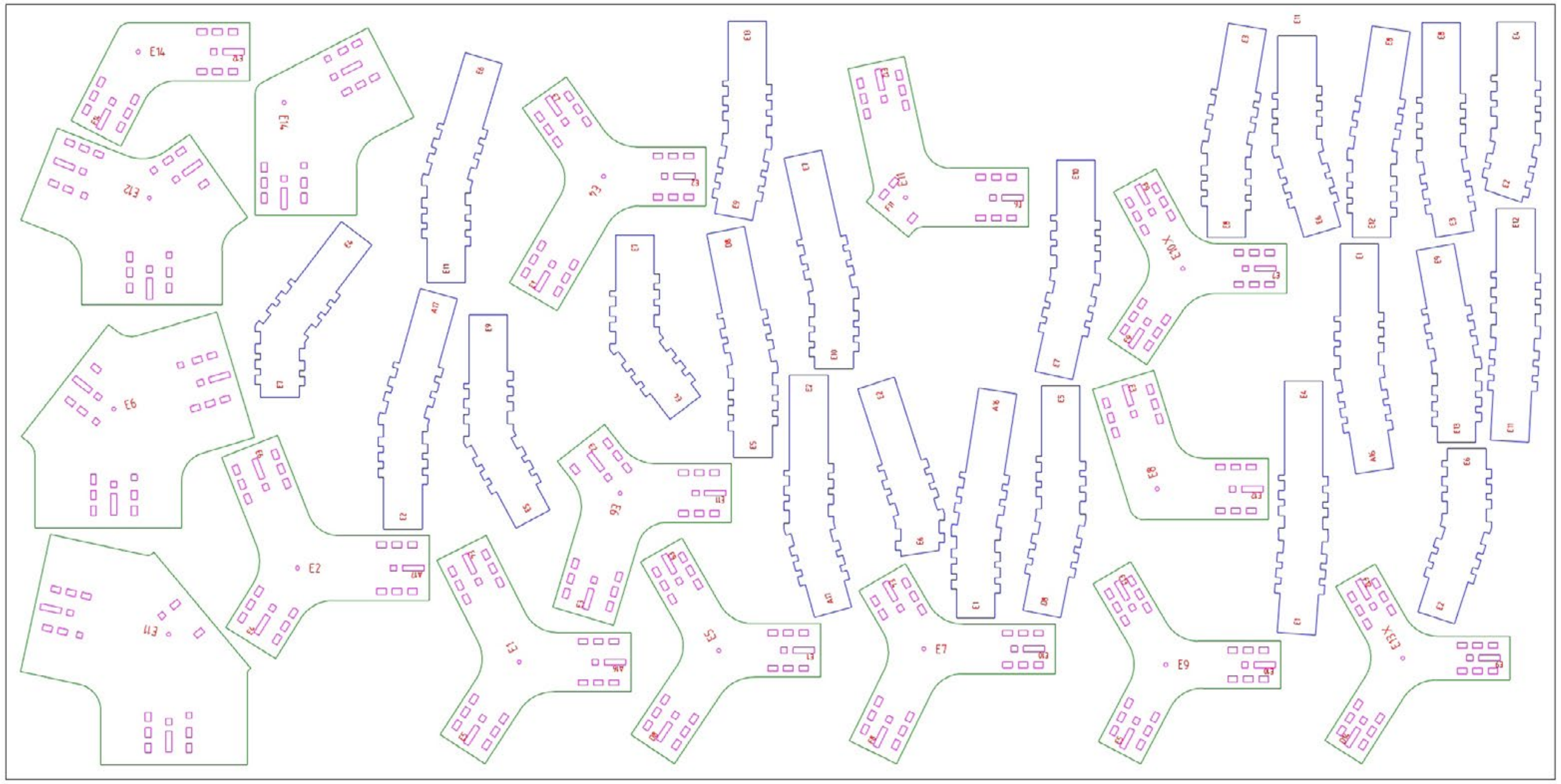
02 Number of parts: 908
Weight: 233 kg

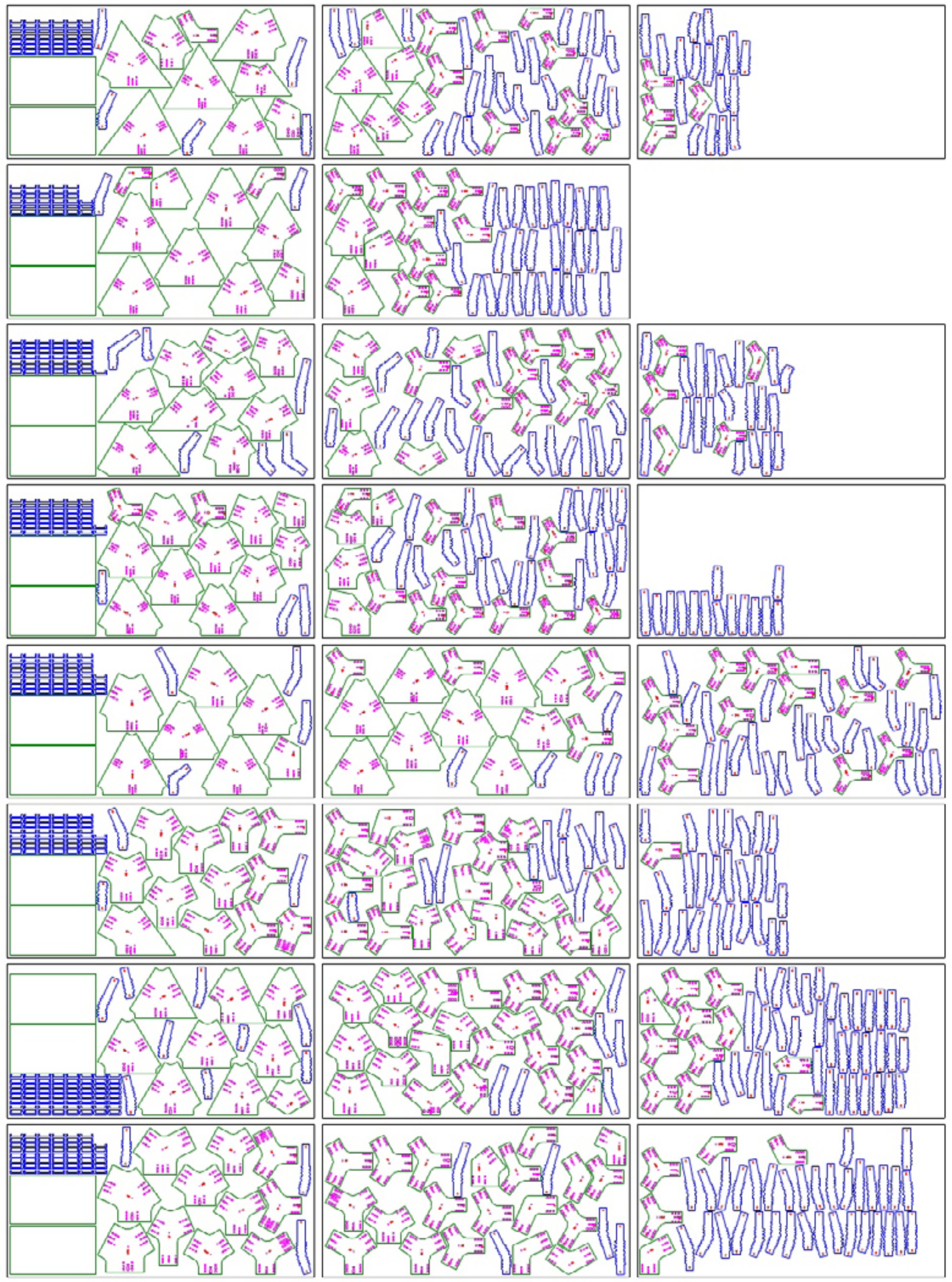


03 Number of parts: 1858
Weight: 482 kg

In addition to defining geometric properties such as plate size, spacing between layers, rib widths, and opening degrees, the system enables the nearly instantaneous generation of 'assembly kits' for various applications, shapes, and sizes.

Fabrication Data





In addition to the spatial representation of the components, primarily used for visualization purposes, all building elements are also placed as contour lines on standard-sized sheets optimized for cutting, enabling their direct use in production.

Representation of all 592 components, nested on sheets with dimensions of 2500 x 1250 mm.

Structural Behavior

The spatial shape of the carapace is mirrored on an inverted hanging form. This largely avoids bending moments around tangential rod axes in the self-weight state. The lattice structure predominantly carries loads within its plane through compressive forces. The doubly curved surface geometry promotes the shell behavior of the structure, regardless of the loading situation.

The hexagonal grid layout is associated with bending moments around rod axes oriented perpendicular to the surface. Figure 1 qualitatively illustrates these bending moments in a hexagonal unit cell (a) and in the overall structure (b). In the support area, higher bending moments occur, similar to the increased compressive forces. A parametrically organized dimensioning of the rod widths responds to this stress. As part of computer-aided design, the internal forces from self-weight and wind are evaluated, and corresponding rod widths are applied (c), which are automatically incorporated into the production files.

The design of the carapace integrates not only structural and user-specific features but also static analysis and dimensioning within a closed, digital planning workflow.

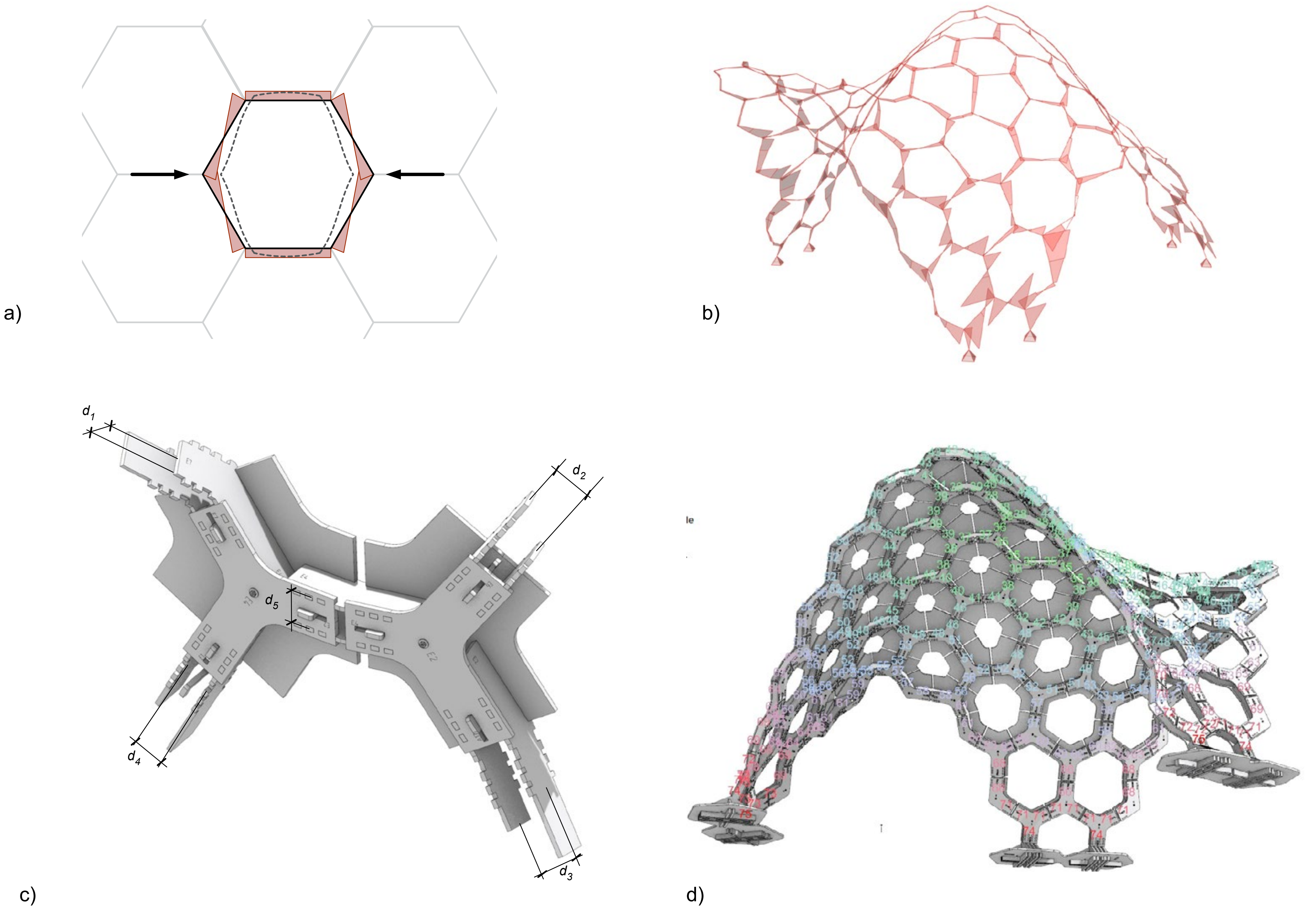
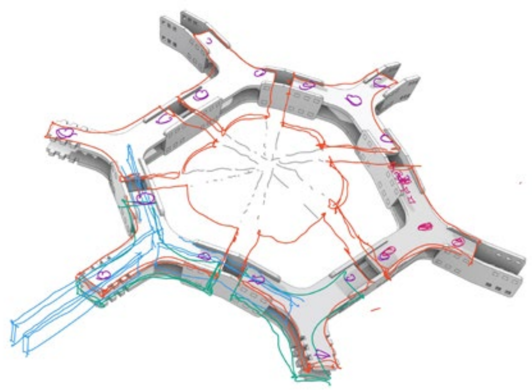
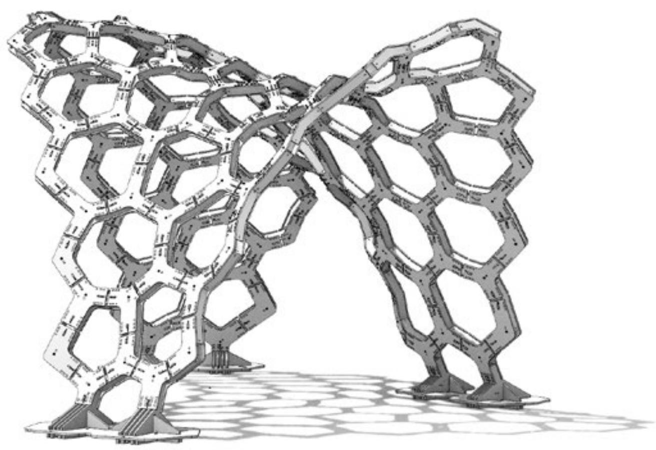


Figure 1) Bending in the lattice plane: a) Schematic distribution of bending moments Mz and deformation shape (dashed line) on a unit cell, b) Qualitative distribution of bending moments in the overall structure, c) Individual rod widths "d" as a result of parameterized dimensioning at the element level, d) Individual rod widths in the overall structure.

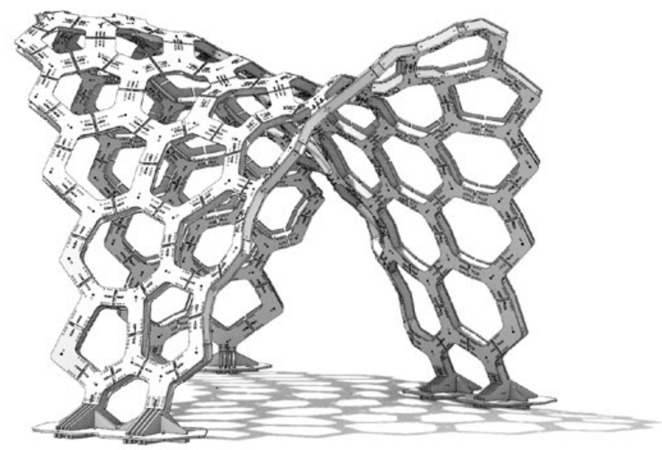
Outer Layer



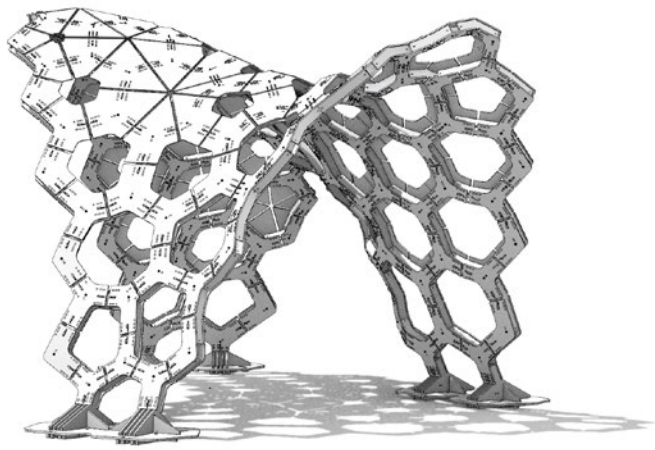
The degree of closure of the outer layer can be adjusted either based on the vertical position or in relation to a freely chosen vector. In this process, the resulting rib width never falls below the value of the corresponding lower nodal plate.



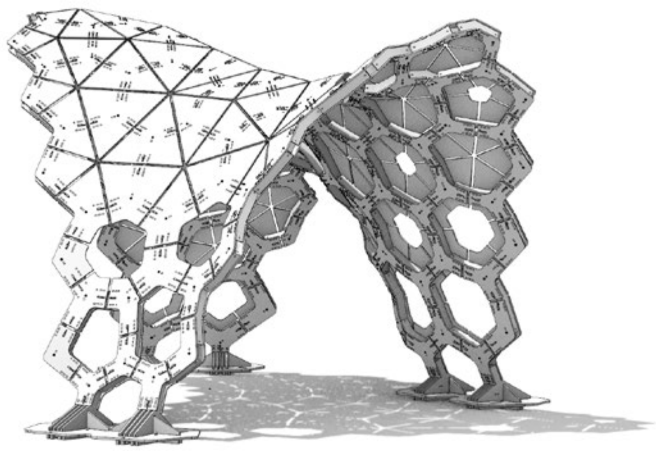
01 Degree of Closure inner layer: 0 %
Degree of Closure outer layer: 0 %



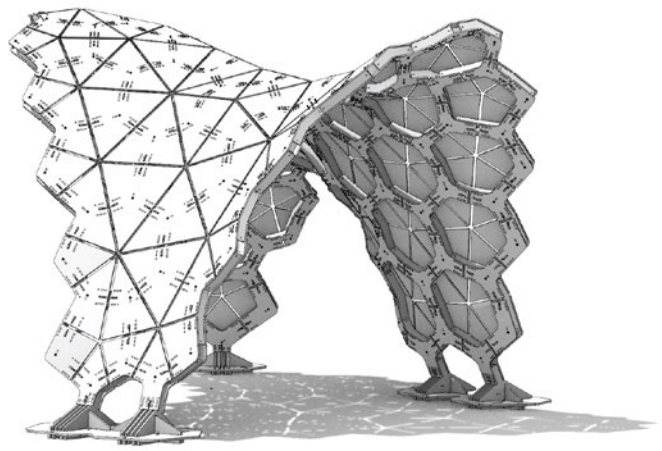
02 Degree of Closure inner layer: 20 %
Degree of Closure outer layer: 33 %



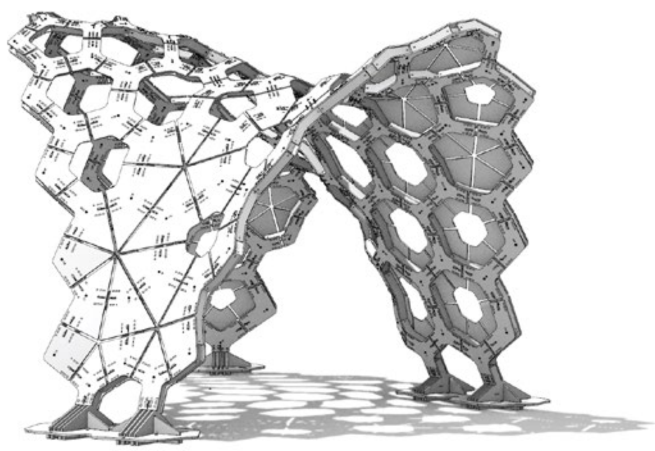
03 Degree of Closure inner layer: 20 %
Degree of Closure outer layer: 80 %



04 Degree of Closure inner layer: 66 %
Degree of Closure outer layer: 100 %



05 Degree of Closure inner layer: 100 %
Degree of Closure outer layer: 100 %



06 Degree of Closure inner layer: 80 %
Degree of Closure outer layer: 20 %

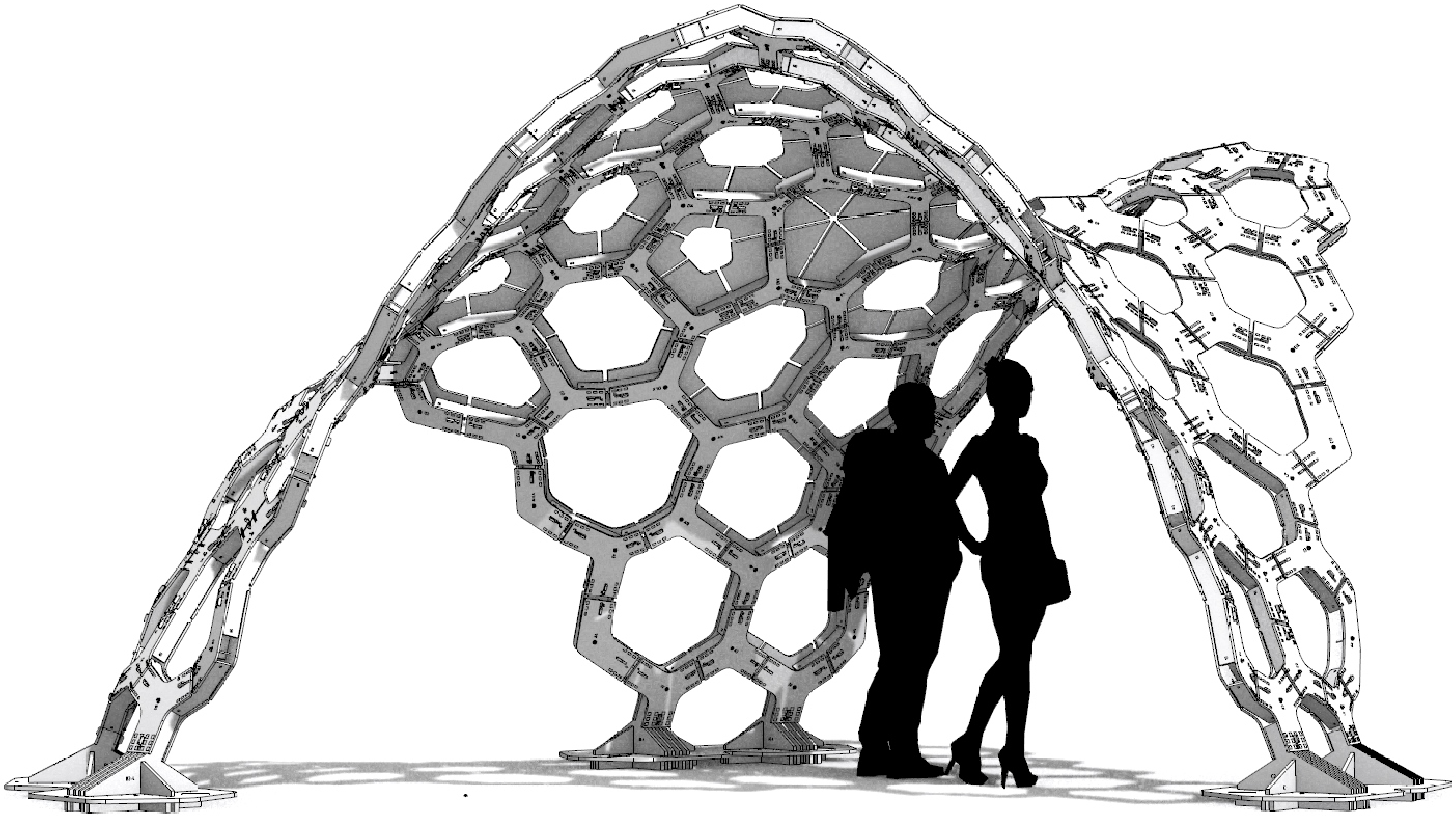
REALIZATION

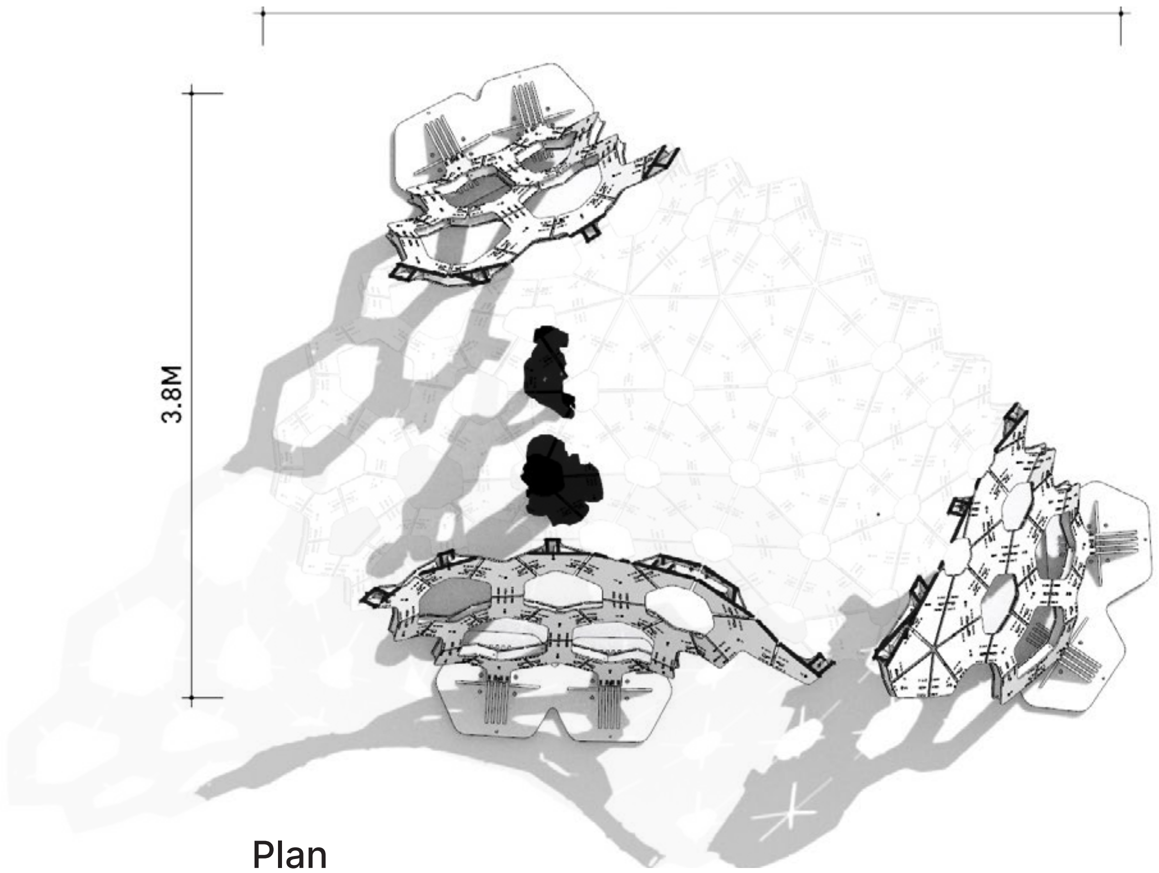
To demonstrate the system, a 1:1 scale pavilion was constructed in the summer of this year using 592 unique wooden elements. After being in place for approximately six weeks, it was then dismantled to be reassembled in a different location on the campus next year.

The prototype was made from poplar wood, while the final structure was crafted from 9mm thick birch plywood. The pavilion's supports are constructed using 15mm thick birch plywood.

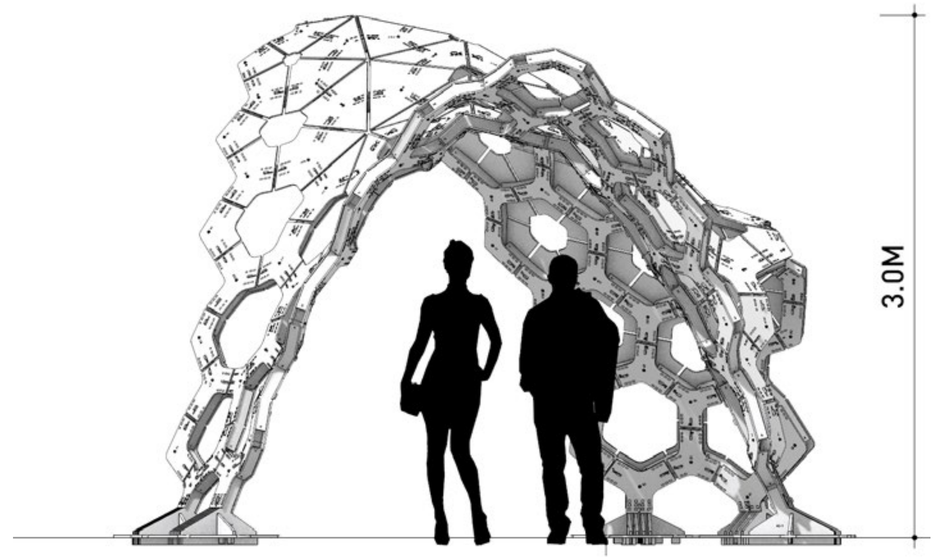
Thanks to the parametric planning process, nearly all components could be adjusted to match the actual thickness of the sheets almost up to the manufacturing stage. As compared to CNC milling, CNC laser cutting enabled a faster production process with 90-degree inside corners. However, the cut edges tended to result in soot formation. To minimize this effect and provide slight weather protection to the wood, all parts were sanded and treated with a primer.

In total, the structure comprises 592 parts placed on 20 sheets. The processing time for one sheet was approximately 40 minutes. Prior to the actual assembly, two trial setups were performed indoors. The assembly itself took place at the University of Applied Sciences in Biberach and lasted for one and a half days, with a team of eight people involved in the process.

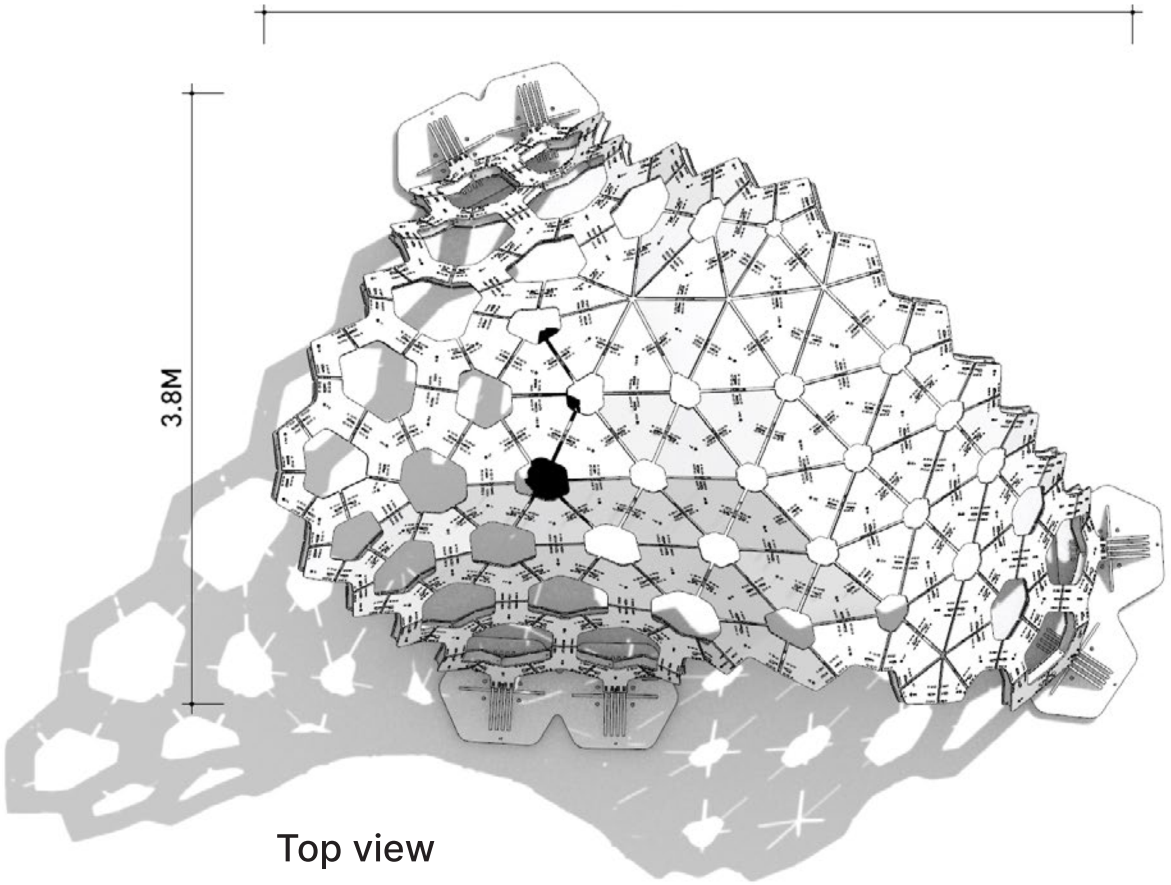




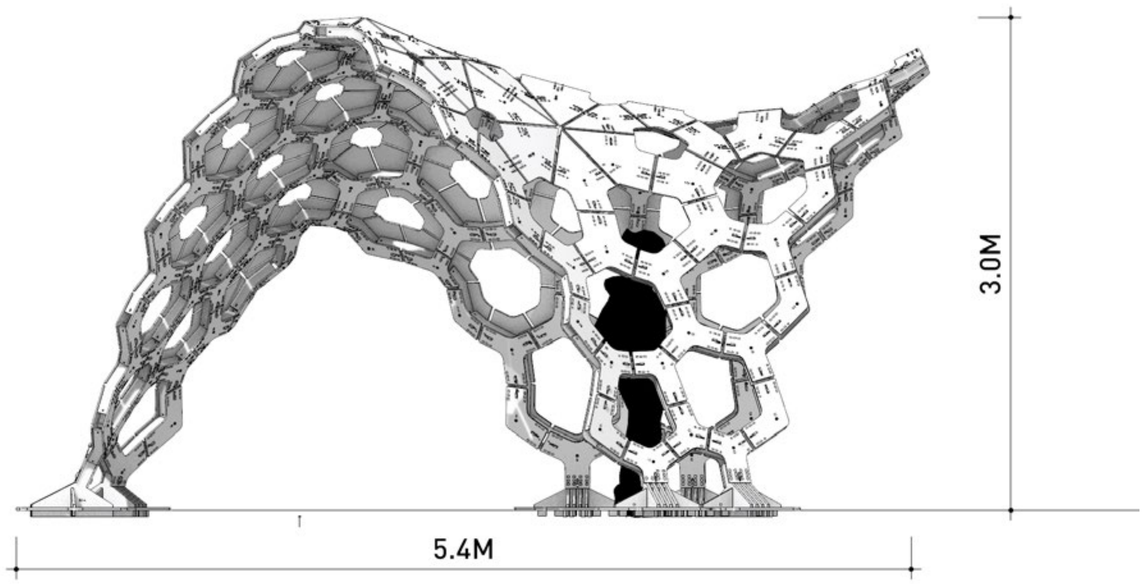
Plan



Southwest Elevation



Top view



Northwest Elevation

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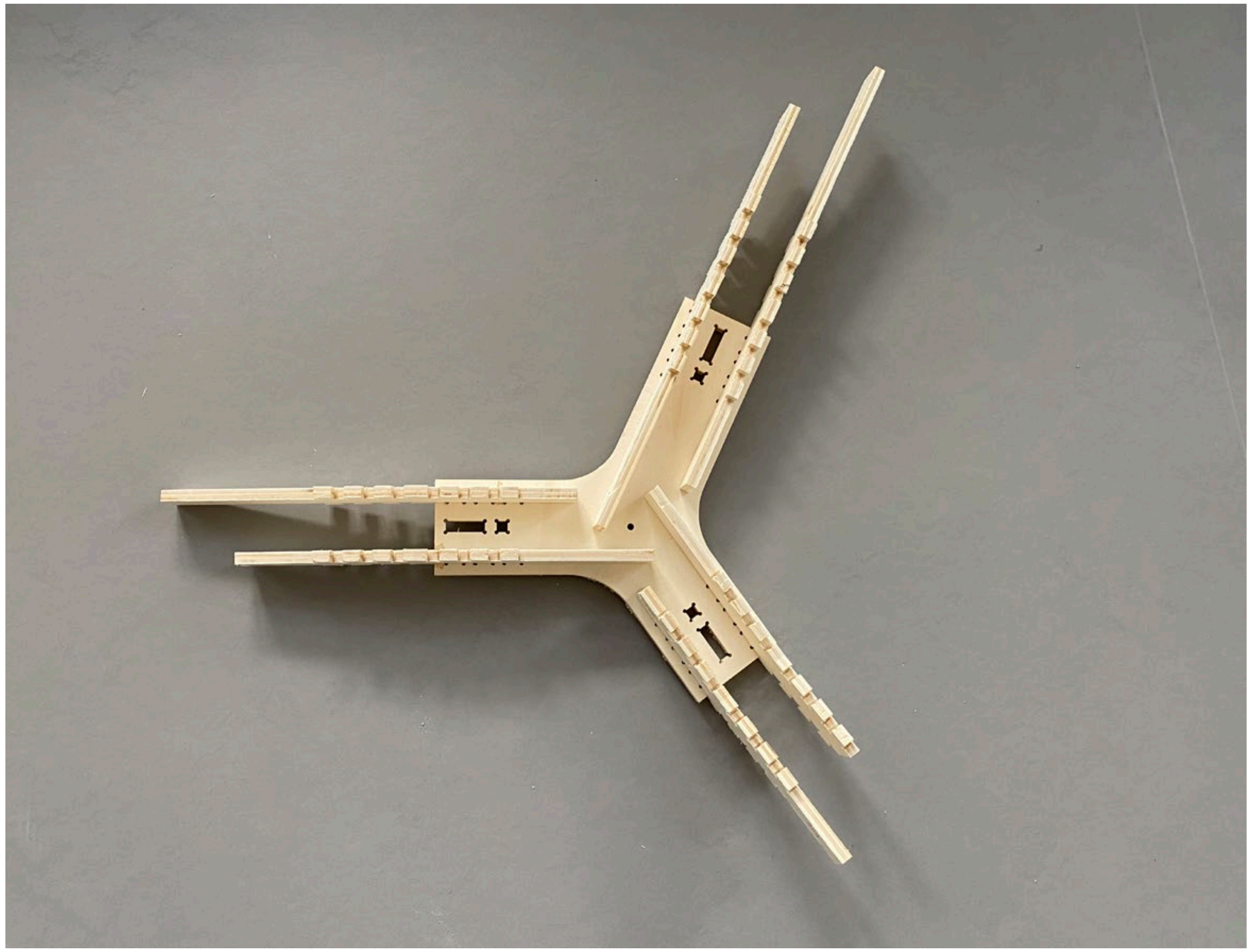
Prof. i. Vertr. Dr. Ing. Jonas Schikore
Prof. Dr. Christina Jeschke
David Ott

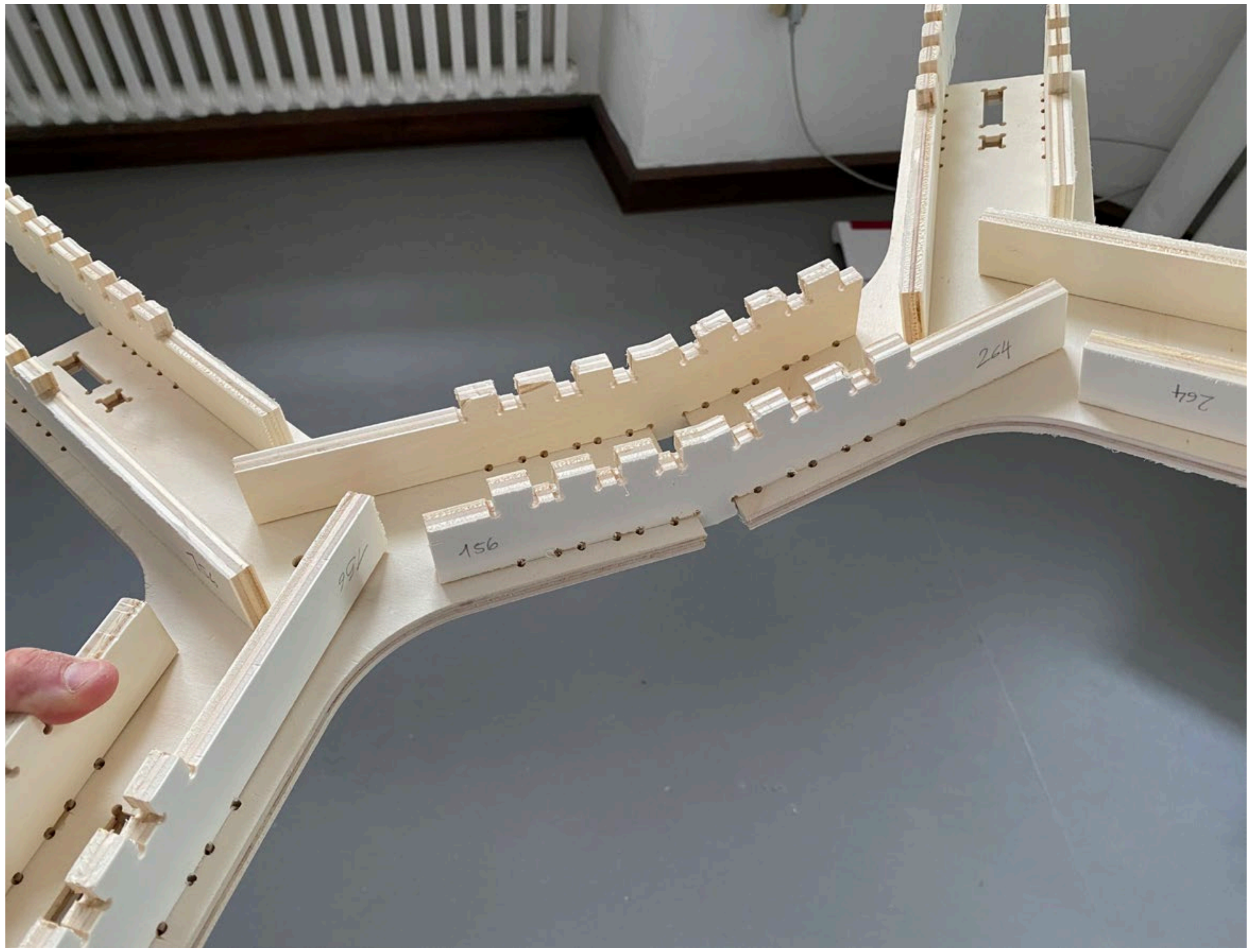
1:1 Prototype

Milled components

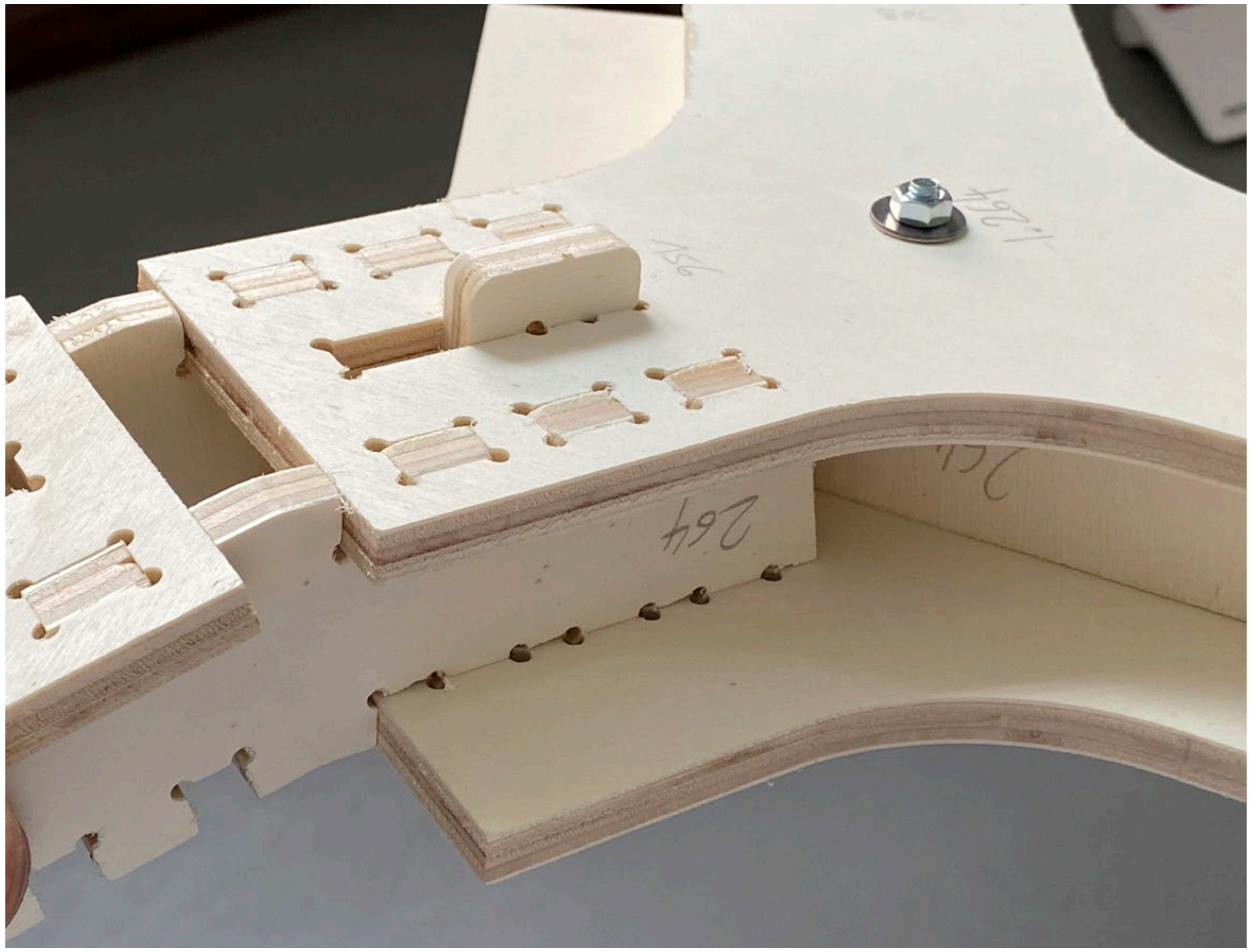


Lower node plate with all adjacent connectors

1:1 Prototype

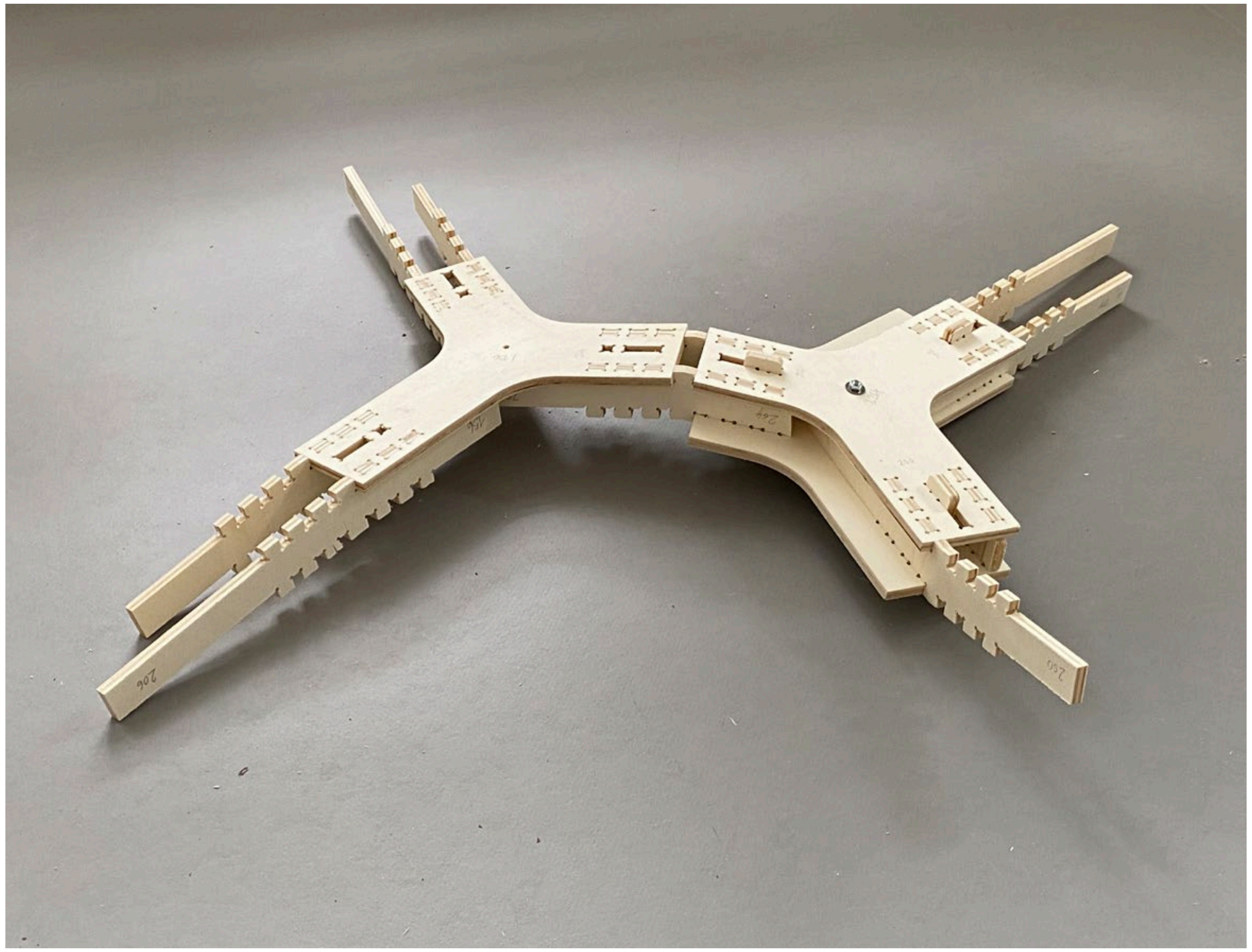


Two modules with internal node plates and all adjacent connectors

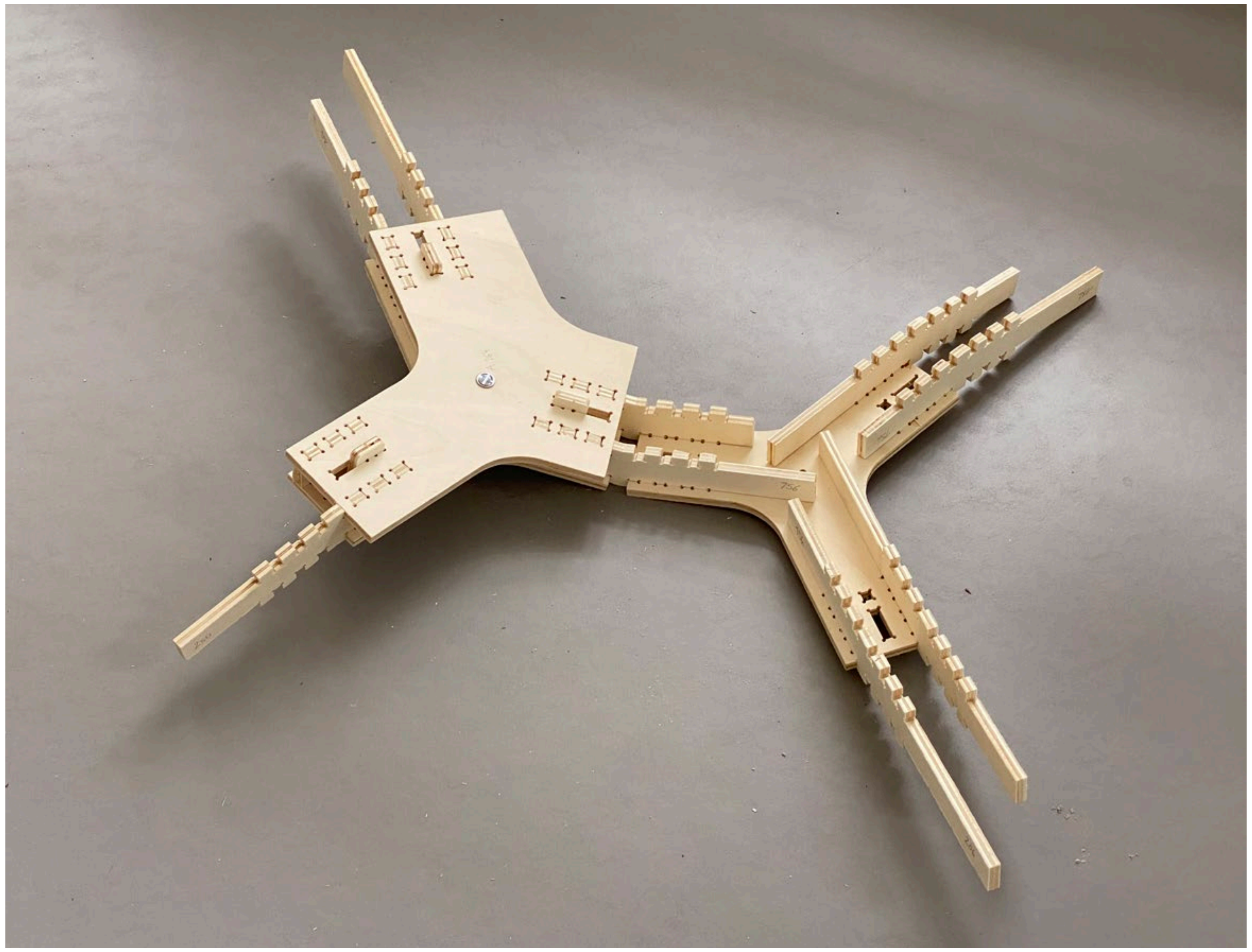


Internal and external node plate, held in place by screw and wooden clips

1:1 Prototype

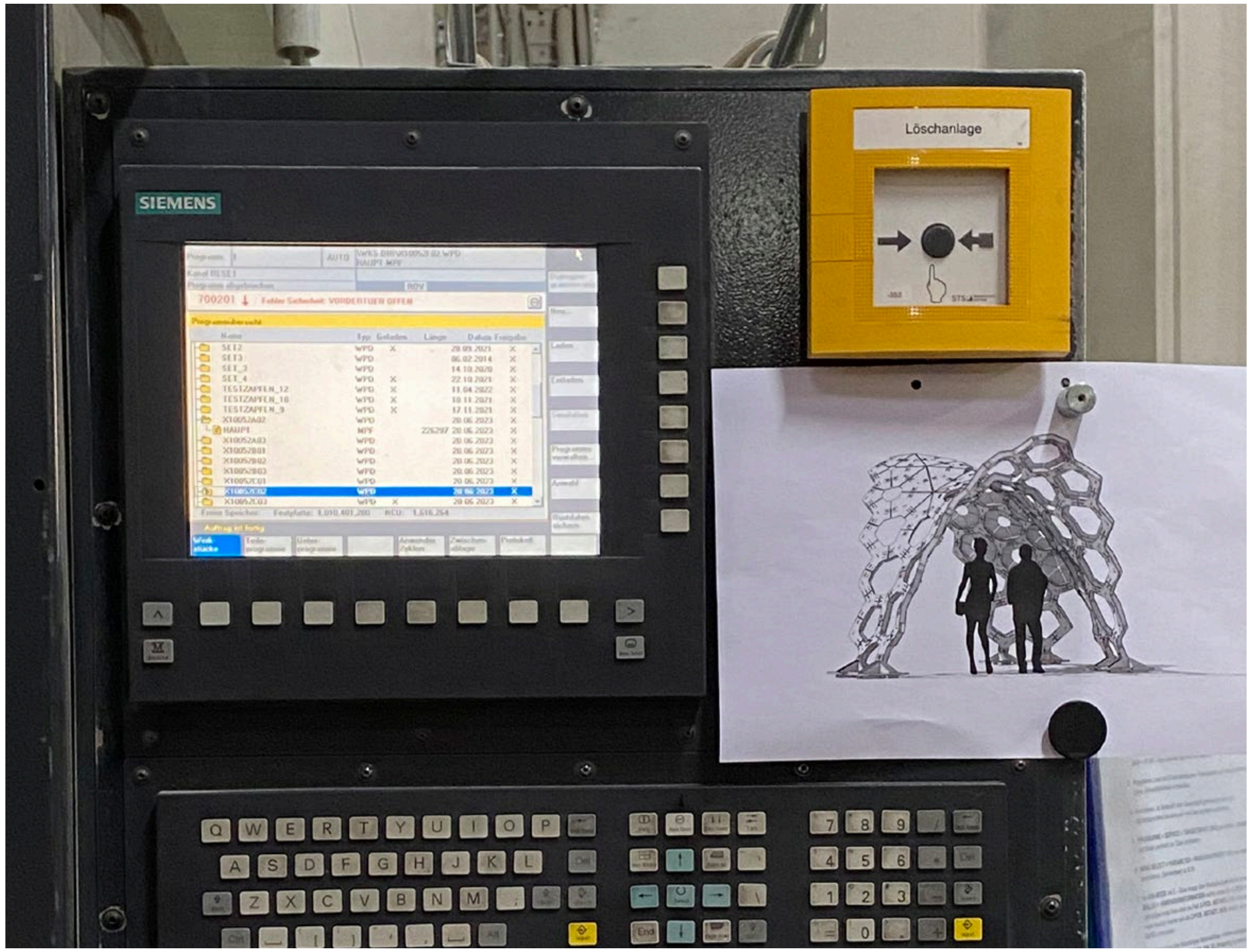


Two modules, view of internal node plates.



Two modules, view of external node plate
(the second external node plate is not installed to
keep the intersecting connector axes visible).

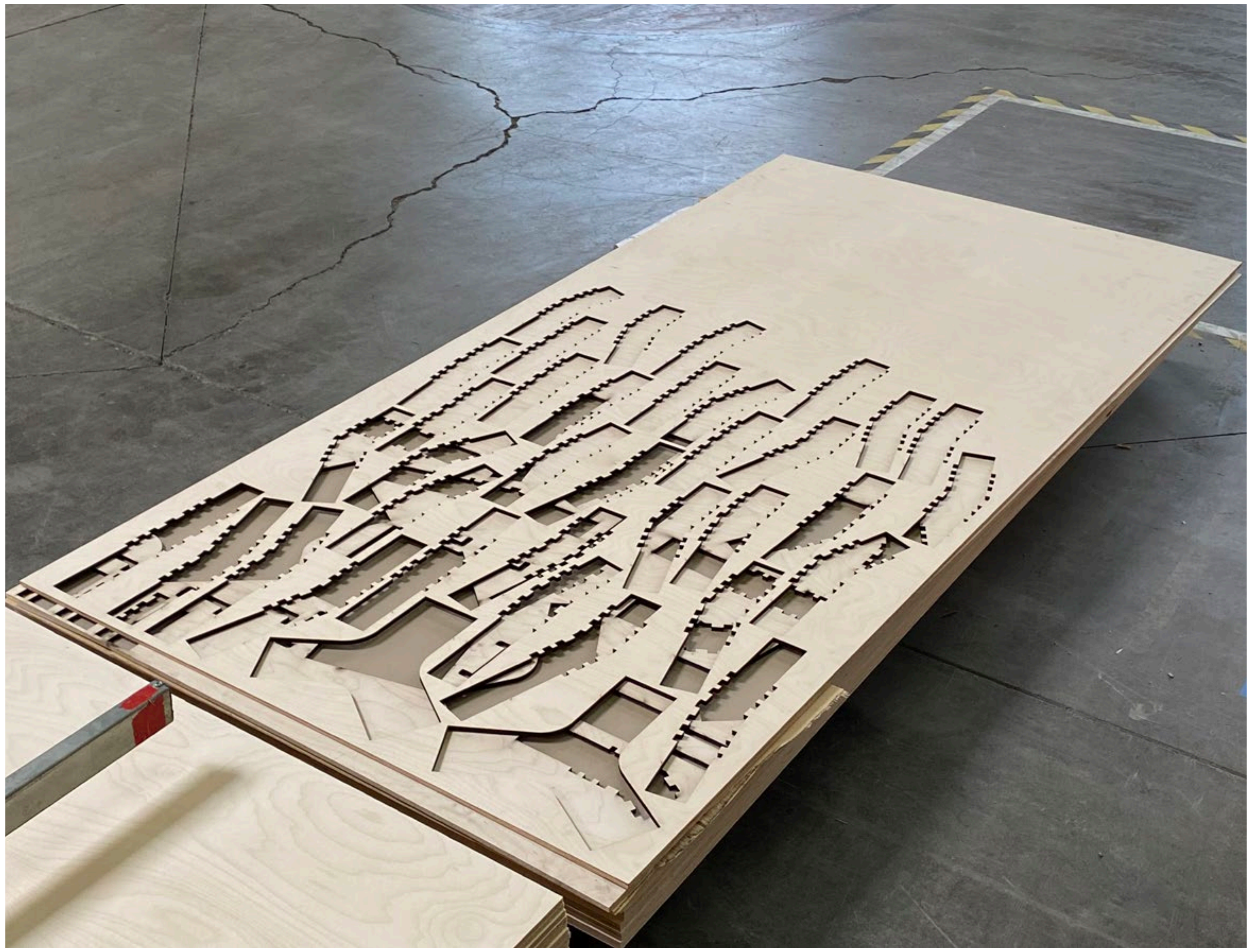
CNC-Fabrication



CNC laser system (Georg Ackermann GmbH)

CNC-Fabrication

In total, the structure consists of 592 components, which were placed on 20 sheets. The processing time for one sheet is approximately 40 minutes.



Raw sheets with negative cutouts

Post-processing

Sanding

Post-processing

Impregnation

Drying

Test
Assembly

Test assembly of two segments

stability test

Transport

Nine boxes with all the individual parts

... fit in the trunk of two station wagons

Assembly - First Day

Laying out all parts of a segment

Completion of segments A, B, and C

Assembly - Second Day

Segments A and B

Placement of the support plates
Positioning using precision distance spacers

Assembly - Second Day

Preparation of Segment C

Assembling the pre-assembled Segment C
onto the corresponding support plate

Assembly - Second Day

Installation of the first segments

Assembly - Second Day

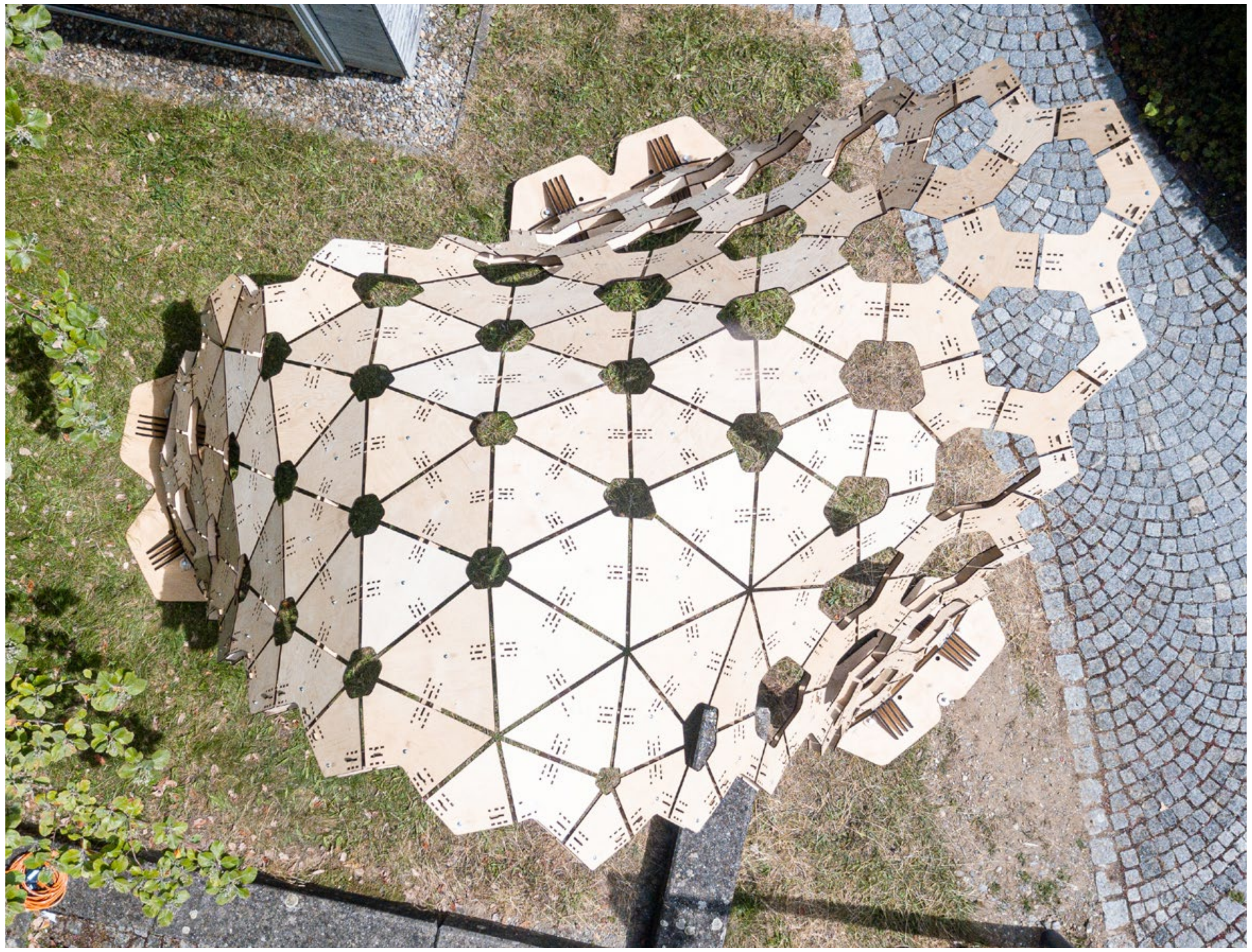
Arch closure between A and C

Assembly - Second Day

Assembly - Second Day

Assembly - Second Day

Assembly - Second Day



Costs

Planning	Approximately 300 man-hours (€100.00 per hour)	Covered by professors and student employees	-
Material	114 m² birch plywood (approx. €15.00 per m²)	Sponsored by the company 'Maurer Holzwerk-stoffhandel' from Ummendorf	€1,700.00
Fabrication	13 hours of machine time on CNC-laser machine: (€60.00 per hour)	Sponsored by the company 'Georg Acker-mann' from Wiesenbronn	€780.00
	54 man-hours of production (laser cut-ting, grinding, priming) (€60.00 per hour)	Sponsored by the company 'Georg Acker-mann' from Wiesenbronn	€3,240.00
Assembly	72 man-hours	Covered by students	-
Total			5.720,00 €

Design Build Seminar

The objective of the Design-Build Seminar led by Dr. Christina Jeschke and Simon Vorhammer in the winter of 2022/23 was to develop systems for spatially efficient structures, where complex forms could be realized using relatively simple means. The parametric planning process was at the core of this. In addition to 'Carapacks,' two other projects from this seminar were implemented for the summer event of the Architecture program.

"Plattenbau"

Concept:

Maxi Adis
Simon Deinet
Daliah Gartenmeier

Development, Production, Assembly

Lena Braunsteffer
Jasmin Brunner
Gina Deffner
Nina Grieser

Lisa Haas
Romy Kuhn
Timo Pahl
Maximilian Weber

The modular pavilion 'Plattenbau' consists of orthogonal interlocking panels that form a walkable, tent-like structure. The alternating orientation of the panels creates a play between solidity and transparency. Despite all elements having the same exterior dimensions, the positions of the interlocking slots vary, connecting each element with at least three neighboring ones. As a result, each piece is unique. Thanks to the embedded labeling system within the components, the pavilion can be assembled without the need for plans.

"Plattenbau"

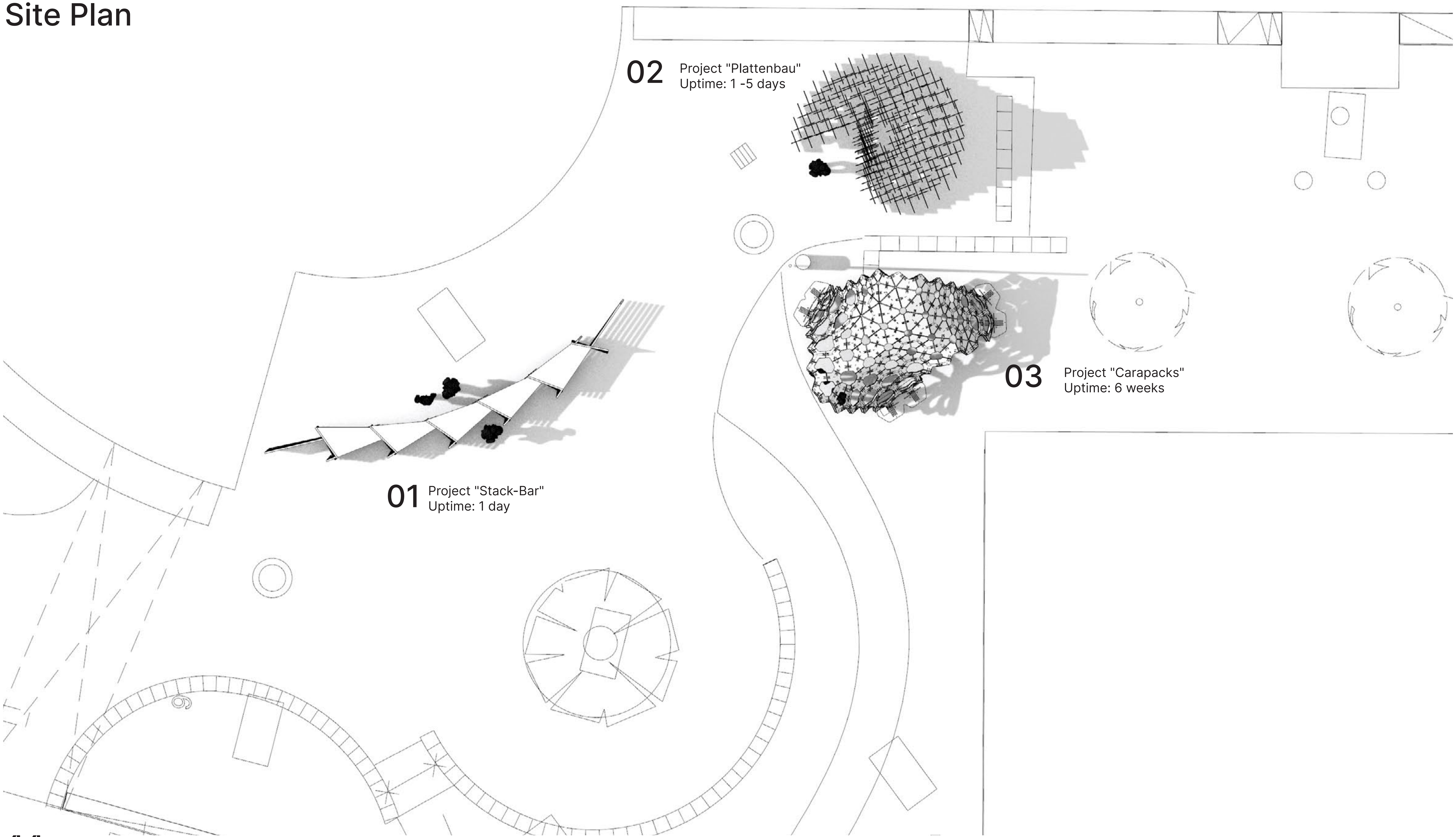
"Stack-Bar"

Concept, Development, Production, Assembly

Salomo Bergmann
Pascal Bulling
Marvin Mai
Berkay Mutlu
Melih Narin
Filip Gregor Rettig
Ben Schucker
René Storz

The 'Stack-Bar' project places its focus on reusability. For the construction of the bar, standard wooden slats of one or three meters in length were stacked and secured with tension straps. The non-destructive assembly principle eliminates the need for screw connections. This allowed the material from the local hardware store to be temporarily borrowed before it returned to the market for sale.

Summer Party
Site Plan



Summer
Party