TEXTILE HYBRID M1 at La Tour de l'Architecte *Monthoiron, France*

RESEARCH ON HYBRID FORM- AND BENDING-ACTIVE STRUCTURE SYSTEMS

Context

The Textile Hybrid M1 at La Tour de l'Architecte is an outcome of the combined research, with the students of the University of Stuttgart, on the subject of textile and bending-active material behavior for new typologies of lightweight structures being developed at the Institute for Computational Design (ICD) by Sean Ahlquist and Institute for Building Structures and Structural Design (ITKE) by Julian Lienhard. The Textile Hybrid M1 is situated at the historically protected site of a stone tower, built in the 1500's, in Monthoiron France. The tower is based on a design by Leonardo Da Vinci from the 16th century, which brought the owners to the idea of making the tower usable for exhibitions. The authors led a design studio with Students from the University of Stuttgart to explore the possibilities of engaging the tower space and developing a cover through form- and bending-active structures. On the basis of a spatial program, such a textile hybrid system was developed where short-cutting of forces produced a minimization of the loading on the tower. In the context of this project, the M1 was developed as a prototypical pavilion (Fig.1 a-b).

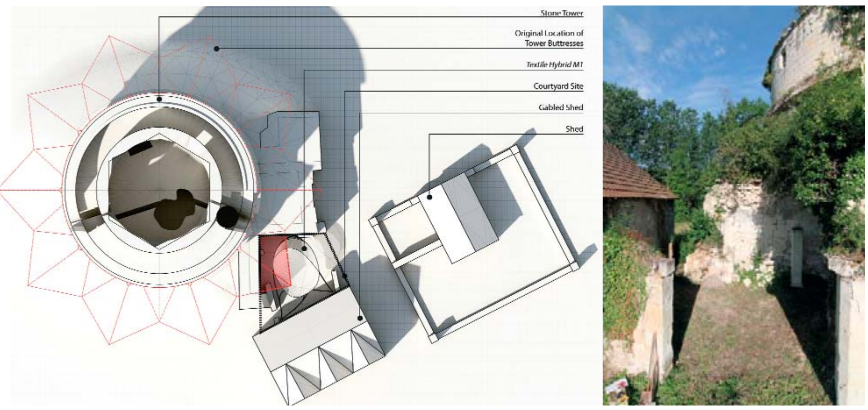

Figure 1 a-b: Site plan, Courtyard next to ruined tower

Research project

The M1 structure showcases the research on hybrid form- and bending-active structure systems. The scientific goal of the project was the exploration of formal and functional possibilities in highly integrated equilibrium systems of bending-active elements and multi-dimensional form-active membranes. The resulting multi-layered membrane surfaces allowed not only for structural integration but also served a functional integration by differentiating the geometry and orientation of the membrane surfaces. The structural concept is spatially and technically oriented to the design of a canopy whose exertion of force is minimal to the surrounding context, abutting buildings adjacent to the tower and staying clear of areas containing sensitive archaeological material. At the same time, its spatial presence on the site is maximally articulated. The longest span, of approx. 8m, provides cover to a region where one of the foundations for the tower's stone buttresses sits (Fig. 2). The minimal external structural exertion was accomplished, at multiple scales, through a macro-system of interwoven bending rods that form leaf-like shapes, and a meso-scale differentiated cell logic. The minimally invasive nature of the lightweight structure was a necessity given the delicate condition of the neighboring stone tower. Aspects of the structural logic were also amplified to investigate the potential for the complexity of the material system to accomplish an articulated spatial experience.

Computation of material behavior

Critical to the development of such complex integrated form- and bending-active hybrid systems was the calibration of design and analytical studies done through both physical experiments and computational methods, within the context of a design studio (Fig. 3). The computational means were continually advanced and calibrated via studies of physical behaviors at varying scales. Such prototyping was necessary to understand the dynamics of the self-organizing system as well as test the relationships between varying material parameters (comparative stiffness and pre-stress between composite rods and textiles) and accomplishing a stable form. The design methodology spanned multiple computational environments and degrees of specificity. For

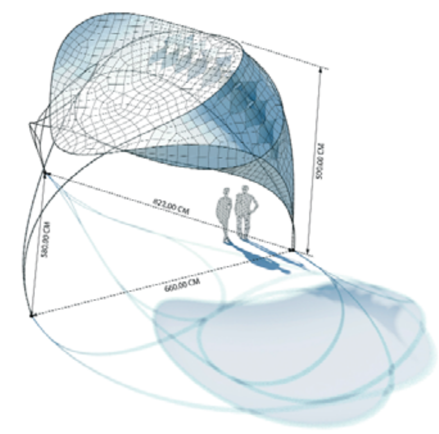

Figure 2: Overall design of the M1

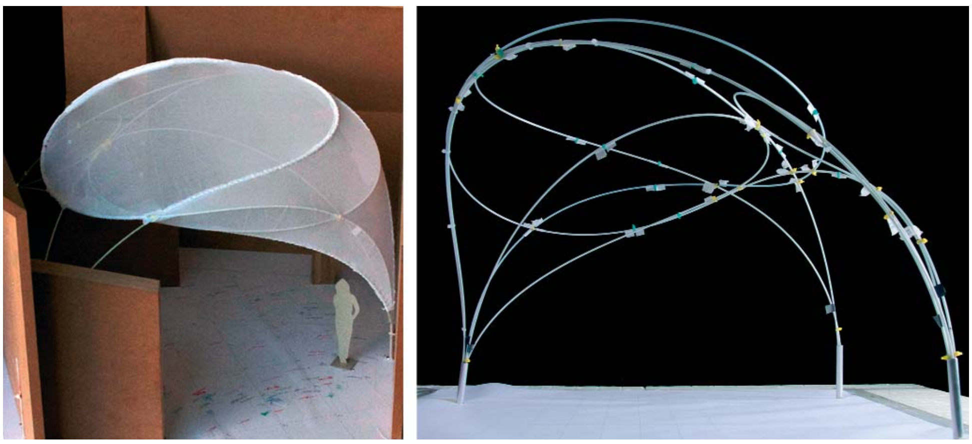

Figure 3: Physical models

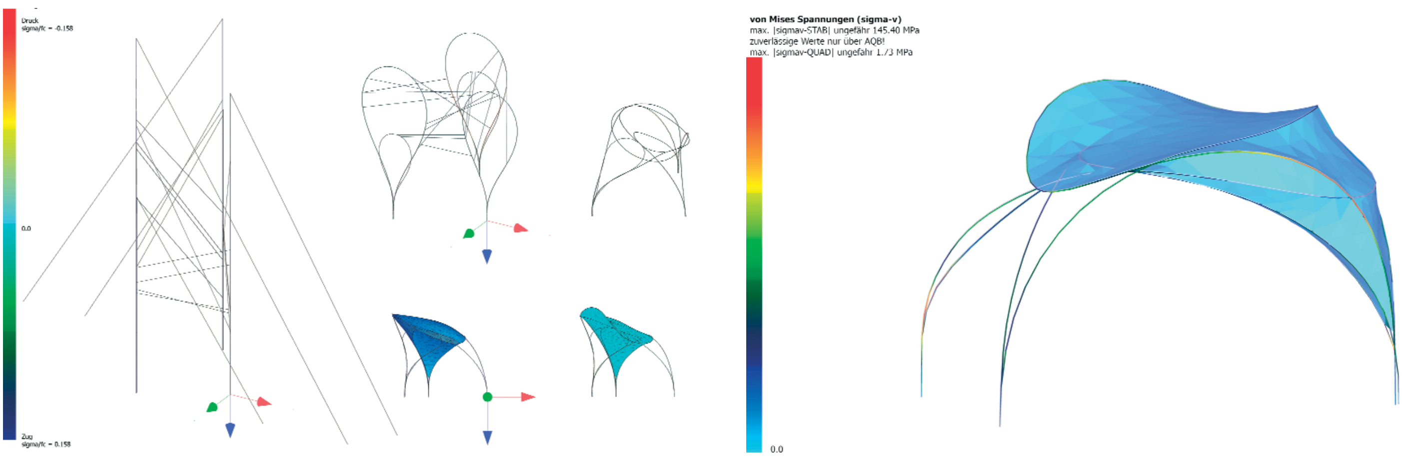

Figure 5a-b: Sequence of form-finding steps in Sofistik® FEM, based on rod associations from physical model b: form-found FEM Model

generative studies, a behavior-based modeling environment, developed in Processing through the research of Sean Ahlquist, was engaged (Fig. 4). The open (Java-based) programming environment allowed for complex topologies to be developed and altered, quickly registering feedback from prototypical physical studies. As both a design avenue and method for material specification, advanced Finite Element simulation in Sofistik® was utilized. Through methods developed by Julian Lienhard, different topological arrangements of macro-level rods and membranes could be studied. The parameters of the complex equilibrium system were explored to determine the exact geometry and evaluate the structural viability. Custom programmed methods in Sofitisk allowed for great degrees of displacement to be calculated in order to form-find the rod positions, starting as straight beam elements that were gradually deformed into interconnected curved geometries and finally reshaped by pre-stressed membrane surfaces (Fig. 5a-b). The geometric data therein was determined by the physical form-finding models which defined the lengths and association points for all rods. This form found structural analysis model allowed verification of the geometrical shape including its residual stress, as well as analyzing the deformations and stress levels under external wind loads. Furthermore the form-found membrane surfaces could be processed directly by the textile module of the software for patterning (Fig. 6a-b). Thus, all three design models; the physical and both generative and specific simulation techniques informed each other in this iterative design process.

Textile Hybrid System

The tectonic strategy for the structure was based on textile logic across scales and details, using Glass Fiber Reinforced Plastics (GFRP) and textile membranes for the main structural parts, as well as traditional Japanese lashing techniques for the nodes (Fig. 7a-b).
The global form orients the structure towards an existing arched wall which once defined a large domed space, also overlapping an area that holds the foundation of one of the tower's buttresses below ground. The longest span of the structure is designed to run across this part of the courtyard, preventing any of the structure from invading the area where the tower foundations sit below. At the macro-scale of the structure, the leaf-like geometries of the rods are interwoven relying upon various lashing and lacing techniques to lock the topology into a rigid frame. The tectonic methods are continued at the base of the structure where the rods are tied into bundles and laced to the GFRP foundation posts. Together with the membranes, the structure advantageously accumulates multiple layers, following previous research in Deep Surface Morphologies, and a structural elasticity. Such features enable the system to withstand varying stresses of wind, rain and snow yet rebound to its initial form-found state, while also mediating spatially the same forces via multiple differential layers. The cells provide a similar structural functionality at a smaller localized scale, but are more oriented towards offering an integrated strategy for spatial differentiation. Working to disintegrate the homogeneous nature of the textile membrane, the cells are constant in their topology, yet differentiated in their form. Utilizing Polyamid textiles for tensile stiffening in the cells and variation of light transmittance, the cell surfaces are articulated at more minute scales in comparison to textile membranes (Fig. 8c).

The integrated structural system is accomplished with glass-fibre GFRP rods of diameters ranging from 3mm-24mm in combinations with textile membranes as continuous surfaces and open-weave meshes. The highly elastic rods gain their stiffness from active bending into curved leaf shaped modules

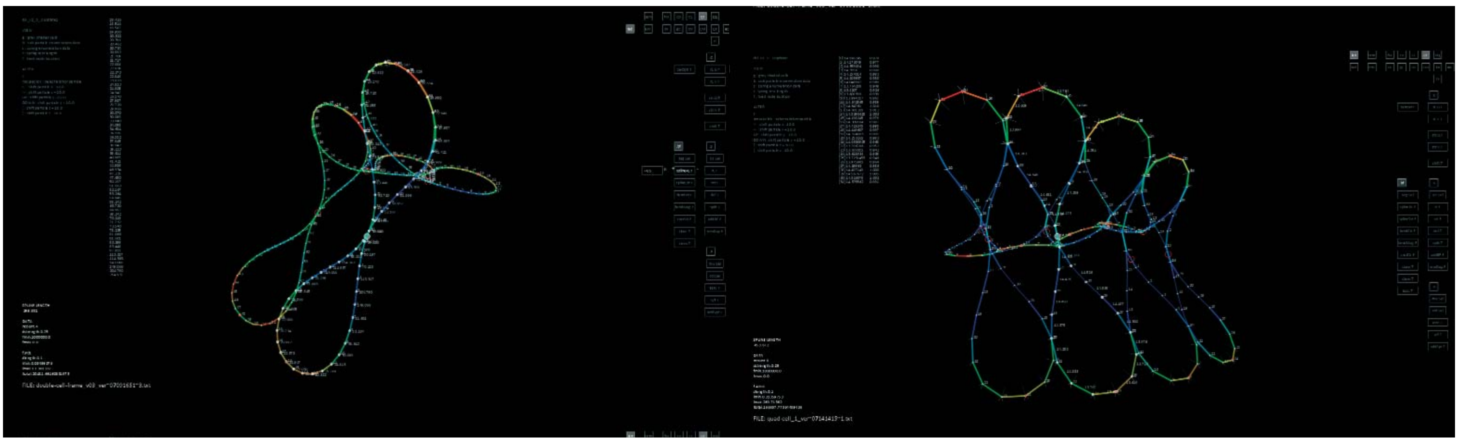

Figure 4: Behavior-based modeling environment

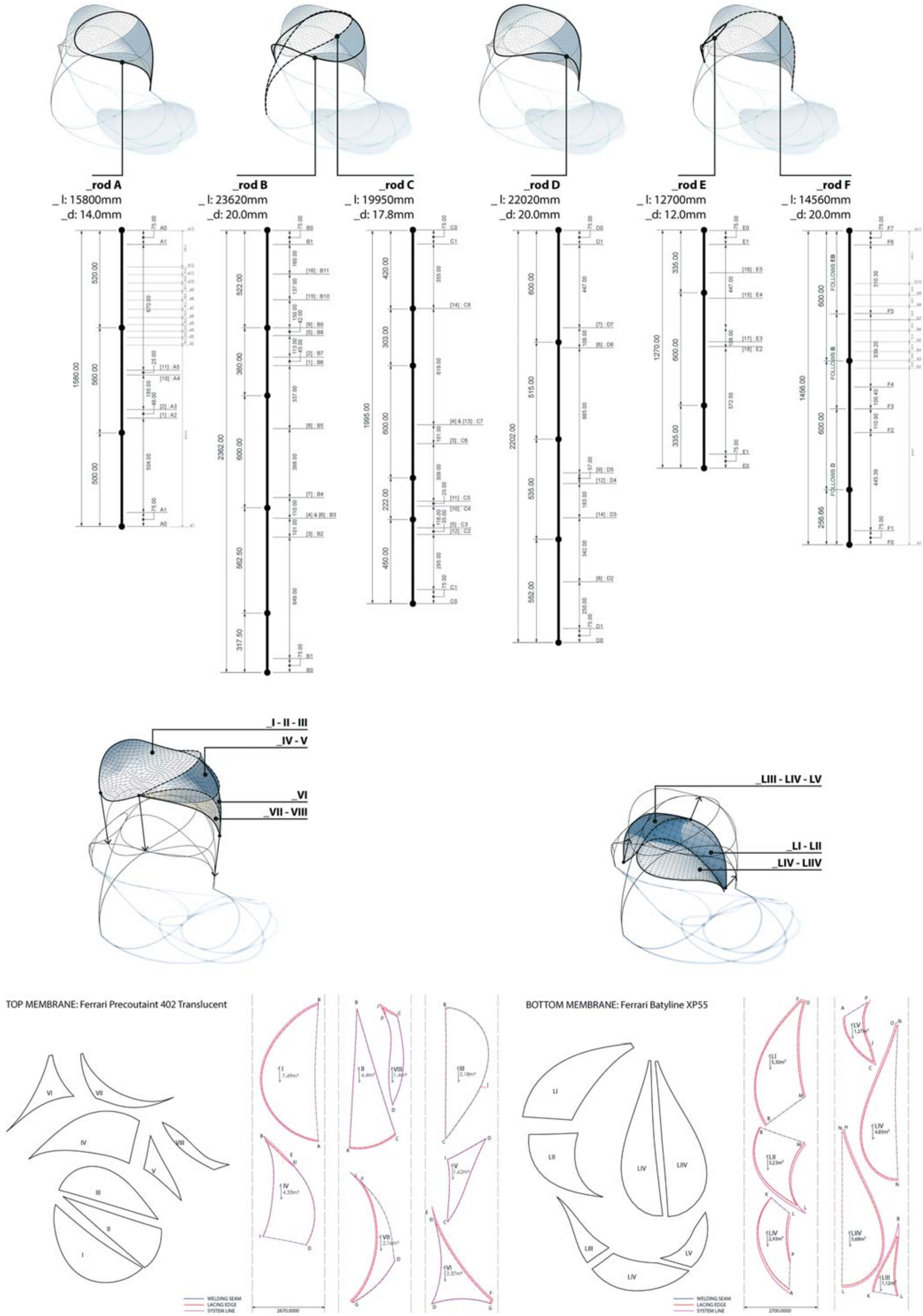

Figure 6a-b: Unrolled geometry of rods and membrane generated with FEM which are networked into a global structural system. Stress stiffening effects are activated by further deformation of the system through the integration of a pre-stressed membrane surface, and thereby creating a fully textile hybrid system. The structure is comprised of 110 meters of GFRP rods, 45m² of membrane material covering an area of approx 20m² and anchored to the ground with only 3 foundations resting against the existing stone structures which neighbor the tower. In total, the building weighs approximately 60 kilograms (excluding foundations), with a clear spans ranging from 5 to 8 meters (Fig 8a-c). Such high performance in the lightweight structure was reached by following a number of principal design rules found in most biological systems:

+Heterogeneity
+Anisotropy
+Hierarchy
+Redundancy
+Integration

A key feature in the design was the structural integration and heterogeneity; leaving the limits of strictly categorized building structures by accumulating different load bearing strategies in an associative system. The anisotropy of the fibrous materials was used as a driving force in the design and form-finding process of the material system. This system was featured on two hierarchical levels; a macro-system of interwoven bending rods that form leaf-like shapes, and a meso-scale differentiated cell logic.

The very nature of the system demanded simultaneous study of how structural equilibrium is formed and determination of the spatial performative capacity of the result. As such, the design methodology was formed to track both, articulation of material properties and differentiation of spatial consequences. M1 serves La Tour de l'Architecte as an exemplification of innovative structures generated of experimental means, as well as provide fundamental function for meeting, workspace and archaeological study within the complex of buildings as the site undergoes redevelopment. For on-going research, the building serves as a prototype for hybrid form and bending-active structures in their realization, as well as computational design methodologies for their generation.

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Figure 7a-b: Lashing details for the GFRP rod assembly

Name of the project:	Textile Hybrid M1 at La Tour de l'Architecte
Location address:	Monthoiron, France
Client (investor):	The Armbruster Family
Function of building:	Research structure, courtyard cover
Year of construction:	2012
Architecture and engineering:	Sean Ahlquist, Julian Lienhard
Students:	Markus Bernhard, David Cappo, Celeste Clayton, Oliver Kaertkemeyer, Hannah Kramer, Andreas Schoenbrunner
Supplier of the membrane material:	Serge Ferrari
Manufacture:	Esmery Caron
Material:	Ferrari Precontaint 402 Translucent, Ferrari Batyline XP55, Penn Polyamid textiles
Covered surface (roofed area):	25m²
Funding:	DVA Stiftung, The Serge Ferrari Group, Esmery Caron Structures

Fig 8a-c: Individual components of the hybrid system: Bending-active GFRP Structure, attached form-active textile membrane, internal cell structure.

Fig 9a-d: The textile hybrid M1: Internal view of multilayer membrane system with integrated cells. External view in the context of the tower ruin.