Rethinking Prototyping

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Architectural “Making” Modes in Relation to Prototype Notions

The Stripe Pavilion: Progression from a Bespoke to a Parametric-Algorithmic Mode

Mania Aghaei Meibodi and Hamia Aghaiemeybodi

Abstract In this paper, the authors address prototyping notions in relation to current digital design and making practices in architecture, parametric-algorithmic techniques in relation to bespoke design and the notion and role of prototype in bespoke design. Illustrative observations regarding the process of designing the *Stripe Pavilion* in Stockholm indicate that three recognized making modes - artistic exploration and sculpturing, physics-based form-finding and digital design/production form-informing - are not necessarily mutually exclusive but may be integrated in a given project.

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1 Architecture and "Making" Practice

Most architects do not make buildings but produce information for visualizing and realizing buildings. They transform ideas into drawings, models, narrative, texts and data, some of which inform the production of buildings. However, understanding of the physical and tactile has always played an important role in design processes. As noted by Sheil (2008, p. 11), "Intimate understanding of the physical and tactile … is central to the holistic scope of the designer's imagination." Furthermore, a niche within the spectrum of architectural discourse and practice defines the built environment as a material culture and identifies the architectural profession as a making discipline and material practice. Researchers, educators and practitioners in this niche develop designs based on the tactility, material, technology, systems and processes of building artifacts.

Recently, there has been a radical shift in the making discipline of architecture following the introduction of CAD-CAM direct communication tools and accessibility of consumer CNC production tools such as laser cutters, 3D printers and CNC milling machines in architecture schools and practices. This has transformed the role and scale of physical making in architectural design processes. In the last decade, digital media has influenced on development of scale physical modelling (Staveric and Stavric, 2013). Full-scale (1:1) physical prototyping in architectural research and design studios has increased. Indeed, it has not merely been encouraged but almost become a default in some architecture studios, and is impacting the architectural language of final products.

For the purpose of this paper, three modes of making the physical and tactile in architectural design processes that inform the formal language of architecture are identified, those driven by: (i) artistic exploration and sculpturing (form-making), (ii) laws of physics (form-finding) and (iii) digital design and production technics (form-informing).

In the first mode, artistic sculpturing, the making involves material exploration in early design stages with no immediate consideration of its realization in a larger or 1:1 scale. Frank Gehry's act of crumpling a piece of paper could be categorized in this mode.

The second mode can be observed in works of architects such as *Antoni Gaudí* and *Frei Otto* where effects of gravity on hanging chains (material components) and *Plateau's* laws on soap films (governing formation of bubbles from foam) respectively formed the artifacts. The artifacts that result from this making practice drive design decisions, affecting both, utilitarian performance and formal repertoires specifically in regards to tectonic design logics.

In the third mode production techniques, material processing techniques and digital objects (NURBS surfaces, curves etc.) are considered in very early design stages. The virtual surfaces and geometry in the digital environment influence the modes of the digital construction of form. The techniques offered by the fabrication tools guide and constrain the creation of designs using digital processes. Thus, all these leave tell-tale marks on the appearance of the final products. Examples of such works are the *Multifunctional Pavilion* by the authors (Fig. 1) and both prototypes and pavilions resulting from waffle-grids, tessellations, sectioning or triangulation modes of rationalising surfaces.

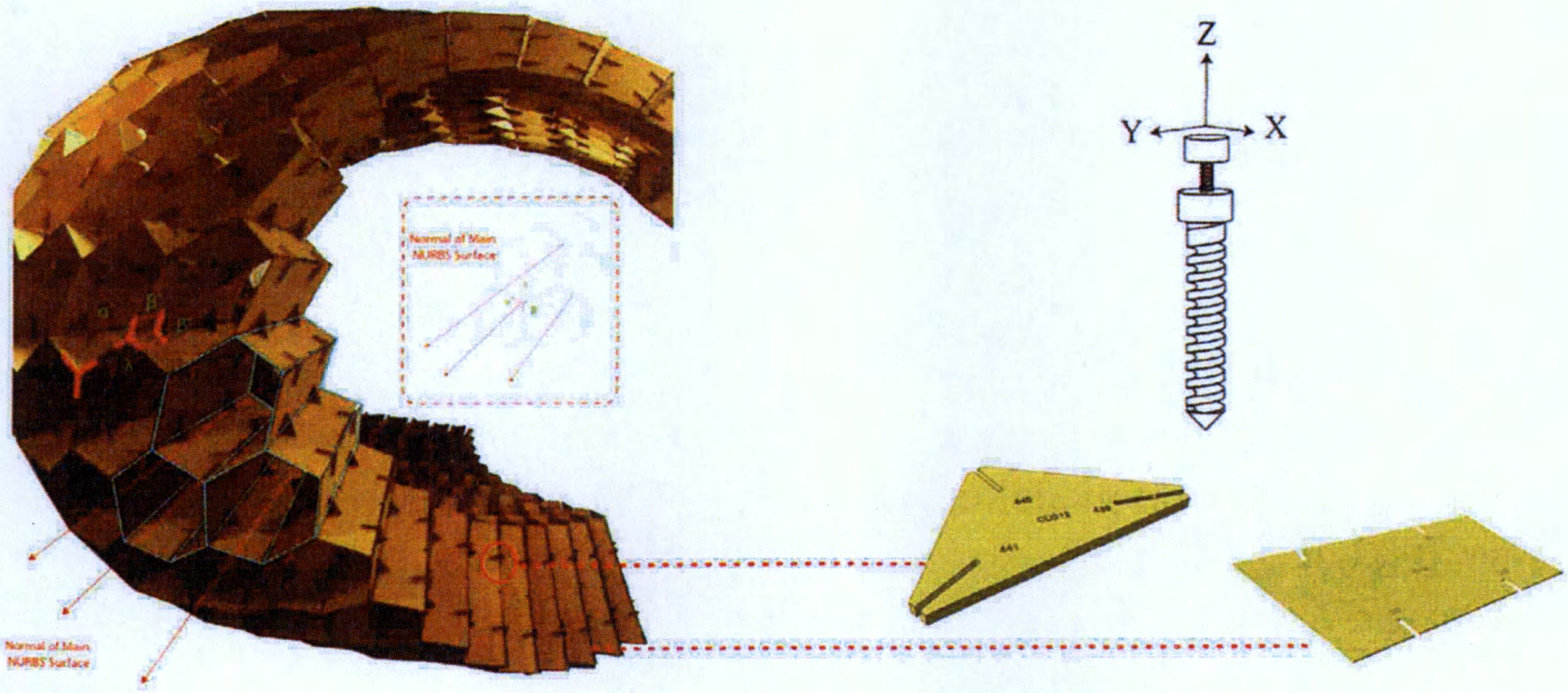

Fig. 1 The Multifunctional Pavilion built in 2012 as part of the Design and Making studio founded by authors. The figure illustrates that the digital design and fabrication tools and technics may constrain the range of form. The fabrication technics and technology (in this case milling and three-axes CNC milling tool) and material con¬straints become the most important force driving the de¬sign and form. Leading to componentization of form to plane joints and plates.

Differences in these making modes may influence our analysis, generation and production of architecture. They may also affect the formal and aesthetic language of architecture. However, there have been attempts to align or combine them. This paper describes a project, in which a pavilion based on a stripe motif was designed using all three making modes defined above, and analyses the prototype notion in relation to each mode.

2 Prototype Notions

Physical prototypes are being increasingly used in architectural practice since they can reduce uncertainty, improve the constructability and feasibility of designs, enable communication and provide archives. Sometimes they may be used continuously as analytical probes for investigating designs. Their use in architectural design is relatively new in comparison to other contexts, e.g. industrial design, electronics and software development, and there is no general agreement on what constitutes an architectural prototype. However, since digital models are widely used in architectural design processes, the prototype notion should clearly encompass more than merely physical objects.

Runberger (2003, pp. 22-25) discusses prototype notions in contexts of various disciplines presented by various authors, among others *Gero* (1990, p. 26), *Schrage* (2000, p. 7), *Capjon* (2004, p.289), *Eppinger* and *Ulrich* (2004, p.7). He stresses that prototypes are real working models, not merely representations, regardless of their scale and medium. He also discusses the notion, presented by *Capjon* (2004, p.289), of clusters or classes of prototypes including *Visiotypes* (models of visionary solutions), *negotioypes* (flexible models for conceptual negotiation between collaborators) and *seriotypes* (product series generated for tests). He comments that this clustering may have arisen from *Capjon's* field of industrial design, in which "prototyping is firmly defined as a physical model used to test design against users and parameters" (Runberger 2003, p. 23).

Eppinger and *Karl* (2004, p. 247) present a more comprehensive system for classifying prototypes with two dimensions, the degrees to which:

- "A prototype is physical as opposed to analytical".
- "A prototype is comprehensive as opposed to focused".

The first dimension concerns the physical, tactile and tangible aspects of a prototype. Physical prototypes are "tangible artifacts created to approximate the product", while analytical prototypes represent products in a non-tangible, usually mathematical manner, and "interesting aspects of products are analyzed rather than built". Examples of analytical prototypes are computer simulations (e.g. finite element and computational fluid models), coded spreadsheets and digital models of 3D geometries. The second dimension concerns scale and number of attributes that is encompassed within a prototype. A comprehensive prototype "implements most, if not all, of the attributes of a final product", in a full-scale, fully operational version of the product. In contrast to comprehensive prototypes, a focus prototype explores only a few aspects of a product, although several focus prototypes are sometimes constructed to investigate its overall performance.

Schrage (2000, P. 128) conceives prototyping as a way of "communicating how organizations use media to manage multimedia innovation processes", in which prototypes are developed incrementally and chosen media strongly influence the design environment, potentially evoking new designs. The prototypes both raise and answer questions, emerging from interactions rather than methodical developmental paths.

Here, definitions of prototype and prototyping by *Eppinger* and *Schrage* respectively are used as starting points for investigating prototype notions in relation to architectural making. To avoid potential confusion, *Eppinger's* term analytical is modified and replaced by virtual within the first dimension of the prototype notion.

3 Convergence of Modes and Prototypes

Using the experimental *Stripe Pavilion* project described below, we postulate that the three making modes are not necessarily mutually exclusive, indeed their integration can facilitate design processes, and explore the relationships between the three modes and types of prototype. We also argue that making physical and digital prototypes, rather than merely physical prototypes, provides more scope for synergistic application of the three modes in architectural design.

Fig. 2 An unfinished 1:1 scale physical prototype of a section of the Stripe pavilion

4 The Stripe Pavilion for Stockholm

The *Stripe Pavilion* (Fig. 2) was initially developed as a proposal for a competition, in which entrants were asked to present a pavilion structure that could be used in various urban environments such as plazas, streets, beaches and modified according to requirements and circumstances, as part of a vision for *A World-Class Stockholm* in the 2030s and a public face for visitors and tourists. We chose a stripe as our starting point, as many Swedes like wearing striped costumes, a striped sweater adds a traditional touch, and the Swedish flag has two perpendicular stripes (in yellow); a common motif in Scandinavian flags.

4.1 Physical Proto-Morph Model

The three making modes emerged during various design stages of the *Stripe Pavilion.* We started with a sculpturing mode to conceptualize cultural aspects and materialize them in a paper stripe.

Our design component, the stripe, was initially materialized using paper to form a physical model and the sculpturing mode to investigate its morphology. The physical paper model served as a conceptual model initially, and subsequently as a tangible tool for exploring spatial and volumetric aspects of the project. It was then documented digitally and used as material for constructing circulation and programmatic diagrams (Fig. 3). More importantly, it served as an armature for shaping and embodying the architectural tectonics. A fold concept then arose through twisting, bending and folding the material component (the paper stripe) i.e. exploration of its behavior in physical making mode.

Fig. 3 Illustrations of the paper model's use as a conceptual element to investigate circulative and volumetric aspects of the Stripe Pavilion.

The sculpturing of the paper model and photography were initial engines for the morphological study of the component's behaviour (Fig. 4). Thus, it served here not as a representation model but as a working model for investigating the behavior and morphology of paper stripe components, and we identify it here as a proto-morph model.

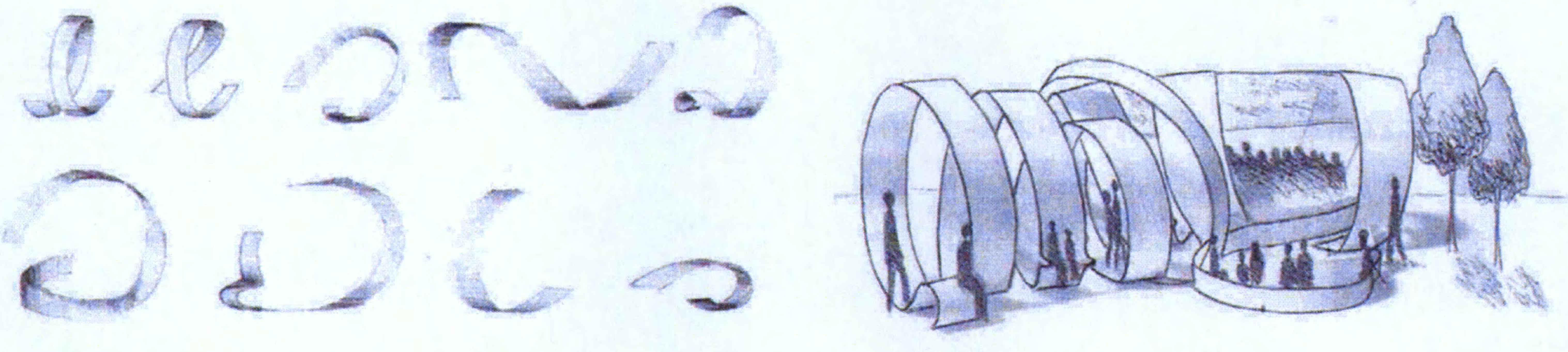

Fig. 4 Morphological variants of the stripe were documented, developed via sketching mode.

4.2 From a Physical to a Digital Proto-Morph Model – Intrinsic Relations between Parametric-Algorithmic and Bespoke Design

Neither digital design nor manufacturing tools were employed in early stages of the *Stripe Pavilion* design process. Instead, the behaviour of twisted and bent paper-stripes was studied through physical interaction. However, to rationalize and further optimize the morphology of the paper-stripe for full-scale production a point cloud model was created by scanning it and a generative algorithm was designed. These two phases can be classified as an extractive process, capturing the physical form digitally and extracting the initial curve from the bespoke model, followed by a generative process enabling generation of virtual paper-like stripes from any given curve.

4.3 A Generative Parametric-Algorithmic Model

In the generative design phase we used parametric design software coupled with scripting to imitate the morphology of the paper stripe components. To maximize control over the composition of the digital stripe the design input was reduced to spatial curves in order to deliver the formal composition. Further, to ensure that any stripe morphology generated from the digital spatial curves had a planar surface that could be cut from sheet material a set of developable surface scripts was developed according to the *Shelden* (2002). From which a developable linear paper-stripe from any given spatial curve could be calculated and generated. Developable or single-curved forms are those that "can be created through ordinary bending of a planar surface without stretching, cutting or wrinkling the material. Developable surfaces are useful because they allow round forms to be made out of flat materials like plywood, sheet metal or cloth" [1].

4.4 An Extractive Mechanism – From Physical Bespoke to Digital Models

The part of the physical model that was selected for full-scale prototyping was scanned three-dimensionally and the resulting point clouds provided templates for extracting spatial curves, which were parameterized to allow modification (Fig. 5). Truly bespoke design occurred when the stripes were designed and articulated physically. Once entering the digital realm, pre-planning started through the application of algorithms and parametric association of the geometries. Once the spatial curves had been reconstructed digitally, they were fed into the generative algorithm as inputs for generating developable linear paper stripes.

Fig. 5 Extraction of curves from point clouds of paper stripes.

4.5 Form-Informing Mode – Focused Physical Prototyping

To realize the project, the paper stripes were rematerialized as laminated *Masonite* stripes, which behave differently from the paper model, and the shift in scale and dematerialization of the stripe introduced two new aspects into the morphological study of the stripe: the wood-laminate material component system, leading to the introduction of joints, and the thickness and layers of the laminated wood material.

For this phase of form-informing making mode, we sought a forming technique based on available manufacturing tools and affordable material. A mold system, for curving and laminating *Masonite* sheets was sought (Fig. 6). The molds were designed and articulated digitally as tangents to the digital stripe, then manufactured by a three-axis CNC laser-cutting machine. The act of making focused physical prototypes was an essential part of learning the geometrical intricacies for each stripe, allowing us to engage deeply with the task of bending the wood and understanding its properties and behavior. Experimentally, several folding's were applied to the Masonite to explore the deformation of the material required to create a potential sculpture for the pavilion.

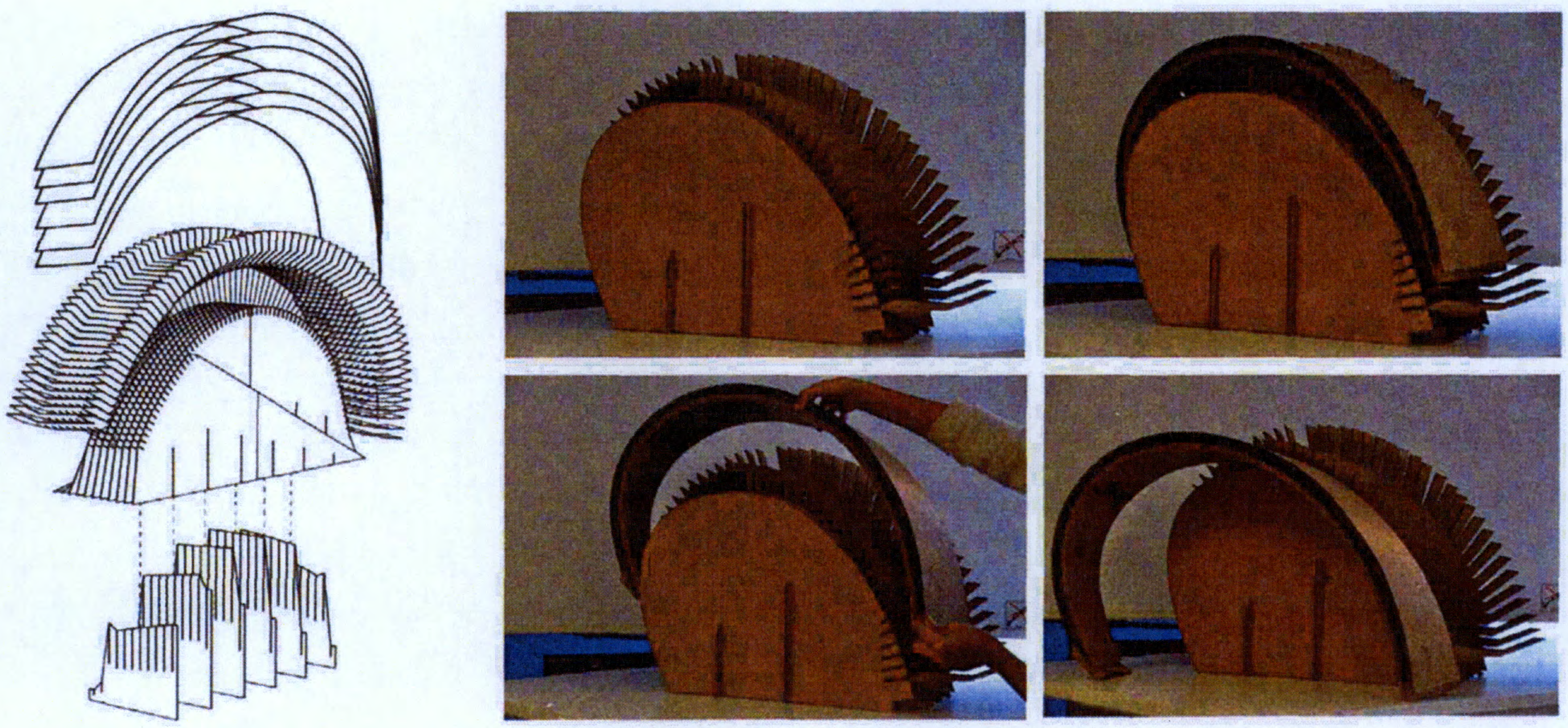

Fig. 6 The axonometric drawings of the mold, which was, used for forming stripe components (right). Forming stripe components on the mold at small scale (left).

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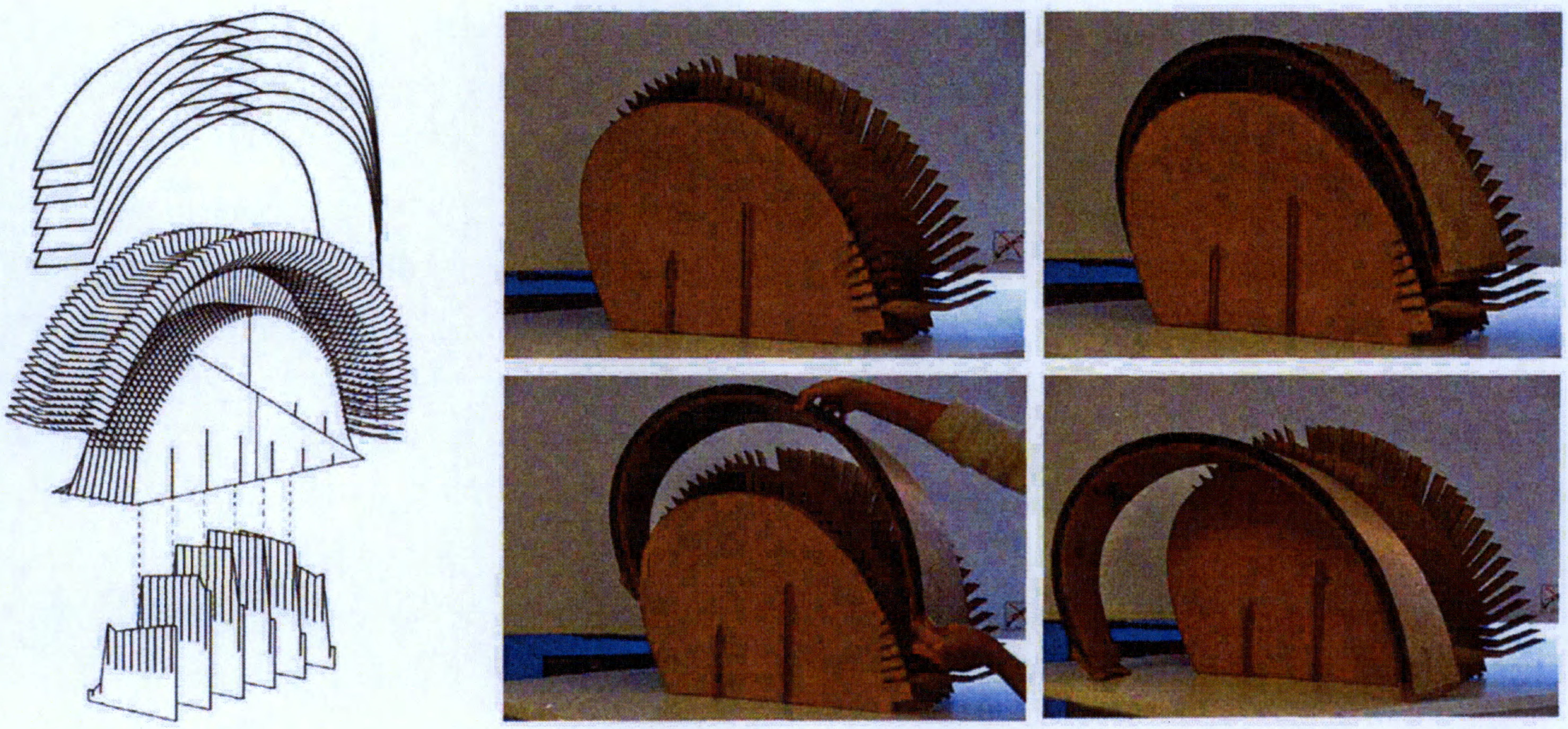

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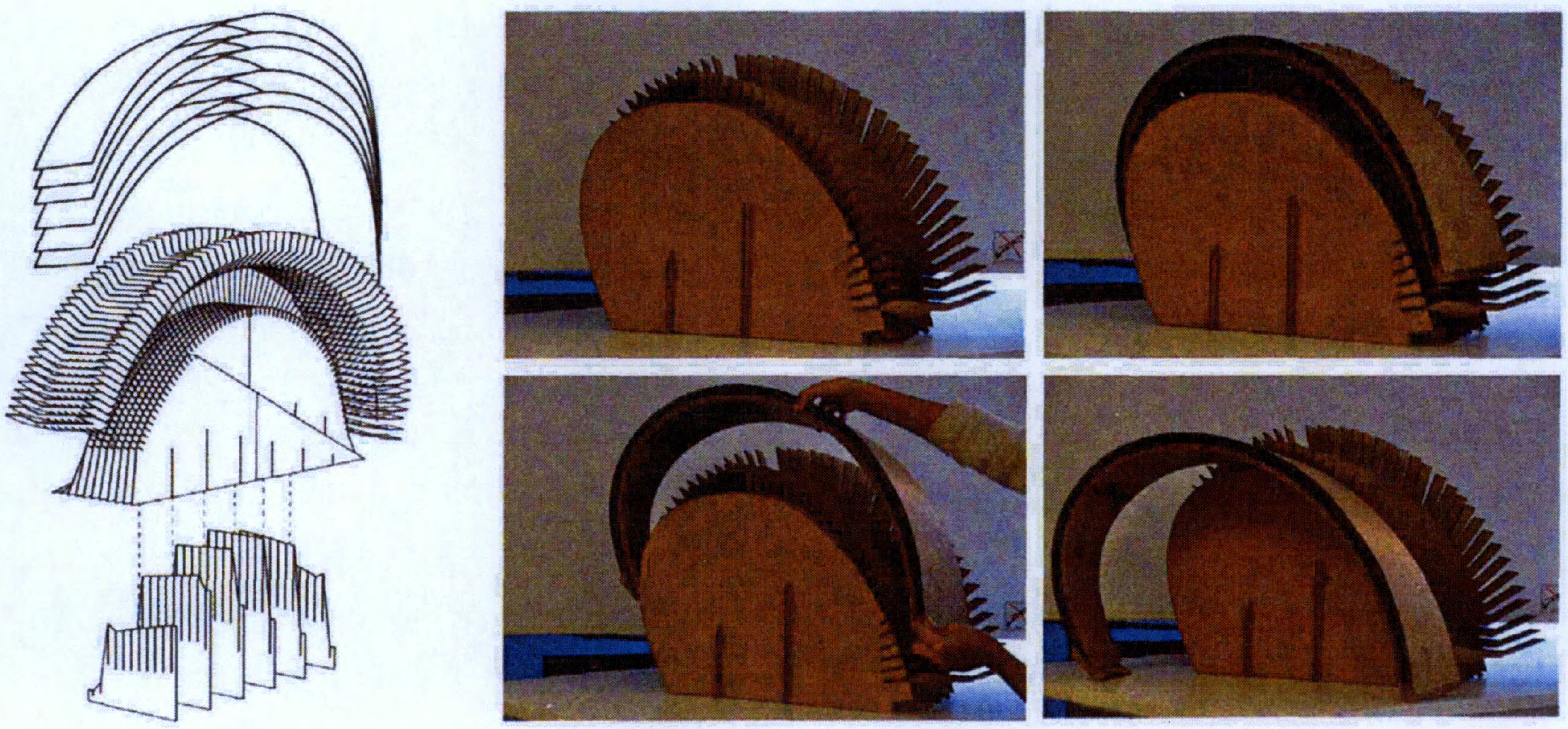

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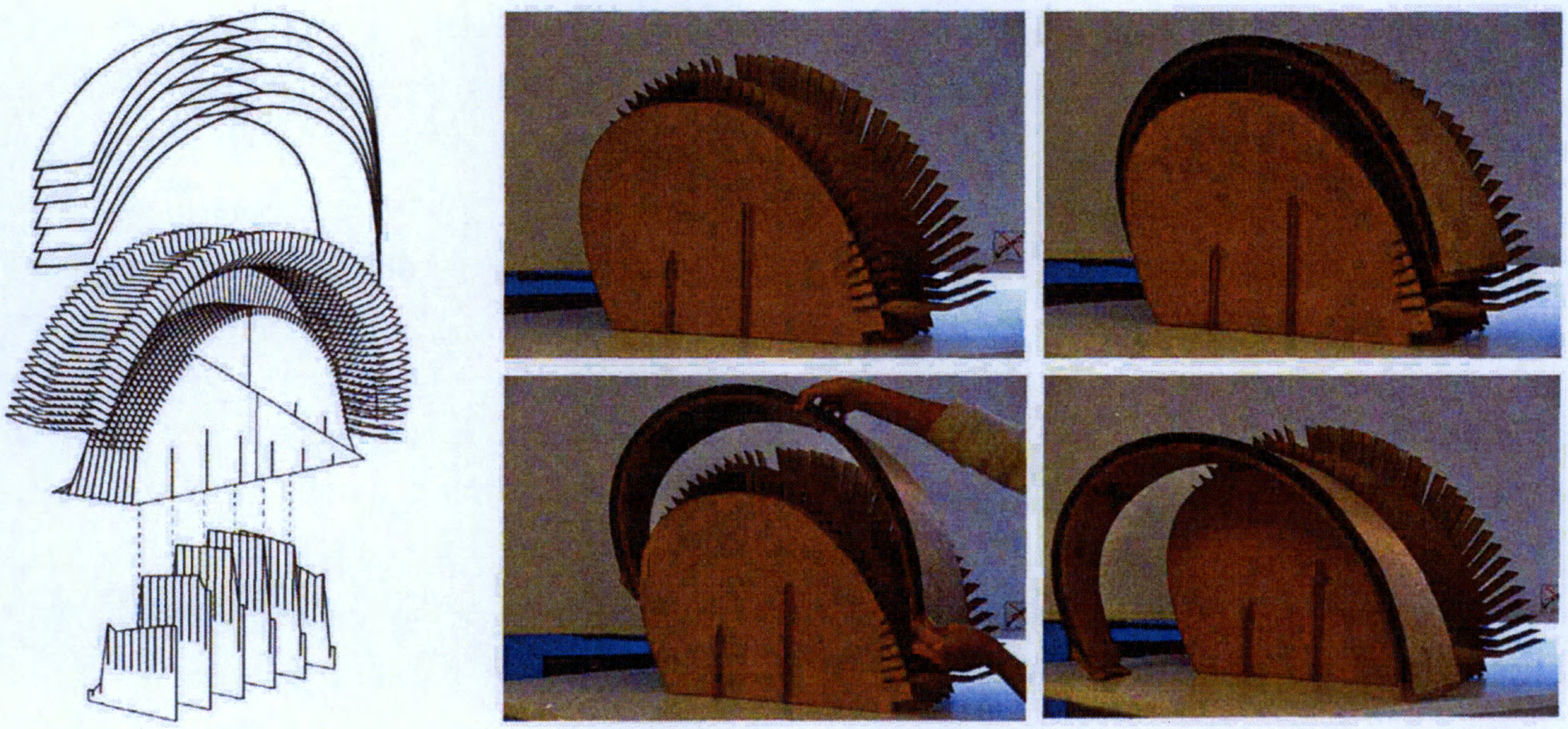

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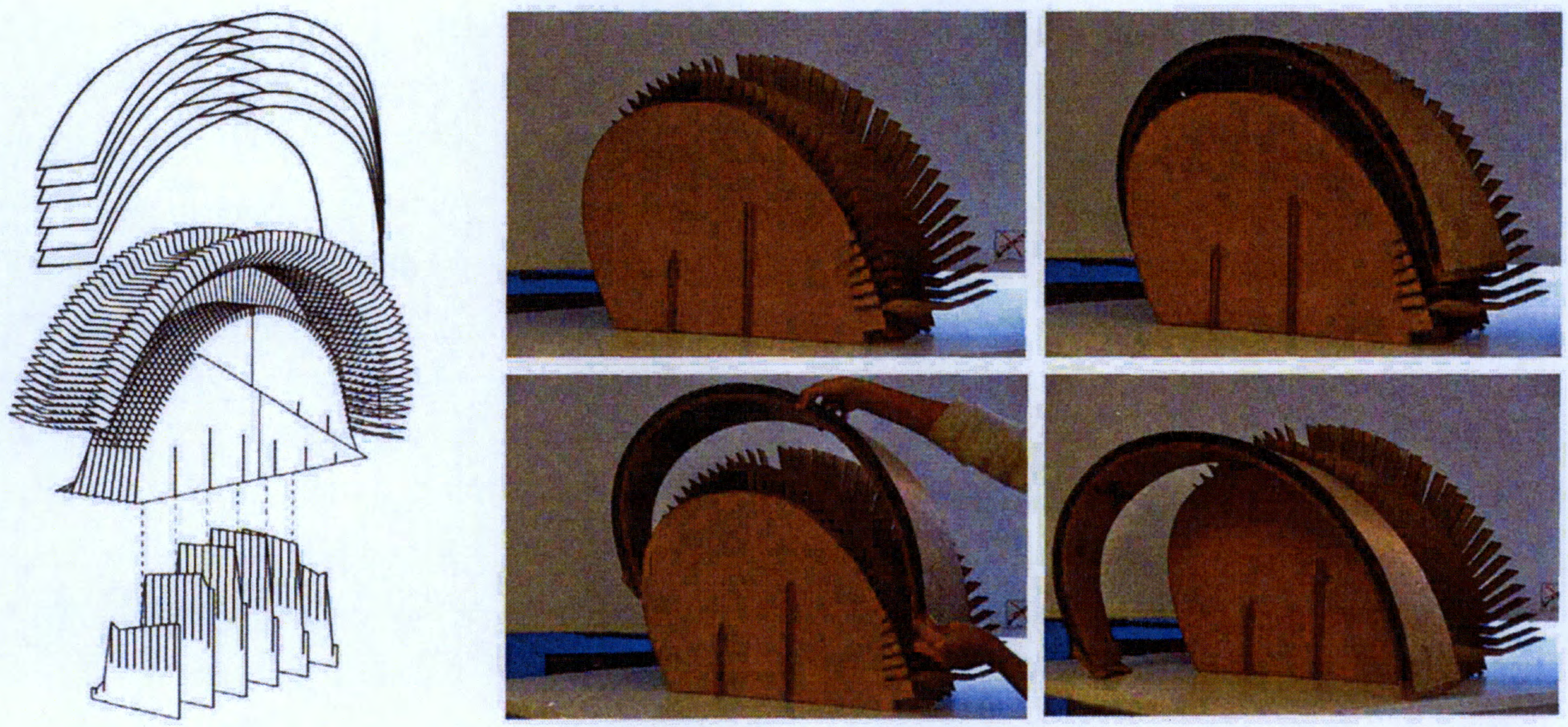

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