

“Archineering” Trends for Tensioned Fabric Structures

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INTRODUCTION

Where architectural and engineering design approaches intersect and communicate with each other, usually a more innovative building structure can be created. We present three recent examples of tensioned fabric structure projects, where the two disciplines inspire each other. In these examples, structural engineering provides a basis for aesthetic design with form-finding and a clear definition of technical boundary conditions.

Unlike conventional structures, which carry loads in bending and have a fixed given desired form, fabric structures take the shape according to the force flow and hence the architect or artist can not initially draw up the final shape of the project. Therefore, engineering support forms the beginning and various ‘design loops’ need to be performed to give the design credibility and stay within given boundary conditions (support forces capacity, span limitations due to material capacity or minimizing risk of ponding, for example). Current projects of the author’s firm that demonstrate this collaboration are:

- Chelsea Art Gallery, NYC (Architect: Studio MDA): suspended ceiling & façade
- ‘Dancing Couple’ Bloomberg Building, NYC (Architect: Pelli Clarke Pelli): fabric art installation
- ‘MOHAWK Teepee’, Woodstock, NY (Artist: Benjamin Ball): metal high-point sail

EXAMPLE 1: CHELSEA ART GALLERY, NEW YORK CITY

The idea of this art gallery project below an abandoned elevated rail line (the historic West Side highline) is to create an elegant, translucent secondary line of defense as a modern, redefined suspended ceiling underneath the rail line (FIGURE 1). The ceiling is demountable to allow the city building authority to visually inspect the highline from its underside. With a non-demountable conventionally clad roof, the project would have lost head height as well as daylight, which enters the space from both sides of the existing roof.

Structurally, a PTFE fabric ceiling is clamped onto three edges along newly constructed side walls and is also taken down as a façade element to be fixed to the ground floor slab, leaving door opening cut-outs and also adding a cable to adjust the curvature near the front entrance to achieve sufficient head height.

Where the fabric would hit the existing steel columns, local cut-outs with specially developed collar flushing details around the columns have been designed, to ensure watertightness. Also, the city does not allow to transfer any forces into the existing highline structure.

Only internal wind loading had to be investigated since outer walls and the glazed façade are not bearing structural loads or more than self-weight. More importantly, ponding in case of leakage of the existing highline structure needs to be avoided, which was investigated under additional rain water loading of 10 psf (0.49 kN/m²) deriving contour lines. Later ponding diagrams were also used to place downpipes at low points along the linear support edges (FIGURE 2).



FIGURE 1 – RENDERING OF PTFE FABRIC AS SUSPENDED CEILING AND FAÇADE UNDERNEATH HISTORIC NEW YORK CITY WEST SIDE HIGHLINE (IMAGE BY: STUDIO MDA [1])

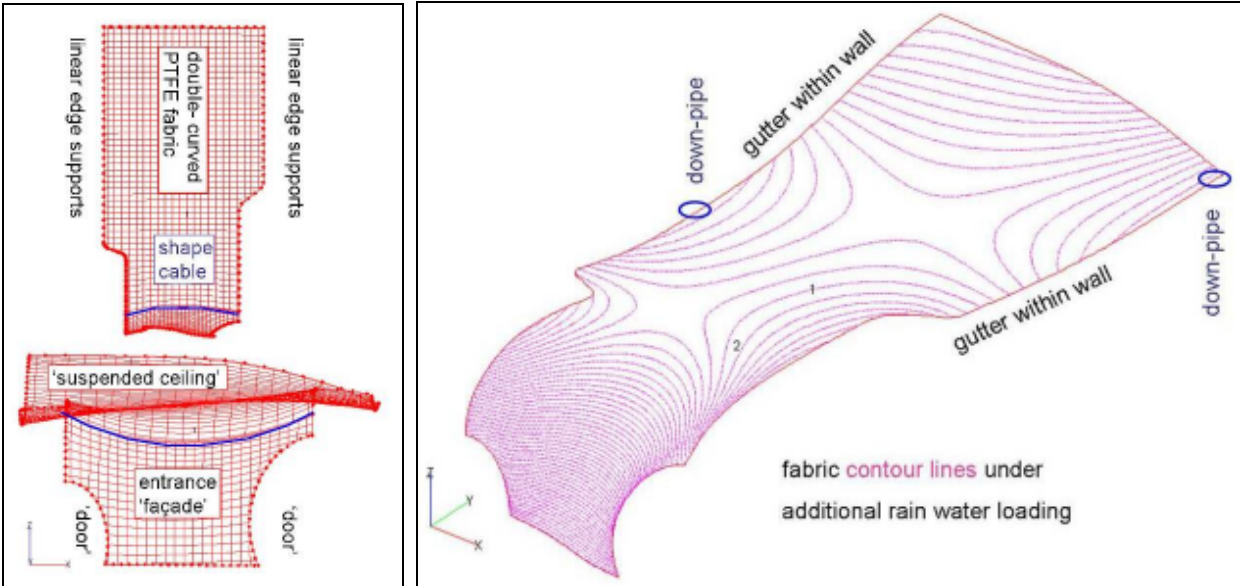


FIGURE 2 – COMPUTER MODEL (LEFT) AND PONDING STUDY WITH CONTOUR LINES (RIGHT)

EXAMPLE 2: ‘DANCING COUPLE’ BLOOMBERG BUILDING, NEW YORK CITY

A fabric art installation is designed to occupy inside the oval courtyard of the Bloomberg Building (FIGURE 3). Due to lack of membrane engineering consulting early in the design, thin stainless steel receiver brackets for the tension cable anchorages had already been built, penetrating the unitized façade at fixed locations, and thereby considerably limiting bracket capacity. The author’s firm helped to re-define the sailing shapes and sizes in a way that minimizes bracket stresses to an allowable limit, so the art installation is still possible from an engineering point of view. This led to the introduction of two ‘counterbalancing’ cables that pull back certain brackets to reduce their weak axis bending moment coming from the PTFE sails subjected to pre-stress and temporary wind loading (FIGURE 4).

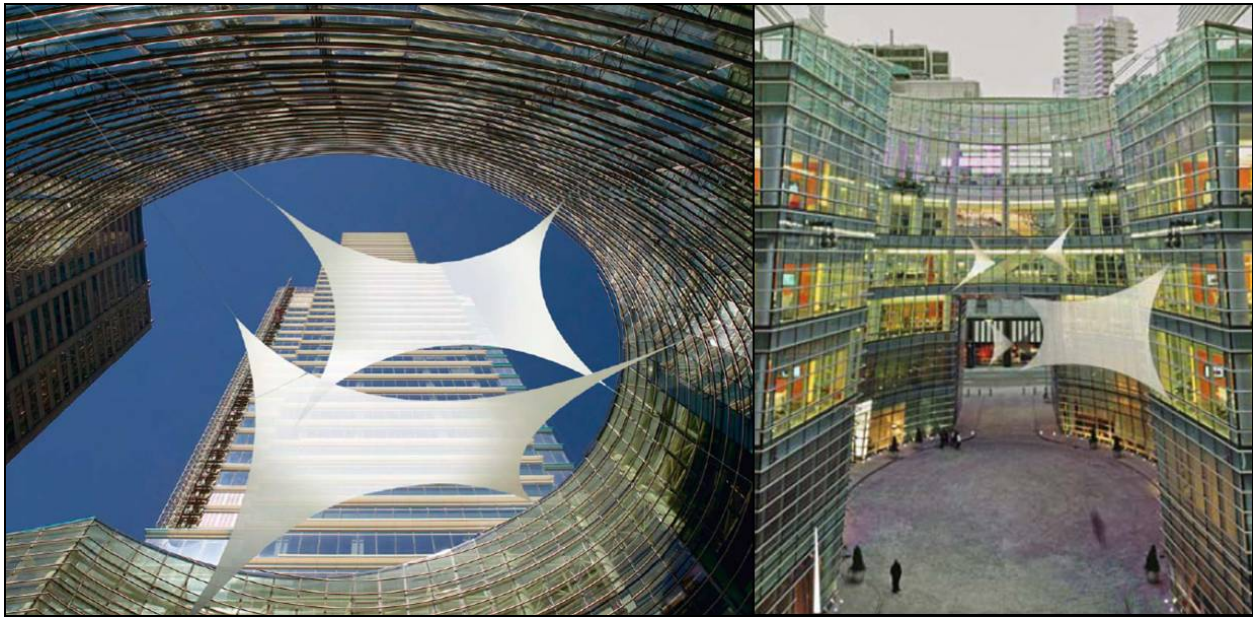


FIGURE 3 – ‘DANCING COUPLE’ ART INSTALLATION, BLOOMBERG BUILDING COURTYARD [2]

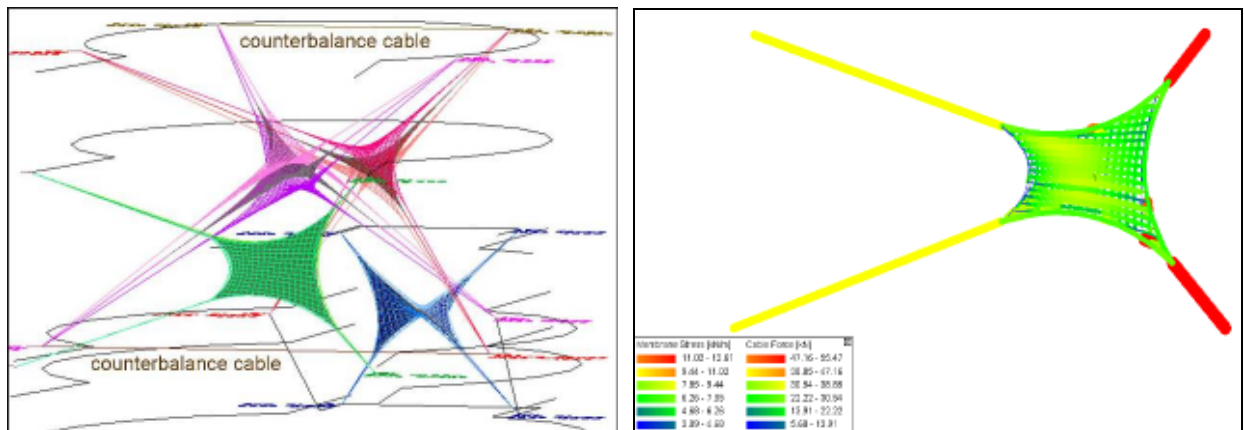


FIGURE 4 – NUMERICAL MODELLING WITH COUNTERBALANCING CABLES (LEFT) AND EXAMPLE OF FABRIC STRESS ANALYSIS TO FIND CABLE FORCES UNDER WIND LOAD (RIGHT)

To check that adjacent cables close to each other do not touch during a storm (and hence could cause cable damage or fatigue), both extreme upward and downward deflections were determined and plotted in 3D space (FIGURE 5). Also, to comply with ASCE-7 static wind loading requirements, the first natural frequencies were calculated to show that $f_1 > 1.0$ Hz (non-dynamic structure).

As a result of our fabric and form-finding engineering, the initial shape of the art installation was revised and a new mock-up model built. Modern computer model form-finding tools are able to come very close to the mock-up shapes, even including cables at all four corners of the sail (FIGURE 6). This project would not have been possible without a close cooperation between architect and structural engineer, given the limited capacity of the support brackets, which formed a limiting condition for the entire fabric art design.

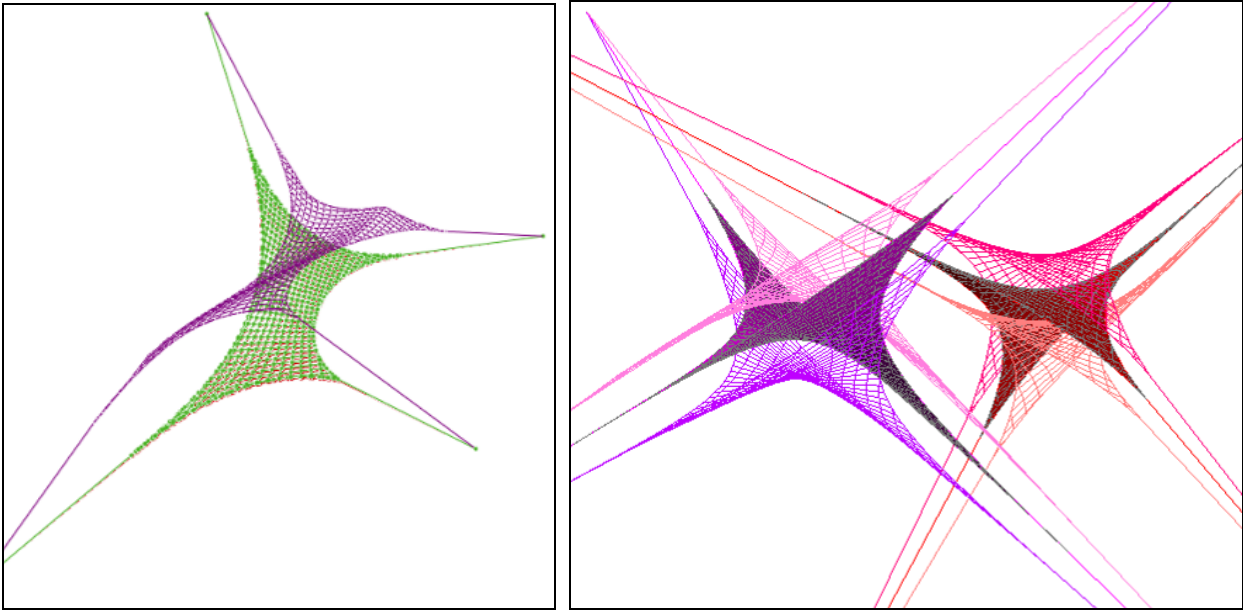


FIGURE 5 – SAIL NATURAL FREQUENCY ANALYSIS (LEFT) AND DEFLECTED SHAPES (RIGHT)

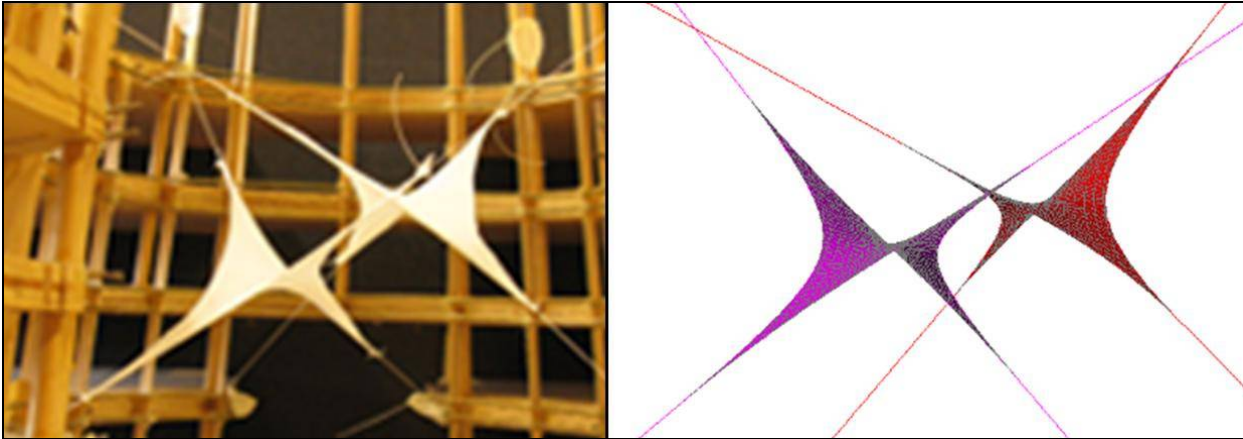


FIGURE 6 – ARCHITECTURAL MOCK-UP MODEL (LEFT) VS. ENGINEERING MODEL (RIGHT) [2]

EXAMPLE 3: ‘MOHAWK TEPPEE’, WOODSTOCK

Ball-Nogue Art Studio [3] experiments with a new type of ‘fabric’ structures, riveting together pieces of nylon leaves to form beautiful structures (FIGURE 6) that are hung from low-cost wooden posts and follow a successful intuitive ‘Let’s get it built!’ approach.



FIGURE 6 – PS1 MUSEUM TEMPORARY SUMMER INSTALLATION CALLED ‘LIQUID SKY’ (LEFT) AND A TEMPORARY OUTDOOR INSTALLATION IN L.A. (RIGHT) USING RIVET TECHNIQUES. [3]

The author’s firm is now helping the artists develop a permanent outdoor highpoint roof that follows a traditional radial mesh design with tension tie-down cables and compression tripod posts, but intends to use many small stainless steel metal triangles that will be riveted together at the points of each triangle (FIGURE 7). Different from the conventional cutting pattern approach where compensation is needed by means of biaxial testing to determine equivalent Young’s modulus in warp and fill directions, the metal leaves undergo negligible pre-stress lengthening.

The engineering challenge for the ‘MOHAWK teppee’ is to determine the optimal metal triangular sizes that make up the roof: 3D form-finding dxf-file results are further processed in parametric Digital Project routines that subdivide the net into ‘basic triangles’ based on the artist’s preference for size and appearance (different per each row and numbered for manufacturing). Then the material overlap for each metal triangle is set, so that local connections (‘rivets’) can be introduced that do not fail under bearing tension (FIGURE 8). Their resulting design forces due to dead load, pre-stress and wind forces are determined by first finding conventional circumferential and radial fabric forces from the membrane model, which are then sub-divided into discrete directions according to rivet force flow.

To avoid rattling and friction noises, additional thin bushing ring pads (silicone or nylon) are placed on either side of the rivet connection.



FIGURE 7 – INITIAL ARTIST RENDERINGS OF ‘MOHAWK TEPPEE’ [3]

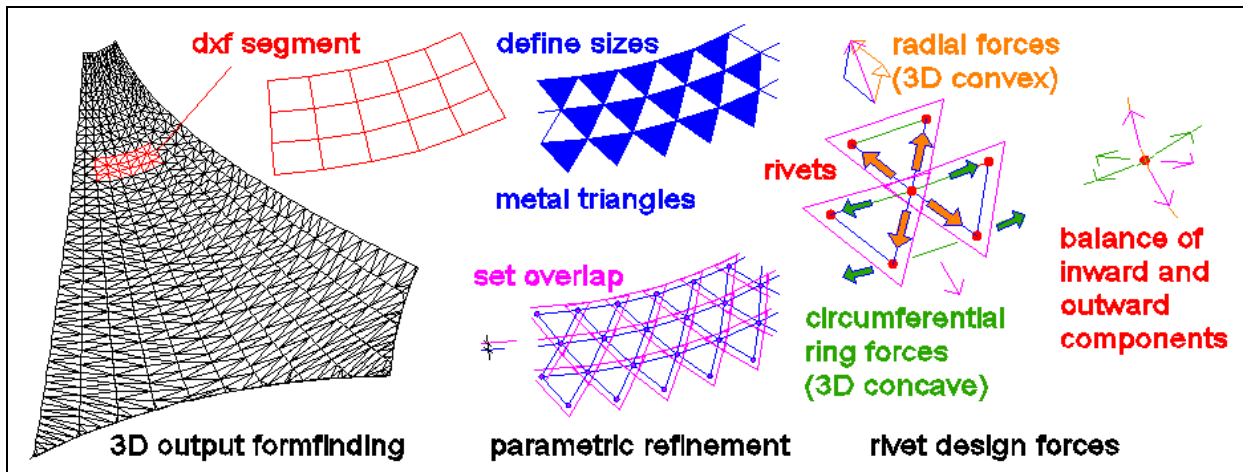


FIGURE 8 – MEMBRANE FORCE FLOW INTO LOCAL RIVETING CONNECTIONS - MODEL

ACKNOWLEDGEMENT

The author acknowledges his firm’s clients for a candid and creative collaboration in these projects and their openness to integrate engineering aspects early in the projects.

REFERENCES

- [1] Architects Studio MDA, New York City. www.studiomda.com/
- [2] Architects Pelli Clarke Pelli, New York City. www.pcparch.com/
- [3] Artists Ball-Nogues Studio, Los Angeles. www.ball-nogues.com/