2 Computational Modelling of Textile Structures

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2.1 Introduction to the computational modelling

Several engineering sectors, as mechanical, civil, electrical and electronic engineering, present a modern design culture focusing on the optimization of the product performance. The optimization procedure lies on the selection of the appropriate dimensional and physical characteristics of the product for the achievement of the desirable performance accounting also the resource limitations and the production cost. It is a repetitive procedure consisting of the development of a product model with the defined properties (design parameters), examination of the product performance and modification of the design parameters for the improvement of the performance – cost ratio. Since the sample production is a cost and time-consuming process, the modern engineering design was implemented computer-based tools for the development and the performance prediction of the sample.

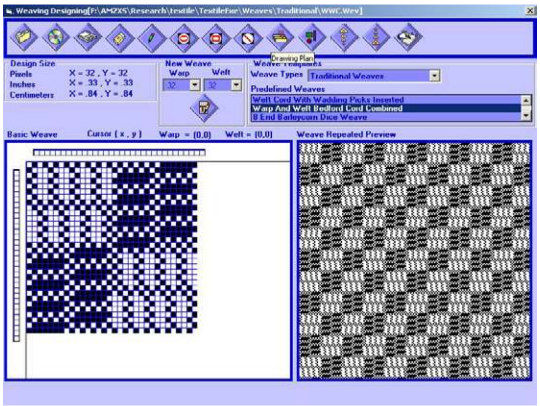
The evolutions in software programming and in the computer hardware performance increased the capabilities of computer-aided tools. The Computer Aided Design (CAD) serves the geometrical representation of the objects and the Computer Aided Engineering (CAE), among other functions, supports the mechanical analysis of the modelled structure. CAD and CAE software products, nowadays, are available in the market and they offer plethora of design capabilities, advanced numerical techniques and special facilities for the solution of the engineering problems.

The mechanical engineering field adopted advanced CAD and CAE software packages for the evolution of consumer products, heavy equipment, industrial components, machinery manufacturing, micro electromechanical systems as well as medical products. The computer based tools improve the aesthetics and ergonomics of product designs by generating advanced shapes, complex surfaces, and patterns. They allow fast design and performance prediction of large scale component assemblies. Static and dynamic structural analysis as well as thermal, fluid and acoustic analysis, support the solution of the mechanical problems.

2.2 The computational modelling in the textile sector

The textile modelling has already met the first computer-based tools focusing on the aesthetic design. Thus some of them are already available as commercial packages for industrial use. To mention some of them,

- *Textile Vision*: Is specified in the visualization of woven textile patterns in two-dimensional sheets (Figure 2.1).


Weaving Designing[F:\AMZXS\Research\textile\TextileExe\Weaves\Traditional\WWC.Wev]

Design Size
Pixels X = 32 , Y = 32
Inches X = .33 , Y = .33
Centimeters X = .84 , Y = .84

New Weave
Warp 32
Weft 32

Weave Types Traditional Weaves
Predefined Weaves
Weft Cord With Wadding Picks Inserted
Warp And Weft Bedford Cord Combined
8 End Barleycorn Dice Weave

Cursor (x , y) Warp = (0,0) Weft = (0,0)

Figure 2.1: Design tools for weave creation (source: Textile Vision software).

- *JacqCAD MASTERS*: Offers extensive features to assist in designing, editing, creating loom control files, and punching of textile designs.
- *Optitex 2D/3D CAD*: Supports solutions from pattern design to manufacturing and retailing process. Offers integrated software solution that uses a combination of both 2D patterns and 3D technology to deliver virtually real sewn products.

- *DesignScope Victor*: Focuses on the mapping of textile patterns in three-dimensional structures (Figure 2.2). The mapping technique includes advanced displaying capabilities as the visual properties of the yarn, light and shadow on the yarn, light and shadow of the pleats and creases, fabric density and transparencies.

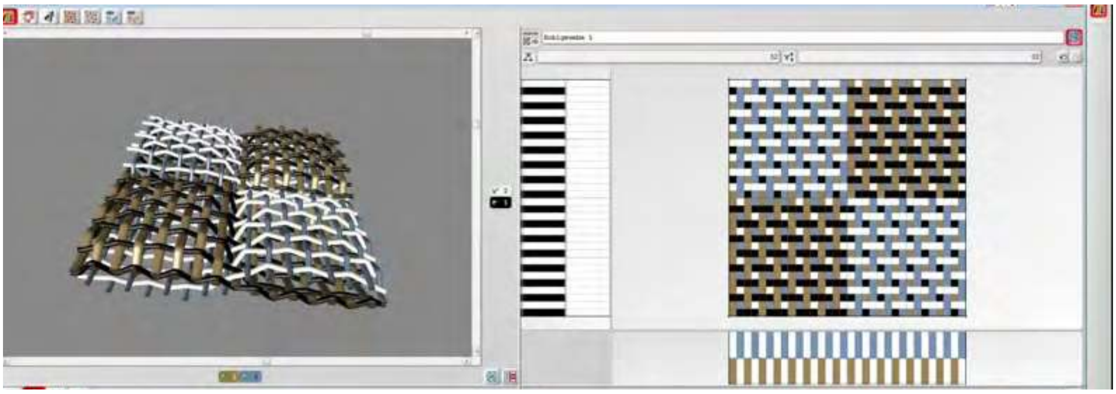


Figure 2.2: 3D Weave modules of "DesignScope victor" software.

Apart from the aesthetic design tools, the textile society inquired mechanical design tools in order to predict the performance of the textile structures. The first researches, conducted in 1940s, focused on the two-dimensional representation of the fabric unit cell (see figure 2.3) and the implementation of analytical methods for the mechanical analysis of them. The basic target of the researchers in that period was the correlation of the structural properties (dimensional and physical) with the mechanical properties and the fabric hand.

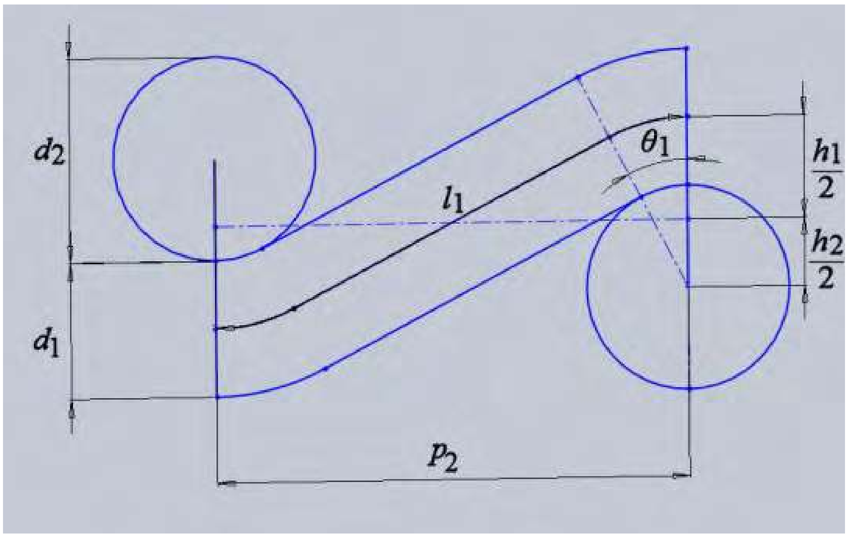


Figure 2.3: Plain woven geometry proposed by Peirce (Peirce 1937).

Nowadays, the development of the textile industry and its dynamic expansion in advanced technical applications converted the design of the textile structures to a complex engineering procedure. In particular, the expansion of the composite structures (including woven or knitted reinforcement) in automotive and aerospace industry necessitated the accurate prediction of their performance. Thus the engineering design tools are adapted gradually for the evolution of the textile design procedure (Hearle 2004, Lomov 2001).

Since the structural hierarchy of a textile comprises the fibres – yarns – fabric unit cells – fabric, the corresponding modelling phases were developed.

2.3 The basic principles of the Finite Element Method

The Finite Element Method (FEM) is, nowadays, the prevalent computational tool for the mechanical analysis of structures. The FEM is a numerical technique for the approximate solution of a wide area of engineering problems based on the discretization of the considered structure.

The implementation of the FEM consists of two principal stages: (a) the mathematical formulation of the physical problem and (b) the numerical solution of the mathematical model. The mathematical formulation is based on certain assumptions regarding the geometry, loading and boundary conditions in order to receive the governing equations. The governing equations are partial differential equations subjected to boundary conditions. Since an analytical closed form solution is unachievable, an approximate solution is desired based on the advanced numerical techniques of FEM.

A simplified description of the FEM concept is the subdivision of the structure into components of simple geometry, the finite elements. The response of the finite elements derives from the displacements of specific points of the elements, the nodes. Thus the total response of the structure is then approximated to the one obtained by the discrete model when assembling the finite element mesh. The basics for the comprehension of the FEM concept when implementing in structural mechanics problems are the following.

- Finite Elements: Are the subdivisions of the continuum structure. Increasing the density of the mesh, the accuracy of the solution and computational cost are increased.
- Nodes: The nodes are the points of the elements where the degrees of freedom are defined. Moreover the nodes define the element geometry and connectivity, using common nodes in the adjacent elements.
- Degrees of freedom (dofs): Correspond to the displacements (translational and rotational) that the nodes of the model present.
- Boundary conditions (BC): Are the values of the dofs that the boundary nodes of the model receive due to the supports.

The basic Element types considering the constitutive properties are:

- Bar (axial loading in members, modelling of trusses)
- Beam (axial and vertical loading, modelling of frames)
- Plate (plane stress and plane strain)
- Shell (plane and normal loading)
- Solid (loading in 3 dimensions)

2.4 Geometrical representation of the textile structures

2.4.1 Geometry of yarn

The ideal structure of a multifilament twisted yarn is considered in the current approach. The basic assumptions are:

- circular cross-sections of the yarn and the constituent filaments
- the filaments follow a uniform helical path retaining constant distance from the yarn axis
- close packing arrangement of filaments.

The geometry of a filament within the yarn structure is easily obtained defining the filament diameter, the helix diameter and pitch.

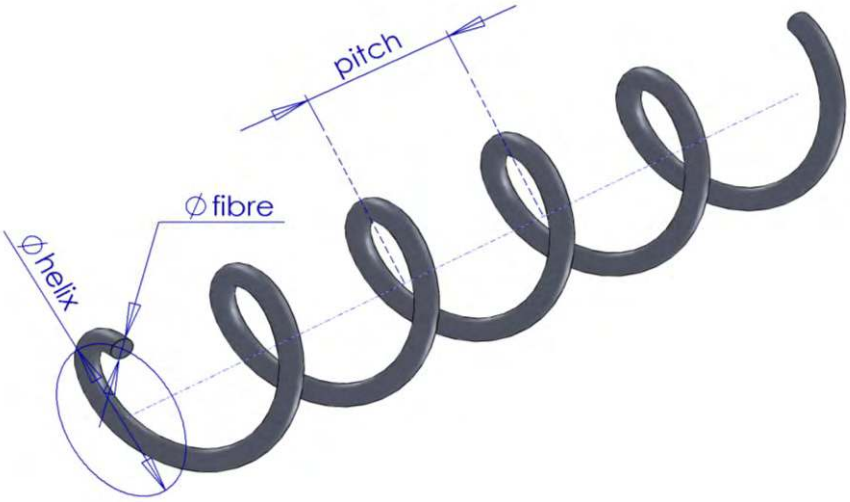


Figure 2.4: The helical path of a filament.

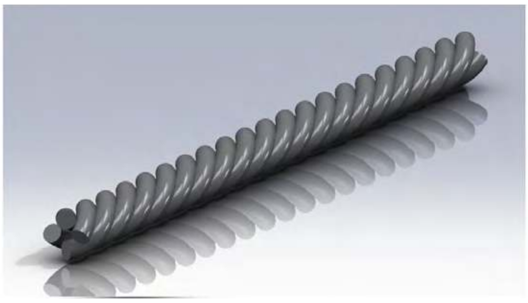
The pitch of the helix is defined by the yarn twist (pitch=1/twist) while the helix diameter is calculated geometrically considering the filament position within the yarn and the filament diameter (d_f). Thus for the first layer of filaments the helix diameter is:

$$d\,(1) = d_f/\cos(\pi/4)$$

while for the i layer (i>1) of filaments the helix diameter is:

$$d\,(\mathrm{i}) = d\,(\mathrm{i}-1) + 2\,d_f$$

The steps for the geometrical representation of an ideal yarn consisting of three layers of filaments are shown in the Figure 2.5.



1 layer of fibres

2 layers of fibres

3 layers of fibres

Figure 2.5: Geometrical representation of an ideal multifilament twisted yarn.

The cross section of the yarn derives from the section view of the model to a plane normal to the yarn axis as shown in the Figure 2.6.

Figure 2.6: Cross section of the modelled yarn.

2.4.2 Geometry of the woven structures

The geometrical modelling of the plain woven unit cell is based on the pioneering study of Peirce (Peirce 1937). The yarns are considered flexible circular cylinders presenting a "just in touch" formulation in the cross points (see Figures 2.7 and 2.8).

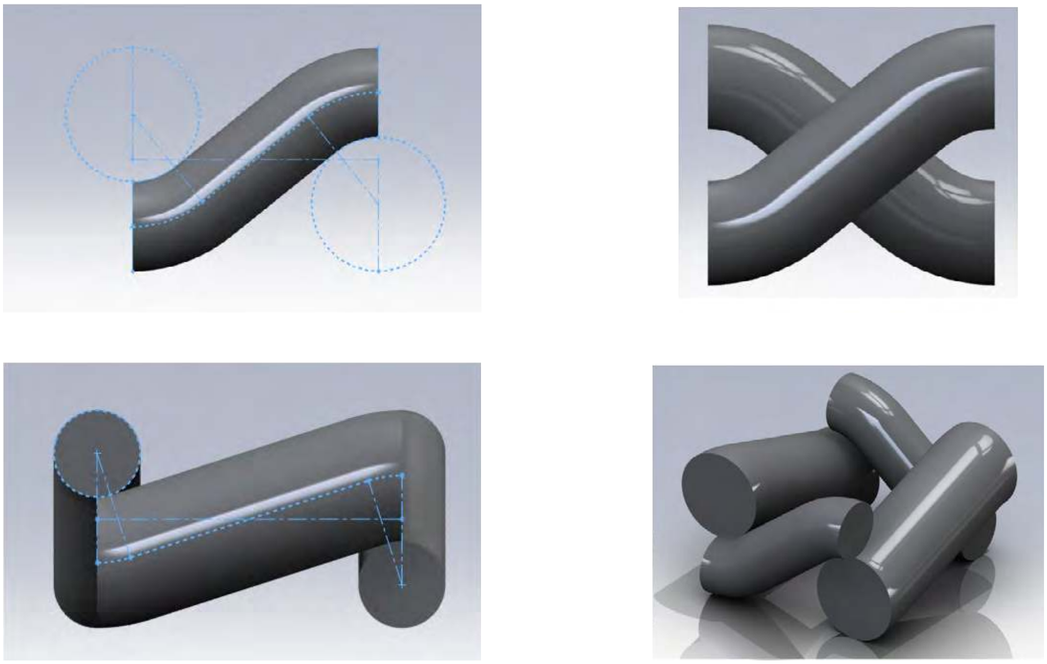


Figure 2.7: Geometrical representation of the plain woven unit cell.

The geometrical modelling is essential nowadays for the design of 3D woven fabrics used in composite materials and sandwich structures as reinforcements. The modern CAD software codes provide advanced numerical techniques (spline curves, NURBS surfaces) and easy-handling tools (features of symmetric or mirror parts and linear pattern) achieve the fast and easy geometrical modelling of complex textile structures.

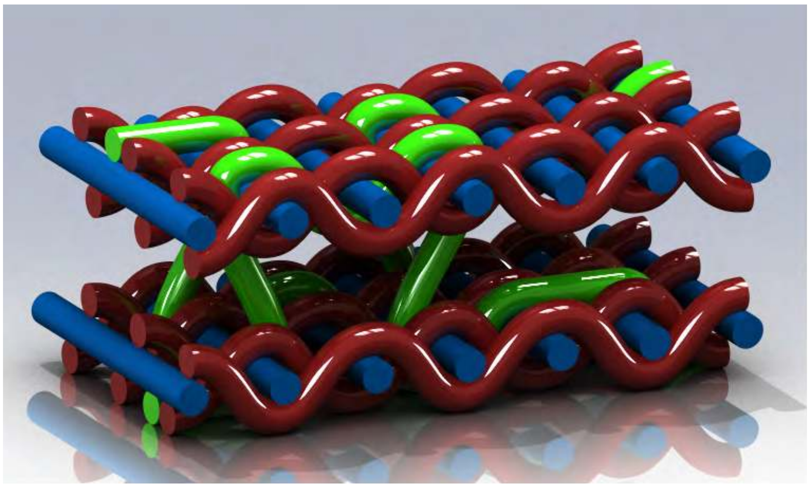


Figure 2.8: Geometrical representation of the unit cell of a 3D woven fabric.

2.4.3 Geometry of the weft knitted structures

In contrast to the 2D path of the threads (central axes) constituting the woven structures, the yarns of the knitted structures follow 3D paths. Thus the implementation of 3D CAD tools is requisite for the realistic modelling of the knitted fabric structure. In the current paragraph a general technique is presented for the modelling of the plain weft knitted unit cell. The calculation of the geometrical parameters for the complete definition of the structure based on the main structural parameters (course-spacing, wale-spacing and yarn thickness) is given in the literature (Vassiliadis *et al* 2007). The 2D representation of the loop central axis derives from the sketch of three circular arcs of equal diameter and the tangent lines connecting two of them as shown in the Figure 2.9. The sketch is projected onto the surface of a cylinder for the generation of the 3D sketch. The central axis of the cylinder lies on the mid-plane that is normal to the sketch.

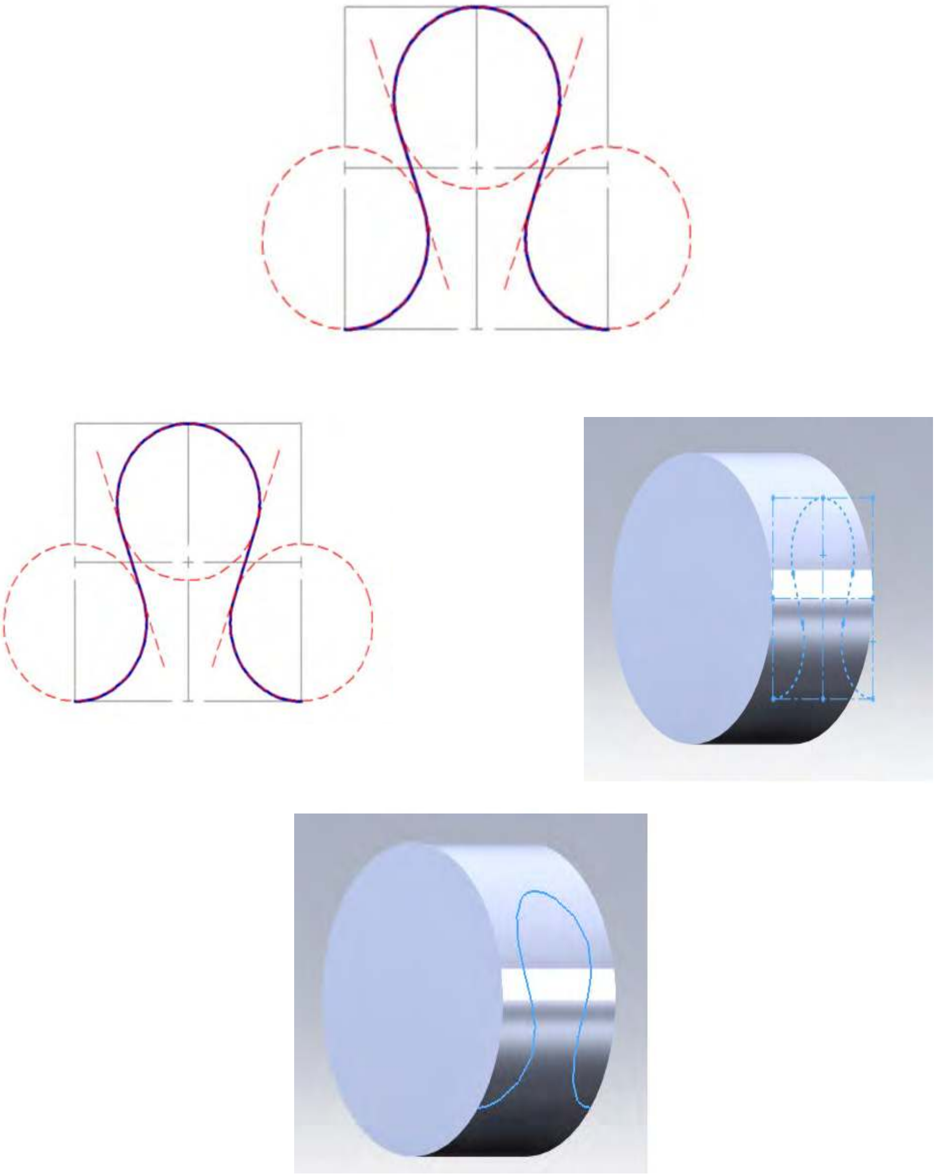


Figure 2.9: 3D sketch for the central axis of plain weft knitted loop.

The front and the side view of the loop are presented in the Figure 2.10. In order to obtain the unit cell of the structure, the adjacent loops are generated (along the wale direction) and the resultant model is cut at the dimensions: wale spacing × course spacing.

Figure 2.10: Modelling of the plain weft knitted loop and unit cell.

2.5 Implementing the FEM in the textile design

2.5.1 Tensile test of a multifilament yarn

The FEM using beam elements is implemented for the mechanical analysis of the multifilament twisted yarns (Vassiliadis *et al* 2010). For the simulation of the tensile test the one end of the modelled yarn is considered clamped. On the other end a uniform displacement is imposed along the yarn axis. The reaction developed in the clamped edge is calculated for the definition of the load – displacement.

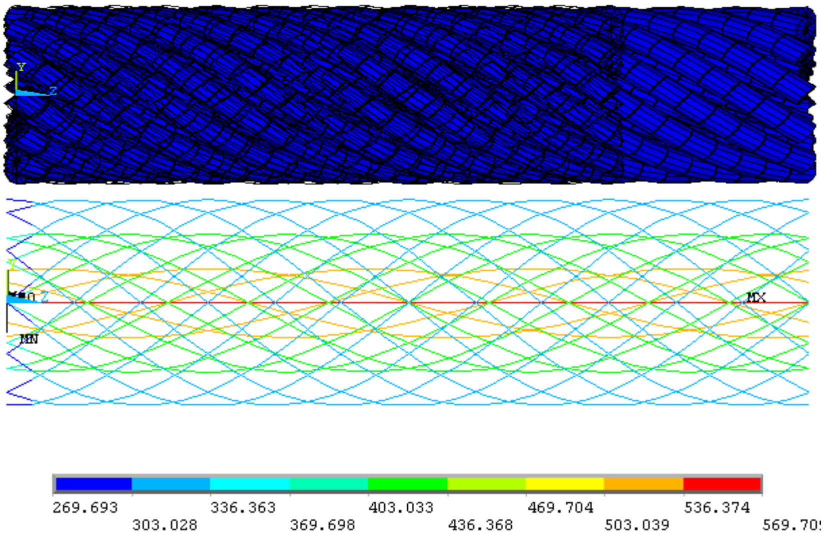


Figure 2.11: Deformed shape and axial stresses (N/mm^2) resulting from the simulation of the tensile test of a 30-filament twisted yarn.

The nodes of the total model are restricted with zero radial displacement. This constraint precludes the reduction of the helix radius and the appearance of penetration between the filaments. Given that the tensile deformation of a single helix corresponds basically to the reduction of the helix radius, the proposed constraint is essential for the simulation. Thus a realistic deformed shape is derived.

The deformed and the free-state shape of the modelled yarn, such as the contour plot of the axial stresses (in N/mm^2) developed in the constituent filaments are given in the Figure 2.11.

2.5.2 Drape test of a woven fabric

The drape of a fabric refers to the configuration resulting when it falls with gravity on a pedestal or a human body. Thus the prediction of the drape performance of a woven fabric is essential for the design and optimization of woven reinforced composite structures.

Geometrically the model consists of an orthogonal surface of the sample dimensions (200×200 mm) subtracting the surface of the circular pedestal. The part of the fabric supported by the table was subtracted by the model for computational simplification and the dofs constraints (simple support) were applied in the lower nodes of the circumference.

The 8-node solid-shell elements with 3 dofs (translational) per node were used for the analysis of the sheet in drape. The apparent elastic properties of the model were calculated experimentally by the respective bending rigidity the considering the model thickness (Provatidis *et al* 2009).

The load application consists in the definition of the apparent density (reflected value considering the model thickness) and the gravity acceleration (9.807 m/sec^2). Thus the model was subjected to complex deformation (bending in double curvature) in low loading conditions (self-weight).

The modelling and the simulation were performed using the ANSYS commercial software code.

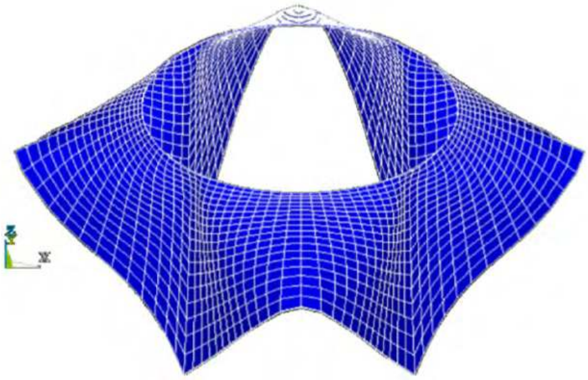


Figure 2.12: Deformed shape of the model resulted from the simulation of the drape test.

2.6 Literature

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