DUCATI SUPERBIKE PAVILION: DESIGN AND MANUFACTURING OF A TENSAIRITY® ROOF

P. BECCARELLI[*], R. MAFFEI[†], R.H. LUCHSINGER[♦] AND J. CHILTON[*]

[*] Department of Architecture & Built Environment
University of Nottingham
University Park, Nottingham NG7 2RD, United Kingdom
Email: paolo.beccarelli@nottingham.ac.uk, john.chilton@nottingham.ac.uk,
Web page: http://www.nottingham.ac.ukinternational

[†] Tensairity Solutions srl
Via U. La Malfa 86/88, 25050 Provaglio d'Iseo (BS), Italy
e-mail: roberto@tensairitysolutions.com, web page: http://www.tensairitysolutions.com/

[♦]EMPA - Swiss Federal Laboratories for Materials Science and Technology,
Center for Synergetic Structures,
Ueberlandstrasse 129, CH-8600 Duebendorf, Switzerland
e-mail: Rolf.Luchsinger@empa.ch, web page: http://www.empa.ch/css

Key words: Tensairity, Coated Fabrics, Ducati, Pavilion, pneumatic, beams.

Summary. This paper offers a detailed overview of the design and manufacturing aspects faced during the design and construction of the Ducati Superbike Pavilion. The first section of the paper describes the architectural design of the pavilion, the size of the components and the requirements of the client. The second section analyses the expected loadbearing conditions and the structural design of the Tensairity® beams. The final paragraph presents the details and the assembly of the roof.

1 INTRODUCTION

In 2014 Ducati Motor Holding S.p.A. commissioned a new itinerant pavilion for the Superbike racing category. The main objective of the client was to find a new shape, able to represent the commitment of the company for new and innovative technologies, and optimise the transportation and assembly of the structure. Due to the reduced number of days available for each competition, the structure should be set up in a few hours by a crew of people with a limited experience in this field. At the end of the event, the structure should be dismantled, packed and shipped to the location of the next competition. The use of a crane or any other lifting devices for the assembly process is considered a disadvantage, which should be avoided in order to minimise transportation volumes.

The use of an inflatable solution addressed the main restraints related to the final weight and volume of the structure. The lack of structural performance was addressed by means of rigid elements assembled according to the Tensairity® principle, which increases considerably the load bearing capacity of the inflatable beams [1] [2]. The Tensairity® system combines the lightness and simplicity of an airbeam with the load bearing capacity of a truss structure. The first developed Tensairity® structure has the shape of a cylindrical beam, where the inflated hull is reinforced with a strut and two cables. After this initial project, the system has been successfully applied in several projects [3].

2 THE DESIGN OF THE PAVILION

The pavilion is designed to cover the distance between two trucks parked at a distance of 12 metres. The roof consists in a series of 5 Tensairity® asymmetric spindle-shaped girders of 12m span inflated at low pressure (150 millibar) able to withstand load generated from winds at 27 m/s. Standard aluminium keder profiles are used as tension and compression elements. The inflated hull is made of a 270 g/m^2 PU coated polyester fabric which combines good structural properties and high translucency. The required airtightness is provided by the inner 250 μm PU bladder. The beams, once deflated, can be stored in one piece, on the top of one of the semi-trailers without detaching the hull from the aluminium part. Within 6 hours, the 156 m^2 roof together with the front and back façade is installed by a crew of 5 people.

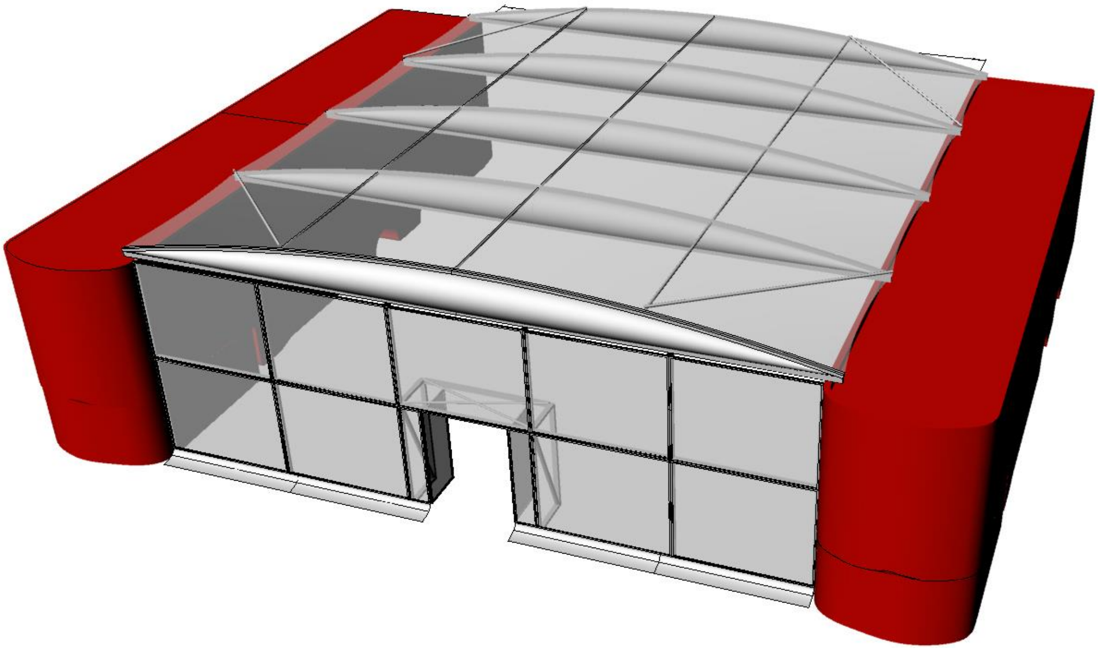

Figure 1: Perspective view of the Ducati Superbike Pavilion.

As clearly described in the literature [4] [5] [6] [7], a "Tensairity® beam consists of a simple air beam and a compression element which is connected by two cables running in helical form around the air beam. The cables are connected to the end of the compression element. Thanks to this connection, the cable force is transferred to the compression element, acting here as a compressive force. The key principle of Tensairity® is to use low pressure air in an attempt to prevent compression elements from buckling" [4].

All Tensairity® girders incorporate a RGB-LED lighting system to enlighten the area underneath the roof but also to light up the beams themselves. The system is controlled by an app which allows users to modify the lights through a smartphone. The blower, which compensates the loss of air due to temperature change, is programmed to keep the pressure of the beam within the design pressure range. In addition, it can also be remotely controlled: when required, the hospitality pavilion can be equipped with a sim card connected to the 3G internet network. It is possible to get access to the control panel from anywhere and modify the pressure of the beams, check the operation time of the blower and the last inflation ramp too. The blower can be remotely programmed in "Standard", "Strong wind" or "Deflation mode".

The preliminary design analysed the advantages and disadvantages of two alternatives for the coated fabrics to be used for the roof: polyester/PVC and polyester/PU. Due to the competitive price, the good mechanical performance and the expected lifespan, polyester has been considered the most appropriate fibre for this project. Polyester fabrics are quite flexible and have been successfully used in several structures for temporary and seasonal projects. In addition, thanks to new technologies, coated fabrics based on polyester fibres, are now recyclable. The selection of the coating was mainly related to requirements of weight, flexibility, durability and translucency required by the client. PVC (polyvinylchloride) is generally used in combination with additional additives and top-coatings to improve the fire behaviour, the expected lifespan, the self-cleaning properties and the colour stability. It can be easily painted or printed and it can attain a life span of more than 20 years. However, the coated fabrics based on PVC currently on the market are characterised by a relatively high thickness of the coating which affects the weight per square meter, the foldability and the translucency of the final product. On the other hand, PU is a polymer composed of a chain of organic units joined by urethane links. Compared with PVC it has better properties in terms of elasticity, transparency, and resistance to oil, grease and abrasion. With thick coating layers it is used for special applications such as biogas plants and flexible tanks. It is easy to weld and due to the higher airtightness it is commonly used for pneumatic structures such as inflatable tents and boats [8]. The material selected for this project is a polyester fabric coated with polyurethane and impregnated with a soiling resistant finish produced by SIOEN. The special coating gives to the fabric a distinctive textile character and outstanding technical characteristics (270 g/m^2 fabric has a tensile strength equal to 230daN/5cm in warp and fill direction). Contrary to the common PU coated fabrics for biogas and inflatables products, in this case the PU coating is relatively thin and the material has to be stitched with the consequent need of the internal airtight bladder realised with a 250 µm clear PU foil produced by Chiorino SpA.

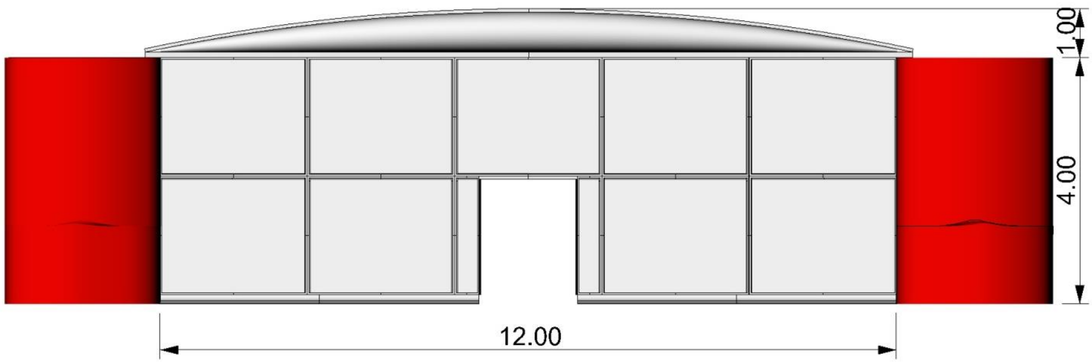

Figure 2: Elevation of the main façade with the two lateral semi-trailers (in red), the translucent façade made with modular panels in polycarbonate, and the Tensairity® roof.

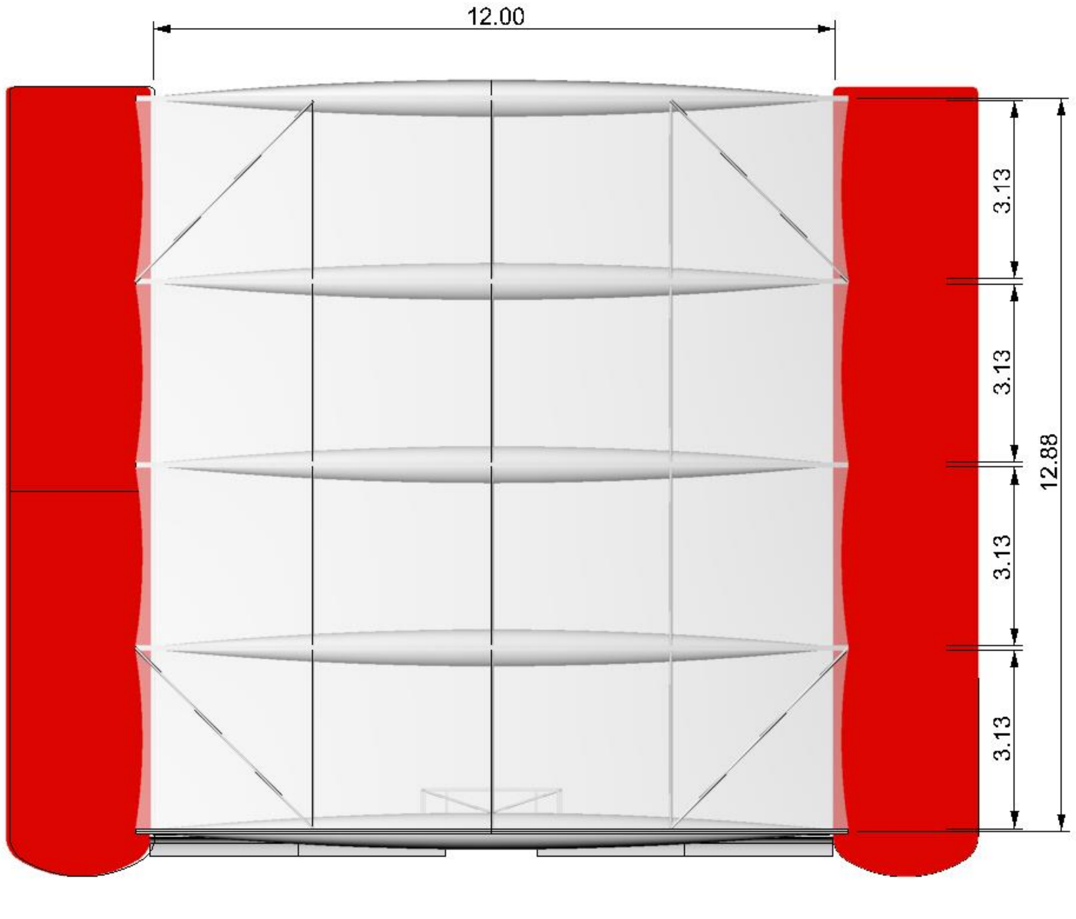

Figure 3: Top view of the Ducati Superbike Pavilion. The five Tensairity® beams are supported by the two lateral semi-trailers and maintained at constant distance by a set of purlins.

3 STRUCTURAL DESIGN

Due to the geometrical layout of the roof, the central beam is characterized by the higher applied load. The load is transferred to the beams by mean of the membrane positioned in between the beams. The longitudinal tensile force can be subdivided into a vertical component and a horizontal component. The horizontal component is mainly counterbalanced by the next span or/and the purlins. The vertical load is supported by the beam and is the main cause of collapse of the roof due to the progressive bucking of the rigid elements of the beam. The instability of the rigid element is prevented by the pneumatic element which is connected to the rigid elements of the beam.

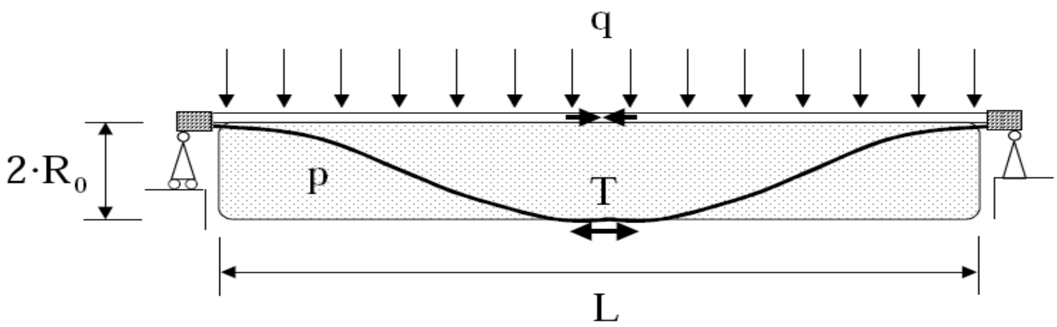

Figure 4: Simply supported Tensairity® beam under homogenous distributed load [9].

The main parameters considered in the design of a Tensairity® beam are: the inner pressure, the geometry (radius, length, slenderness), the cross section of the structural profiles used and the details used for the connection to the lateral support. The pressure required to support the expected applied loads varies between 160 and 220 millibar which.

According to the formulas available in the literature the hoop force can be calculated through the equation:

$$n = p \cdot r \qquad (1)$$

Where:
R is the radius of the beam
p is the pressure required to support the applied load
n is the stress in the membrane due to the inner pressure

In the case of a spindle shape and larger span, it is also recommended that a check of the instability of the beam be performed, as described in [10].

The risk of laceration of the membrane in the beam can be verified comparing the expected stress in the membrane due to the inner pressure and the tensile strength of material used. In this case, for a pressure between 160 and 220 millibar the stress in the material varies between

8 and 11kN/m which is below the maximum tensile strength (46kN/m) divided by the safety factor.

The stress distribution in the membrane between the beams has been investigated through a Finite Element Analysis. The most relevant load case (wind suction) is represented in Fig. 5 where it is clearly visible that the expected maximum stress (6.5kN/m) is below the tensile strength of the PU coated fabric divided by the safety factor.

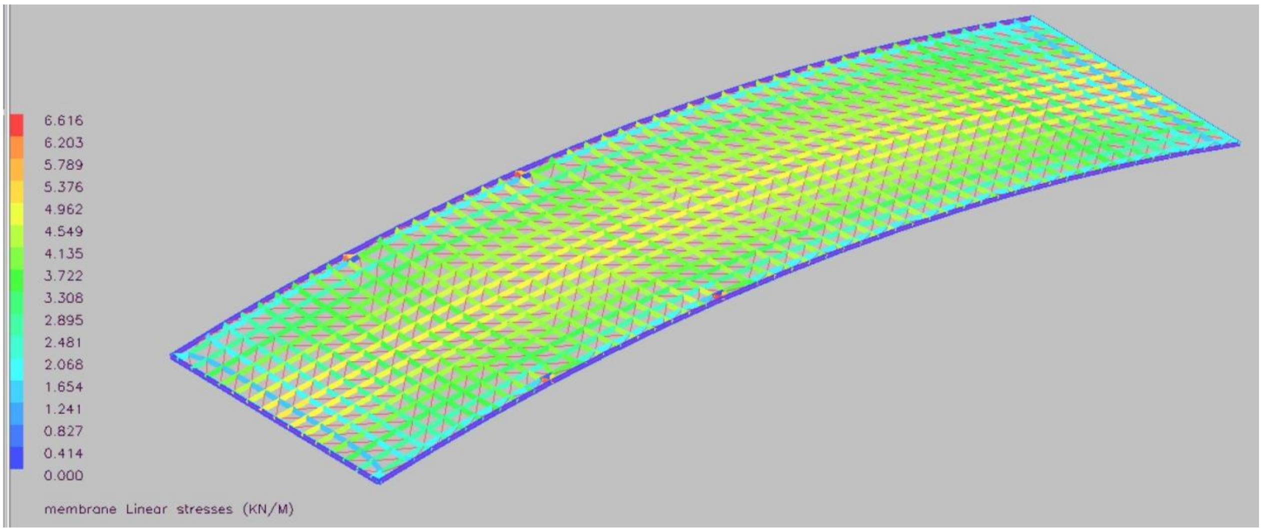

Figure 5: Stress distribution in the roof membrane subjected to an applied wind suction load equal to 0.49 kN/m^2 (wind speed equal to 27m/s)

4 DETAILING AND ASSEMBLING OF THE ROOF

The main driver for the design of components and connections was the reduction of the total weight and transportation volume of the pavilion. The weight is a crucial factor because the structure should be assembled by a crew of 5 people without the use of large lifting equipment. On the other hand, the Ducati Superbike Team has only two semitrailers to transport the complete structure and all the equipment to host the events connected to Superbike racing,

The rigid components of the beams are made of aluminum profiles with a rectangular cross section and four keder rails, one at each vertex. Through the inner keder rails the rigid profile is connected to the pneumatic cushion which, under pressure, transfers a distributed force to the aluminum profile reducing the risk of buckling and instability. The remaining external keder rails are used to connect the panels of fabric between the beams (top chord) or the lighting/sound equipment (bottom chord). A set of aluminum purlins provides the required lateral stability of the roof.

The pneumatic component of the beam can be opened with a special zip which allows the inspection and replacement of the bladder without reducing the mechanical performance of coated fabric. The connections have been tested by means of an experimental programme based on several uniaxial tests on several alternatives (Fig. 6), rupture tests on the bolted connections (Fig. 7) and loading tests on a 1:1 scale mock-up ((Fig. 8)

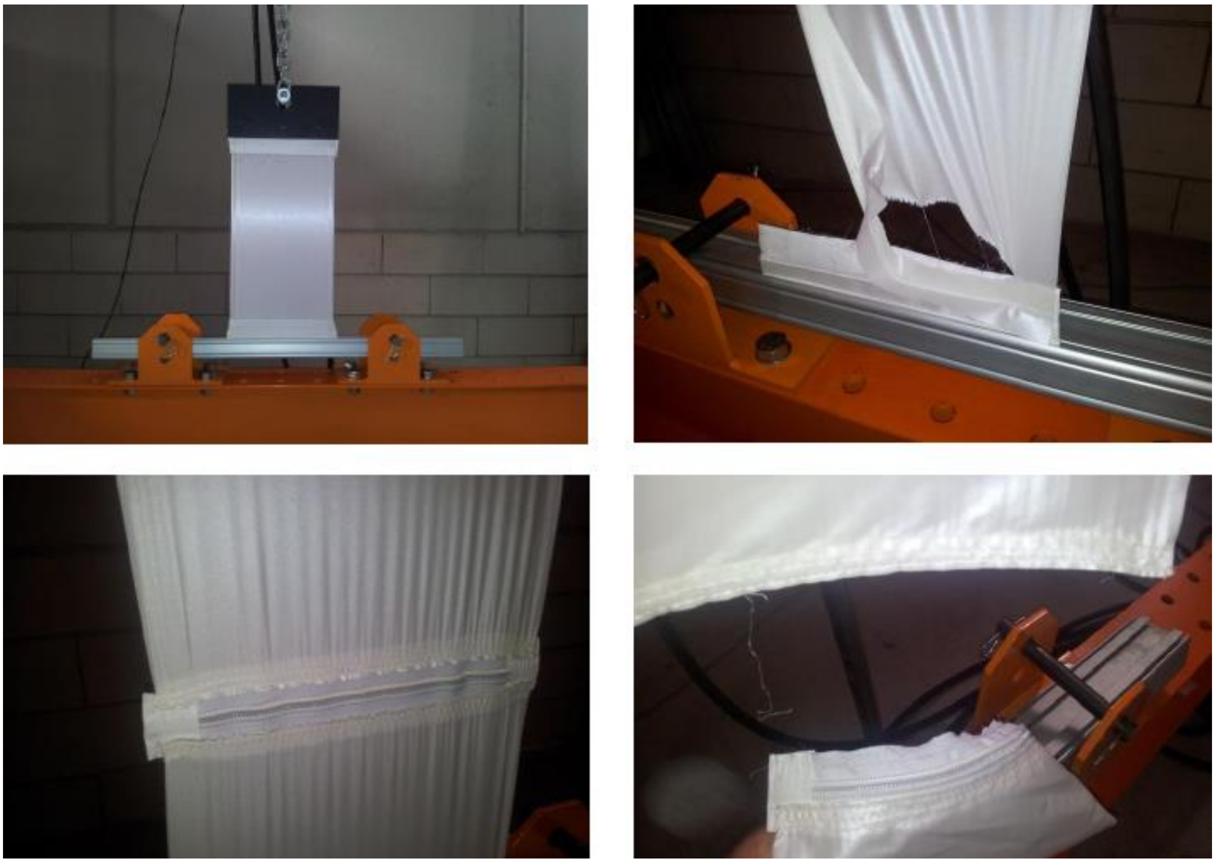

Figure 6: The uniaxial tests on the connections between the fabric and the keder (top) and zip (bottom).

Figure 7: Rupture tests on the connections.

Figure 8: Loading tests on a 1:1 scale mock-up .

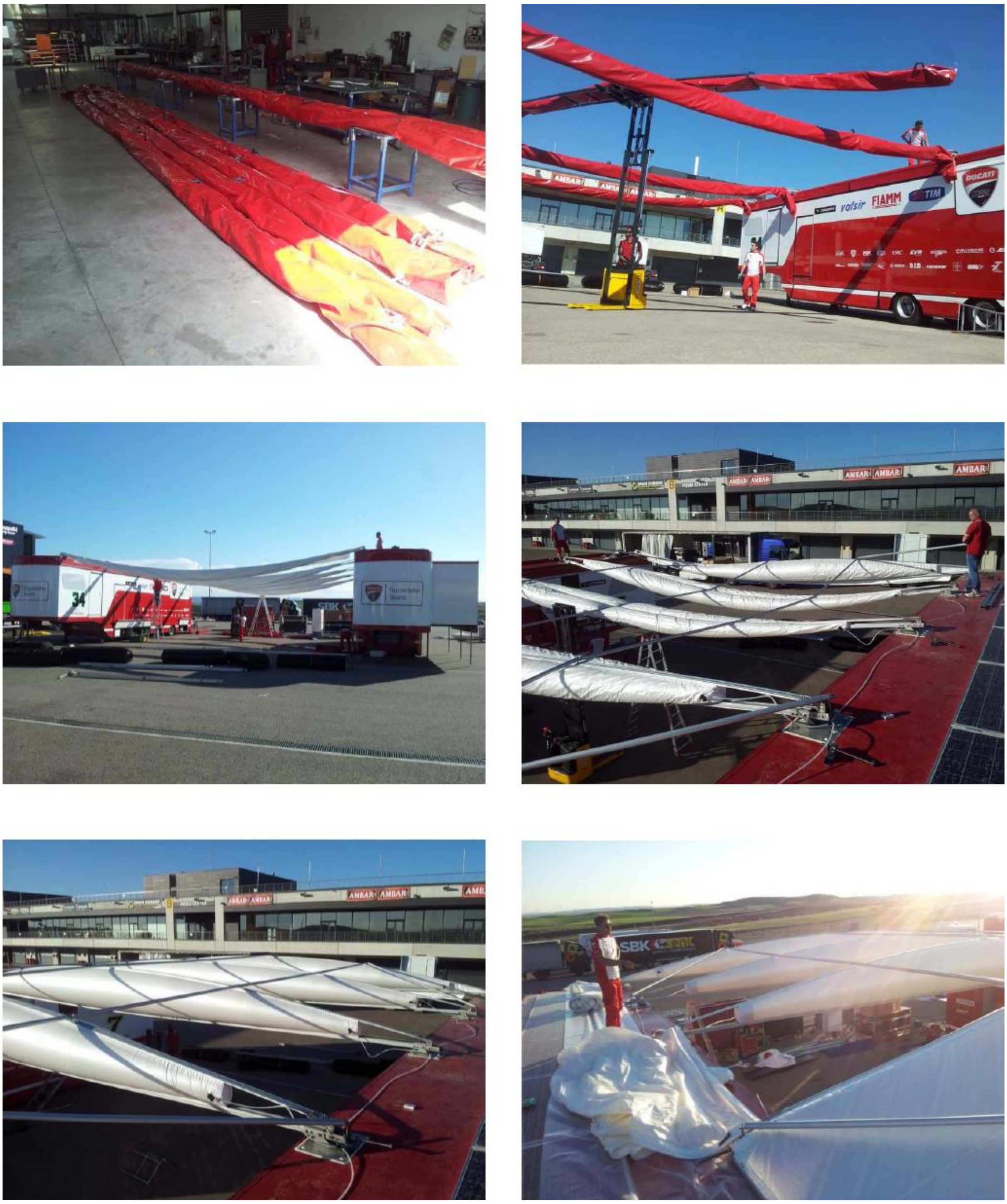

Figure 9: The erection of the Ducati Superbike Pavilion at the Aragón circuit. The deflated beams are positioned and connected to the roofs of the semitrailers. The pressurised air circuit is connected and the beams inflated. Finally, the roofing membranes are connected to the beams.

Figure 10: The LED light applied to the Tenairity® beams.

Figure 11: The Ducati Superbike Pavilion assembled .

The assembly process for the Ducati Superbike Pavilion is shown in Figure 9, for an event at the Aragón circuit. First the deflated beams are positioned and connected to the roofs of the semitrailers used to transport them. The pressurised air circuit is then connected and the beams are inflated. Finally, the intermediate roof membranes are connected to the beams. The finished pavilion is shown in Figures 10 and 11.

5 CONCLUSIONS

The application of Tensairity® for temporary structures opens new opportunities and scenarios which appear very promising and exploit the advantages of the Tensairity® principle extensively .
This paper presented the main design and manufacturing aspects faced during the design and construction of the Ducati Superbike Pavilion. The architectural and structural design of the pavilion is presented here in detail together with several images of the assembly procedure.

REFERENCES

[1] R. Maffei, "*Sheltering in emergency: processes and products textile kit for immediate response*", PhD Thesis, Politecnico di Milano, (2013).
[2] R. Maffei, C. Galliot, R.H. Luchsinger, A. Zanelli, (2013), "*Comparative study about the behaviour of inflatable and Tensairity arches*", IASS Symposium 2013, Wroclaw, Poland, 2013.
[3] R.H. Luchsinger, *The new light-weight structure Tensairity*. In: R. Motro (ed). Flexible composite materials in Architecture, Construction and Interiors, 100-111, Birkhäuser, Basel, 2013.
[4] Luchsinger R.H., Pedretti, A., Steingruber, P. & Pedretti, M. (2004): The new structural concept Tensairity: Basic Principles, in Progress in Structural Engineering, Mechanics and Computation, ed A. Zingoni, A.A. Balkema Publishers, London.
[5] Rolf H. Luchsinger, Antje Sydow, René Crettol (2011) Structural behavior of asymmetric spindle-shaped Tensairity girders under bending loads, in Thin-Walled Structures
[6] Luchsinger, R. and Galliot, C. (2013), Structural Behavior of Symmetric Spindle-Shaped Tensairity Girders, Struct. Eng.,139(2), 169–179
[7] Maffei R., (2013) Sheltering in emergency: processes and products, Building & Environment Science & Technology Dep., Politecnico di Milano, Ph.D., 2013.
[8] Beccarelli P. (2015) Biaxial tests and procedures for fabrics and foils, SpringerBriefs in Applied Sciences and Technology, Springer.
[9] Luchsinger RH, Pedretti A, Pedretti M, Steingruber P. *The new structural concept Tensairity: Basic principles*. SEMC 2004, The Second International Conference on Structural Engineering, Mechanics and Computation. Cape Town, South Africa, 2004.
[10] Luchsinger RH, Sydow A, Crettol R. Structural behavior of asymmetric spindle-shaped Tensairity girders under bending loads. Thin-Walled Structures, Volume 49, Issue 9, September 2011, Pages 1045–1053.