An innovative Pedestrian-Bicycle Bridge Shape for Environmental Sustainability and Structural Efficient Improvement

***Lucci Melania[1], †Viskovic Alberto[1]**

[1]Department of Engineering and Geology, University "G. D'Annunzio" of Chieti-Pescara, Italy.

*Presenting author: melanialucci@hotmail.it
†Corresponding author: alberto.viskovic@unich.it

Abstract

Planning pedestrian and bicycle bridges to overpass rivers, highways or roads with intense traffic, represents a smart way to enhance a territory and to reduce the massive and improper use of public and private transports with high environmental impact. In this research work we would like to show how, thinking different, cold be possible to improve the concept of mobility in a sustainable way. Proper design choices on shape, with high structural efficiency, and material, with low footprint on nature, are fundamental for this process. Thanks to its great shape stiffness, the hyperbolic paraboloid surface has proven to be good choice. It represents a ruled surface capable of realizing complex curvatures simply derived from straight lines crossed between themselves. About the material, we have chosen the Cross Laminated Timber (CLT) as an interesting alternative to the traditionally used materials for this kind of structure. The very good strength/weight ratio, the orthotropous behaviour and the flexibility in designing and forming structural elements of different sizes and shapes are some of the main features of the CLT. The geometric modelling of the bridge is created in Rhinoceros using a parametric approach. The algorithm, developed through a visual programming language Grasshopper, is written in such way that the size of the geometric element can be rapidly and parametrically modify as necessary. The structural analysis is based on a Finite Element Method (FEM) through MIDAS/Gen. A software chosen for its flexibility, the wide material and finite element library and the possibility of modelling the orthotropous behaviour. In particular, we have chosen "plate" as finite element with proper material characteristics according to an implemented well oriented mesh. In conclusion, the aim of this research work is to design a cycle and pedestrian bridge in which choices on material and shape move towards a sustainable mobility. The possibility of in-site rapid assembly process should not be neglected.

Keywords: **Sustainability. Efficiency, Wood, Bridge, Paraboloid, Parametric, FEM**

Introduction

In recent years, the urban development of Western countries has produced a clear separation between the art of building the city and the attention to places. The starting point of the following research work is the awareness that engineering, architecture and urban planning must return to assume a central role within the city, looking at the sustainable development of the urban landscape to "satisfy two human instances: [...] the physical and the spiritual one [...] " [1].

The design of cycle walkways is one of the concrete ways to follow this philosophy. It offers the possibility of experimenting with innovative forms and materials to create something that is not just a simple means of connection between two places

Modelling and Structural Analysis

The installation of a walkway that allow passing over rivers or busy roads is an intelligent way of enhancing a territory and reducing the massive use of public and private polluting vehicles.

At the base of the following research work there is the will to enhance, in an alternative way, the concept of slow and sustainable mobility. The decision to design a "structural architecture" was fundamental to this process. It is intended as an aptitude for combining forms and structures by attributing aesthetic value to the "backbone" of an architectural project. Therefore, the search for design solutions different from the classic types used for the design of driveway bridges. The adopted choices regarding the form, the material, the structural, constructive and economic feasibility, have the aim to obtain a result with a low environmental impact and high structural efficiency.

Thanks to its great stiffness in shape, with a membrane behaviour and an optimal thickness distribution, the meeting point between structural efficiency and sustainability was obtained through the choice of the hyperbolic paraboloid. A quadratic striped surface for the realization of only apparently complex curvatures, obtainable thanks to simple translation of straight lines into the space, through a simple and flexible construction process.

The structure has been designed with Cross-Laminated Timber (CLT) wooden plates making the material work according to its natural attitude of orthotropic and combining its technical performances with the energetic and ecological ones. The excellent strength-weight ratio, the properties of orthotropic, the excellent resistance and reaction to fire and the great flexibility in the design of structural elements of different sizes and shapes are some of the important peculiarities of CLT.

A key factor for a successful approach in the design of this boardwalk was the integration between architectural-parametric and structural modelling.

In particular, in the geometric modelling, a parametric approach was chosen using the Grasshopper software. A modelling therefore that does not follow the logic of CAD or 3D, but algorithmic. It is generated from a list of instructions that process inputs through a logical sequence of descriptive geometry operations. Only with the algorithm terminated, the surface has been edited with the help of the Rhinoceros Software.

From a square-based hyperbolic paraboloid [2] a hyperbolic paraboloid of rhomboidal base has been made. The surface has been cut out of the dimensions and features compatible with those of the boardwalk in question, implementing equations and parametric, as shown in Fig.1. Therefore, since the solution is not unambiguous in this way, design constraints have been inserted regarding the context, the structural and architectural properties and the normative apparatus in force. The obtained solution represents the fusion between geometrical features (derived from the most disadvantageous load conditions) and the optimization of results concerning the structural efficiency and the aesthetic dimension.

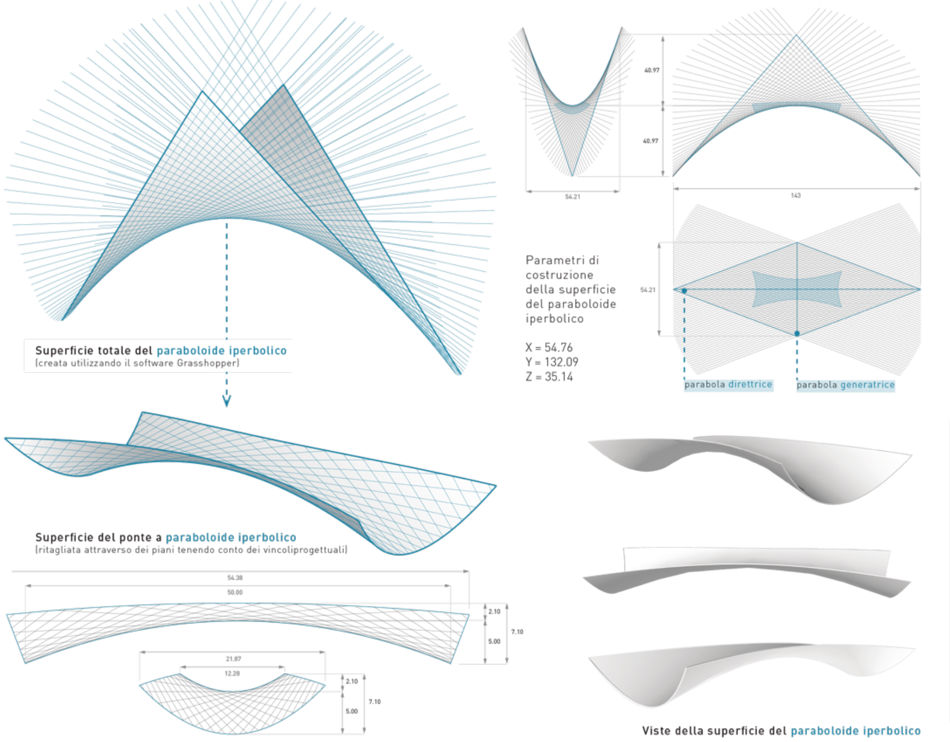

Figure 1. Geometrical and parametric modelling of the boardwalk surface [3]

The structural analysis, based on the Finite Element Method (FEM) has been realized through the MIDAS-Gen software. This choice derives from its flexibility, the possibility of having a very large library available to the user, both as regards the materials (customizable if necessary) and the finite elements, from the implementation of the orthotropic properties of the chosen material. from the ability to import and export files in many formats (it is perfectly oriented in the world of Building Information Modelling - BIM [4]).

The modelling was carried out following a computational method. In particular, established form, size, type of material and model loads, we have moved to its resolution. By determining deformation, strain and displacement, the structural verification of the element has been achieved.

The implementation of a simplified structural scheme with respect to the architectural model was fundamental. The inclusion of simplifying hypotheses has allowed to reduce the computational cost from the software point of view. However, the discretization of the model in 2D finite elements, called "plate", has been strongly influenced by the orthotropy of the material. The orthotropic behaviour was implemented by inserting the mechanical and physical properties of the material according to the orientations of the local (non-global) axes of the individual plate elements. Considering this choices, the creation of a manual mesh was necessary. Elements were created as close as possible near to be rectangles or squares, oriented in such a way that the values assigned to the mechanical properties in the material definition were consistent with the designed structure. It was specifically obtained by generating the transversal and longitudinal parabolas whose joint nodes are placed on the lines of connection between the various surfaces (surface, bridge deck and diaphragm in Fig.2).

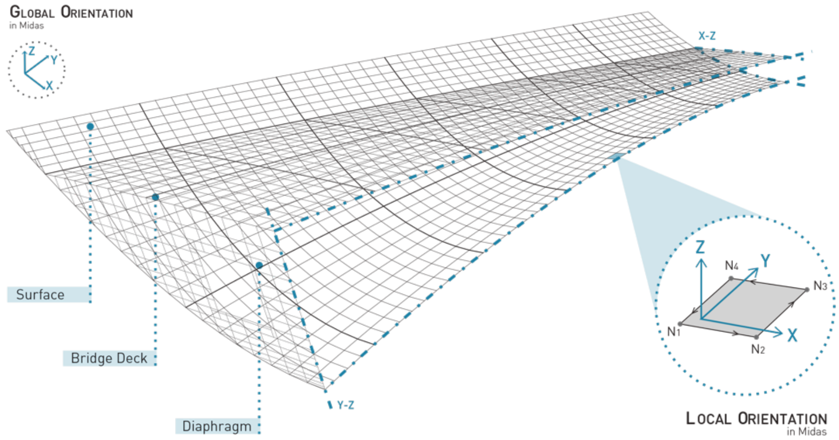

Figure 2. Structural model and mesh [3]

The first model created is certainly the most comprehensive of approximations with relatively poor reliability results. In it, the main approximation is made in the calculation of "equivalent" Young's modulus to be assigned to the mechanical properties of the material.
One of the design constraints involved in the realization of different study models is represented by the orientation of the CLT panels in crossed layers. It does not follow that of the Cartesian reference system for which the values of the mechanical properties for the different directions are assigned by the literature [5], but it is dictated by the inclination of the generating lines of the ruled surface. Furthermore, since the 2D plate elements are finite, the different layers of each single panel are composed and the respective mechanical properties are taken into account in the introduction of the "equivalent" Young's modulus. The fundamental steps are:

- Computation of the projection of the "equivalent" Young's modulus, longitudinal (E'0) and transverse (E'90), based on the inclination dictated by the geometry of the surface compared to the XY global reference system;
- Multiplication of the previous components for the number of layers respectively provided for both directions;
- Considered an "equivalent" thickness (equal to ¾ of the real one) to have values of stiffness, axial and bending, not too far from the actual values (consequence of the approximation reported in the first point).

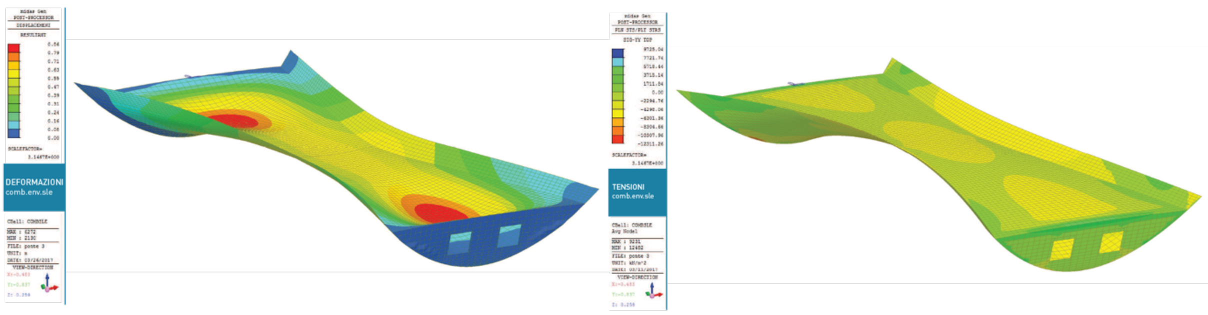

Figure 3. Displacements and strain results of the first model [3]

Because of the excessive approximations made, the results obtained by this model (shown in Fig.3) are unreliable. After several iterations in modelling, in which the transversal components (E"0 and E"90) of the Young's modulus were not neglected, a further division of the plates in subgroups, was carried out. For each of them, the longitudinal component of the Young's modulus E (E'0 and E'90) has been recalculated and projected from time to time depending on the inclination of the elements in the global mesh. Furthermore, an equivalent thickness of ½ of the real one was considered. This last model implemented show results that are the most reliable and all verified according to the limits set by the Italian code. In particular, keeping unchanged the mechanical properties assigned to the material once the approximations relative to the first model have been eliminated, in the last one a stiffening operation of the deck structure was carried out by inserting specially sized beams. In fact, despite being designed with an inclination of lamellar wood panels placed at 45 °, it turns out to be the only element to have no enough stiffness in shape. As shown in the graphs in Fig.4), the deformation of the deck is much higher than those of the striped surface of the hyperbolic paraboloid.

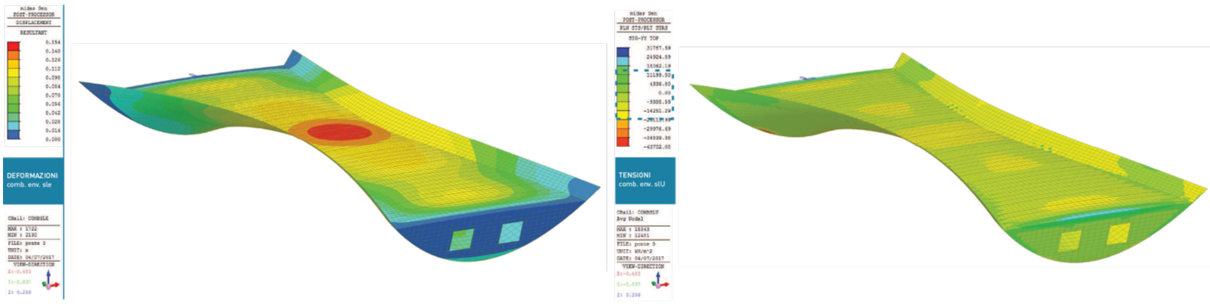

Figure 4. Displacement and Strain of the updated model [3]

In this model, the structural analysis is satisfied. However, from the graphs shown in Fig.4, it can be seen that in the diaphragm-bridge deck connection zone this check is not satisfied because of the geometry of the mesh and higher deformations in the deck.

The desire to enhance, in an alternative and innovative way, the concept of sustainable mobility design has been fulfilled by creating a meeting place; a new public space in which to stop, in a sensitive relationship with the surrounding environment. To complete the work and the tasks for this research work, an extension of the surface of the hyperbolic paraboloid used as a parapet was created in order to obtain a seat (in glulam wood) with soft shapes and in harmony with the whole boardwalk (Fig. 5). Furthermore, the upper surface of this additional element was exploited by inserting flexible and light solar panels used in the naval field [6]. The electric power produced allows the arrangement of a higher number of lighting devices than those provided for the classic walkways. So, a new urban space in which to experience a simple way of living, stopping, observing, listening, riding, walking.

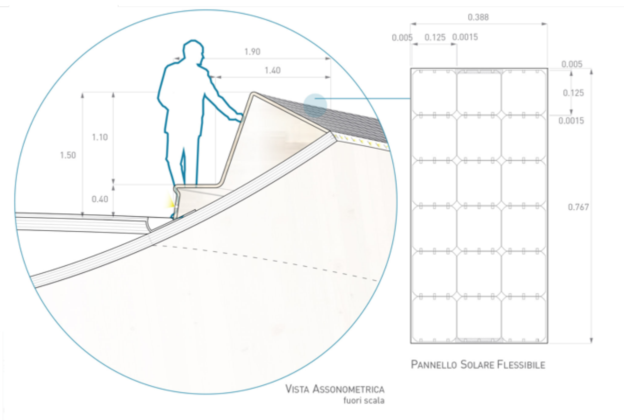

Figure 5. Detail of the realing-seat [3]

Conclusions

The goal of this work is to give a new identity to the design of cycle-pedestrian walkways; a new way of conceiving form, linked not only to aesthetics but also to structural efficiency; an alternative design of sustainable mobility through the choice of unusual materials and shapes.
Finally, it is important to underline how this project turns out to be a specific case but adaptable to any other context with different conditions. The simple construction (it may be assembled near the site and placed by two cranes in the right position), combined with flexible replicability are important features. Not last, the possibility of further optimizing the structure by pushing towards new structural models and more reduced thicknesses.

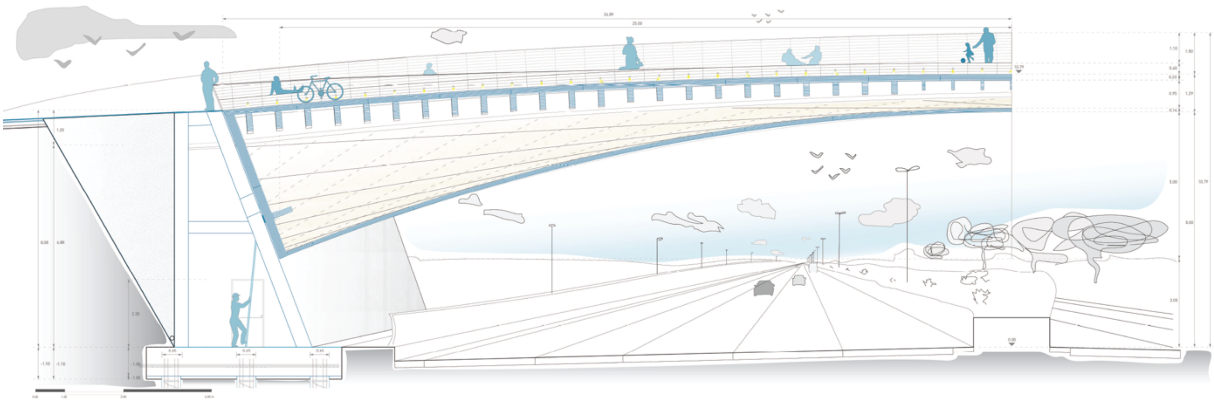

Figure 6. Longitudinal Section [3]

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