MONUMENTAL TREE PROTECTION BY AN UNIQUE PEDESTRIAN BRIDGE

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ABSTRACT

This paper describes the conceptual design, the structural analysis and the results of a viewpoint pedestrian bridge, situated in Daya Vieja (Alicante-Spain). This structure is designed to protect a land-mark palm-tree from wind loads. This six – trunk palm tree was declared monument by the Valencian government in 2012. The structure that now protect it appears to fly around de palm tree creating a helicoidally skywalk made of steel, while retrofitting the lateral trunks of the tree to protect them from collapse. An 18 m long straight beam starts on the top of this helix, and stretches towards a lookout point that offers a view of the whole village and its surroundings. The reduction of the visual impact of the structure on the tree was a major aim for the project design. The structural elements are as slender as possible to avoid the visual obstruction of tree. This structure has been a finalist in the Architecture Awards for the 2010-2014 best construction projects, held by the Diputación of Alicante.

Keywords*: Steel structure, pedestrian bridge, trees loads, elevated pile cap, tree wind loads.*

1. INTRODUCTION

The structure described in this paper is specifically designed to help a unique six-trunk palm tree bear strong wind loads. This palm tree is in Daya Vieja, a small town located in the south east of Spain in the province of Alicante. The tree appears in the catalogue "Arboreal Monumental Heritage of Valencia", published by the Valencia Region Government in 2006 and its new version (that includes the modification and enlargement of it) that was published in 23/11/2012 [1], once the construction of this structure was already finished. As a catalogued tree, the law enforces its preservation and enhancement. The tree is a Phoenix Dactylifera variety more than 210 years old, with a height of 20.50 m and a perimeter of about 18.85 m; it is located in the main square of the town. The decision to design a structure to retrofit the tree was taken after the collapse of one of its trunks during an episode of strong wind.

The first requirements that were imposed on the project were that it should neither harm the tree nor acquire a higher prominence than it. The project was designed to highlight and to protect the tree, while it has a specific use. The project was step by step adjusted from the initial conception to the final version considering many different options. The three dimensional steel frame structure was finally chosen as the one that best complies with the prerequisites both in service and during its construction.

The final proposal was based on the external geometry of the Guggenheim Museum in New York. The structure consists of a helical steel truss beam that completes three ascending laps enveloping half the height of the trunks, embracing completely the tree. At the top, there is a steel ring where each trunk of this palm is anchored through cables in several points. Those cables significantly reduce the forces and moments that wind loads generate on the base of the trunks and their clamping with the ground. It reduces the possible breakage and / or excessive deformation of each trunk due to wind. [2]

The design also intended to visually connect the town center with the surrounding fields to show the visitors the relationship between the town and its surroundings and the change of the landscape along the different seasons. A

lookout landmark, with a spiraling promenade that culminates in a narrow overpass that juts out over a major town thoroughfare, was created. El Mirador de la Palmera offers stunning views of the “Vega Baja”, “Rojales” and “La Marina” areas. The result of this special structure is the "Variation Guggenheim 3", or "Viewpoint from the Palm Grove," a three dimensional steel frame spiraling walkway. Despite the fact that this construction certainly uses more materials and takes up more space than a simply retrofitting system, the designed structure allows visitors walking closer to the trees, to live an especially pleasant experience, and to create a valuable architecture icon as well. In addition to the alluring views and the fun pedestrian walk, the idea of making the tree a focal point and, conversely, to extol it, is an example of the sustainable thinking that infiltrates much of today’s architecture.
The tower resembles a roller coaster made for pedestrians. This roller coaster offers, instead of speed, awesome 360 º views of Daya Vieja and unique points of view of the palm tree, while protecting it from collapse.
El Mirador de la Palmera designed in Spain, serves both as a spiraling walkway/lookout tower and a brace for the unique palm tree that embraces.
In 2014 this structure has been finalist on the Architecture Awards held by the Diputación de Alicante for the 2010-2014 best construction projects.

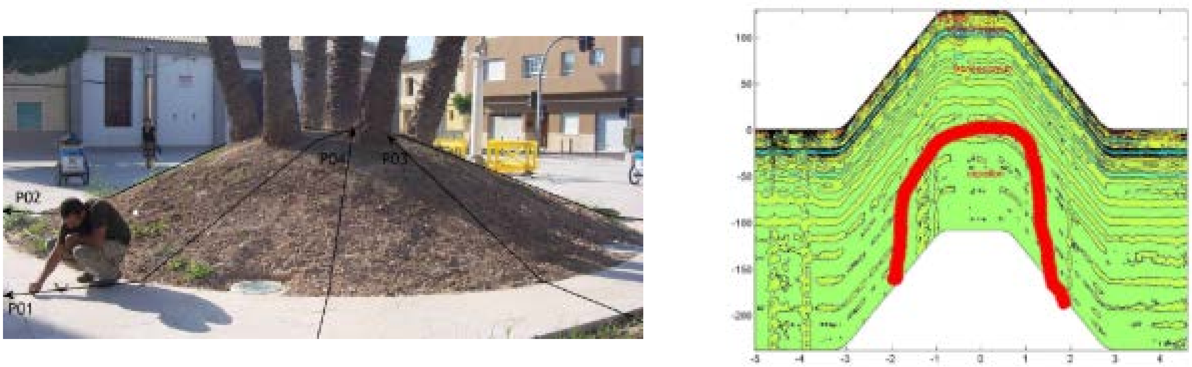
2. PRELIMINARY STUDIES

The choice of the foundation design was strongly influenced by the characteristics of the soil and the location of the roots of the tree which must be protected. In order to design it, a series of geotechnical tests were carried out.

(i) Surveys: They indicated that the groundwater table level was at 1.2 m from the surface, this level vary considerably during the different seasons reaching up to 1.0 m depth. A 10 m depth lithological column was obtained consisting of loose fine sand and silt with some soft clay layers in between.

(ii) Tomography: Performed to detect the location of the tree roots and bulb, where the three trunks meet. The detection of these elements of the rooting system was crucial to avoid damaging them during the construction of the foundation. A soil tomography test with Ground Penetrating Radar (GPR) was conducted using a 500 MHz antenna. A diameter of 15 m around the palm tree was tested making longitudinal sections (Figure 1a). This system allowed knowing the characteristics variations of the materials up to 2 m below the location of the GPR [3].

Finally, the deep foundation using micro-piles option was the most suitable one due to its better performance in terms of damages reduction to the bulb where the trunks of the palm tree meet, its adaptable bearing capacity able to provide sufficient strength only enlarging the micro-piles through the existing layers of soft soil, the reduction of the expected settlements and the small size of the machinery needed to do the work. The foundation system were completed with a concrete floating ring pile cap elevated 200 mm above the current level of the ground, avoiding any damage to the roots due to its construction, while performing perfectly its duty and having the shape and functionality of a bench.



(a) ***(b)***

Fig. 1. *Preliminary research: GPR (a) longitudinal sections studied. (b) Location of the main root of the tree*

3. GEOMETRICAL DESCRIPTIONS

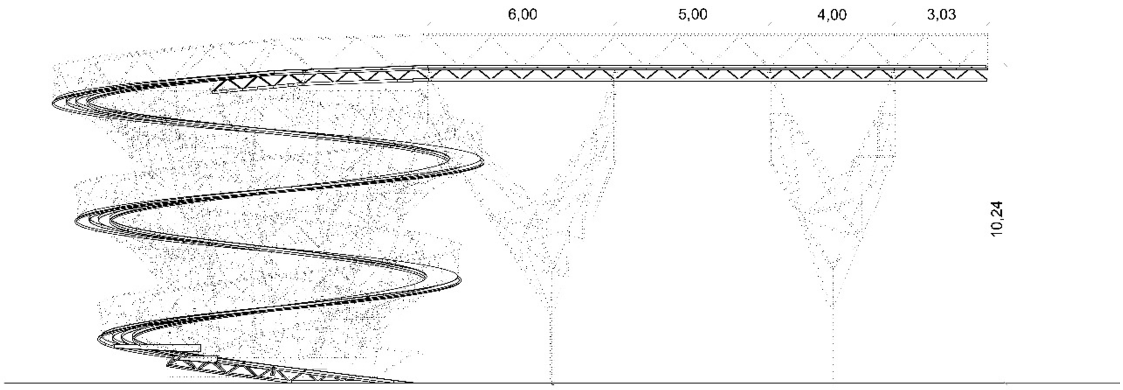
The main structure is a double spiral-shaped steel three dimensional frame structure. The spiral radius grows at the same time that it goes up along the complex shape. The exterior radius at the foundation level is 3.5 m. and ends with a length of 5 m at the top. The double spiral-shape was designed to balance the momentum loads triggered by the spatial steel walkway along with those due to the wind exposure of the structure itself and the palm tree. The distance between the main double-spiral bars is 1.15 m. The spatial frame (wire-like) structure, has a shape similar to an inverted cone.

In order to rationalize the structure, it was designed using bars of the same diameter, easing the construction and providing rhythm and neatness at the same time. To support the spiral three dimensional frame, 24 twisting solid steel bars ∅63.3x15 mm were laid on to circles over the concrete ring foundation, twelve in each one. The rhythmical staggered disposition, and the twisted shape, responds to the idea of dividing the double spiral into equal segments, 3 m long. The main supporting structure is made of quasi-vertical components retrofitted one to another that laid on the foundation and reach the level of 9.5 m. These elements end attached to a planar ring-shaped beam that provides rigidity to the whole supporting structure. Finally, in order to reduce buckling lengths of the slender rods were designed pinned round bars connectors ∅20 mm were added between the two layers of the quasi-vertical elements.

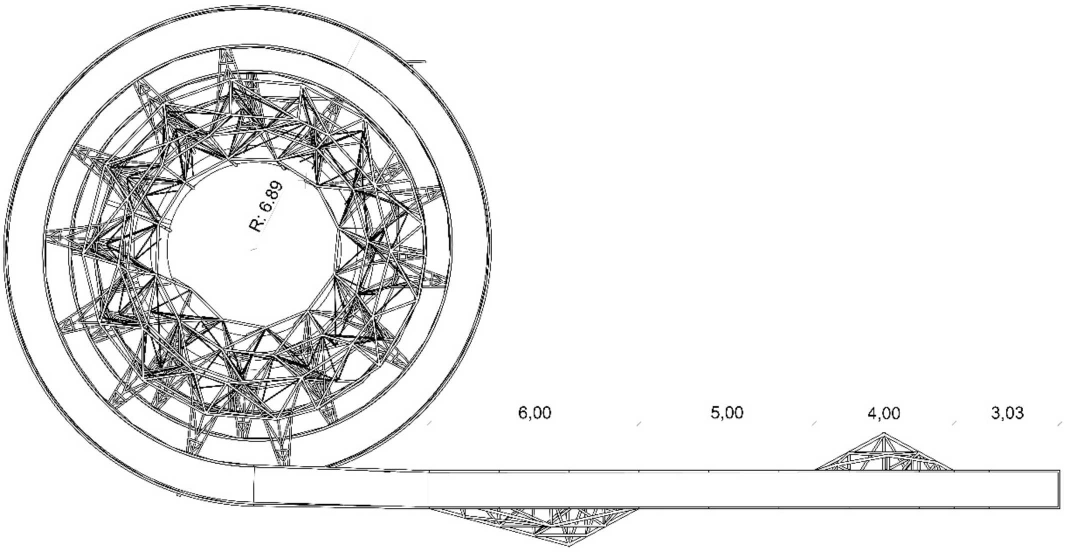
This structure supports a triangular truss helix beam made by round bars ∅63.3x4 mm. The steel walkway is 1 m wide and it is separated from the main structure a distance greater than 2 m. (Fig. 2). The supporting structure of the pedestrian bridge is anchored to the backbone by a spatial structure (so-called duck beak) and horizontal bars that are articulated to the supports to avoid the appearance of additional bending moments in these very slender elements (Fig. 3). This geometry is intended to create a blurred view, like looking through an irregular fabric, avoiding interferences of regular patterns to the tree view that would have changed the natural perception of it.

The truss beam that forms the pedestrian pathway stretches to reach the level of the main street of the town resting on two tree-shaped pillars 10 m high. It provides a lookout at an elevation of 11.0 m over the street, more than any other construction in the town with the exception of the church tower.

The section of the footbridge was made up of a tetrahedral triangulated truss beam. The lower tubular profile is a steel round bar ∅88.9x4 mm. The upper base plate has two stiffening gussets and diagonal profiles ∅20 mm. Because the section design of the beam the side rails were very light and their structural contribution was only to absorb pedestrian loads. This continuous beam placed the observation point farther than 15 m from the main structure, ending its closure on a glass railing that generates greater freedom of vision.



(a)



(b)

Fig. 2. *General geometrical description. (a) Lateral view (b) Plan view.*

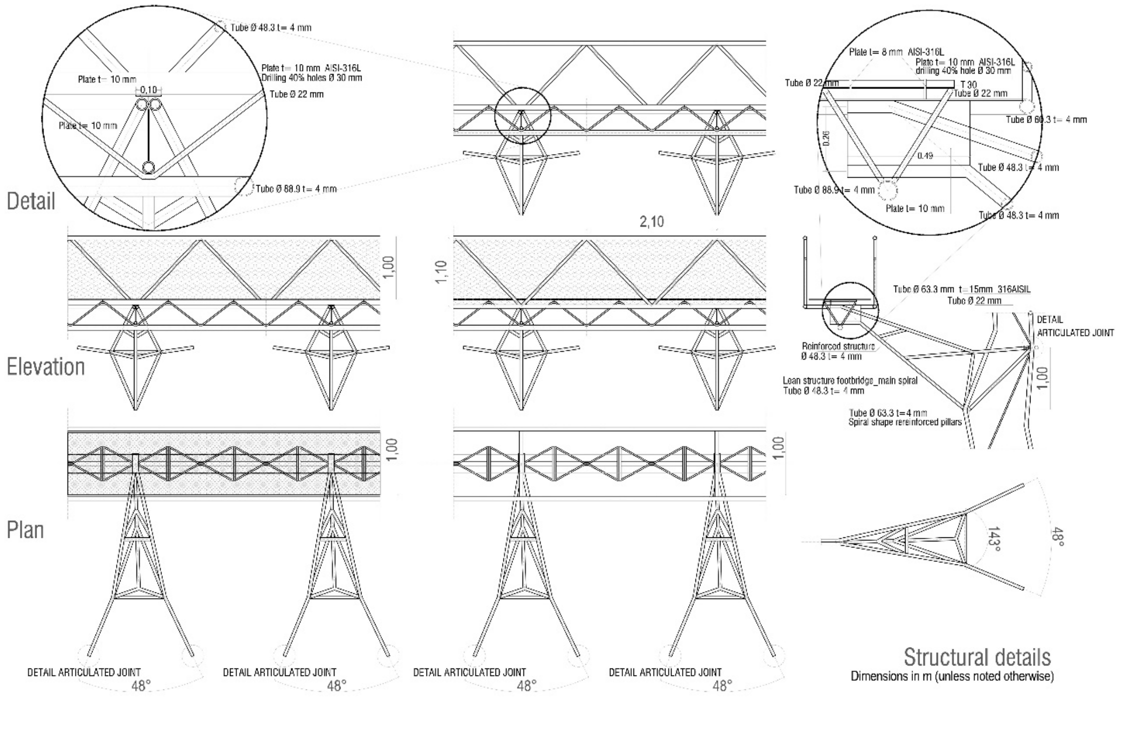


Fig. 3. *Structural system to support the helical walkway on the main structures.*

The tree-shaped pillars were made of steel tubular sections ∅80x20 mm, three-dimensionally triangulated and reinforced with steel gusset plates at the starting and/or supporting points (Fig. 4). The clamps of these elements to the foundation have small stiffness in the longitudinal direction of the bridge. This forces the main structure to provide the main longitudinal bracing to the complete structure and, conversely to bear the subsequent load effects. In contrast, the rigidity of the pillars in the transversal direction is high, due to their truss configuration, not needing any helping from the rest of the structure.

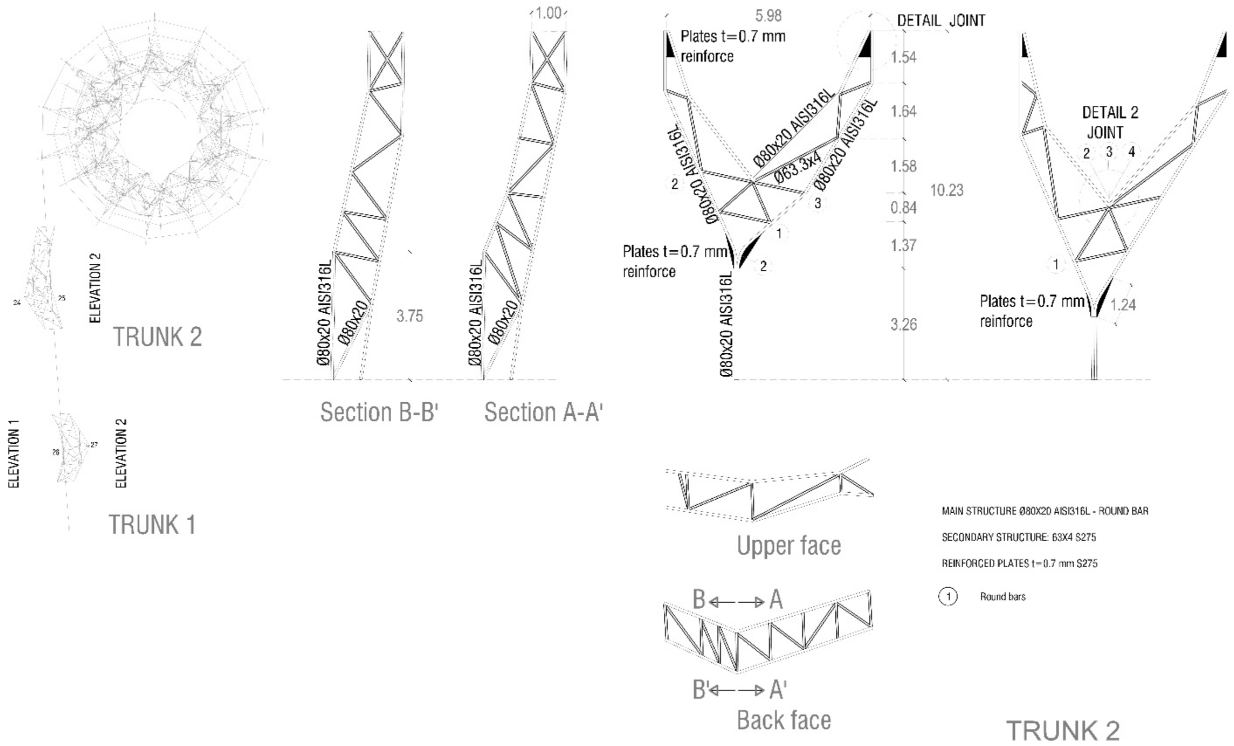


Fig. 4. *Structural details of the tree-shaped pillars*

A deep foundation was designed as result of the preliminary studies. Sixteen ∅100 mm concrete-steel micropiles 15 m in length were bored and constructed through the bulb and raw system of the palm tree. They are located under the pile cap: a circular ring 1.0 m high, with 7 and 5 m of outer diameter for the former and inner diameter for the later, made of reinforced concrete. The micropiles are clamped to the pile cap in a staggered configuration, seven to the inner part and eight to the outer part of the ring. The pile cap is floating 300 mm over the ground and has the shape of a public bench (Fig. 5).

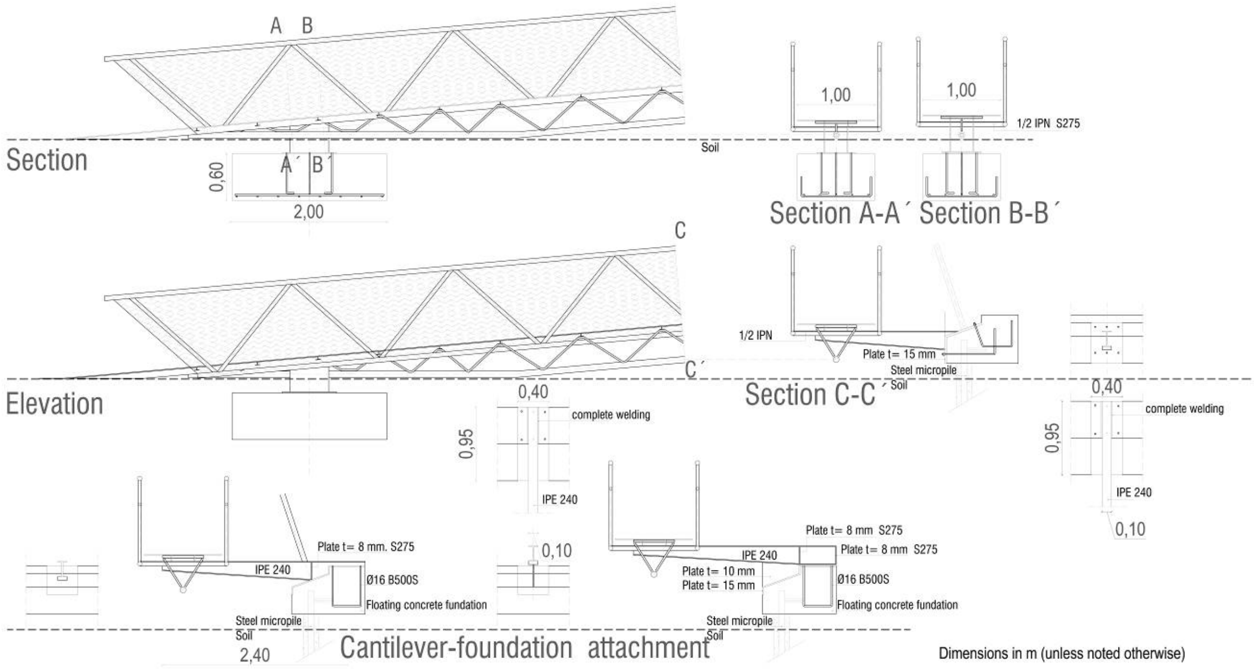


Fig. 5. *Structural details of the walkway and the pile cap.*

4. STRUCTURAL ANALYSES

Structural analysis software [4] was used to create a 3D model of the pedestrian bridge by the Finite Element Method (FEM). Different structural alternatives were defined to reach the existing shape. The project design was developed together between expert agricultural engineers, the architect and the structural engineers to adapt the geometry and loads to the final geometry to verify the Ultimate Limit States, the Serviceability Limit States and to assure the integrity of the tree to wind loads.

"Frame" elements were used to simulate the 27554 degrees of freedom model in all the structure, "shell" elements were used to simulate the deck segments and "link" elements were used to simulate the boundary conditions with the soil. (Fig. 6)

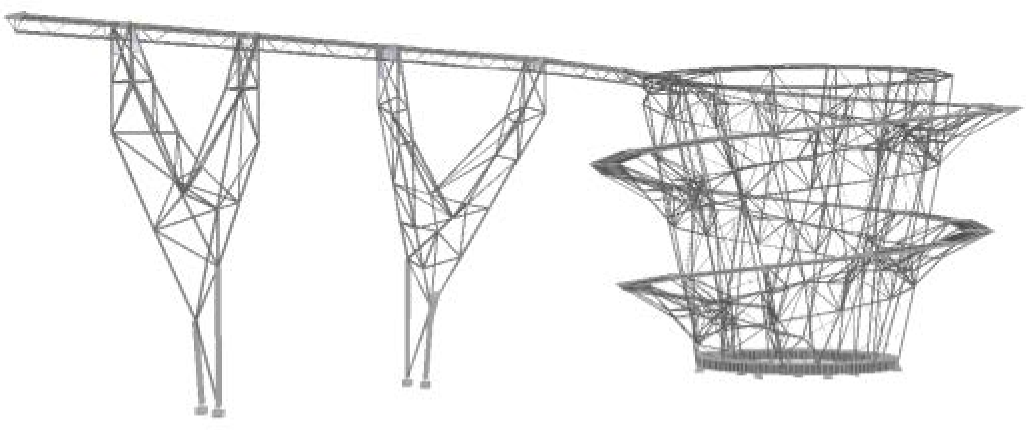


Fig. 6. *Overall geometry and mesh finite element model, frame elements.*

For analyzing the structural behaviour, the classical loads defined by the standards were considered: Self weight, pedestrian's live load, snow, seismic loads, wind and thermal effects [5-8]. In Addition, a particular load was considered on the structure: the load generated by wind on the branches of the palm tree and transmitted to the structure [9]. To estimate these loads, 12 branches of each trunk with a total exposed wind surface of 12.5 m^2 were considered. Each branch was assumed as a flag, with a pressure coefficient of 1.2 and a force coefficient for flag of 0.25. The wind velocity considered for each branch was 34 m/s. A force of each trunk on the structures of 0.28 kN was calculated. This simplified procedure presented results accurate with the ones obtained by [10] a Phoenix canariensis palm tree applying Eurocode 1 and its dynamic effects. These six loads were distributed on the top circular ring. They were anchored to the structure by stainless steel cables. European and Spanish standards have been used to the final design of the complete structure. [11-13]

6. CONCLUSIONS

The steel spatial walkway and lookout now connects the center of the town Daya Vieja with the surroundings, the fields and the landscape. It was decided to achieve two things at the same time: a structural solution for the monumental six – headed tree and an audacious footbridge to provide a view of the surrounding territory. The design plan was to construct a three-dimensional light steel frame structure to protect the palm tree and to protect the palm tree while projecting a unique structure aimed to promote the image of this small southeastern Spanish village (Figure 7).

The experimental design was iteratively designed on the computer in order to get the most accurate shape to the structural function and to the plan for the town. Different software was used to rationalize the dimensional thickness and the floating sensation for the walkway. The whiteness of the main frame structure provides the construction with an abstract composition that contrast with the spatial green walkway that today floats in the town center. The "Variation Guggenheim 3" is a new facility for the citizens to understand the natural and artificial nature of Daya Vieja.

(a) (b) (c)

***Fig. 7** General view of the structure. (a) Lateral view. (b) Bottom view. (c) Helyce's view.*

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