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COMPUTATIONAL DESIGN FOR THE PRESERVATION AND ENHANCEMENT OF HISTORICAL HERITAGE. A PREFABRICATED COVERING PROTOTYPE FOR ARCHAEOLOGICAL SITES IN RURAL CONTEXT

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Abstract

In Italy, many archaeological sites in peri-urban and rural areas are in a deep state of neglect, with unprotected remains and no prospects of enhancement. The paper shows the results of a study aimed at developing a parametric prototype of a prefabricated coverage, to be adapted to various conditions. The Roman Domus of the Acropolis of Populonia in the archaeological park of Baratti and Populonia in Tuscany was chosen as case study. The prototype was parametrically realized using heuristic algorithms based on natural selection (Genetic Algorithms), associated with multi-objective optimization criteria. The algorithm was conceived to optimize the support pillars' position and the visiting path, in relation to the main points of interest of the archaeological site. The final product consists of a wooden structural covering with 11 steel circular-section pillars, completed with a casing made of wood slats and opaque white PVC sheets.

Keywords: **Archaeological sites; Computational design; Covering structures; Cultural heritage, Parametric architecture; Parametric engineering.**

1. INTRODUCTION

In recent years, the growing debate at national and international level about the musealisation of archaeological heritage has highlighted the need of safeguarding an archaeological finding and publicizing it in order to enhance it as a communal heritage. The archaeological heritage has the added value of memory, involving the territory and its landscapes. In this sense, the landscape itself becomes not only object of research, but a real museum of cultural evolution.

Today, we are witnesses of a contradictory phenomenon: on the one hand, we try to evoke the cultural context exposing the archaeological findings in a museum, on the other hand no efficient expedients are adopted *in situ* to encourage the visitor to understand forms, contents and transformations of the archaeological findings.

In this paper, we aim to present a first study for the development of a prefabricated covering prototype for archaeological sites in rural or peri-urban areas, with the function of both protection and musealization of

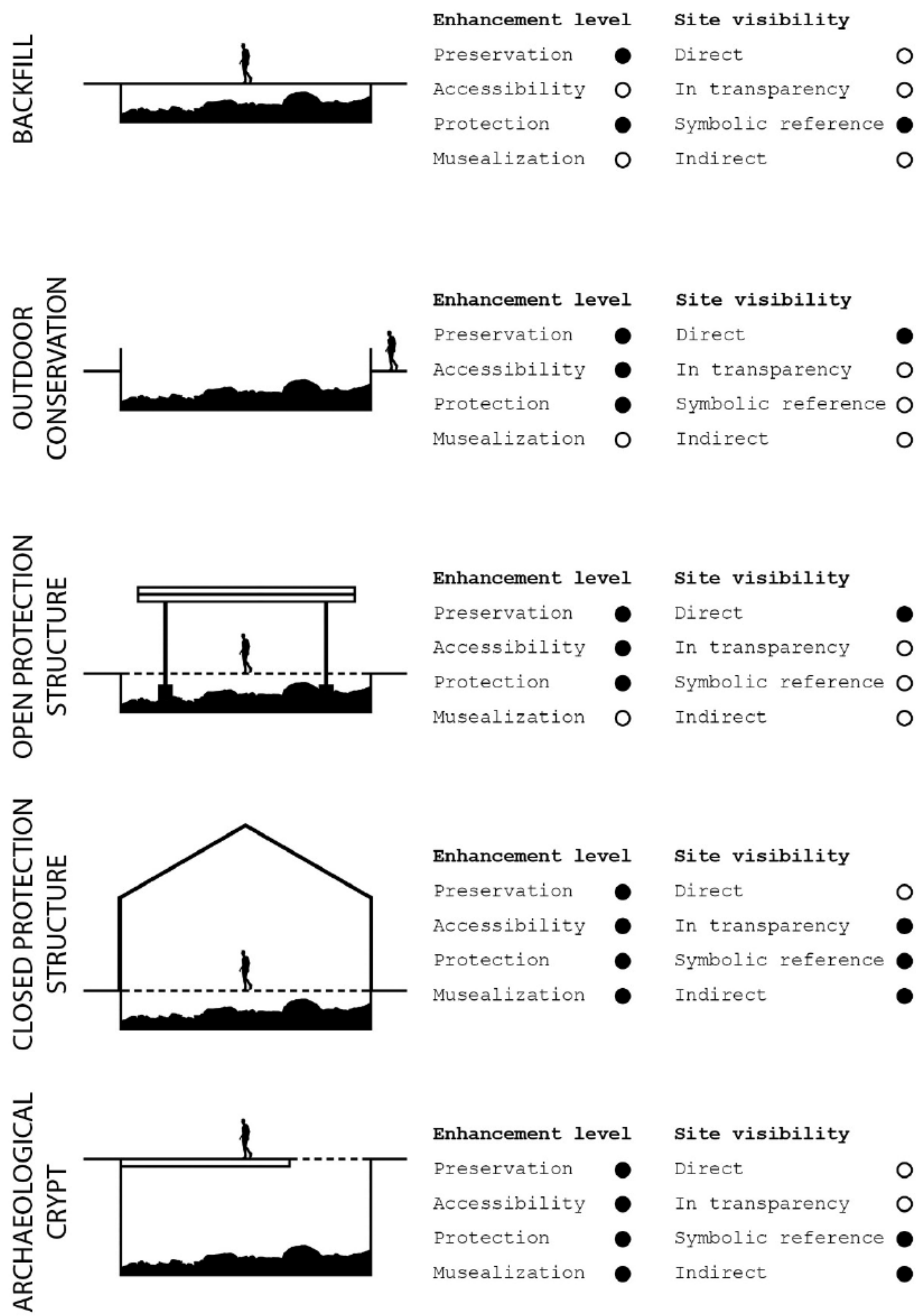

Figure 1.
Types of intervention for the conservation. of archaeological sites (drawing author: F. Iardella)

archaeological findings; the prototype has been applied to the dig of the Roman Domus of Populonia (Gulf of Baratti, Tuscany, Italy), chosen as a case study.

2. INFORMATION

2.1 The musealization of the archaeological areas

The necessity of preserving the relationship between an archaeological finding and its context is fostering the choice of conservation and musealization in situ. With regards to this, Ruggieri Tricoli identifies three main categories of intervention for archaeological digs: without protective structure; inside a building; with protective structures (Fig. 1) [1].

The use of protective structures is mainly adopted for medium-sized sites where the value of the finds requires a higher level of protection. In addition to realizing an effective temporary protection of an archaeological dig, these structures must be designed taking into account many factors, such as the primary function, the relationship with the evidences and the environmental impact [2]. Moreover, coverings, besides conservation and site respect, must guarantee fruition, flexibility of use, expandability and reversibility.

In Italy, protective structures show to date a level of inadequacy in terms of enhancement of the archaeological finds, even when ensuring a good protection [3]. On the contrary, at the international level, we can find many interesting hybrid systems of covering, both simple structures of protection and actual museums in situ.

For the development of our project, some of these international examples were critically analyzed, and in particular: the protective structure of the domus in the archaeological site of the Ciudad Romana de Clunia in Burgos [4]; the wooden covering of the roman baths of the Illeta dels Banyets in Alicante; the huge steel covering structure of the Roman Villa La Olmeda in Palencia [5]. In the case of the mosaics of the Roman Villa of Veranes in Gijón [6], the covering structure designed by the architect Manuel García, consists in a box-like building that stays suspended from the ground, ensuring continuity with the rest of the ruins outside.

In other cases, instead, technological experimentation led to the creation of highly impacting structures, as in the case of the covering structure for the Parque Del Monlinete in Cartagena designed by the architects Atxu Amann, Andrés Cánovas and Nicolás Maruri (2011).

This analysis highlighted that a covering structure must primarily represent an opportunity of enhancement of an archaeological site and its context.

2.2. The generative approach in architecture

In this study, we used a generative design methodology, based on the parameterization of the design space, in which a finite set of input parameters are used to define a complete set of possible solutions. Once the space and some parameters of evaluation has been defined, it is necessary to use an optimization algorithm to find a range of high-performance projects. The optimization problem can be solved through two approaches: deterministic (direct application of a set of defined steps) or stochastic (introducing a certain level of randomness). In architecture, where the optimization problems are particularly complex, designers generally use meta-heuristic algorithms, which are stochastic algorithms based on the principle of the weak law of large numbers [7].

Among these, the oldest and popular optimization algorithm is the Genetic Algorithm, the one we choose to use in our project as its rules and operations are directly inspired by the evolutionary process in nature; this allowed us to exploit some of the potential of the natural design.

2.3. The case study: The Roman Domus of the Acropolis of Populonia

The archaeological park of Baratti and Populonia, located in the southern part of the Livorno Maremma and the "Etruscan Coast", includes the coastal area of the homonymous gulf and the promontory of Piombino [8].

The archaeological site, with findings starting from the Neolithic age, is part of the Val di Cornia's system of archaeological parks. The park encompasses part of the Etruscan and Roman city of Populonia, the *necropoleis*, the calcarenite quarries and the industrial districts. Currently, there are two points of access: the first located on the Gulf of Baratti (*Necropolis*) and the second in the historical centre of "Populonia Alta" (*Acropolis*). A network of itineraries and thematic routes connects the area, even if in a not yet fully legible way [9].

In the *Acropolis* (Fig. 2), the first nucleus is probably represented by the late republican Roman building known as "Le Logge", a sort of terracing that once housed cisterns and served as a base for other buildings [10], such as a sanctuary of Venus, as suggested by the separation between the terracing area and its southern part and the presence of votive mosaics [11].

In the saddle between the two hills that characterize the park, a sacred area has been recognized consisting of three temples (temple A, temple B and temple C) and another building (D), dating back to the 2^{nd} century B.C. (Fig. 3) [12].

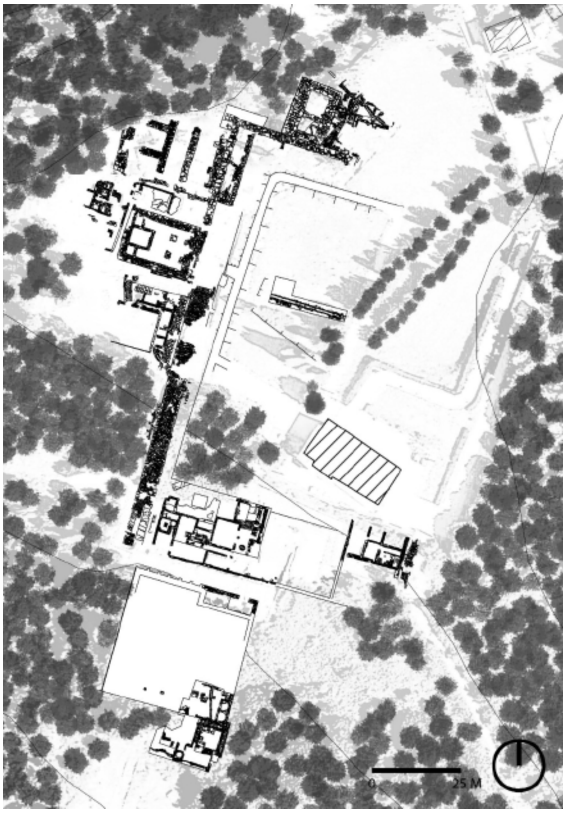

Figure 2.
General plan of the archaeological site of the Acropolis of Populonia (drawing author: F. Iardella)

On the artificial terrace downstream of the Logge, lies the building chosen as a case study. It consists of the ruins of a Roman domus, organized in several spaces connected to many construction phases, as the archaeological excavations carried out in 2006 and 2007 evidenced investigating a global area of about 745 m^2. In the area, 260 stratigraphic units have been recognized, some integrated into already identified activities, the others grouped into 63 new activities that can be dated from the first half of the 2nd century B.C. (period V) to the modern and contemporary age (period XIII).

The western area was occupied by a thermal complex that included with an *apodyterium*, a *balneum* and a *calidarium* with *alveus* and a small exedra for the *labrum*. On the north, the building overlooked an open courtyard. The East façade, instead, had a portico with calcarenite columns placed on the lower terrace of the Logge (Fig. 4).

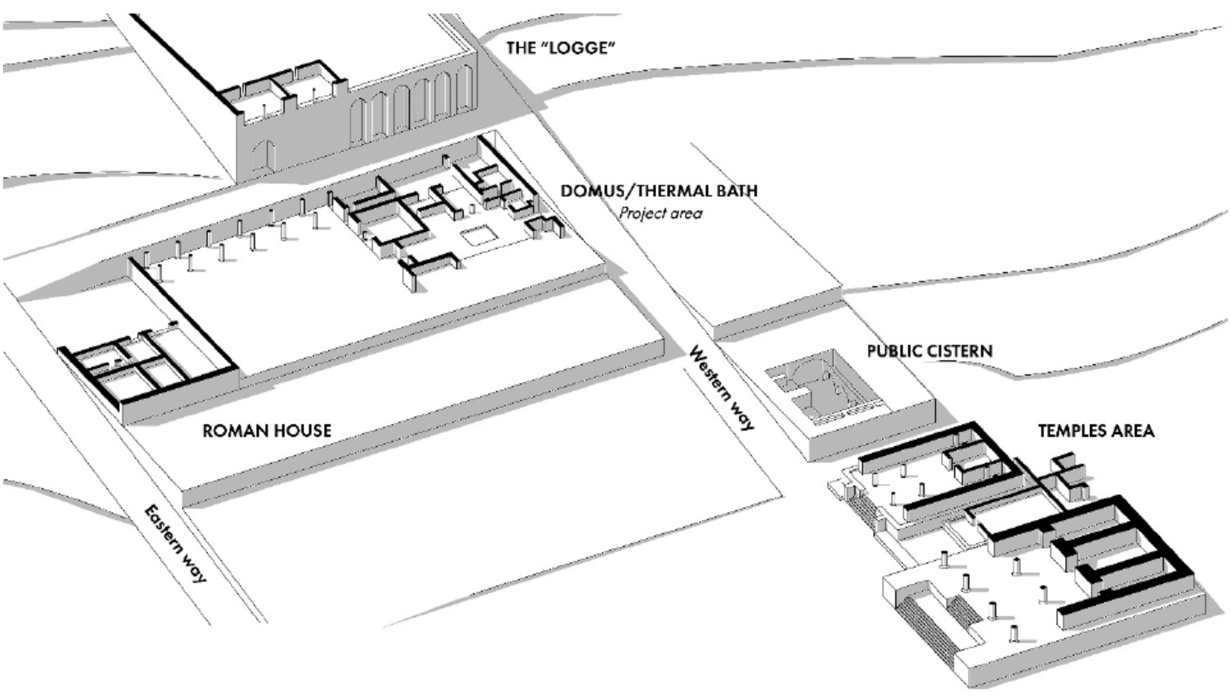

Figure 3.
Partially reconstructive axonometric view of the buildings in the Acropolis of Populonia (drawing author: F. Iardella)

Figure 4.
Photos of the current state of the Roman domus (photo author: F. Iardella)

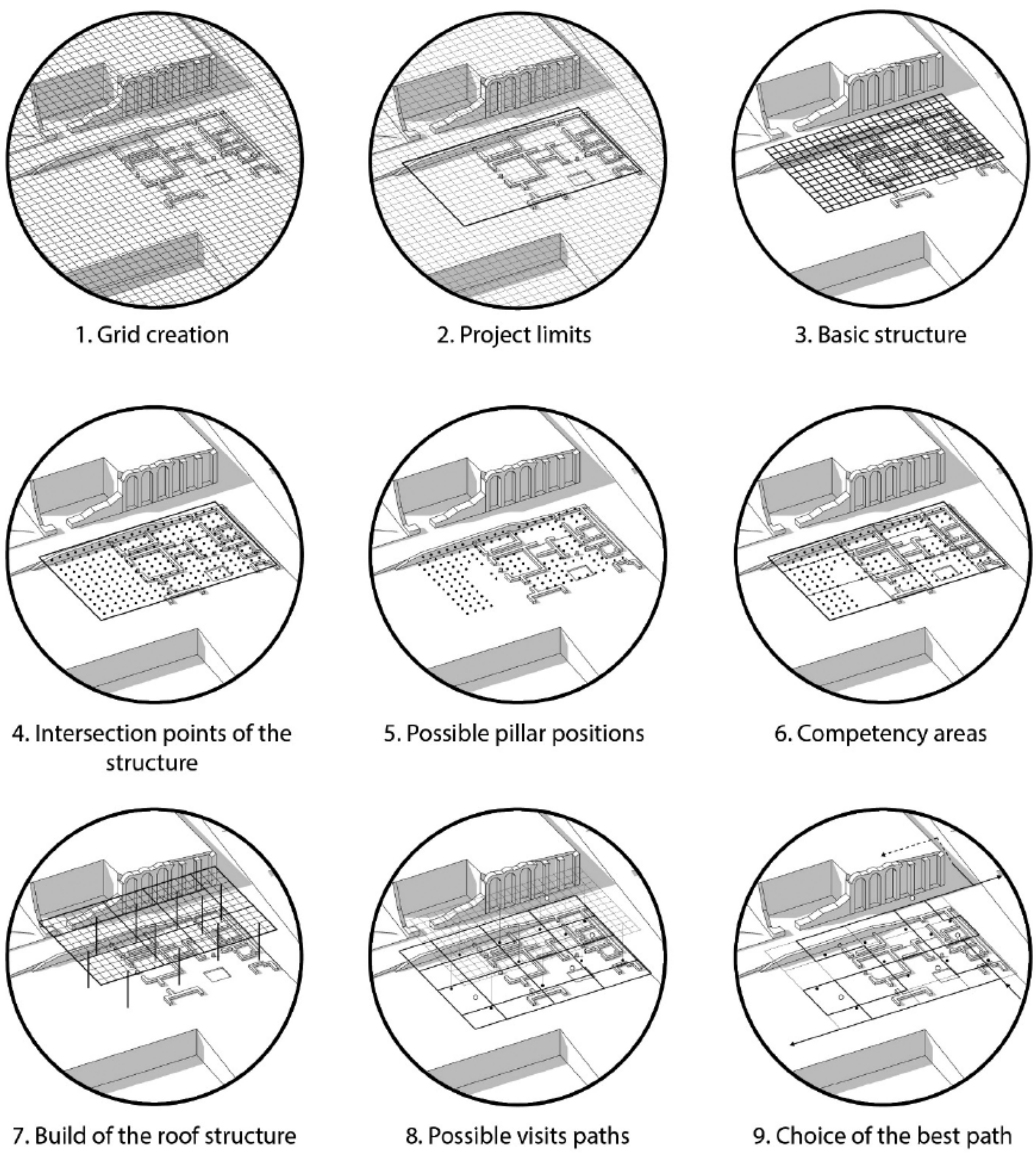

Figure 5.
Illustrations of the steps of the generative process (drawing author: F. Iardella)

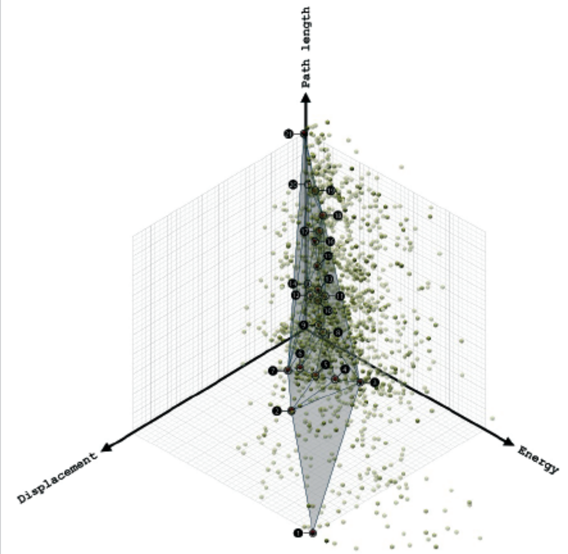

Figure 6.
Pareto Front Diagram of multi-objective optimization (drawing author: F. Iardella)

3. THE PREFABRICATED COVERING PROTOTYPE

3.1. Project workflow

The aim of the study is to use a parametric approach based on genetic search algorithms, to combine information expressed in numerical data with non-numerical information obtained from design evaluation. The project was developed using Rhinoceros, Grasshopper and some plugins:

– Karamba 3D, developed by Clemens Preisinger in collaboration with Bollinger + Grohmann Ingenieure, used for structural analysis.

– Octopus, developed at The University of Applied Arts Vienna in collaboration with Bollinger + Grohmann Ingenieure, used for multi-objective optimization.

– Shortest Walk, developed by Giulio Piacentino, used to find the best route to visit the archaeological site.

The generative process can be divided into 3 steps: creation of the basic structure; positioning of the pillars; creation of the visit path (Fig. 5).

By loading a 2D and 3D survey of the archaeological site in the algorithm and choosing the size of the structural grid modules, the surface that you want to cover, the height of the roof, the number of pillars and points of interest of the site, you can automatically generate a coverage with its own visiting path. Lastly, the A* Algorithm is applied with the Shortest Walk component. Described by Peter Hart, Nils Nilsson, and Bertram Raphael in 1968 [13], this algorithm identifies the best path between two nodes using a heuristic approach.

In the case study we used a structural grid of 1.75 × 1.75 meters and a rectangular limit of 22.75 × 38.50 meters to recall the shape and proportions of the domus. We used 11 pillars to subdivide the structure into 11 parts, in order to design different areas of the domus in different ways. The pillars are placed in the areas left free by the algorithm.

3.2. Optimization criteria

In engineering, shape or topological optimizations are used to reach an optimal solution given a set of parameters [14]. In this project we used a structural shape optimization to find the most efficient positioning for the pillars and the best visit path for that configuration (Fig. 6). Once a configuration has been analyzed, the process starts all over again with the next configuration, in a loop that tries to converge to a result. The last part of the algorithm is implemented by the multi-objective search component Octopus which allows to indicate the parameters and the objectives to minimize. In this case we considered three objectives :

– Nodal displacement of each element of the structure, for each fundamental combination.

– Internal axial energy of deformation of each element of the structure.

– Length of the path created for the corresponding pillar configuration.

The optimization process analyzed 6000 configurations in about 8 hours and 30 minutes. Starting from the least efficient generation, we selected 21 projects (Fig. 7) using 4 exclusion criteria to choose the best:

1. Percentage of optimization.
2. Length limit of the visit path.
3. Presence of no-exit paths (cul-de-sac).
4. Visibility of the entire archaeological site.

The best configuration is n.15 which has a short and better articulated path.

3.3. Structural Model

We carried out the structural analysis and the design of the construction details in conformity to the national and international regulatory framework including the Eurocode 1, 2 and 5.

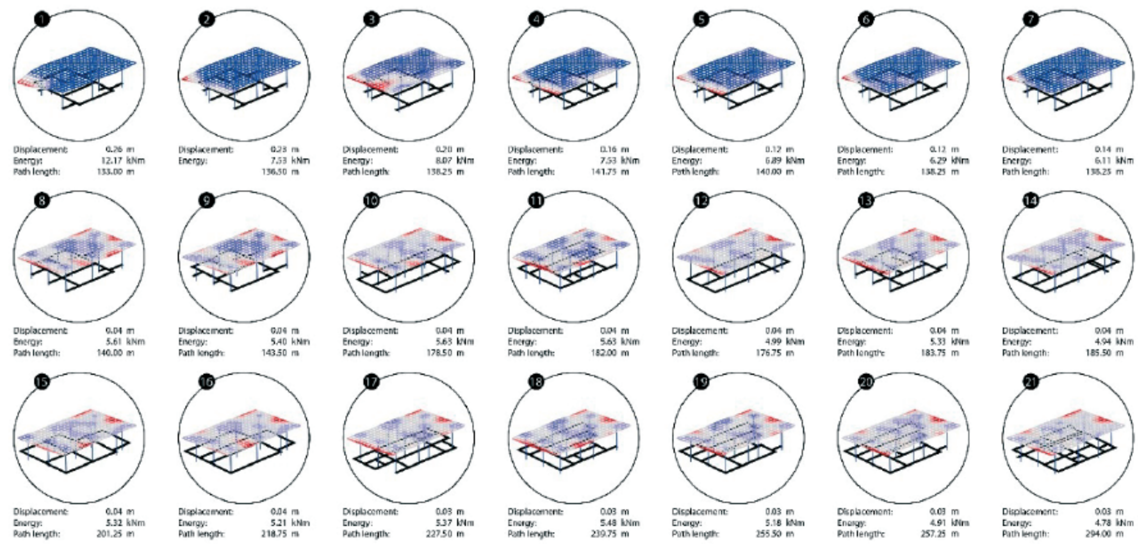

Figure 7.
The 21 best configurations analyzed (drawing author: F. Iardella)

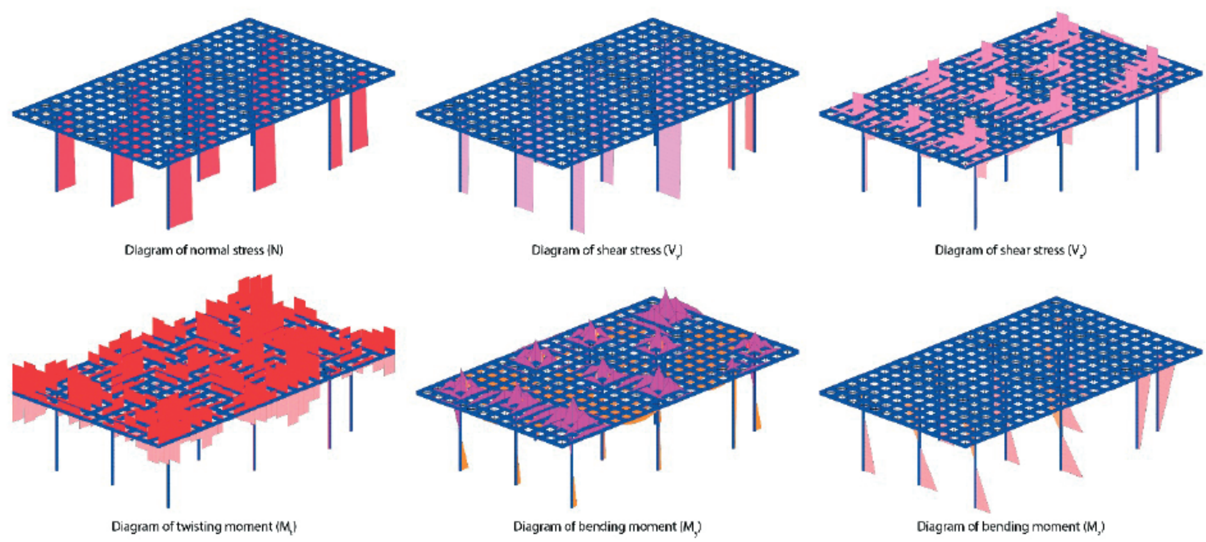

Figure 8.
FEM structural analysis of the final configuration (drawing author: F. Iardella)

The structural analysis was done with Karamba 3D, assigning the dimensions and characteristics of the materials to the elements of the model (Fig. 8). The structure is composed of 11 modular pillars to simplify transport and assembly on – site job without the use of heavy vehicles.

Each pillar consists of a steel tube, with a diameter of 323.9 mm and a thickness of 12.5 mm made up of several modules connected by means of joints. Once we defined the size of the central modules and the joints, the foundation module is the only variable, as it adapts to the 3D survey inserted in the algorithm. The roof structure is composed by a 22×13 grid with a square module of 1.75 meters, made of 1625 mm laminated wood beams, 120 mm wide and 440 mm high connected by flanged cylindrical hinges, the latter made up by a profile of 60.3 mm of diameter 12.5 mm thick with a threaded interior for inserting secondary structures that carry the cover. At the same time, we studied the assembly phases of the structure on the job site (Fig. 9). The structure, in fact, is not completely assembled on the ground, but

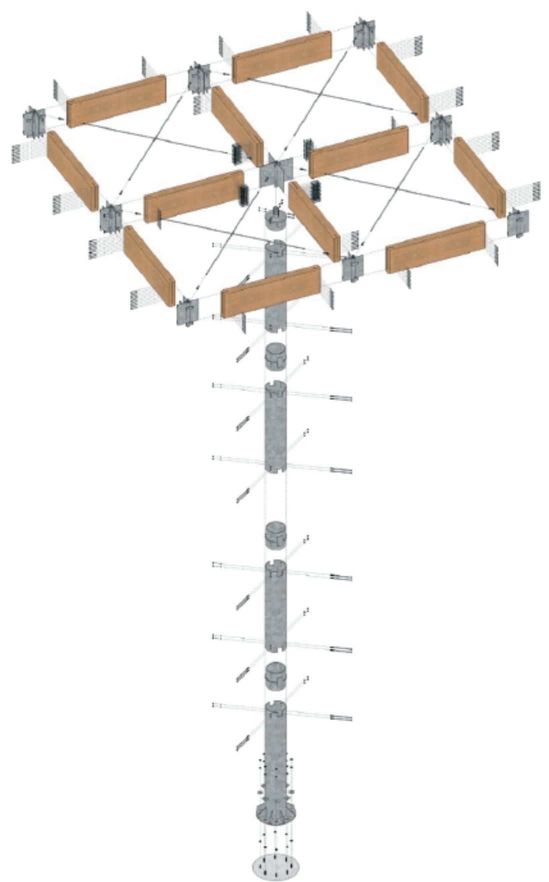

Figure 9.
Axonometric exploded view of the structural components (drawing author: F. Iardella)

the modules that directly connect the pillars are assembled first and then completed: this situation can be schematized as a frame made up of multiple double-restrained beams. Each module of the roof structure is braced by horizontal rigid bars with threaded forks, organized in a “St. Andrew’s cross” (Fig. 10).

The roof is made up of wooden thin sheet or opaque white PVC sheets to highlight the domus environments with a game of full and empty spaces. The goal is to create a large protective box that recalls the external and internal volume of the domus. The horizontal PVC covering is designed with 4 inverted pitches, so that rainwater flows first vertically at the pillars and then horizontally under the path. As in the mentioned case of Veranes, to avoid completely excluding the archaeological site of the domus with the context, it was decided not to completely close the building (Fig. 11).

5. CONCLUSION

With this study we propose not only a viable solution for the domus in the Acropolis of Populonia, but also a solution to the more general problem of protecting archaeological sites in peri-urban contexts. With this approach it is possible to find, in no time, the best configurations for further case studies. Moreover, having designed a modular structure, with small-sized components, the times of construction, transport,

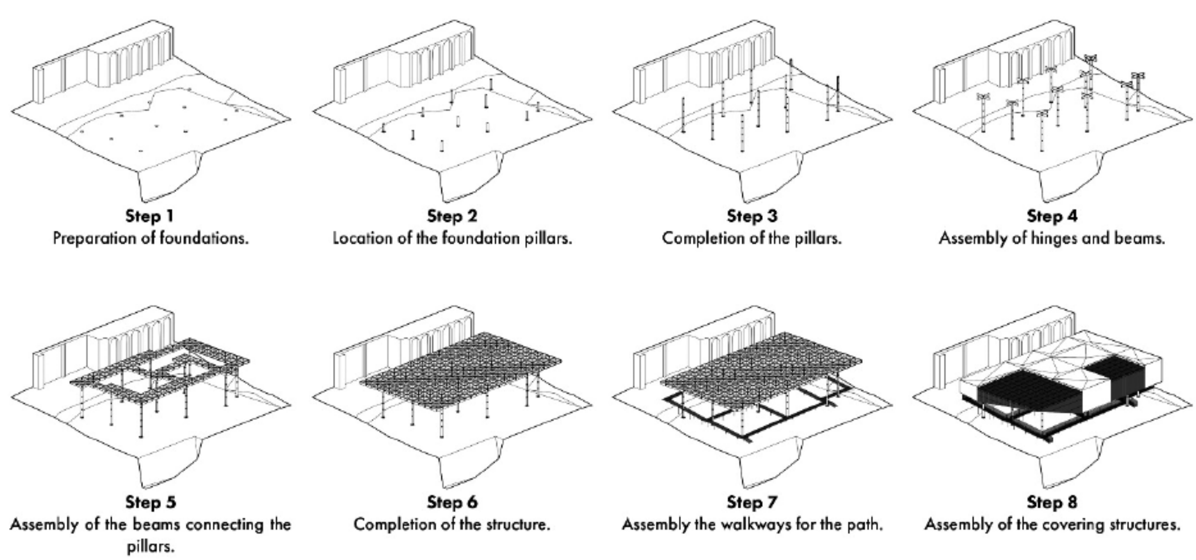

Figure 10.
Illustrations of the assembly phases of the structure (drawing author: F. Iardella)

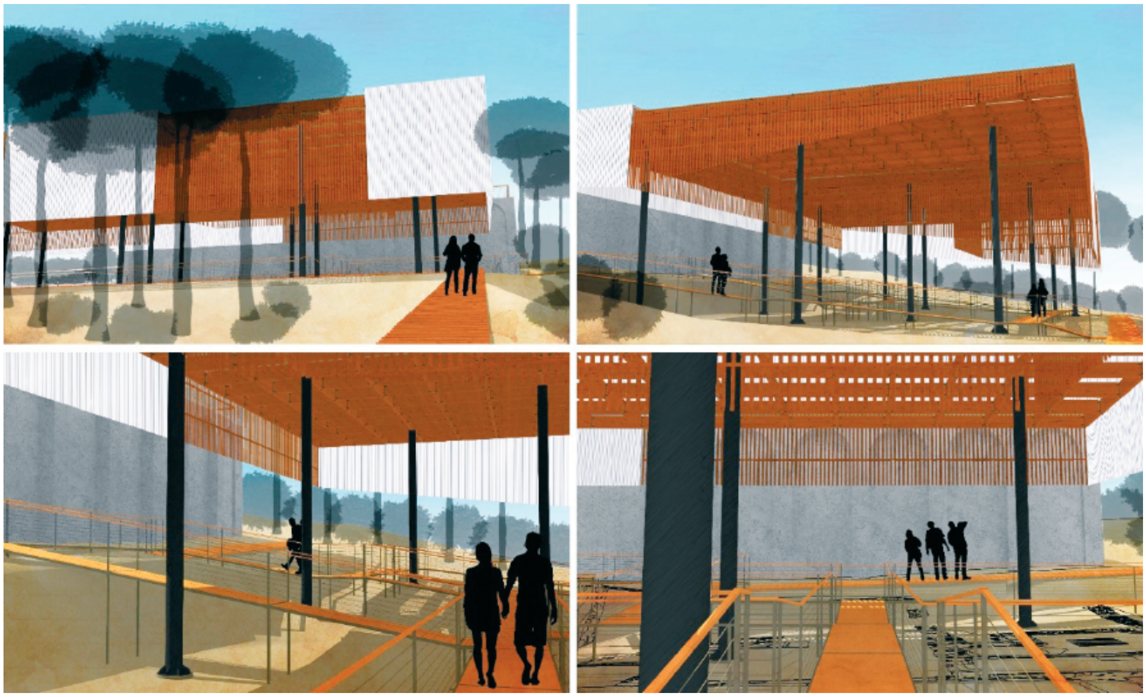

Figure 11.
Perspective view of the final project (drawing author: F. Iardella)

assembly and maintenance are reduced. The future development of this study will be oriented towards the improvement of the design algorithm in terms of ease, adaptability and accuracy. With tests on further case studies it is possible, in fact, to obtain a more dynamic and adaptable process.

Finally, it will be necessary to study in detail the structural analysis that evaluates the imperfections and the geometrical and material nonlinearities of the construction components. Despite having verified the most critical assembly phases, it will be necessary to analyze the issues related to the construction and organization of the building site.

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