

Innovative Building Technologies for Sustainable Architecture in Heritage Sites: Detailed Design of Two Full-scale Prototypes in the Ancient Greek Colony of Megara Hyblaea in Sicily

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The present research shows some results obtained by the PON project entitled "An early warning system for cultural heritage / EWAS". In this national funded project, Sicilian research institutions, universities and companies work together with the common goal of developing new technologies for the protection and enhancement of historical and cultural heritage and also aim to improve its strategic management and protect it from risks. With a view to pursuing the primary objectives of the EWAS project, it was planned to realize two full-scale prototypes. The first one is a lightweight shelter, the second one is a micro-architecture for facilities. They are able to reduce the environmental impact, they are responsive and they are designed to protect the sensitive areas of the excavations and at the same time to facilitate the use of the archaeological site. In order to test these prototypes, the archaeological area of Megara Hyblaea has been chosen, the most ancient Greek colony in Sicily. It is immersed in an industrial landscape that stretches along the coast of eastern Sicily from Augusta to Syracuse. The sense of the original place has been erased by an indiscriminate occupation of the land by industries which has left, here and there, an archipelago of "heritage relics" of various kinds, which are equally close to the smelly chimneys and the horizon of the sea. This landscape of contrasts, dominated by petrochemical industries, has over time hindered a cultural tourism appropriate to the representativeness and importance of the findings, despite the efforts made by the authorities responsible for its protection.

Introduction

The EWAS (an Early Warning System for cultural heritage) project aims to promote and stimulate a policy of protection from degradation and prevention at the level of historic settlements which are conceived, in their morphological and functional whole, as a vital component of urban centers in line with the strategies defined by the recent UNESCO (United Nations Educational, Scientific and

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Cultural Organization) Recommendation on "Historic Urban Landscape" and "urban conservation".¹

Environmental Safety and Structural Safety are among the essential requirements that historic settlements and historic buildings, containers of cultural assets and activities, must ensure for their protection and preservation. However, meeting these needs, it takes a combination of different knowledge and techniques that pose a number of significant technological challenges.

Therefore, the aim of the EWAS project is to obtain an innovative platform for the monitoring of cultural heritage based on the latest technological solutions, capable of fast and on-demand diagnostics following critical situations through the implementation of a continuous monitoring system over time, multisensory, multi-scale (control of the structure and surrounding area and detailed diagnostics), multiresolution, with low or no invasiveness on monuments and surrounding areas. This is achieved through advanced systems based on wireless networks and sensors supported by the most modern diagnostic methodologies, allowing to produce in a Smart City actions on issues related to natural and man-made hazards and to security (Smart Environment and Smart Living) for the protection and the valorization of cultural heritage at the urban scale.²

In order to pursue these objectives, the project makes use of the following studies, investigations, technological and industrial developments and technical tools.

- 1) Evaluation and diagnosis of the state of deterioration and safety (danger, vulnerability and risk) of heritage buildings and artifacts in archaeological test-site areas.
- 2) Development, realization and production of a new low-cost Smart Wireless urban environmental monitoring system and of a telecommunication network realized ad hoc for the continuous and multiparametric environmental control of structures and artifacts.
- 3) Verifications and evaluations on vibrating table of the characteristics and performances of the devices that will be used for the SHM (Structural Health Monitoring).
- 4) Installation at the selected test sites of an innovative wireless hybrid monitoring system (static and dynamic) with the purpose of verification of structural safety (SHM) and identification of crisis conditions such as to generate preventive alarms.
- 5) Installation in the selected study cases of a prototype of a low cost Smart, deformation and seismic-accelerometric monitoring network, integrated with a satellite monitoring system.
- 6) Design and implementation of a continuous monitoring system on a limited number of museum objects (statues, works of art of high cultural value).

1. The UNESCO Recommendation on the Historic Urban Landscape. Report of the Second Consultation on its Implementation by Member States, 2019, UNESCO World Heritage Centre. Available at: <https://whc.unesco.org/en/hul/>

2. Available at: <https://www.ewas.eu/en/home-english>.

- 7) Design of an innovative protection system for findings in archaeological areas, consisting of a lightweight shelter controlled by a sensor network.
- 8) Design of an innovative system for the enhancement of archaeological sites, based on a multifunctional and sustainable architectural module for the reception of visitors and the support to the visit of the site.
- 9) Realization of a prototype "Early Warning" system for the mitigation of environmental risks.
- 10) Realization of an information system, based on GIS (Geographic Information System) logic, which will contain the geometries and all the data acquired during the project.

EWAS has important implications in the enhancement of the cultural heritage of historical centers, especially those falling within the UNESCO heritage. In fact, the project aims to strengthen the specific skills in an approach of "structured collaboration" on issues of protection, security and enhancement of historical buildings. Moreover, the definition of standards, methodologies and tools for data acquisition, analysis and sharing favors the optimization of building interventions of redevelopment, restoration and renovation.

As to the protection and the support of archaeological areas, the traditional systems are invasive and not very flexible. In order to respond to these problems, EWAS plans to experiment with innovative architectural components that are highly performing thanks to their integration with a monitoring system. The aim is to reduce the disturbance on the site and to adapt the behavior of the components to the needs of users. For this goal, the area of Megara Hyblaea has been chosen as test-site for studies and technological developments of the lightweight shelter (objective 7) and of a multifunctional and sustainable architectural module to support the visit of the site (objective 8).

In this paper, the authors will show part of the result of this study. For the valorisation of the areas, EWAS proposes an innovative architectural module, called Experience Pavilion (EP) and developed as a prototype of the experimental technology called ICARO (Innovative Cardboard Architectural Object). For the protection of the archaeological findings, EWAS develops a kinetic responsive envelope, based on the origami art, called KREO (Kinetic Responsive Envelope by Origami). Both of them will be prototyped in full-scale and tested in the archaeological site of Megara Hyblaea, one of the most important of the southern part of Italy.

State of the Art: Value of Archaeological Sites and Project Issues

The enhancement of an archaeological area responds, according with Militello, to the following needs:³

3. P. M. Militello, "Archaeologists and Archaeological Cover," in M. Vanore (ed.), *Archaeology's Places and Contemporary Uses*, 49-65 (Venezia: IUAV, 2010).

- the preservation of the material remains;
- the arrangement of the site for users;
- the valorisation and promotion of the site.

The realization of a protective shelter for archaeological findings is often one of the main responses to the first requirement.⁴ This element is, in some cases, necessary for the protection from material decay, due to weathering.

The use of a removable shelter could solve the problem of invasiveness that protective shelters made in the past have often shown. In some cases, they can also be harmful, profoundly altering the visual spatial perception of places.⁵

To realize this kind of shelter, in the EWAS project it has been decided to create an easily controllable material, such as a sheet of paper. It could be easily moved by folding it. The fold would also make the surface corrugated, giving it an extra strength by shape.⁶

The valorisation of the site could be achieved by introducing in it some architectural multipurpose modules, which can be useful to illustrate the site and to introduce other facilities for the visitors (i.e., ticket office, kids laboratory, coffee-corner, multimedia information boxes, etc.). In the traditional layout of the sites, these services are concentrated in one point, generally near the entrance. The use of this innovative modules, make possible to spread them in the area and introduce a new concept of visit, in which the visitors are accompanied along their walk.

There are several examples in which this approach has led to very appreciated solutions.⁷ Generally, the modules are less invasive and easily removable.

The layout design must be driven by a reconfiguration of the area. The final goal is to improve the comfort of the places for touristic purposes and to facilitate the interpretation of the remains by users (through the creation of new spatiality, paths, lighting and so on). In the lack of this step, the introduction of architectonic elements could be a risk, because it could introduce a relevant disturbance in the site.

This is not the case if the architectural design is put in tension with a landscape approach. As Jean Nouvel recently stated in his *Manifesto* inaugurating his year as guest editor of the historic Italian journal *Domus*, architecture has to foster characterisation and belonging, bearing in mind the depth of recollection, the milestone of the time, the geography, the natural landscape, the materialisation

4. Z. Aslan, S. Court, J. M. Teutonico, and J. Thompson, *Protective Shelters for Archaeological Sites: Proceedings of a Symposium, Herculaneum, Italy, 23-27 September 2013* (Roma: The British School at Rome, 2018).

5. G. Rizzi, "Considerations on Archaeological Shelters: A Practitioner's Viewpoint," in Z. Aslan, S. Court, J. M. Teutonico, and J. Thompson (eds.), *Protective Shelters for Archaeological Sites: Proceedings of a Symposium, Herculaneum, Italy, 23-27 September 2013 – Roma* (The British School at Rome, 2018).

6. V. Sapienza, and G. Rodonò, "Architecture and Foldable Surface," *Athens Journal of Architecture* 2 (2016): 223-236.

7. V. P. Bagnato, *Nuovi interventi sul patrimonio archeologico* (Universidad Politécnica de Cataluña, 2013); M. Vaudetti, V. Minucciani, and S. Canepa, *The Archaeological Musealization* (Italy: Umberto Allemandi & C., 2012).

of responses to the climate.⁸ In resonance with this approach, architectural interventions was conceived in relation to topographical aspects (relationship between ruins and landscape) and visual aspects (relationship between the aesthetics of the ruins and the morphology of the landscape), and not only to the control of the architectural elements themselves.⁹

So, the architectural project was carried out in parallel with an inter-scale strategic landscape design, inspired by the principles of European Landscape Convention¹⁰ and the idea of *territorial heritage* developed in the research of the Italian *Scuola Territorialista* founded by Alberto Magnaghi.¹¹

From the technological point of view, some important measures can be put in relation with this cultural posture, even at the design level of the individual building, to reduce the impact not only on archaeological assets but also on the general environmental context. The main ones are as follows:

- use building materials with high levels of environmental sustainability;
- use building components that can be dry-assembled;
- use of lightweight structure, without foundations.

Starting from these considerations, have been designed two mentioned innovative technologies, that will be discussed in the following.

Research Methodology

Responsive Shelter

In recent time, the use of the so-called textile architecture¹² or fabric structure¹³ has improved. Generally, the base material is a composite with a reinforcement in natural or synthetic woven and the matrix is a polymeric material that increase mechanical properties and durability, as shown by Houtman.¹⁴

By folding the composite, it is possible to strength it, thanks to the form resistance.¹⁵ It is also possible to move the sheet, because each fold is a hinge. This configuration can be achieved through a thermoforming process using a mould

8. J. Nouvel, "Spirit, Are you There?" *Domus* 1063 (2021): supplement.

9. S. Calvagna, P. M. Militello, F. A. Reale, G. Rodonò, and A. Tornabene, "From the Landscape of Contrasts to the Landscape of Invisible Cities: A Strategic Landscape Design for the Revitalization of the Ancient Greek Colony of Megara Hyblaea in Sicily," *Athens Journal of Architecture* 8 (2022): 1-33.

10. Council of Europe, *European Landscape Convention* (2000).

11. A. Magnaghi, *Il progetto locale. Verso la coscienza di luogo* (Torino: Bollati Boringhieri, 2010).

12. B. Maurin, and R. Motro. "Textile Architecture," in R. Motro (ed.), *Flexible Composite Materials in Architecture Construction and Interiors*, 26-38 (Germany: Birkhauser, 2013).

13. J. Llorens, *Fabric Structures in Architecture* (England: Elsevier, 2015).

14. R. Houtman, "Materials Used for Architectural Fabric Structures," In J. Llorens (ed.), *Fabric Structures in Architecture*, 101-121 (England: Elsevier, 2015).

15. A. S. Muljadinata, and S. Darmawan, "Redefining Folded Plate Structure as a Form-resistant Structure," *Journal of Engineering and Applied Sciences* 11 (2016): 4782-4792.

with the assigned pattern. So, the folded composite material could be used to realize a lightweight kinematic shelter (Figure 1).

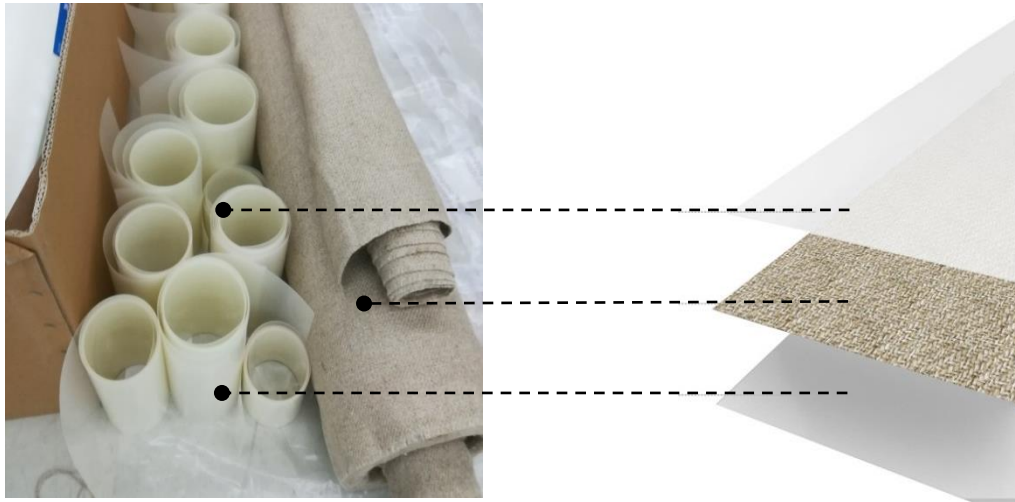


Figure 1. *Composed Material Used for EWAS Project*

The EWAS project has been focussed on the optimization of this innovative material, i.e., choice of the raw materials, stratification, mechanical characterization and post-production thermoforming process¹⁶ (Figure 2). Through the numeric modelling, it has been fixed a suitable workflow to optimize the physical parameters of the shelter.¹⁷



Figure 2. *Post-production Thermoforming Process*

The design of the shelter is based on the analysis of the folding geometries, for which the reference is the Japanese art of Origami and the folding patterns

16. A. Astuti, F. Giusa, A. Monteleone, G. Rodonò, V. Sapienza, and M. Voica, *Componenti innovativi per involucri architettonici smart* (Catania – Italy: New Horizons for Sustainable Architecture - Colloqui.AT.e 2020, 2020); V. Sapienza, and G. Rodonò, “KREO - Kinetic Responsive Envelope by Origami,” *TEMA 2* (2016): 42-52.

17. G. Rodonò, E. Naboni, V. Sapienza, F. Cucchi, and G. Macrelli, “Simulation Workflow for Parametric Optimization of Outdoor Comfort-based Origami Shelter,” *Journal of Architectural Engineering* 26 (2020).

already used in the engineering and architectural field, as discussed by Casale and Valenti.¹⁸ For this reason, the authors called the experimented technology KREO; in fact, in this acronym the "O" represents the word origami.

To test this innovative technology, it has been developed a full-scale prototyping phase. Before this, it has been realized a virtual model to analyse the thermophysic and the mechanical behaviour. The simulations have been addressed to several focus, i.e., to define of a mechanical system to move the folded sheet and to automatize the prototype, with a suitable script. The full-scale testing phase will be also finalized to fix the climatic parameters for the opening and the closing of the shelter.

Multipurpose Architectural Module: The Experience Pavillion

According to the project requirements, the building materials for the construction of the architectural module must have the following features: easy availability, low economic price, lightness, low environmental impact. They must also come from recycled and recyclable raw materials. Moreover, in order to reduce the activity in the building site, and so the risks for the archaeological finds, prefabrication has been adopted as the main construction technology, by focusing on the realization of a modular panel for the vertical building envelope. According to these purposes, it has been chosen multilayer fir wood and corrugated cardboard as building materials. The first one is used to realize the frame of the modular panel; corrugated cardboard is arranged in box shape to infill space between the frame components. In this way the panel assumes both the role of structural element to support the roof and the role of main component of the envelope, which is then completed with a second outer skin. To increase the panel's structural performance, a pre-stress procedure is adopted. So, the cardboard boxes are not only complementary elements, but their presence makes stronger the panel. This innovative technology is called ICARO.

The gap inside the boxes can be fill in different materials to improve the thermo-acoustic comfort.¹⁹ The panel is completed with a ventilated façade, to improve the indoor comfort conditions and also to improve the protection of the cardboard from the rainwater. A number of materials has been tested as finishing, both for their technological features and their compatibility with the high assets value of the context. *Shou Sugi Ban* wood (burned wood) has been chosen for its high durability²⁰ and visual and sensory qualities. The southern façade will be used to fix a set of photovoltaic cells to assure the off-grid operation of the module. They have been embodied in a composite fabric, the same tested in KREO, to have lightness and flexibility and to mitigate the visual impact by removing the reflective effect of ordinary photovoltaic panels.

18. A. Casale, and G. M. Valenti, *Architettura delle superfici piegate: Le geometrie che muovono gli origami* (Italy: Kappa, 2013).

19. D. L. Distefano, A. Gagliano, E. Naboni, V. Sapienza, and N. Timpanaro, "Thermophysical Characterization of a Cardboard Emergency Kit-house," *Mathematical Modelling of Engineering Problems* 5 (2018).

20. T. Kilian, "Shou-Sugi-Ban," *Wood Des. Build.* 66 (2014): 42-44.

The base of the module is a grating in steel element. They are settled with telescopic legs, in plastic material, to arrange the horizontal layout; a sheet of nunwoven fabric has been set below, as interposition with the archaeological ground.

The prototyping of ICARO technology has been carried out in two phases.

In the first one, some panels have been realized, in reduced scale, with different modality of pre-stress. By analyzing them, the best solution has been chosen and it has been realized a full-scale panel. This is called Panel Zero.

In the second phase of the research, the suitable number of panels and the other elements will be realized, in order to build the full-scale architectural module, called Experience Pavillion (EP) in the test-site. The test phase will conclude the experimentation.

Valorisation Project of the Archaeological Site

The archaeological site of Megara Hyblaea has been chosen as test-site for the testing phase of ICARO and KREO, for a series of conditions that make it suitable for this aim.

Megara Hyblaea is one of the sites the highest historical and archaeological significance in Sicily. A part from the oldest traces of an entrenched Neolithic village, in it the remains of a Greek colony dating back to the 8th-7th century BC (founded in the 727 BC from colonists coming from Megara Nisea) are conserved. The city of Archaic period (end 8th - early 5th century BC) and that of smaller dimensions of Hellenistic period (end of 4th-3th century BC) are then superimposed on it. After its final destruction in 214 BC, at the hands of the Romans, the city was not rebuilt. For these characteristics is therefore configured as one of the most important centers of Sicily and Southern Italy.²¹

In spite of this, Megara is practically neglected by tourist routes. The reason of this, perhaps stays in the location of the site, that is very closed with the industrial complex of Augusta-Priolo, from whose expansion it was saved thanks to the intercession of the Superintendence in the early 1960s.

The architectural and technological project has been framed in a wide-ranging and inter-scalar strategic landscape design. Starting with the analysis of the landscape features of the site, the purpose was to rediscover a new narrative centered on the system of local values, as to put the experimentation of innovative construction technologies in harmony with the archaeological landscape.

The Strategic Landscape Design process was intertwined with a dialogue with stakeholders (local authorities, superintendence, association of the touristic guides, cultural associations, associations for the environmental protection, and so on), in order to understand if the local community identifies with its territorial

21. M. Gras, H. Tréziny, and H. Broise, *Megara Hyblaea 5, Le ville archaïque. L'espace urbain d'une cité grecque de Sicile orientale* (Roma: École Française de Rome, 2004); M. Gras, "La colonizzazione greca e la Sicilia, Megara Hyblaea e la nascita dell'urbanistica in Sicilia orientale," in C. Ciurcina (ed.), *La colonizzazione greca la fondazione di Siracusa e sviluppo della città antica* (Regione Siciliana, 2006).

heritage,²² and re-weave a network of physical and immaterial relations between archaeological heritage, place and community.

After this phase, it has been defined a masterplan of the site, in order to define:

- the new viability, both pedestrian and vehicular;
- the most fragile areas, to protect them with the responsive shelters;
- the most sensible areas, to equip them with multipurpose architectural module.

Discussion and Results

The Test-site of Megara

Megara Hyblaea was a prosperous city, especially in the Archaic period, and was full of rich monuments. Mostly of them are located near the large *Agora*, in which the main axes of the city cross each other. A *Stoa* closes the north side of the *Agora*. In the north west corner, there was the *Heeron* (a sacred area). The *Zeus Temple* was along the north side, it remains several entablatures and other decorated elements of it; in the south part of the city it was the *Prytaneum*, a public building for the distinguished guests. The *South Temple* of the Archaic period had a central line of columns, in Doric style; it is overlapped by the Hellenistic structures. Near the corner south west there is a *Hellenistic Bath*, which is very unusual for its circular plan. A part of these monuments, there are many other interesting buildings, as the *House 13,22* (Figure 3), which its marvelous pavement in *opus signinum* (mosaic), or the *Metal Workshop*.²³ Due to the subsequent destruction, it survives only foundations and masonry bases of mostly of them (Figure 4).

22. A. Magnaghi, *Il progetto locale. Verso la coscienza di luogo* (Torino: Bollati Boringhieri, 2010).

23. G. Vallet, F. Villard, and P. Auberson. *Mégara Hyblaea 3. Guide des fouilles* (Italy: Ecole Française De Rome, 1983).



Figure 3. *The House 13,22 Pavement*



Figure 4. *The Metal Workshop Foundation*

To set the prototypes of ICARO and of KREO, a new layout of the site has been designed (Figure 5). In it, the entrance of the archaeological area is located near the west gate of the Archaic city. So, the visitors have the opportunity of a walk troughs the large area surrounding the historical city in which it will be recovered the autochthonous agricultural crops. Through this path people reach up to the coast line. Here there is the *Faro Cantera*, a lighthouse, and a *masseria*, that is partly nineteenth-century but the building of the *baglio* dates from the eighteenth century. The first one is a guesthouse for the archaeologists, the second one is the *Antiquarium*. The new gate is just outside the archaeological area, thanks to this, it is possible to realize there a parking and other facilities. The current entrance of the site, maintains its functionality only for the workers and for people with disabilities.

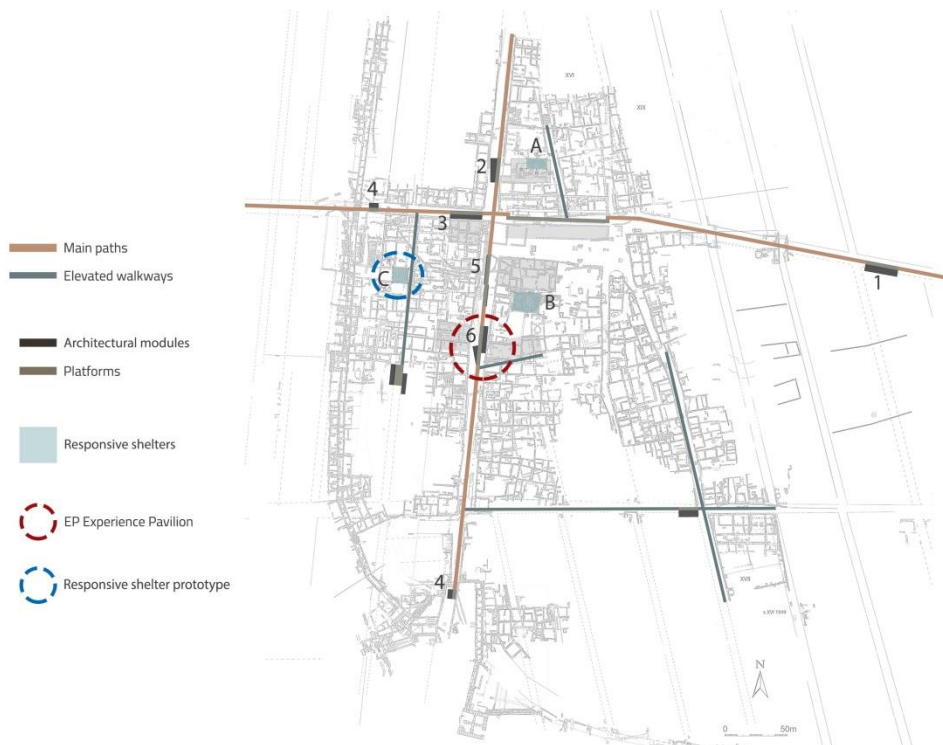


Figure 5. *The Layout of the Archaeological Site*

When the path arrives in the ancient city, it is overlapped on its main axes, west-east; it crosses the second axes of the city, with north-south direction, in the *Agora*. They are highlighted with an elevated walkway and form the main visit route. Along these two axes some protection and valorization structures are dislocated.

There are three protection shelters:

- A. on the area on the *North Temple*;
- B. on the *Hellenistic Bath*;
- C. on the *House 13,22*.

There are also nine multipurpose architectonic modules, three in strategical paths point and seven located as following:

1. near the touristic entrance;
2. near the *North Temple*;
3. near the *Heeron*;
4. near the *Metal Workshop*;
5. near the *Hellenistic Bath*;
6. between the *Prytaneum* and the *South Temple*.

The project EWAS finances the realization of the responsive shelter C (on the House 13,22 - Figure 6) and the module number 6 (between the *Prytaneum* and the *South Temple* - Figure 5 b) named Experience Pavilion (EP), as already said (Figure 7).

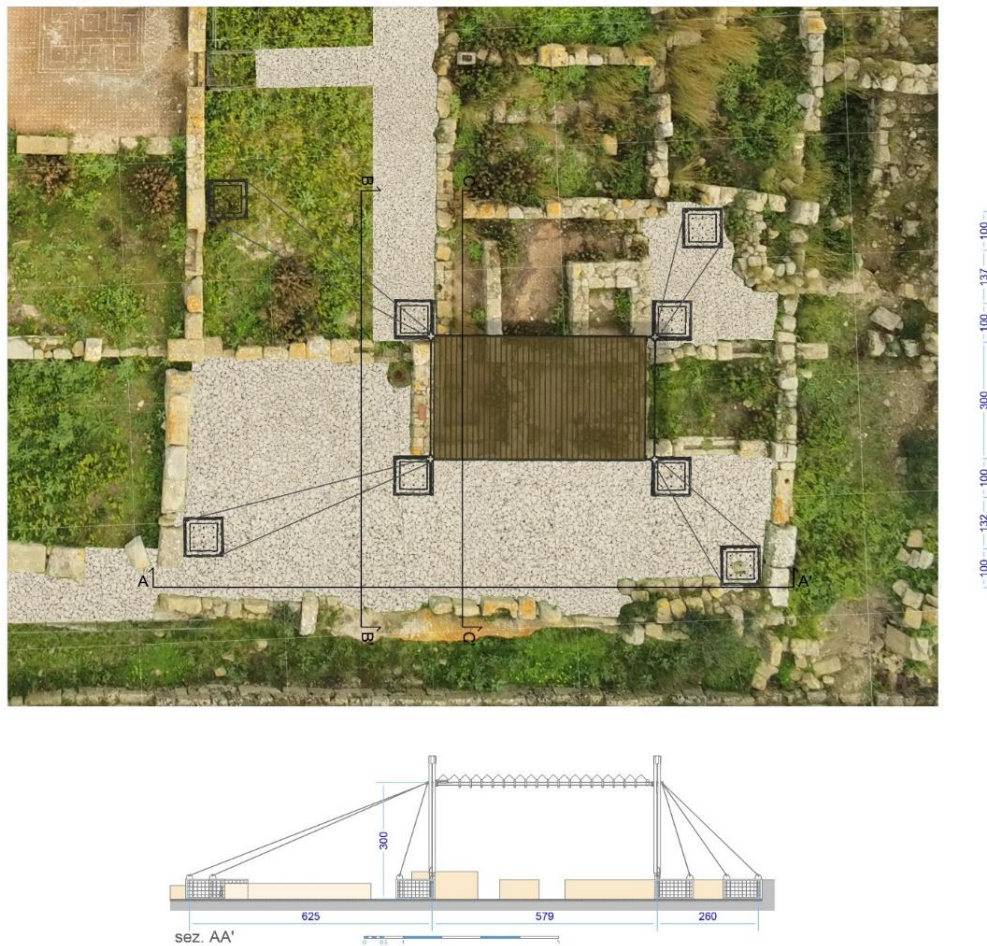


Figure 6. *Responsive Shelter C on the House 13,22*

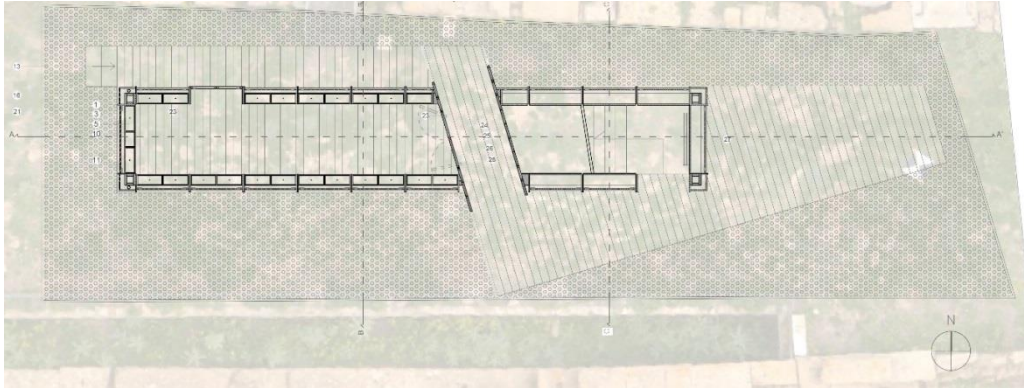


Figure 7. *Plan of the Module Number 6 (EP)*

Design of the Responsive Shelter Prototype KREO

In order to test KREO technology a full-scale prototype has been realized, which measures 4.00×5.00 m (Figure 8). The loadbearing structure is in steel and it is made up by four cruciform pillars (Figure 9). The concept of the design is to reduce the disturbance in the site. To get this achievement, the structure is lack of beams and foundations.

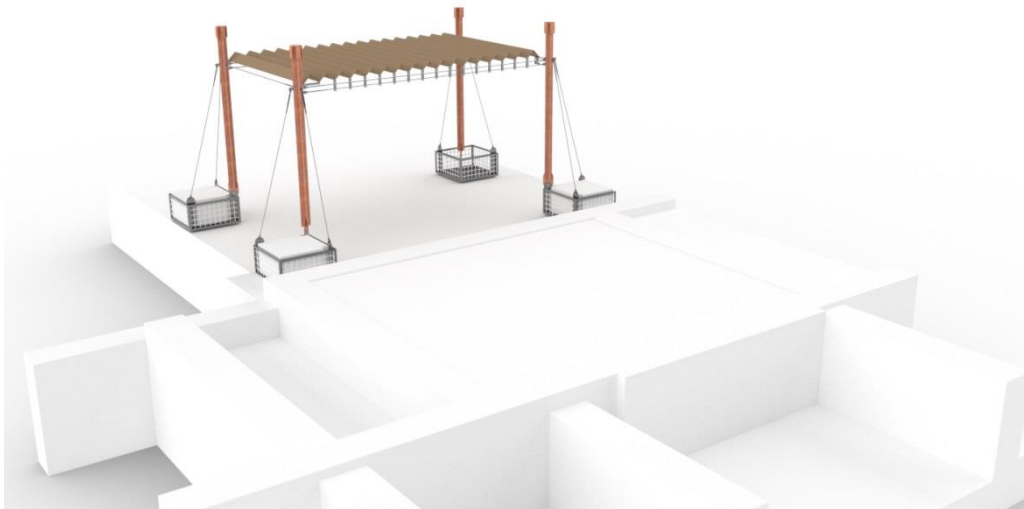


Figure 8. *The Model of KREO Shelter*



Figure 9. *The Cruciform Pillar*

The pillars are connected at the top by a series of steel tie rods. The horizontal ones are used for the movement of the covering surface, using a trolley system with triple pulleys (Figure 10). Trolleys are able to slide in both directions, allowing to open and close the shelter.



Figure 10. *The Connection Between Pillar and Steel Tie Rods*

At the base of each pillar there is a welded mesh boxes that is full of concrete bricks, to form a ballast to stabilize the pillar (Figure 11). Other six ballasts, with similar shape, are located in the corners, along the diagonals of the shelter, to get the necessary weight for the stability. In this way, it is not necessary to provide foundations and so it avoids excavation works or other invasive actions on the archaeological site. To link the pillars to the ballast boxes, stay steel cables are used.



Figure 11. *The Connection Between Pillar and the Welded Mesh Box*

The shelter has been designed as a flexible, componible building component. It is flexible because it is suitable for many uses and many types of sites. It is componible because, by replicating it, you can cover large area with very low invasiveness.

The realization of the prototype of the shelter KREO has shown several criticalities. They will be correct in view of the realization in the site.

The steel structure has two functions: on one hand it is the load bearing structure, on the other hand, it is the guide for trolleys. It means that in the assembling it is necessary the perfect alignment of the pillars to allow the sliding of the trolleys. It is also necessary to control the mid-span deflection for the movement of the pulleys. So, the ballast boxes must be improved. According with the high dimensions, the foldable material must be stiffened and strong stucked to the trolley.

The composite material for the covering surface is formed with the following stratification (from the top to the bottom): EVA (Ethylene Vinyl Acetate), PTF

(polyvinyl fluoride used as back sheet), EVA, Biotex Flax and EVA. The flax tissue is the reinforcement; the back sheet improves the rigidity of the material; the EVA is the matrix and it sticks the various layers. The folds are obtained with a secondary working process of thermoforming. The chosen folding pattern consists in an accordion with rectangular tassels. Thanks to its simplicity, the mold consists in plates of aluminum. In the first step the composite is stratified; all components are arranged in flat in a laminator, in the correct order. In the second step the composite is folded; the semi-finished product is wrapped around the plates and tight and put in an oven for fifteen minutes, at 120°.

The control system of the shelter is still under development. It will be realized by a series of sensors (for rain, wind, solar radiation and so on) connected with Arduino. According with the climatic conditions, the control system will open the shelter, making it smart. The engines are equipped with encoders and a limit switch sensor will allow the automatic shutdown of the system.

Design of the Multipurpose Module Prototype EP Whit ICARO Technology

The Panel Zero of ICARO technology (Figure 12) is formed by ten modules and it is 2.80 m high, 1 m large ad 0.30 m deep. It has been realized by using the following materials:

- the triple wave cardboard, type of the “Cartonificio Fiorentino” (called Euro 22-24/14);
- spruce laminated panel, 20 mm tick, technical class SWP/2 S L3



Figure 12. *The Panel Zero of ICARO Technology*

The finishing is realized by five panels of composite material, supported by a wooden frame. They realize a sort of ventilated façade, thanks to the air gap between them and the cardboard.

The pre-stress system is realized by using two threaded rods that run median in the boxes. They are tightened at the ends with bolts. The type of cardboard has been chosen according to its strengthening. The double-wave one has a not sufficient strengthen and it tends to collapse during the pre-stress. so, the triple-wave one is more preferable, even if it has higher costs.

After the construction of Panel Zero the design of the multipurpose module EP has been defined in detail.

EP is a mini-architecture located within the archaeological excavation site. It aims to allow a deeper reading of the remains. Its shape is generated by the projections of the footprints of some representative buildings along the main routes of the ancient colony.²⁴

EP is a parallelepiped 12.00 m long, 2.00 m wide and 4.50 m high. It has two doors, to make easy a linear flow of visitors, from one part to the other one and it has two levels. The ground floor is a closed rectangular space where informative materials about the place's monument is displayed. Two doors are located near both of the shorter sides, to make easy a linear flow of visitors, from one side to the other one. The upper floor of EP is a terrace that is accessible with an external stair, to have a panoramic view of the archaeological site (Figure 13).

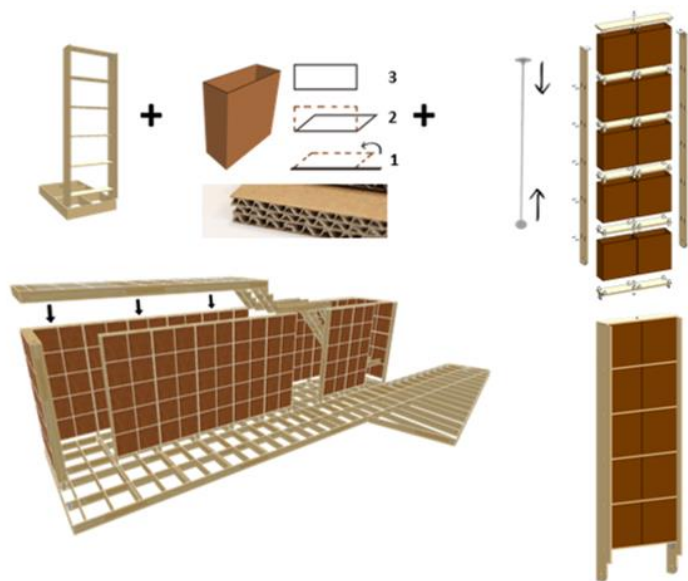
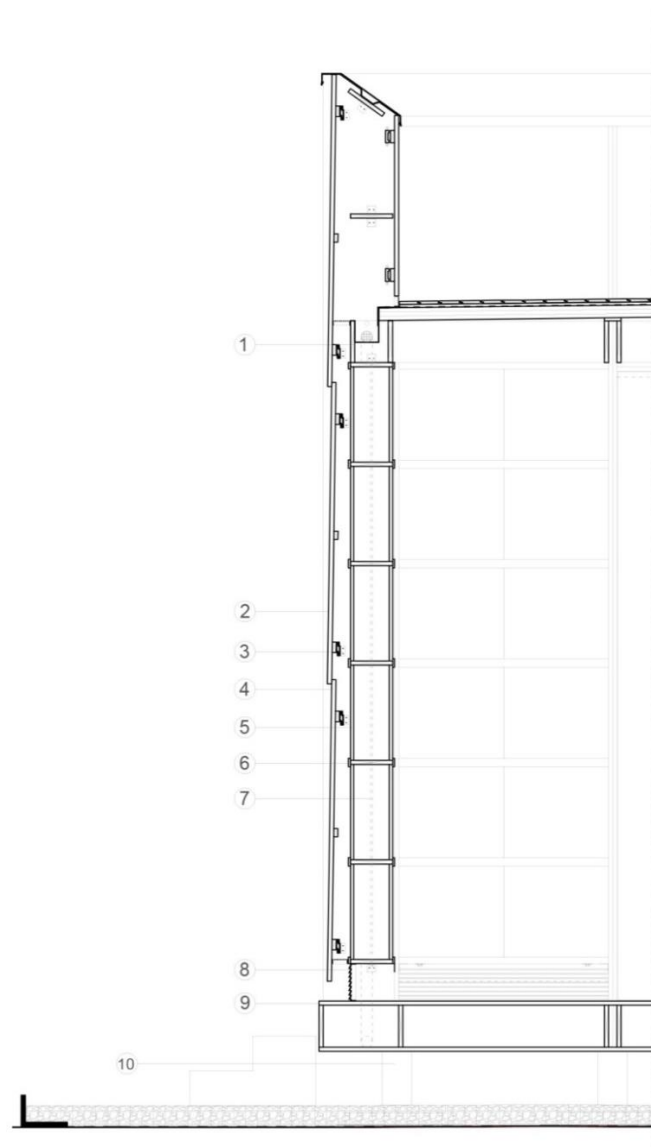


Figure 13. *The Model of ICARO Pavilion*

Considering the feedback of the structural analysis, 42 mm thick wooden elements were adopted. The depth of the wooden uprights is 40 cm, while the

24. For further details about the architectural project see the already mentioned article: Calvagna, Militello, Reale, Rodonò, and Tornabene, "From the landscape of contrasts to the landscape of invisible cities: a strategic landscape design for the revitalization of the Ancient Greek colony of Megara Hyblaea in Sicily," 2022.

depth of the transoms is 24 cm, to leave sufficient gap for the ventilation, between them and the finishing. The fixing between uprights and transoms is realized through slotted holes, to allow shifting during the pre-stress phase (Figure 14).



LEGEND

- 1 Phenolic plywood double-beam curb 2x20cm
- 2 Phenolic plywood stud 2x34 cm
- 3 Coupling system for prefabricated finishing panels with ventilated façade system
- 4 Prefabricated finishing panels with wooden frame and matchboarding in acetylated radiata pine, burnt with impregnating oil finish, 2 cm thick
- 5 Triple corrugated cardboard tubes (1.4cm thick) 20x50x45.5 cm
- 6 Phenolic plywood noggings 2x20 cm
- 7 Threaded steel tie rod Ø1 cm
- 8 Metal ventilation grid
- 9 Acetylated burnt radiata pine plank decking with impregnating oil finish 2 cm thick
- 10 Adjustable pedestals for decking wood

Figure 14. *The EP Constructive Section*

The base of the module is a grid in steel, each element is a couple of C profiles in galvanized steel S275. The profiles will be bolted in site to reduce the weight of the beams, because the transportation inside the archaeological site will be manual. In the gap between them, the uprights of the panels are fixed, with a steel plate to improve the contact area. Their weight is not sufficient to contrast the action of the wind, so the basement will be ballasted with concrete brick. According with the usage of the module and the short permanence in it, the filling in insulating material can be avoided.

The covering is formed by a wooden grid of beams, connected to the uprights. The connection is guaranteed by nine through bolts M10 strength class 8.8. On the top, there is an x-lam floor. The thrust of the wind, which is the highest horizontal stress, is countered by the knee beams of the stair, that are fixed on each wooden upright, with a steel element.

In the internal side, the finishing is missed and cardboard and wood are exposed. In the external side, the finishing is formed by burned wooden slats, which has been preferred over composite for its high durability. For fire protection of the cardboard, the use of a treatment with a two-component, water-based, transparent and colourless fireproof bottom coat has been planned.

As to the external finishing, slats are connected with steel elements, to realize a matchboarded panel. It is fixed to the structure with the so called Fitlock system.²⁵ The high of the panel is covered by three elements, which leave free an air gap, for the ventilation of the façade in the bottom.

The module will be equipped with digital and analogical informative materials. For the first type, there is a multimedia device with the virtual reconstruction of the *Stoa*, which is the most important monument of Megara. For the second type, there is a tridimensional model of the area of Megara, obtained from a cellular lightweight concrete block thanks a subtractive prototyping procedure.

The electricity for the devices and for the lighting will be supplied by the photovoltaic panels embodied in the finishing of the south façade. Each panel is realized with 15 solar cells in monocrystalline silicon with high efficiency (realized by SunPower Maxeon) 125 mm x 125 mm (Figure 15). The system is patented.²⁶

According to the hypothesized scenario of use, it is necessary to use three couples of photovoltaic panels. It is also necessary to provide the module with a backup battery, for the cloudy days.

25. Available at: <https://www.fitlock.it/>.

26. V. Sapienza, G. Rodonò, A. Monteleone, and F. Giusa, *Adaptive Kinetic Device for Architecture* (Patent Request no. 102019000025819, 2019).



Figure 15. *The Photovoltaic Panels Embodied in the Finishing Layer of the South Elevation*

Conclusions

In the valorisation of the archaeological site, there are three actions that are showed in the literature as efficient: the preservation of the remains; the communication to promote the site; the arrangement of the site. In the EWAS project these three actions are implemented with the KREO and ICARO technologies.

The realization of a shelter is one of the most efficient systems for the preservation of the archaeological areas; the possibility to remove it, when it is unnecessary, could be a good strategy to reduce the disturbance on the site. This achievement can be reached by using a pre-folded composite material. To be sure about its performance, a campaign test on full-scale prototype is useful.

As to the communication for promotion, a relevant strategy is to introduce in the area some architectural multipurpose modules, which can be useful to illustrate the site and to provide facilities for the visitors. This aim could be obtained through lightweight material, as corrugated cardboard and wood. The prefabrication of the envelope can reduce the disturbance on the site. A campaign test on full-scale prototype is useful to verify technology issue and comfort performance.

The experimented technologies show a high innovation level in comparison with the current solutions, for similar aims. This goal has been obtained thanks to the use of building materials with high levels of environmental sustainability; the use of building components that can be dry-assembled; the use of lightweight structure, without foundations.

Shelters and architectural modules can contribute, together with the study of a system of paths, to redefine the arrangement of an archaeological site with the aim of improving the reading of the complex system of stratifications that characterizes it. The set of linear and small punctual elements can promote an approach of widespread and non-invasive reception to the archaeological heritage.

The realization of the prototypes, scheduled for the next months, will show the real effectiveness of the designed technologies and also the possible future implementations. Thanks to their flexibility, the designed technologies are useful for the applications in other archaeological sites and also in other fragile sites (in order to revitalize the historical centres or to improve the accessibility of the naturalistic areas, etc.). The design team is working on these subjects to implement the studies already carried on.

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