DESIGN NOVEL COVERING SYSTEM FOR ARCHAEOLOGICAL AREAS

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INTRODUCTION

The shelter design process for archeological areas present many difficulties, due to the multiplicity of constraints and the complexity of the application context. Working on the archeological areas includes dealing with some contradictions.

The shelter for archeological areas aims to protect ruins from damages, in order to preserve their historical values. On the other hand the work of excavation represents itself a destructive action, which causes environmental variations on the sites. Protecting an archaeological site is an act of compromising, seeking a balance between minimizing the impact of the shelter on land and producing a more comfortable area for the archaeologists and the visitors [1] [2].

The latter contradiction is related to the necessity of having both very flexible and adaptable solutions, which could fit with the different work needs, and a deeply relation with the context of application. In fact, each monument or historical find has its own peculiarity, therefore needs a specific shelter solution designed for the particular area of employment [5]. The controversy of the topic derives from these premises.

The necessity to cover archaeological areas depends on the necessity to protect the materials and the discoveries from the solar irradiation, the changes of temperature and all the external factors that could entail material damages. Meanwhile, the protected area should be accessible for the workers and the restores. For that reason the shelter has a double function: on one side, protecting the finds from external agents and the climatic variations (daily and seasonal changes), and, on the other, covering the workers during the excavation and protecting materials during the restoration activities. Accordingly, the solution has to fulfil different requirements. The covering should be appropriate to the different climatic conditions and adaptable to several climate zones, protecting the excavations from external agents, ensuring the protection from water and condensation damages, allowing the light transmission through filtering the UV radiation. The solution should be reversible and has to guarantee the finds integration. Therefore, the structure should be lightweight, especially for what is concerning the foundation system or the anchors, which should be punctual and non-invasive. Finally, the system should be easy to assemble and dismantle, without the employment of crane or heavy vehicles. Based on these conditions, the application of textile lightweight constructions as shelters for archaeological sites appears interesting.

The paper presents a new concept of textile lightweight solution. The elasticity of the proposed textile material – that is a polyurethane-coated knitted textile - is a key aspect for the system re-configurability, which becomes adaptable to different set of problems.

TEXTILES SHELTERS FOR ARCHAELOGICAL AREAS

For many reasons, textile lightweight solutions are a sustainable choice for covering archaeological areas. Their peculiarity is to be very adaptable and versatile both in shape and dimension of the covered space. They can be assembled in modular sails, which allows the possibility to create different configurations based on the identified needs and ease the optimization of the packaging and transport on the site [4]. Moreover, the membrane structures are fast erecting and easy to dismantle, which made them reversible solutions, minimizing the impact on the environmental area surrounding the excavations. Thanks to their low weight, they need usually thin frameworks, allowing the employment of less invasive foundation and anchoring system. Finally, the possibility to create a multi-layer fabric system facilitates the ventilation, avoiding condensation problems that could damage the materials. The application of different textile layers allows the implementation of the solution, which can be adapted either to the climatic variations or to the several climate zones. The shade net guarantees the screen from UV irradiation during the summertime and the waterproof layer positioned below offers protection from the rain and ice during the winter. In the same way the structure could be used as simple shading roof in arid climate, while in humid climate, the roofing system could be implemented becoming waterproof and be shaped in a more enclosed configuration.

The membrane and textile structures for archaeological site can be divided in two categories based on the durability: the permanent fabric structures and the temporary fabric structures. The first solutions are more durable and look more like enclosed buildings. The latter ones are more simple built, cheaper and purely functional [1].

Temporary fabric systems are mainly used for simplify the management of archaeological areas. Thanks to their versatility they can be adapted to tourist flows, restoration and maintenance activities. These aspects allow that the workers, without the support of skilled personal, directly manage the arrangement and the dismantling of shelters. These features made their application very interesting in the first phase of excavations, when the workers need protection from the sun and rain during their activities. In the second phase of archaeological site management, when the area is open to the public, permanent and durable solutions are more advisable.

Other categorizations of shelter for archaeological areas can be based on their application purposes. Grounded on the overview on protective shelters used in the field [2], the following distinctions could be established: architectural shelters, shelters with museological approach and service (or functional) shelters. In the first case the protective function of the shelter design is secondary to, or eclipsed altogether by, the architect's vision of how a designed shelter responds to site, topography, landscape, meaning and context [2]. This approach results innovative, but often does not take into account the conservation function as primer purpose in the design process. These types of shelters are indicative of the gap existing between architecture and conservation point of view on the topic. An example is the refurbishment of Villa Casale in Piazza Armerina [3]. The second shelter type represents the museological approach to archaeological areas, in which the shelter aims principally to represent the site for the visitors. The tourist tour is enhanced by the shelter design, its walkways and its configuration. An example of this concept is the intervention on the site of Tell Mozan/Urkesh in Syria [2]. The service shelters represent the third type. With this term we identified the temporary shelters used by archaeologists and workers while excavations are in progress or waiting for a permanent solution. An early example of functional shelter could be represented by the 'hexashelter' for the Orpheus mosaic in Cyprus [2].

These service structures are largely used in the management of archaeological sites, but they aren't frequent discussed in the current literature. Often people in charge of the daily maintenance use small fabric shelters and canopy that can be folded or easily taken down. They are typically poor design and made of local, non-durable materials like polyethylene plastic sheets and they do not have foundations system [1]; for ensuring the stability to the wind loads the operators use, normally, provisional expedients and makeshift solution. Furthermore, these structures work only as roof and do not offer protection on the sides, required by the technicians and archaeologists working in windy areas. The service structures are low budget, removable and reversible.

The design approach adopted in this paper is based on the know-how of shelter design for the emergency field. The emergency solutions, as the archaeological ones, are characterized by similar restraints, such as the economical limit, the minimum weight and volume for ease the transport, the employment organised by unskilled personnel and the provisional foundation systems. Last but not least, emergency constructions should be adaptable to different set of requirements and for that reason should be designed to be implementable according to their applications.

The aim of the work here presented is designing a textile covering system with lightweight foundations, in order to minimize the impact of the structure on the surroundings. ARCHeoSHELTER is a deployable covering system based on two structural elements (arches), which have a double function. On one side, they support the textile roof allowing the creation of a lightweight structure, which leans 'tiptoed' on the ground. On the other side, the arches function as sliding track for the textile layer, which can be rotated depending on needs.

DESIGN BOUNDARY CONDITIONS: THE CASE STUDY OF NORA (SARDINIA)

The Italian cultural heritage authority's request is to cover the mosaics of the Nora's archaeological area, in Sardinia (Italy). Nora is an ancient Phoenician settlement situated on a headland (Capo Pula) in the southwest coast of Sardinia. This cultural site consists of different historical settlements, dating back to different periods. The oldest finds are related to the Phoenician colony dated VIII century B.C, on which a Roman province settlement overlaps. The oldest finds are related to the Phoenician city. The all area presents valuable mosaics of different ages that need to be preserved from the external damages. The context surrounding the location is critical. Due to the collocation on a promontory, the ruins are exposed to the different winds and external factors that could entail damages and erosion. The sea proximity causes the presence of soluble salts and sand in the air, which provoke find and mosaic degradations. Moreover, the thermal excursions and the solar irradiation are considerable. The continual wind exposition from different sides worsens the situation.

The request of the Soprintendenza ai Beni Culturali (Italian National Trust) is to design a covering system able to protect the mosaics of ancient baths area in Nora. The necessity is to conserve the mosaics and to shelter the workers during the restoration activities. The demand is for a lightweight shelter system that limits the environmental impact and uses non-invasive foundations. Furthermore, the structure should be changeable in front of climatic conditions, both throughout the year and the 24 hours cycles and to the wind variations, which as main direction North-West and register speed less then 10 m/s (speed: 1-1,5 m/s summer-autumn; 0-0,5 winter-spring; secondary wind orientation: NE in summer, SE-SW in autumn, NE- NW winter) [6]. Finally, the frame should be easy to dismantle, re-move and re-use in other part of the site without the support of crane or heavy machineries.

DESIGN OF NOVEL COVERING SYSTEM

Due to the little span needed to cover the mosaic room of Nora (length from 3-5 m up to 7-9 m maximum), a structural solution completely solved with thin bending active elements is feasible. This solution allows the configuration of a kinematic structure directly on-site by means of bending linear fibre-reinforced profiles with different curve. Thus, the same arch can be used for covering rooms of different span, from 3 m to 6 m (fig. 1).

By analysing the current literature [7], we can affirm that a two-hinge arch is a stable structural system for elastically bent elements. The generated form is named as "bending-shape". The bending-shape depends on the distance of the two supports and the length of the bent element. For lowering the bending moment of the curved arch, a cable restraint system – made of a bottom edge-cable that connects the end points of the compressed arch and a radial connection-cable system – can equilibrate the axial forces in each node of the curved arch.

The above-described force-equilibrium system can be also obtained by using a membrane-restraint system in which a textile pocket connects the bottom cable to the curved arch in substitution of the radial cables. In both case, for reducing the stress of actively bent element between 15-20%, the literature has verified the necessity to tend to a semicircle shape (fig. 2).

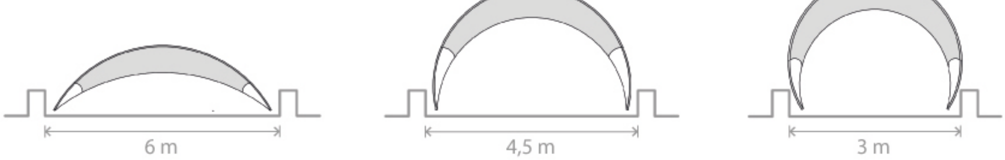

Figure 1. Adaptability of the ach span to different mosaic rooms.

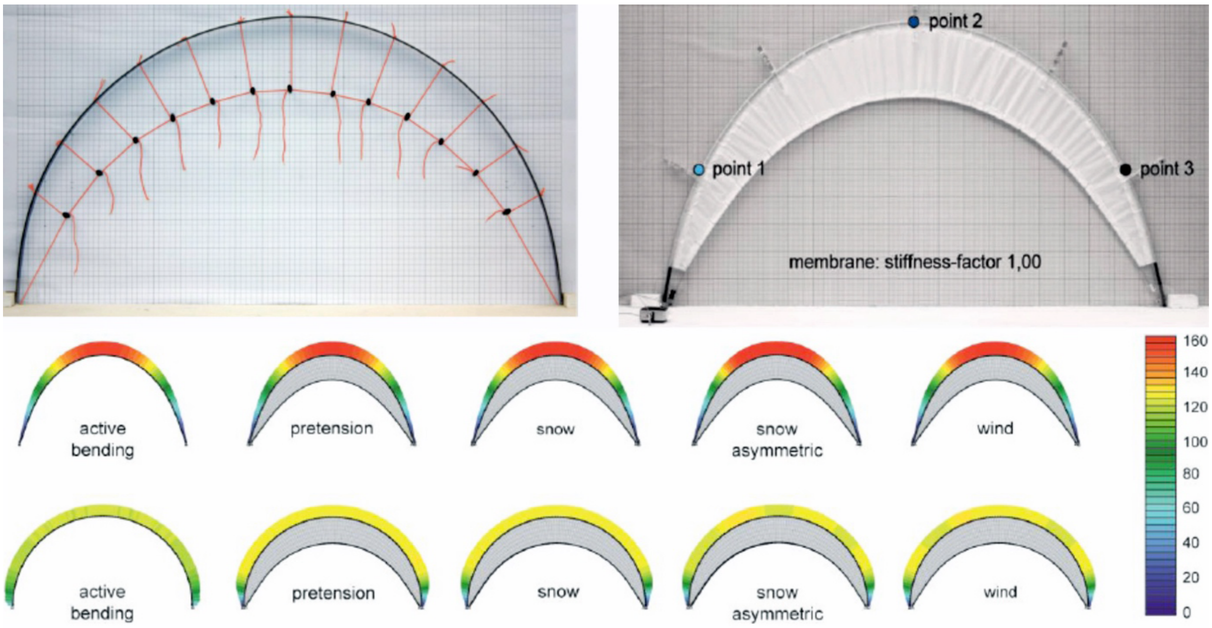

Figure 2. Comparison between a static model with linear struts and cables and a second model with a membrane-restrained system; numerical results (N/mm^2) of membrane FE-models with bending shape (top) and circular shape (bottom) (Source: Alpermann, Gengnagel, 2012).

The actively bent-arch shaped with a membrane restrained system is suitable to be used as structural element for covering little and medium areas during excavation works (fig. 3). Once arrived on site, two or more arches can be shaped into a circular geometry by closing the cable loop at the base of each GFRP board [8]. The shape of the arches depends from the dimension of the mosaic or the room to cover. At their footholds, four small steel foundation-plates are provided with hinges. If the outside walls of archaeological rooms can easily support the obtained lightweight arches during the erection stage, the membrane used to shape it can be made of a unique stretchable fabric (e.g. polyester-PU coated) that connects the arches and covers the mosaics (fig. 5). The membrane can be tensioned to the ground by means of sandbags filled on site, reducing the weight of the whole system for transportation. Polyethylene sandbags commonly used to anchor sport sails can anchor the membrane in several points along the longitudinal side of the roof. This arrangement allows the adjustment of the fabric tension without moving the previously filled ones (fig.4).

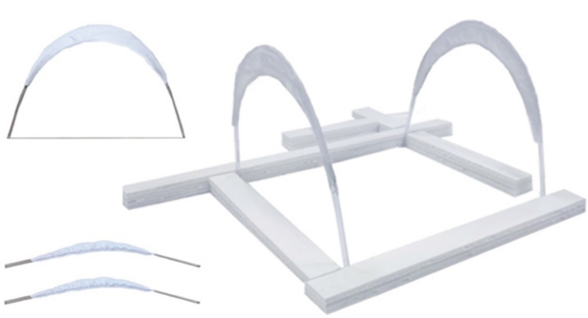

Fig. 3. Scale model of the bending-active arches.

Fig. 4. Sandbags used to anchor the shelter.

Fig. 5. Physical model and renderings of the covering system.

This anchoring system permits to develop an adaptable solution for the membrane layer, which takes into account the climatic variations (daily and seasonal changes). The structure has different configurations obtained by rotating the membrane along the bent linear elements. The membrane can be shaped in a more protective configuration for the wintertime, when the mosaics should be repaired from the external conditions. Alternatively, it can follow the workers necessities, allowing solar and wind protection during the summertime work (fig.5).
The system is also implementable with an additional shading layer made of a polyester mesh. The shade net filters the solar radiation directed to the membrane, so reducing the mean air temperature below the roof. Clamps block the mesh on the arches and permit it to slide along the bent element, while the additional sandbags that are used to anchor it to the ground are useful for stabilizing the whole system (fig. 6).

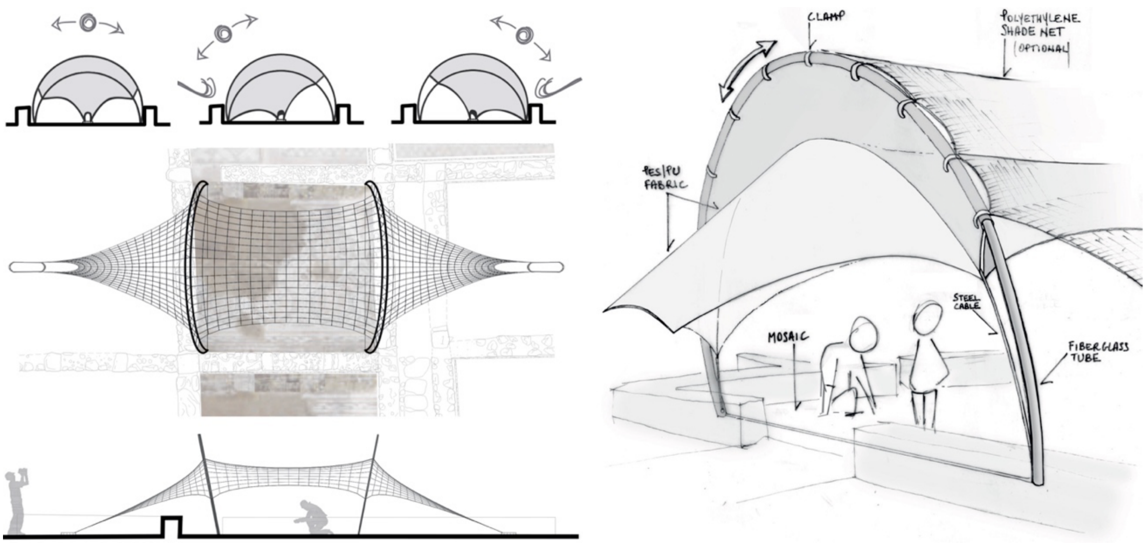

Figure 6. Scheme of textile layer orientations and architectural drawings (plan and elevation) of the covering system (left). Sketch of connections with arches (right).

During the design development of the covering system, the form finding stage has validated the equilibrium of the structural shape initially tested with a physical model at scale 1:10 (fig.5). The actively-bent element has been shaped with the physics simulation plug-in Kangaroo for Rhinoceros Grasshopper, while the membrane shape with span of 6 m has been obtained by using Rhino Membrane (fig. 7). Three catenaries - differently oriented on the curved arch - have been designed for replicating the relative membrane configurations in polyester-PU coated, where the distance between arches is always 5 m. The first one reflects the closed layout for wintertime, while the other ones are oriented on the arches in a symmetrical way (second configuration) and in an opposite way (third configuration). Thanks to the small span to cover, it was possible to apply an anisotropic pretension to fulfil the requirement of using flexible-webbing belts in substitution of steel edge-cables along the longitudinal edges of the membrane roof [9]. External loads are not considered at this design stage (fig. 8).
For obtaining a reliable pretension on the stretchable membrane, each configuration involves a specific inclination of the arches from perpendiculars to the ground, that are stabilized by changing the position of the sandbags at the end points of the roof. The inclination has been tested in all configurations. Its angle decreases of 10° by changing the membrane configuration from the symmetric one to the twisted one.
Variations of the arch width are also verified starting from the configuration 1 and 3 with arch span of 5 m, in which the pretension of edge cables should reach around the value of 20 N to fit with an arch deformation compared to the semicircle arch [7]. If the span of the arch changes, the value of pretension will be also altered.

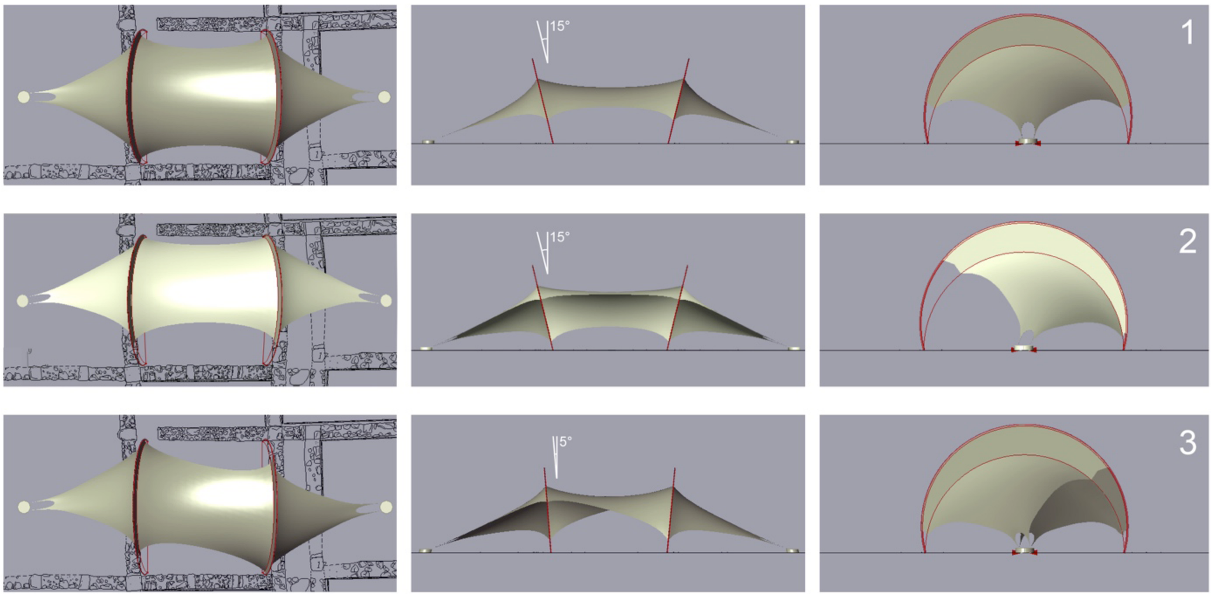

Figure 7. Three configurations designed in Rhinoceros. The inclination of the arches changes to pretension the membrane. Configuration 1: wintertime layout. Configuration 2: layout following wind and sun orientation. Configuration 3: summertime layout.

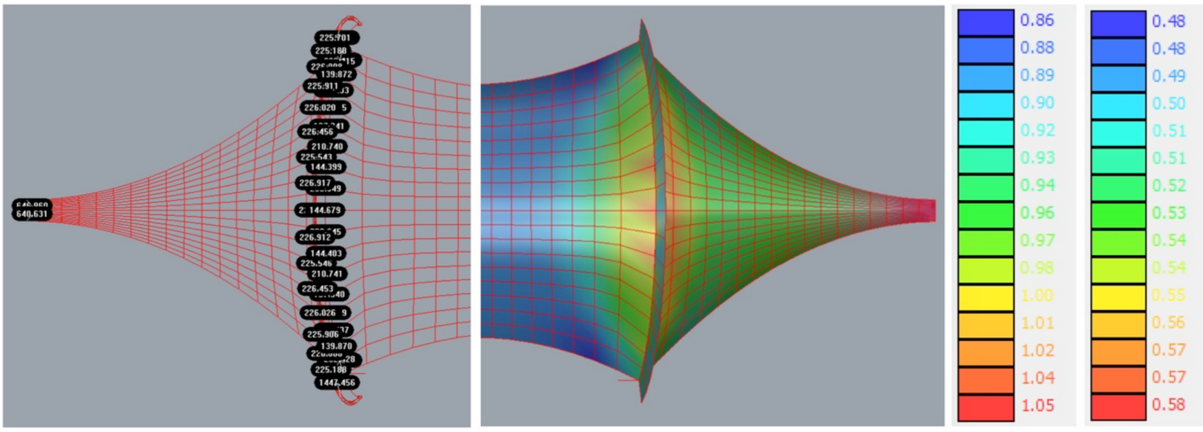

Figure 8. Reactions' analysis and stress plot in warp and weft direction (KN/m) calculated with Rhino Membrane.

Through the pattern design stage, the three dimensional surface, found by means of the form finding, has been flattened, obtaining a two dimensional cutting pattern for the manufacturing that follow the primary load-carrying direction of the canopy. Flat pieces incorporate the fabric useful to realize the pockets between the bent elements and the cables.

In the case of a stretchable material, such as PU-coated membranes, the stripes obtained from the cutting pattern should consider the compensation due to the elasticity of material [10]. Therefore, each stripe must be cut-off smaller than its final dimension. The reduction percentage has been calculated in different ways in warp and weft direction, to fit with the anisotropic stress ratio when the welded-joined membrane will be stretched into its final shape (fig. 9).

During the fabrication, particular care on connections realization will be taken. According to the literature, the welded overlaps between the stripes should not decrease the membrane strength less than the 90% of its original value [11]. Welded seams of pockets can be reinforced due the continuous sliding of membrane along the arches.

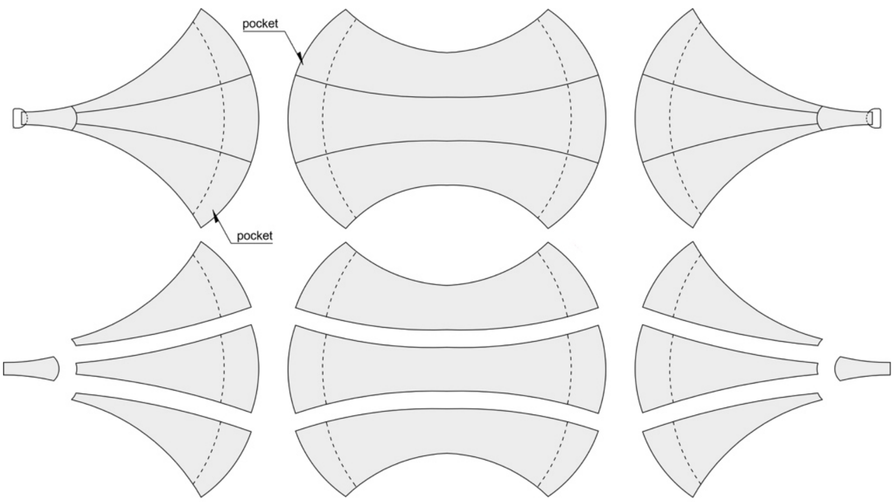

Fig. 9. Strips obtained from the cutting pattern of the membrane.

CONCLUSIONS

The project has been articulated in different phases, focusing on three levels of investigation: architectural, technological and form-finding. The research aim is to develop a solution ready-to-use for archaeological sites, to employ during the excavation works or as temporary shelter. Thanks to its modularity and its adaptability, as well as its idea of easy setup, the structure could be applied for different purposes and changing function during its lifetime. Besides the protective aim, the structure could be used for cultural events organized in the area or for the fruition, offering a shelter for the visitors or a covered space for the site management activities.

To end the project development, some further surveys should be considered. The first step should be the verification, with a real scale prototype, of the textile behaviour, in order to verify if it is behaving as expected from the virtual simulation. In the same way the structural stability of the bending arch should be confirmed.

Another aspect to be deepened is the erection of the structure on the field. The concept is based on the idea of having a lightweight structure, easy to set-up and remove also by unskilled people that work inside the area. This is still a conceptual level of development and should be tested with a prototype, to ensure that the assembling operations are easy and fast. Finally, the feasibility of having sandbag as anchoring system for the textile layers has to be investigated. In the common practice in the case of emergency shelter sometimes this expedient is adopted, but it needs to be tested for this configuration, taking into account the loads resistance to ensure the system stability.

REFERENCES

[1] A. Zanelli, *Architectural fabric structures in the refurbishment of archaeological and cultural heritage areas*, Fabric Structure in Architecture, Elsevier, 2015, p.485

[2] T. Roby, M. Demas, *Protective Shelter for Archaeological Sites*, Mosaics in situ. An overview of literature on conservation of mosaics in situ, The Getty Conservation Institute, 2013, p.3

[3] F. Minissi, *Protection of the mosaic pavements of Roman Villa at Piazza Armerina (Sicily)*, Museum 14, 1961

[4] A. Zanelli, E. Rosina, P. Beccarelli, R. Maffei, G. Carra, *Innovative solutions for ultra-lightweight textile shelters covering archaelogical sites*, Proceedings of the second international conference on structure and architecture ICSA, 2013

[5] M. Bartolini, M.P. Nugari, S. Ricci, A. Roccardi, *Le coperture delle aree archeologiche: Museo aperto*, Gangemi Editore, 2006, pp. 92-93

[6] E. Rosina, E. Romoli, *Shelters for archaeological areas: the issue of materials conservation*, Lecture for ‘General Course of Sheltering: Temporary Architecture, Lightweight Construction, Textile Technology’ [TEAL-S], Politecnico di Milano, January 2015

[7] H. Alpermann, C. Gengnagel, *Shaping actively-bent elements by restraining systems,* Conference IASS-APCS 2012: From Spatial Structures to Space Structures, Seoul, 2012

[8] R. Motro, *Flexible Composite Materials*, Birkhäuser Verlag GmbH, 2013

[9] M. Seidel, *Tensile Surface Structures*. *A Practical Guide to Cable and Membrane Construction*, Ernst & Sohn, 2009

[10] C.G. Huntington, *Tensile Fabric Structures – Design, Analysis and Construction*, American Society of Civil Engineers, 2013

[11] J. Knippers, J. Cremers, M. Gabler, J. Lienhard, *Construction Manual for Polymers + Membranes*, Edition DETAIL, 2011