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# Textiles and Archaeological Sites: Towards a Methodology for Designing Lightweight Protective Structures

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**Abstract.** The shelter for archaeological areas aims to protect ruins from damages, in order to preserve their historical values, while the excavation work represents a destructive action. The shelter design process for archaeological areas includes dealing with some contradictions, due to the multiplicity of constraints and the complexity of the application contexts.

The article aims to state the appropriate use of membranes and temporary structures in these fragile environments through a new concept of textile lightweight solution coming from a decision support matrix. In this applicative example, the elasticity of the proposed textile material – that is a polyurethane-coated knitted textile – and its combination with a bending-active structural element, become a key aspect for reconfiguring the whole system to different sets of problems. The example therefore understands active bending as an approach to generating new structural forms, in which common load bearing behavior is found due to the structures inherently large elasticity and inner stress state.

## Introduction

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]. The necessity is to having both very flexible and adaptable solutions, which could fit with different work needs, and a deep 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 [2].

The controversy of the topic derives from these premises. The aim of the work here presented is to study and show the adaptability of different typologies of membrane structures to the archaeological field. A rhizomatic, synoptic matrix has been developed for supporting the definition of the optimal configuration for textiles and their structural elements, in relation to the specific context and utilization. Diverse technical solutions are included in a decision tool, which should support key actors during the decisional process, and are linked to the most important requirements related to archaeological sheltering. The article also presents a new concept of a textile shelter that protects excavations from external agents. Due to its lightness and reversibility, this solution is adaptable to protect temporary excavation and restoration activities, thus it can be transported to other sites and easily reused,

## Overview of Archaeological Sheltering

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. Therefore, become needed the disposition of partial protective system or architectural shelter, defined as archaeological coverings. Recently, in addition to the protective function, other values had been added. The coverings could represent a key of lecture for the context in which they are inserted and could be both, a mean of presentation and reinterpretation of the site, and a support system for the visitors' fruition. For this reason they constitute a subject of extreme interest for the architectonic project, where the relation with the location is critical [3].

After having agreed that the archaeological shelter has a deep link with the archaeological item that protects, two different approaches could be chased in the design process. In the first case, the added part may be positioned autonomously, highlighting the difference in form and composition with the historical context. In the second case, the archaeological layout of ruins closely influences the spatial and distributive arrangement of the additions. In spite of the inevitable differentiation of materials and building techniques employed, the aim remains the evocation of a lost image and spatiality.

As previously outlined, the design of covering system for archaeological areas is a controversial topic for many aspects. The state of the art of protective shelters presents, within the normally employed systems, a wide set of negative examples to take into account. The bad design of archaeological coverings entails different consequences and problems, including the waste of economic resources, already lacking in this sector. Bad practices in archaeological areas are due to inefficient structures, which may be designed to be temporary and become permanent without upgrading the system, the lack of attention on the maintenance planning or the structural life time not considered, which entail problems of wear or project mistakes. These errors caused economic losses, worsen by the inefficient management of interventions and the necessity to operate with special actions to protect the finds from the damages caused by the bad design.

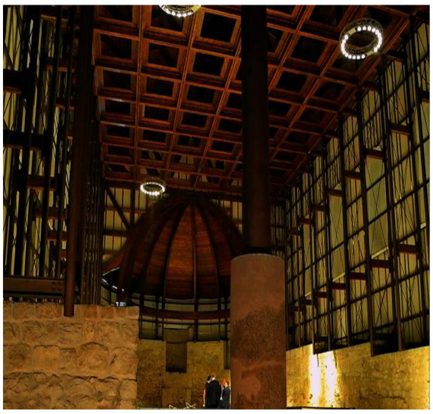
Archaeological shelters could be divided in different categories related on their principal purposes. Based on the overview of protective shelters used in the field [4], the following distinctions could be established: architectural shelters, shelters with museological approach and service (or functional) 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. This approach often does not take into account the conservation function as primer purpose in the design process, pointing out the gap existing between architecture and conservation's orientation on the topic. An example is the sheltering history of Villa Casale at Piazza Armerina (Fig. 1a). The former roof designed by the architect Franco Minissi in the 1950s consisted of a lightweight metal skeleton, which supported rigid plastic sheets. The designer aimed to recall the volume of the ancient rooms, clearing the ground level with raised wall-walks that allowed visitors to see the pavements without walking on the mosaics; unfortunately, the cladding system, composed by transparent plastic plates, caused 'greenhouse effect' inside the covered space entailing damages for the mosaics. In addition to this, the metal skeleton produced several shadow zones, compromising the view of mosaics. To overcome these problems the new roof designed by architects Guido Meli and Gionata Rizzi has replaced the old structure. This project, inspired by the previous work, preserves the idea that the shelter should suggest the original volumes, but changes in its architectural skin [5]. The new structure is composed by aluminum elements and wooden trusses, which supports the opaque panels for the vertical enclosures and the copper roof, trying to integrate lost architectural elements. The result is an invasive construction that has lost the lightness of Minissi' shelter that creates a false picture of the original context.

The second shelter type represents the museological approach to archaeological areas, in which the shelter aims, in addition to preserve the finds, to represent the site for the visitors. The tourist tour is enhanced by the shelter design, its walkways and its configuration. A successful example of this concept is the intervention on the site of Tell Mozan/Urkesh in Syria (Fig. 1b).

In the early 90's, the excavation works on the ancient Urkesh brought to life ruins that date back to 2500-2700 B.C. The director of the site, Giorgio Bucellati, has studied an uncharacteristic protective system to preserve the mud-bricks of the walls, and, at the same time, shaping the architectural spaces and volumes of the finds, in order to interpret and present the site for the outside visitor. With this goal, the walls were re-shaped whit textile structures, following the ideal of a three-dimension rendering on the computer. The system consists of a metal structure that closely follows the outline profile of the walls and of a fitting canvas cover, made by local tent maker [6]. Thanks to the modularity of the system, the inspection of the walls is effortless; the fabric can be removed from any portion of the walls in any moment. Last but not least, the shelters are completely reversible and can be easily dismantle.

Finally, 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; they aim to provide provisional protection for finds and operators from external agents (rain, sun and wind). This service structures are low budget, removable and reversible. An early example of functional shelter could be represented by the 'hexashelter' for the Orpheus mosaic in Cyprus (Fig. 1c).



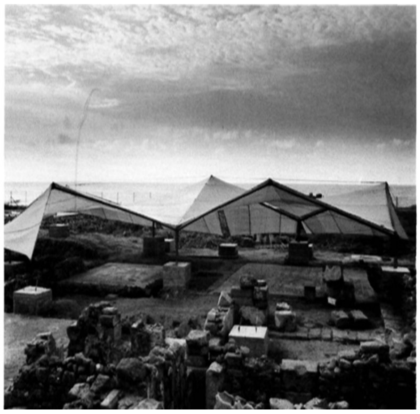


Fig. 1 - (from the left to the right): a) G. Meli and G. Rizzi project for Villa Casale in Piazza Armerina; b) Protective systems for mud-brick walls in Tell Mozan/Urkesh. The walls are shown as volume in their original shape; c) 'Hexashelter' prototype for protecting the Orpheus mosaic in Cyprus (Source: Rizzi, 2008; Agnew & Coffmann, 1991)

'Hexashelter' is a prototype of a temporary structure designed to be mainly functional to the archaeological works. It is thought to be lightweight, modular, easy to erect and relatively cheaper if compared with more conventional structures. It can be employed also in areas presenting irregular topography and minimizes the impact on the surface of sensitive sites [7]. An aluminum framework with membrane roof and side panels composes the structure.

The system has six sides (hexagon) and draws a zig-zag profile made by high and low points, giving more stability to the system and working both as support for the roofing material and stabilizing truss. The all structure is fixed to the ground by means of cable supports. Since the Hexashelter is a prototype, its level of development remains on a conceptual stage and has limited its application.

Even though the service shelters aren't frequently discussed in the current literature, they are largely used in the management of archaeological sites. Often people in charge of the daily maintenance use small fabric shelters and canopies that can be folded or easily taken down. They are typically poor designed and made of local, non-durable materials like polyethylene plastic sheets. Due the temporary need, they do not have foundations system; for ensuring the stability to the wind loads the operators normally use provisional expedients and makeshift solutions. Furthermore, these structures work only as roof and do not offer a proper protection on the sides as required by the technicians and archaeologists working in windy areas.

## Overview of Textile Sheltering

The above-described examples show how all the typologies of archaeological shelters need a high level of adaptability and structural lightness, both for allowing non-invasive foundations system and for limiting the environmental impact. Compared with traditional constructions, requirements of reversibility and cheapness well support the application of textile structures in substitution of traditional building materials. 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 allow the possibility to create different configurations based on the identified needs and ease the optimization of the packaging and transport on the site [8]. Moreover, the membrane structures are fast erecting and easy to dismantle, which made them reversible solutions. 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 and the solar filtration, avoiding condensation problems.

According to the literature, membrane structures can be subdivided in tensioned membranes and pneumatic structures [9]. Tensile membranes are realized by means of lightweight, highly flexible membranes with a level of pretension, which generates stiffness in the surface (Fig. 2a). The surface load bearing capacity is provided by its double curvature and the pretension has introduced by means of one-dimensional flexible elements such as cables or ties. These components can be applied as flexible edge boundaries and increase the surface curvature through ridges and valleys. Rigid edges realizing closed frames or single, linear supporting members – generally subjected to compression and/or bending – provide the overall equilibrium of the structure. Under imposed load due to snow or wind, the fabric surface undergoes large displacements and a consequent increase in the material stress, which can increase up to ten fold [10].

The term ‘pneumatic structure’ includes the lightweight structures in which the load bearing capacity is achieved by means of air under pressure (Fig. 1c). They are mainly subdivided into two categories: the structures characterized by a single layer, stabilized by a slight difference in pressure between the inside and the outside, and the cushions, made by two or more membrane layers stabilized by air under pressure.

Based on the durability, the textiles structures can be divided in two categories: the permanent fabric structures and the temporary fabric structures. The first solutions are more durable and often look more like enclosed buildings. The materials employed should be durable for lasting long-term utilization and the planning process should consider the details of the maintenance, the fruition facilities and the user’s fluxes.

The foundation systems are normally more invasive than the temporary solutions, but the environmental impact could be reduced through accurate design of details. The provisional fabric structures, on the contrary, are simpler built, cheaper and purely functional to a temporary need. Generally, the priority of these temporary solutions is covering and protecting the space from external agents and the climatic variations. Moreover, they may ensure the protection from water and condensation, and, meanwhile, allowing the light transmission through filtering the UV radiation. Finally, a temporary shelter should be easy to assemble and dismantle, without the employment of crane or heavy vehicles and should be manage by un-skilled personnel.

Fig. 2 - Textile sheltering examples, supported by (from left to right): a) tensile structures; b) a framed structures; c) removable pneumatic membrane arches (Source: www.tensinet.com; www.tensoformsrl.com; ww.vonsternberg.com)

## Design Guidelines and Decision Support Matrix

This section defines a synoptic framework of all the usability methods of textiles in archaeological contexts. Membranes or textiles and tensile structure, which found a place in shelter design beginning in the 1980s, are still very popular but, except some exceptional cases, the planning is fixed to the last decades [11]. In this work, relative technical solutions are included in a decision tool, which should support the public authorities during the decisional process, and are linked to the most important requirements related to archaeological sheltering.

The design approach adopted in this survey is based on the know-how of POLIMI research group [12] in 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 organized 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.

As happens for emergency shelters, the textiles structures for archaeological areas may be adaptable both in relation to the location (context of application) and to the time (durability). This means that the structure can be progressively upgraded - by using different layers of textiles - in relation to the restraints of the local context, changing towards the climatic variations (daily and seasonal changes), the several climate zones or the morphology of the territory, or following the excavations development during the time (Fig. 3).

For what is concerning emergency shelters design, the period after a disaster is divided in phases, which correspond to different shelter needs and helps the operators in the organization of rescues. The disaster's phases are: emergency, recovery (or temporary shelters) and durable solutions (or permanent reconstruction). This subdivision identifies the shelter needs in relation to the period of application and to the economic resources. Immediately after a disaster the principal necessity is to offer a covered space and the solutions employed are normally cheap and simple. On the contrary, in the reconstruction phase, when resources has been arranged and assigned to the affected communities, the shelter solutions increased in their quality and cost, becoming permanents. Based on this approach, the management of archaeological sites can be divided in phases. Therefore, coverings are not seen as objects, but as supports for a progressive process and, in that sense, textiles and membranes structures result appropriate for their ongoing adaptability. The scheme below synthetizes this idea, join together the evolution of excavation works and their needs during the time, the equivalent shelter necessities and their economic impact.

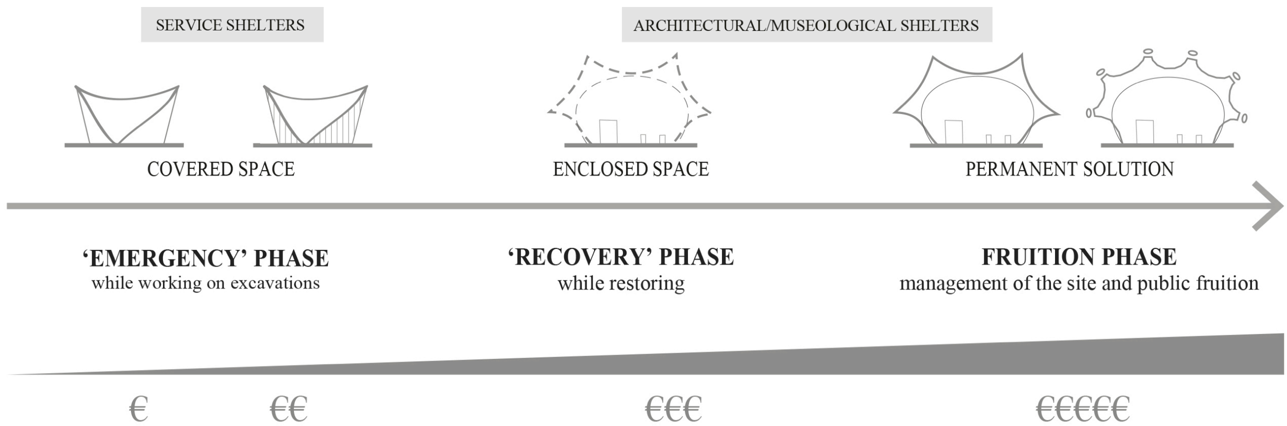



Fig. 3 - Scheme of archaeological sites' management: subdivision in progressive phases (Source: Barozzi et al., 2015)

Taking into account the researchers background and the previous premises, this work has interpreted the systemic structure of the methodology matrix as a network of needs that follows the different requirements of archaeological shelters. Gilles Deleuze and Félix Guattari use the term "rhizome" and "rhizomatic" to describe theory and research that allows for multiple, non-hierarchical entry and exit points in data representation and interpretation. In "A Thousand Plateaus" they oppose it to an arborescent conception of knowledge, which works with dualist categories and binary choices. A rhizome works with planar connections, while an arborescent model works with vertical and linear connections [13].

Based on the “rhizomatic” method the decision support matrix characterizes a set of textiles technical solutions to be combined for meeting the requirements. The procedure of identifying the guidelines can be outlined in five steps: (i) gather environmental and conservative data of the context; (ii) gather data in terms of customers’ needs, regulations and budget; (iii) interpret the data in a set of requirements that have to be solved in the specific site and – if necessary – establish their relative importance into a priority scale; (iv) link the requirements to a set of technical specifications and materials (ideal values) that can be applied for obtaining the required performances; (v) combine the ideal ¬values in one or more layouts (rhizomatic connection) that represent the geometrical and structural guidelines for the design and engineering stages.

In the archaeological matrix (Fig. 5), the set of requirements (input) should be solved so that all the materials and components are horizontally interchangeable and compatible both in terms of transport and assembly for the erecting stage, and with their usability and maintenance during the operative life. The ideal output would be a coherent, singular tensile item that can work both alone or associated each other for generating modular shelters that are ‘genetically’ open to local adaptation.

The matrix sets different levels of protection. Environmental ones range from sun shading to the protection against wind, rain, snow or high variations in temperature. Also, the level of translucency (from translucent with good overall levels of natural daylight to opaque) depends on the membranes used and can be chosen in relation to the conservative need of ruins, just like the insulation level (applying a single thin layer or highly insulated multi-layers). Still depending on the technical textiles used and the relative structural support, the shelter is temporary or for permanent use (lifespan of the technical fabrics can also be of 30 years) and anchored to the ground with several not-invasive systems, chosen in relation to the covering span. Span and structure also depend on the need to suggest the original volume in a contemporary manner; due to the great advantage in terms of lightness and cheapness related to membrane architecture, this last requirement is obviously secondary than the structural, thermal and functional ones [14].

Fig. 4 - Functional textile details for solving the principal needs of archaeological shelters. From the left to the right: a) roof openings integrated into textile roof for indoor ventilation; b) vertical partitions and rainwater system; c) removable sandbags for tensioning the membrane (Source: www.canobbio.com; Zanelli, 2015; www.tess.fr)

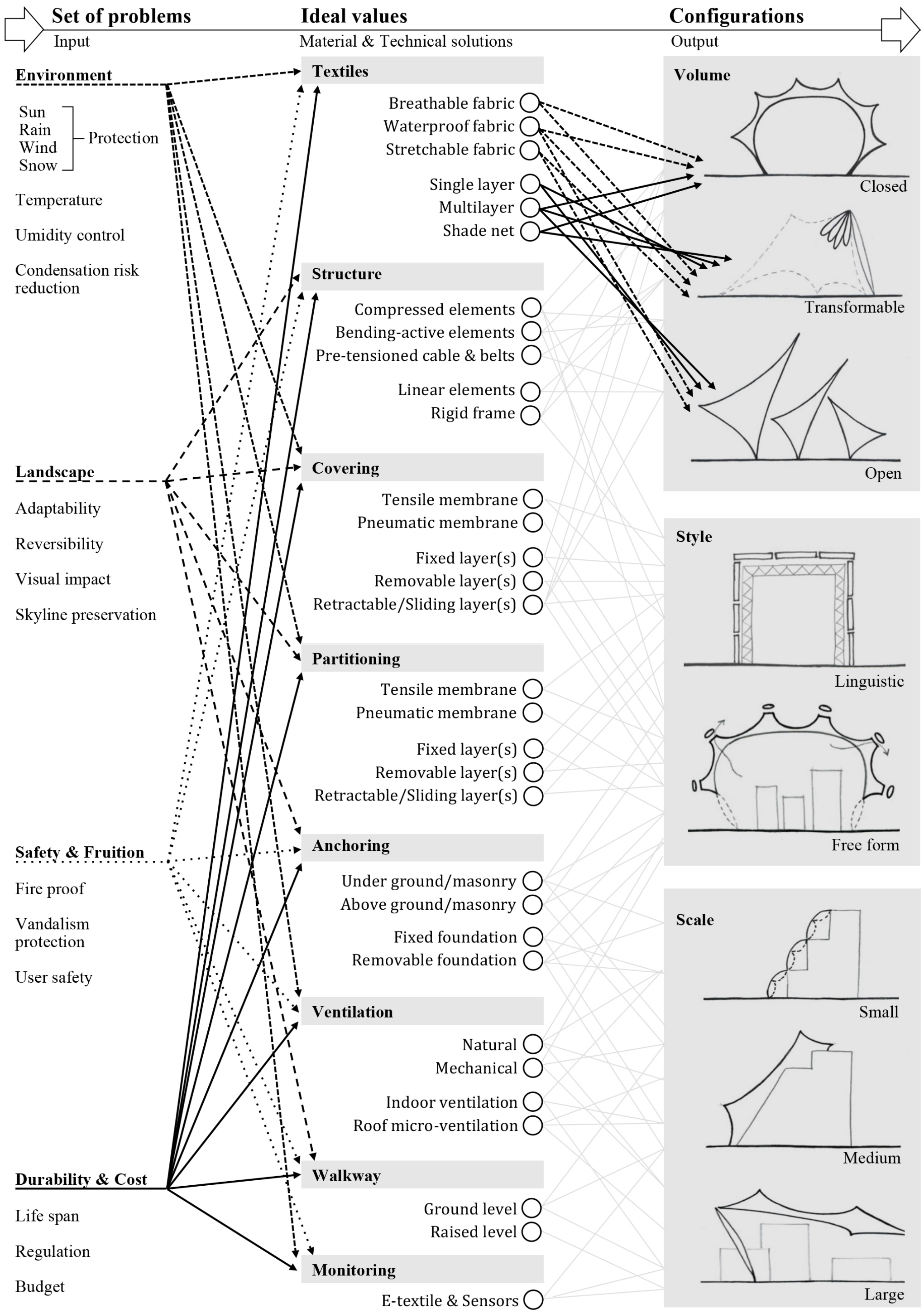



Fig. 5 - Methodological matrix supporting the design process of progressive textile structures for archaeological application

## Concept Design of a Temporary Shelter for Archaeological Areas

An applicative example of the employment of the decision matrix during the design process is here illustrated: the design goal is an ultra-lightweight and progressive shelter, able to be implemented and easily modified, following the often changing needs of the excavation site [15]. The Italian cultural heritage authority's request was to cover the mosaics of the Nora's archaeological area. Nora is an ancient Phoenician settlement situated on a headland (Capo Pula) in the southwest coast of Sardinia (Italy). This cultural site consists of different historical settlements;

the oldest finds are dated back to the Phoenician colony (VIII century B.C), on which a Roman province settlement overlaps.

The context surrounding the location is critical. Due to the collocation on a promontory and the sea proximity, the ruins are exposed to the different winds and external factors that could entail damages and erosion. Moreover, the thermal excursions and the solar irradiation are considerable.

The request of the Soprintendenza ai Beni Culturali (Italian National Trust) is to design a covering system able to protect the mosaics of the ancient baths area. 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 than 10 m/s [16]. 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.

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 (Figg. 6-7). This solution allows the configuration of a kinematic structure directly on-site by means of bending linear fibre-reinforced profiles with different curve. The actively bent-arch shaped with a membrane restrained system [17] is suitable to be used as structural element for covering little and medium areas during excavation works (Fig. 8). 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. Different shelter configurations are feasible, throughout the excavation process and the daily care of the archaeological area. 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. The membrane can be tensioned to the ground by means of sandbags filled on site, reducing the weight of the transportation system. Polyethylene sandbags commonly used to anchor sport sails can fix 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.

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. 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.

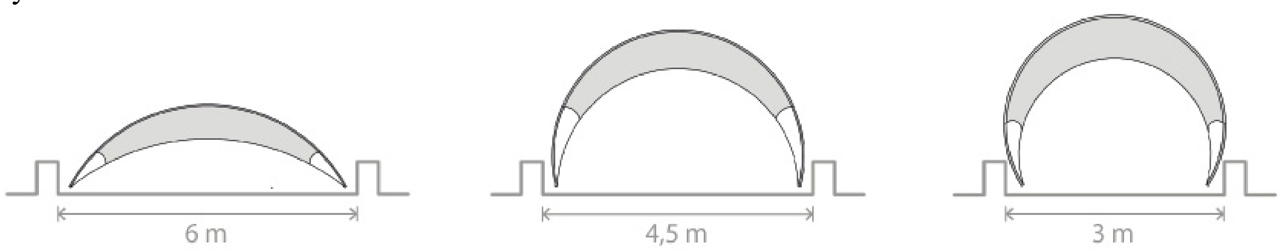



Fig. 6 - Adaptability of the ach span to different mosaic rooms (Source: Barozzi et al. 2015)

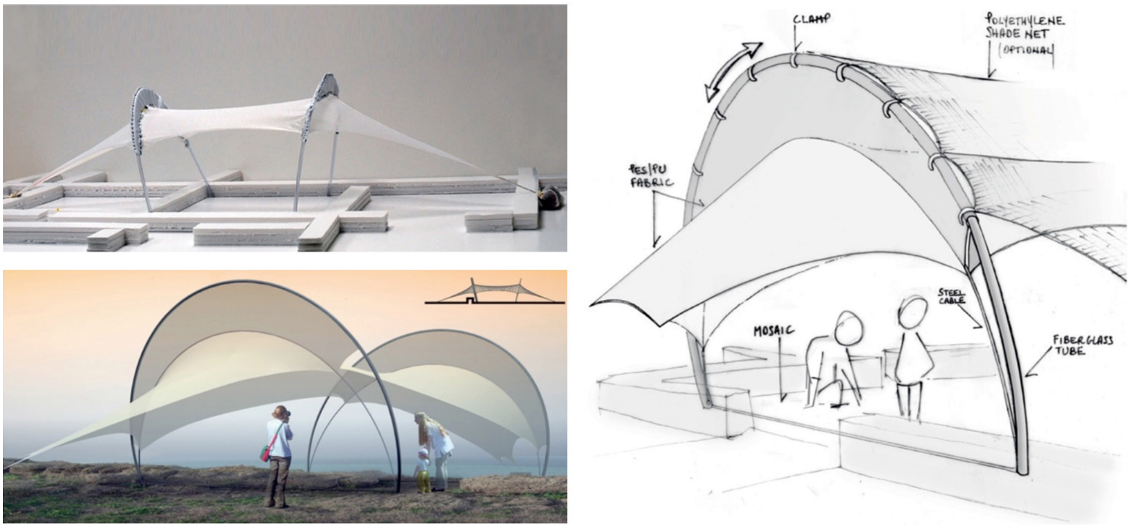



Fig. 7 - Physical model, renderings and a detail sketch of the proposed shelter (Source: Barozzi et al., 2015)

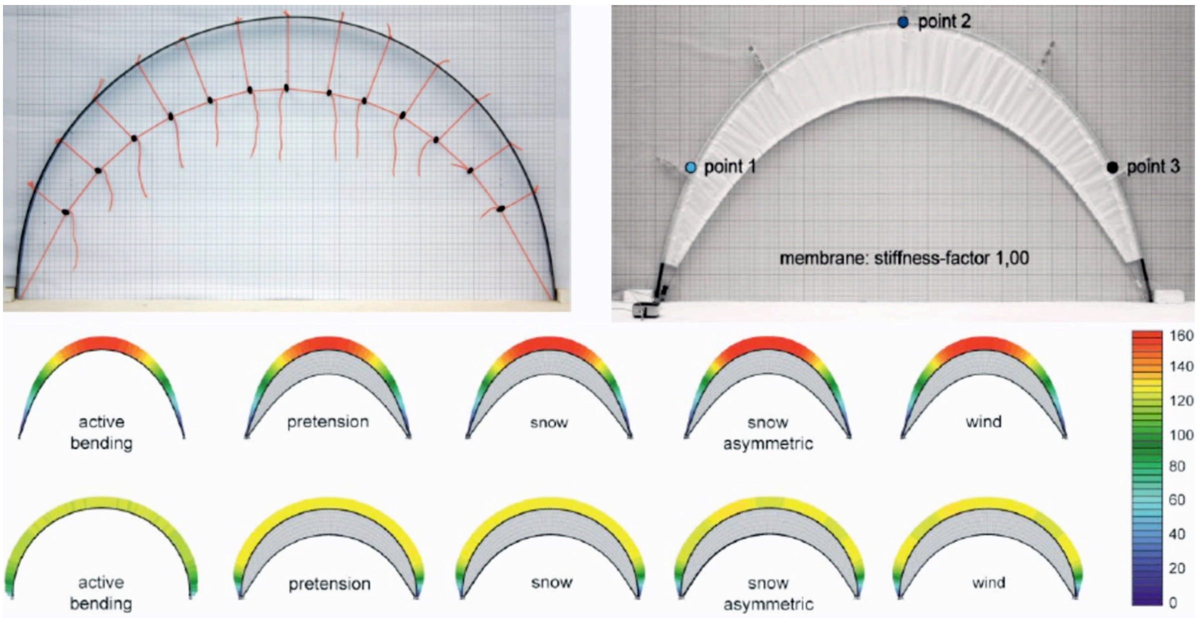



Fig. 8 - Comparison between a static model with linear struts and cables and a second model with a membrane-restrained system; numerical results (N/mm2) of membrane FE-models with bending shape (top) and circular shape (bottom) (Source: Alpermann, Gengnagel, 2012)

## Conclusions

Some relevant examples of protective shelters for archaeological areas have been presented, in order to better understand the common building practice on the field. Thereafter, a general overview on textiles technical solutions is introduced. Tensile surface structures offer several advantages such as high flexibility, low or aesthetical visual impact, natural shapes, modularity, suitability for any geometry, reusability, light supporting structure, easy transportation, low maintenance requirements and fast installation or dismantling, but all these have to be checked with respect to the criteria for the archaeological or heritage site under consideration. Projects can vary according to the design brief and creativity can steer a wide range of possible solutions for frames, forms and lightness [14].

To support the decisions during the design process, a synoptic framework of all the usability methods of textiles in archaeological contexts has been elaborated. A decision support matrix, which characterizes a set of textiles technical solutions to be combined for meeting the requirements throughout the whole process of archaeological works, is the result of the survey. To better clarify the methodology behind the decision tool proposed (general matrix), an applicative example of the employment is presented. The case study treated is the design development process of a textile lightweight solution for covering the mosaics in the archaeological area of Nora.

**References**

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

[2] M. Bartolini, M.P. Nugari, S. Ricci, A. Roccardi (2006), *Le coperture delle aree archeologiche: Museo aperto*, Gangemi Editore.

[3] M.L. Germanà (2013), *Archaeological construction and its relationship with place: the theme of shelters*, Urban Archaeology Enhancement. Valorizzare l'archeologia urbana, Edizioni ETS.

[4] Z. Aslan (1997), *Protective structures for the conservation and preservation of archaeological sites*. Journal of Conservation and Museum Studies, 3, pp. 16-20.

[5] G. Rizzi (2008), *Sheltering the Mosaics of Piazza Armerina: Issues of Conservation and Presentation*. Archaeological Institute of America, https://www.archaeological.org/news/hca/7. Accessed on 22 Apr 2015.

[6] G. Buccellati (2006), *Conservation qua Archaelogy at Tell Mozan/Urkesh*, Proceeding of Conservation Theme at the 5th World Archaeological Congress, Washington, D.C., 22–26 June 2003, Of the Past, for the Future: integrating Archaeology and Conservation, The Getty Conservation Institute, Los Angeles,

[7] N. Agnew, R. Coffmann (1991), *Development and evaluation of the Hexashelter*, The conservation of the Orpheus mosaics at Paphos, Cyprus, The Getty Conservation Institute, Los Angeles, 1991.

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

[9] W. Lewis (2003), *Tension structures. Form and behavior*, Thomas Telford Publishing, London.

[10] P. Beccarelli (2016), *Designing with membranes.* In: A. Zanelli, L. Spinelli , C. Monticelli, P. Pedrali (Eds.), *Lightweight Landscape: Enhancing Design through Minimal Mass Structures.* PoliMI SpringerBriefs, Milan, pp. 40-48.

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

[12] EU 7$^{th}$ Framework Programme Collaborative Project *"S(P)EEDKITS, Rapid deployment of shelters, facilities and medical care resources following a major disaster"*, www.speedkits.eu. Accessed May 2018.

[13] G. Deleuze, F. Guattari (2004), *A Thousand Plateaus: Capitalism and Schizophrenia.* University of Minnesota Press, Minneapolis.

[14] M. Mollaert, L. De Laet, A. Verdonck, S. Lombardi, P. Beccarelli, A. Zanelli (2011), *Textile shelters for archaeological or heritage areas: design references*, *Structural Studies, Repairs and maintenance of Heritage Architecture XII*, eds. brebbia & L. Binda, published by WIT Press.

[15] M. Barozzi, S. Viscuso, A. Zanelli (2015), *Design novel covering system for archaeological areas*. In proceedings of VII International Conference of Textile Composites and Inflatable Structures (Structural Membranes 2015), Barcelona, 19/10/2015-21/10/2015.

[16] E. Rosina, E. Romoli (2015), *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.

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