DETAILING FOR REFURBISHMENT WITH STRUCTURAL MEMBRANES

JOSEP I. DE LLORENS

School of Architecture, Barcelona (ETSAB). Technical University of Catalunya, Spain
e-mail: ignasi.llorens@upc.edu
web page: http://sites.upc.es/~www-ca1/cat/recerca/tensilestruc/portada.html

Key words: Textile Roofs, Structural Membranes, Refurbishment, Detailing.

Summary. The connections of new structural membranes to historic buildings are explored on the basis of traditional examples and recent experiences.

1 INTRODUCTION

Structural membranes have been recognized as being suitable for the refurbishment of existing buildings. In a previous paper [1], 80 interventions in 24 countries were investigated to identify the design strategies together with the conformity of the solutions with the principles established by the International Council on Monuments and Sites. The research has continued, including more case studies and analysing the different ways of connecting new structural membranes to old existing buildings.

Left to right and top to bottom: Fig.1: Imagination Headquarters, London, 1989. Fig.2: Dresden Station Redevelopment, 2006. Fig.3: Corbera d'Ebre Church, 2013. Fig.4: Salzburg Central Station, 2013. Fig.5: Baluart de Ses Voltes, Palma de Mallorca, 1991. Fig.6: Roof for the central courtyard of the "Palacio de Minería", Mexico City 2002. Fig.7: Fachada andamio Puerta Tierra, Cádiz 2007. Fig.8: Wroclaw railway station.

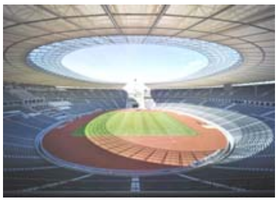
The strategy of integrating membranes into the building layout while preserving its architectural character and construction integrity is illustrated by the roofs added or replaced in the Imagination Headquarters of London, 1989 (fig.01), the Dresden Station Redevelopment, 2006 (fig.02), the Corbera d'Ebre Church, 2013 (fig.03) and the Salzburg Central Station, 2013 (fig.04).

Other options rely on independency, establishing a dialogue with the pre-existing elements such as the “Baluart de Ses Voltes“ in Palma de Mallorca, 1991 (fig.05), the roof for the central courtyard of the “Palacio de Minería” in Mexico City, 2002 (fig.06), the “Fachada andamio Puerta Tierra” in Cádiz, 2007 (fig.07) and the Wroclaw railway station, 2013 (fig.08). A third option is to introduce a totally new concept by juxtaposing an outstanding new shape, which could be an appropriate choice if the context lacks character or definition. Some outstanding examples have been identified: the Urban Loritz Platz in Vienna, 2000 (fig.09), the Julianus Shopping Centre in Tongeren, 2008 (fig.10), the Luxembourg Central Station, 2012 (fog.11)) and the Bus Station of Aarau, 2014 (fig.12).

Left to right and top to bottom: Fig.9: Urban Loritz Platz, Vienna 2000. Fig.10: Julianus Shopping Centre, Tongeren, 2008. Fig.11: Luxembourg Central Station, 2012. Fig.12: Bus Station, Aarau, 2014. Fig.13: Arena, Nîmes 1988. Fig.14: Olavinlinna Castle, 2000. Fig.15: Bellver Castle, 2006. Fig.16: Kleiner Schlosshof, Dresden 2009.

On special occasions, the preservation of the external image of the building is added to the aforementioned principles. It is a requirement that considerably affects the design, as the case of the ancient Arena of Nîmes that was covered with a lens-shaped pneumatic form (fig.13). The roof is not visible from outside and no changes had been made to the classical structure of the Arena. Another example is that of the new roof of the Olavinlinna castle courtyard, scarcely visible from outside (fig.14). It had to harmonise with the historical building, new insertions to the old walls were not permitted and the whole structure had to be such that it could be erected and dismantled efficiently. A combination of both solutions is the short-term use roof for the Gothic Bellver castle in Mallorca to protect the yard during seasonal events (fig.15). Sand bag ballasts instead of anchors were used to support wind loads up to 100 km/h. The old walls remained untouched. More sophisticated is the roof of the Dresden Castle Kleiner Hof (fig.16). It hides behind the ridges and gables and had to take them into account while not being obtrusively visible from the outside.

It is also noticeable the suitability of membranes to cover large areas on existing stadiums and arenas. This capability is based on the lightness, translucency and compatibility of the intervention that does not alter the basic outlines and preserves the architectural character being easily differentiated and in some cases, easily removed. (figs.17 to 20).

Left to right and top to bottom: Fig.17: Vista Alegre - Bullfight Arena Roof, Madrid 2000. Fig.18: Berlin Olimpic Stadium, 2004. Fig.19: Kiev Stadium, 2011. Fig.20: Poznan Stadium, 2012. Fig.21: Shelter for terrace house 2, Ephesos, 2000. Fig.22: Sachsenhausen Memorial, 2005. Fig.23: Nuestra Señora del Rosario, Antigua, 2005. Fig.24: Megalithic temples of Malta, 2009.

The same features are also convenient for the protection of ruins and archaeological areas that require minimal and reversible interventions. Their particularities have been previously exposed in Barozzi et al.[2], Beccarelli et al.[3], Lombardi & Canobbio [4] and Zanelli[5]. Some prominent examples are the shelter for the Terrace House 2, Ephesos, to preserve the ruins, fulfil the climatic requirements and make the monument accessible (fig.21), the protective shelter for the remains of the crematorium of the Sachsenhausen concentration camp in the form of a translucent envelope structure with a homogeneous surface (fig.22), the roof of Nuestra Señora del Rosario ruins in Antigua, Guatemala (fig.23) and the fast and reversible intervention on the megalithic temples of Malta (fig.24).

3 CASE STUDIES

3.1 Corbera d'Ebre Church restoration. F.Vizioso & N.Bordas, Architects, 2013. Manufactured and installed by IASO.

To recover the use of the church as a public space, preserving its character of ruin as a memorial of the devastation produced by the civil war (1936-1939), a transparent light roof made of ETFE was envisaged. Its connection to the stone walls was solved with a reinforced concrete ring on top of them to anchor the frames made of cold-formed U steel channels, painted in white to be clearly distinguished, subdivided by tubular arches and valley cables. A gap between the frames and the supporting frames prevent from confusions between the added parts and the old ones.

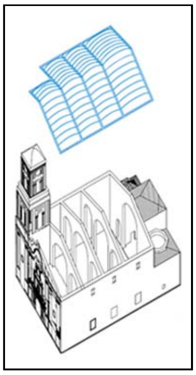
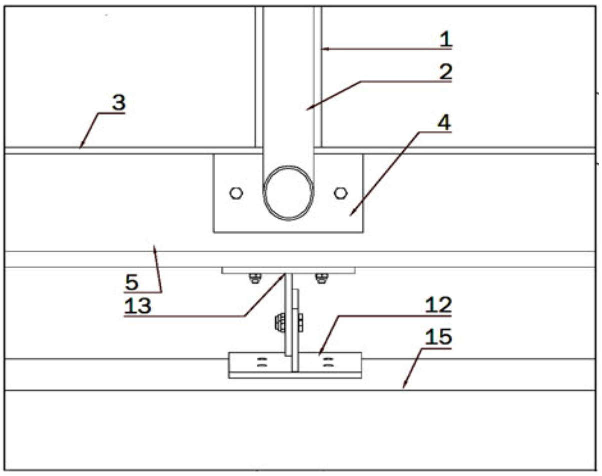
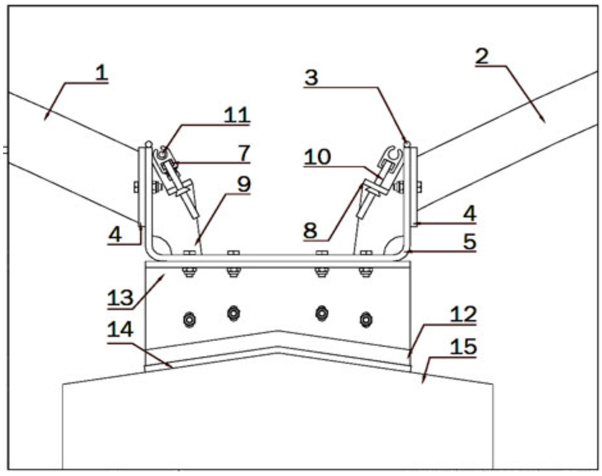
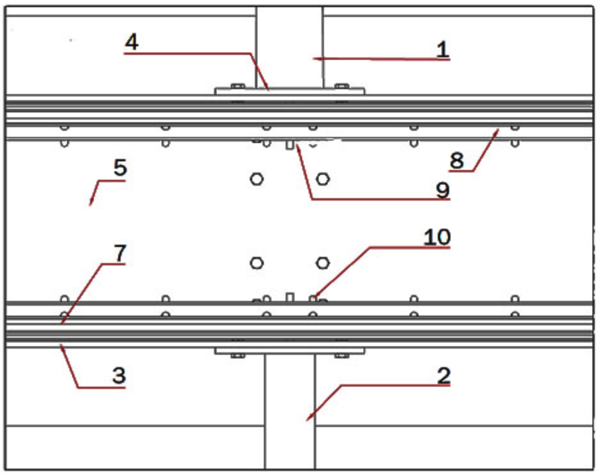
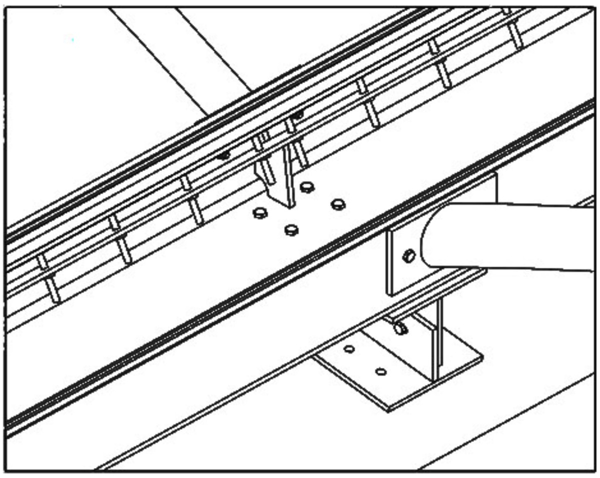



Fig.25: Axonometric view. Figs.26 and 27: The transparent roof. Fig.28: Reinforced concrete ring on top of the walls.

Figs.29 to 32: 1 CHS Ø 101,6 x 3,6 mm. 2 CHS Ø 76,1 x 3,25 mm. 3 CHS Ø 10 mm. 4 End plate. 5 Channel 400 x 180 x 6 mm. 7 Aluminium extruded section. 8 Longitudinal steel flat plate receiving threaded rods 10. 9 Gusset plate. 10 Threaded rod to tighten the ETFE foil. 11 Keder rail. 12 Plate anchored to the ring. 13 Plate screwed to 12. 14 Ø 12 mm threaded rods embedded into the ring. 15 Reinforced concrete ring (Courtesy of F.Vizoso).

3.2 Awning in Palma de Mallorca. J.A.Martínez Lapeña & E.Torres with J.Llorens & A.Soldevila, Architects, 1989.

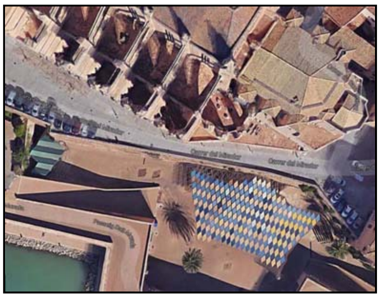
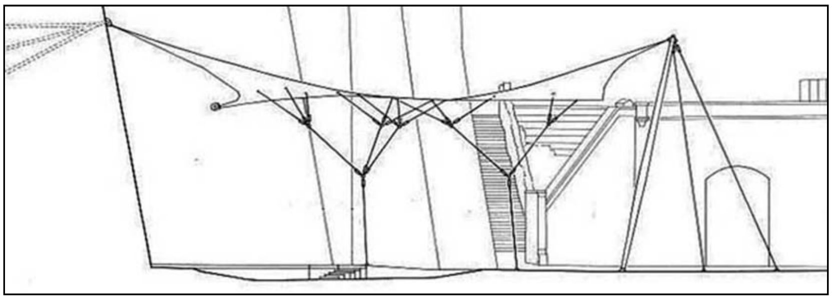
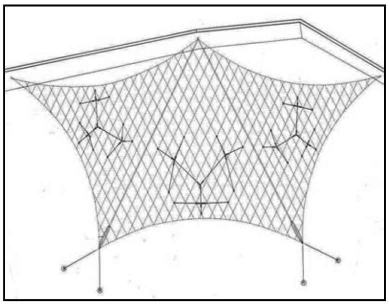



Fig.33: aerial view. Fig.34: Cross section. The main cables are anchored to the city walls.



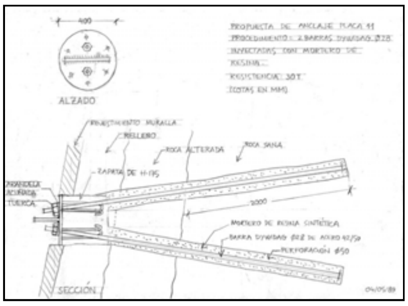


Fig.35: Plan. Figs.36 and 37: Anchor to the city wall.

A small outdoor theatre in the former moat beneath the cathedral of Palma de Mallorca has been covered with a steel cable net filled with coloured lozenges made of polyester fabric. (figs 33 and 35). The main cables are anchored to the city walls and to two hinged masts held in position by cable stays. Complementary tree-like cable systems attach the net to the ground to keep the awning as rigid as possible (fig.34). Anchors to the wall are Ø 28 mm steel bars grouted in 50 mm drilled holes. Their total length include at least an embedment of 2 m into the unaltered rock behind the superficial cladding (figs.36 and 37).

3.3 Roof for the central courtyard of the "Palacio de Minería", Mexico City. J.G.Oliva, M.Ontiveros, & I.Ortiz. Manufactured and installed by Carpas y Lonas El Carrusel SA.

The "Palacio de Minería" in old downtown Mexico City was designed by the Architect Manuel Tolsá and built between 1797 and 1813. It is considered a masterpiece of Latin American neoclassicism that has to be preserved. The schedule included the requirement of not altering neither the existing structure nor the external look, meaning that no structural elements of the roof might be seen from the streets (Figs.38 and 39). This requirement implied that the intervention had to be very light and the height of the masts limited. Also, to reduce the impact to a minimum, plates for anchoring and supporting masts were embedded in the concrete slab poured in 1973 during a restoration work to replace the former wooden beams and brick roof (figs.41 to 43). Therefore the intervention was limited to the screwed removable plates. In summary, the historic building has been enhanced by the functionality of the membrane designed taking into account the formal guidelines of the Palacio to preserve its architectural configuration. The membrane is easy to erect and dismantle, light enough to rest on the existing structure without special reinforcements and flexible to admit the irregular sinking of the site (a former lagoon). In addition, if the roof is removed, all its elements would disappear and the courtyard would return to its original situation.

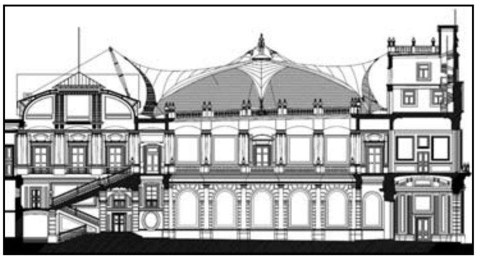






Fig.38: Palacio de Mineria courtyard. Fig.39: Section. Fig.40: Aerial view. Fig.41 to 43: Plates anchored in the concrete slab of the roof (poured during a previous restoration). Fig.44: Installation.

3.4 "Camp de Mart Auditorium", Tarragona. Tensoforma, S.Bertino, 1993.

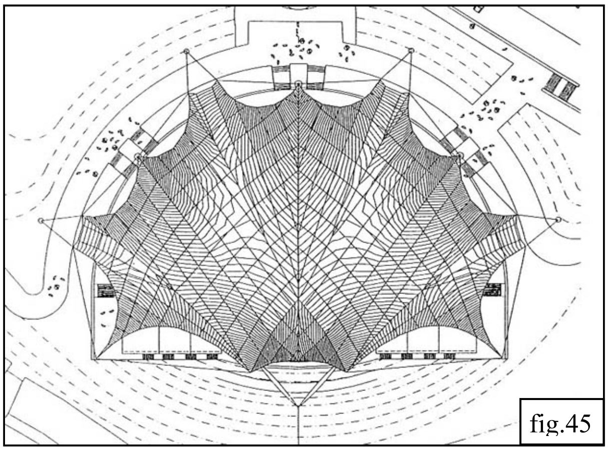


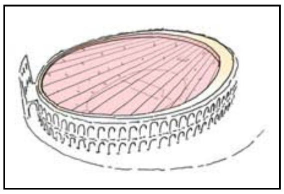
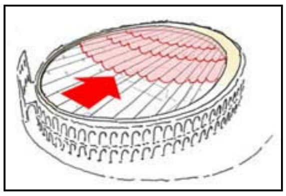
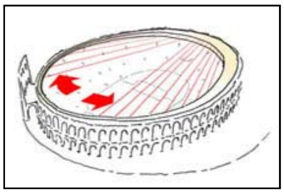
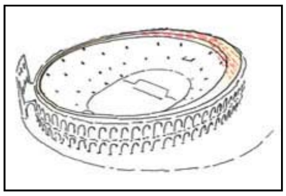
fig.45


fig.46

The Camp de Mart auditorium in Tarragona is a 3000-seat open-air amphitheatre located close to the city's Roman walls (fig,45) [6]. The proximity of the historical enclosure was of great concern during the design and construction processes. Work was interrupted by the local historical/archaeological authorities, who were not able to accept such a combination of styles, materials and technologies. But they finally accepted a tensile roof due to its openness, light weight, translucency and the ease with which it could be dismantled and could (almost) disappear (fig.46) [7].

3.5 Roofing the Roman amphitheatre of Verona. gmp Architects with Schlaich, Bergermann Partner, 2017.

An international competition was launched to find ideas for a retractable roof over the Verona Roman amphitheatre. The brief required a structure fully reversible, visually coherent with the amphitheatre and its historical surroundings, cost-effective, structurally feasible, functionally and acoustically compatible with the live events and concerts which the Arena regularly accommodates, and at the same time it should include an artificial lighting system, being retractable, and have no negative impacts on the original building.

The controversial winner scheme is a 12.000 m^2 foldable membrane sliding through a radial set cables, hidden and stored beneath the compression ring, when not in use. The solution claims to be "a subtle intervention that will not take focus away from the architecture of the historical arena". But main unknowns are the compatibility between the structure required by such a roof and how its foundations would be executed without substantially affecting the existing building (figs 47 to 51) [8].

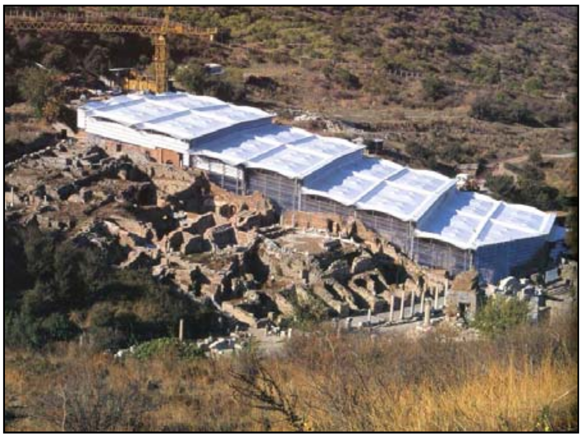
3.6 Berlin Olympic Stadium new roof, gmp Architects with Schlaich, Bergermann Partner, 2004.




Figures 52 to 55: The transformation of the Berlin Olympic Stadium into a modern arena has been reconciled in accordance with conservation constraints. The most importance change is the new lightweight roof that plays down the politically motivated heaviness of the stone. Some fans object to the slender columns in the upper tier of stands, but, as a result, the old stadium has been recycled and upgraded [9].

3.7 The shelter for Terrace House 2, Ephesus, O.Häuselmayer & W.Ziesel, 2000.

Recent contributions based on textile architecture for protecting excavations and ruins prove to be compatible with the general configuration of different sites and adaptable to particular requirements of functionality, geometry, structure and environmental impact. It is the case of the terrace houses of Ephesus.



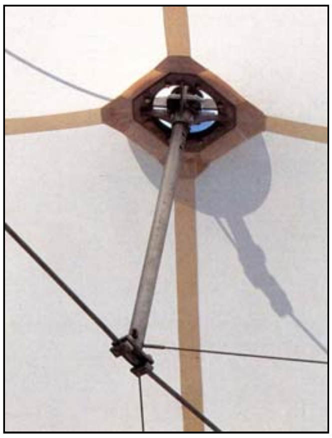
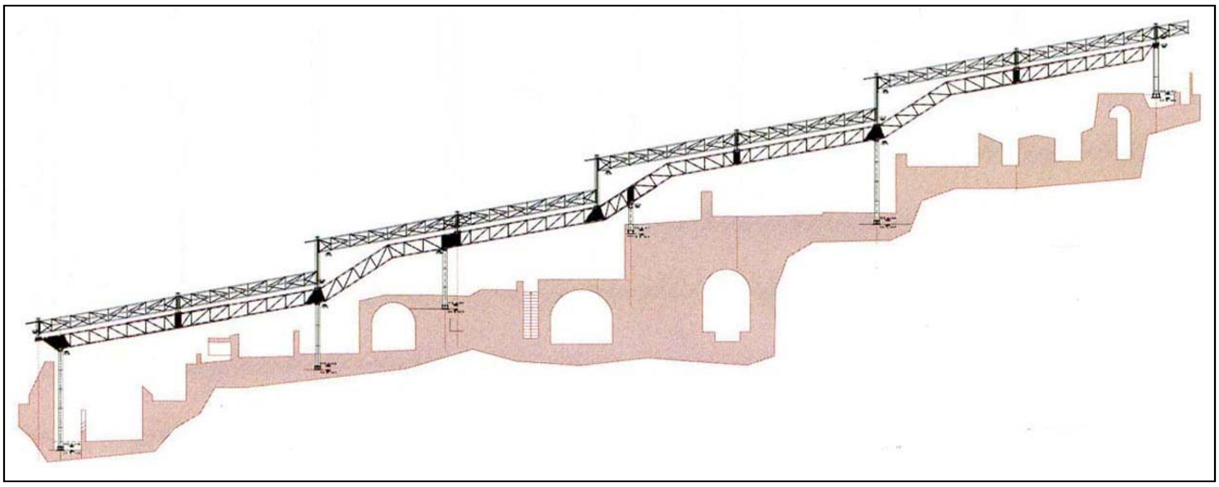



Fig.56: The shelter for Terrace House 2, Ephesus. Fig.57: Housing unit 6: Marble Hall (room 31) and peristyle courtyard (roo 31a). Fig.58: Detail of flying mast. Fig.59: Longitudinal section.

After the discovery of the monuments in 1962, it became clear that the painting and mosaic decorations should be left on site. It was necessary, therefore, to protect the ruins with a roof for climatic protection and also make the monument accessible to the public. The entire Terrace House 2 has been covered by a roof with a bearing steel structure conforming to the gradient of the slope The material of the light roof is a translucent a textile Teflon coated fibreglass membrane. In this way, the protective structure conserves the monument and allows for the contemporary presentation of the remains. A year-round conservation season independent of the weather conditions, is ensured [10].

3.8 Covering the Amphitheatre House ruins in Mérida, J.Llorens, Ch.García-Diego & H.Pöppinghaus, 2003.

A competition was launched to find a solution for the preservation of the 4th century "Amphitheatre House" ruins of the Roman city of Emerita Augusta, modern-day Mérida, Spain. As the ruins of the "Amphitheatre House" were uncovered, they lied exposed to the rain and UV rays. A noticeable degradation process was observed over the course of the last 50 years. Moreover, excavations are slated to continue, more remains will need protection and the solution had to be capable of being extended according to what excavations and discoveries were made. Because the site is frequently visited, the routes of the visitors also had to be preserved.

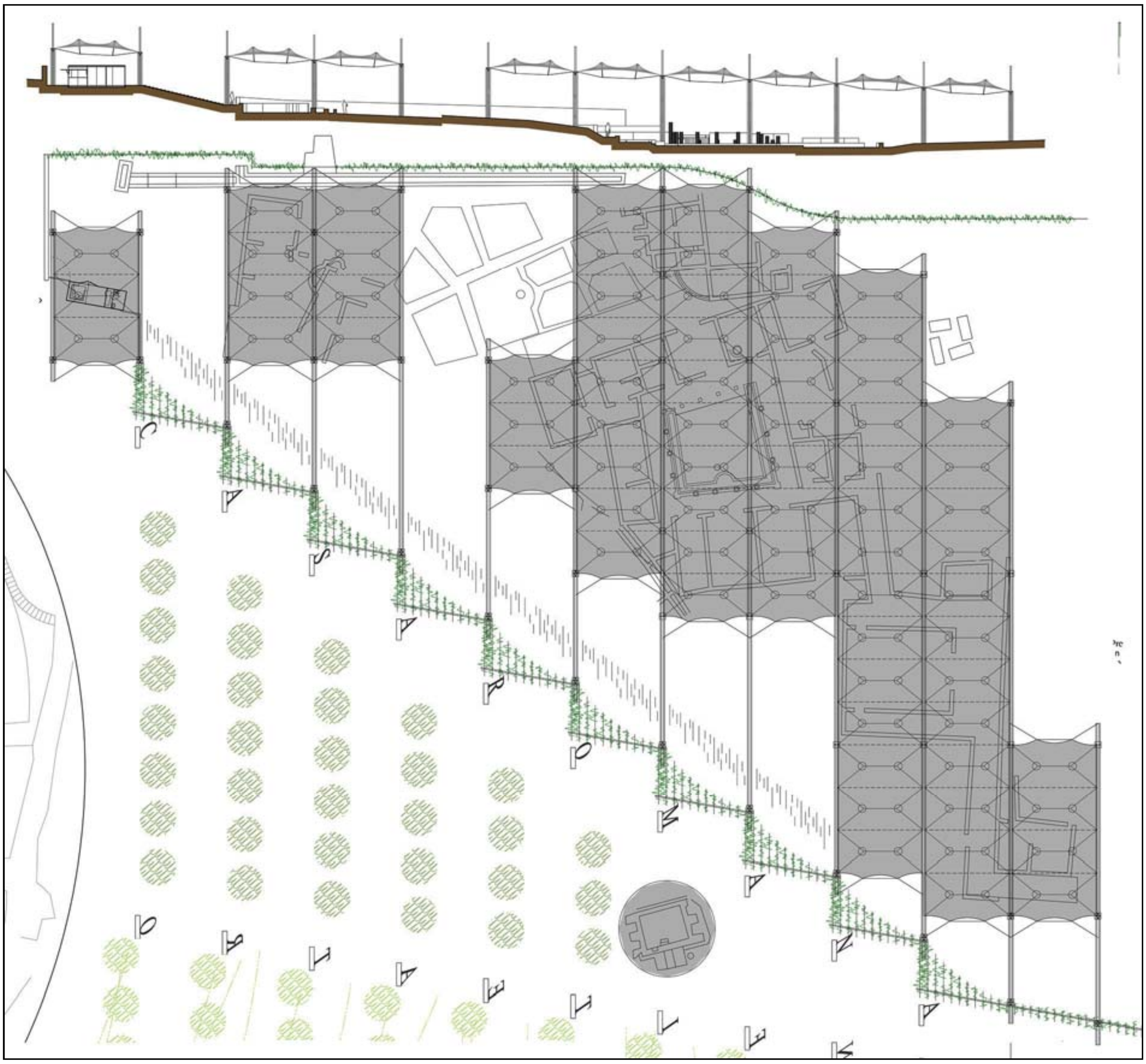


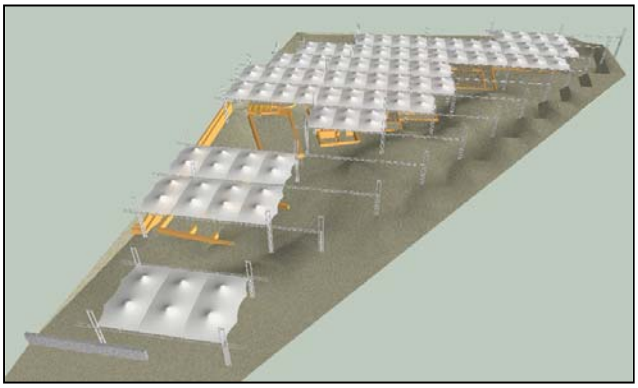
Figs 60 to 62: The ruins of the Roman House have been protected with a conventional steel structure. F.Visedo, 2014 [11].

The proposal that was adopted is a conventional structure made of steel sections and metal sheets. It adversely affects the general perception of the site because it changes the natural conditions by interfering with and obstructing natural light.

Another proposal (not retained) based on tensegrity principles, was a modulated lightweight and translucent textile roof that would have been able to adapt to cover whichever areas needed to be protected. It would have been made up of a tensile membrane stretched across frames made of hollow sections supported by masts. Their position would have been able to vary so as to avoid interferences with mosaics and ruins. It was conceived as a uniform, translucent white plane that would have acted as a diffuser of the natural light yet not interfere with the general atmosphere, character and environment of the site [12].

The structural system would have been based on a series of frames made of tubular latticed box girders hung from masts forming a succession of 11.2-metre-wide strips that could be extended in any direction, so as to increase the spans, the number of supports or to add more strips. The spans in each frame would have been changed to fit the dimension of the ruins and bending in the span reduced by tie bars. The foundations would have not been made of heavy blocks of concrete but rather screw anchors or grouted bars according to the resistance of the soil. The roof itself would have been a prestressed structural membrane stretched across the trussed beams and extended by flying masts pushed up by adjustable cable nets. As the membrane is structural, neither purlins nor ties to the ground were necessary; the system was





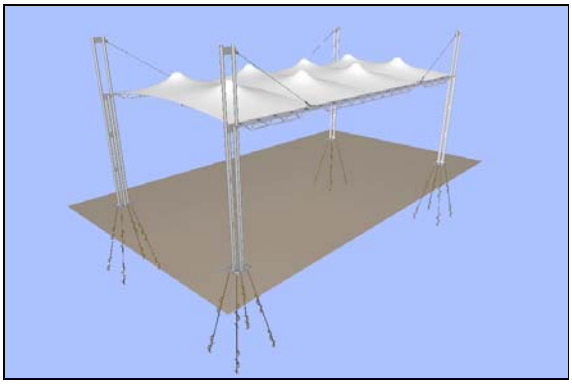


Fig.63: Plan of the modulated latticed frames adaptable to whichever areas needed to be protected. Fig.64: Axonometric view. Fig.65: Detail of the module.

self-stabilizing. The self-weight of the roof with its fittings would not have exceeded the range 50 to 100 N/m^2. As the membrane is structural, neither purlins nor ties to the ground were necessary; the system was self-stabilizing. The self-weight of the roof with its fittings would not have exceeded the range 50 to 100 N/m^2.

3.9 Juxtaposed roofs by N.Kugel & A.Rein, Architekten und Ingenieure.

The juxtaposed roofs designed by N.Kugel & A.Rein are mentioned as an illustration of the principles of the International Council on Monuments and Sites (ICOMOS) referring to "differentiating from the historic parts" and "reversibility"[13].

Fig.67: Kufstein fortress, 2006. Fig.68: Felseinreitschule Salzburg, 2008. Fig.69: Salzburg Residence courtyard, 2012. Fig.70: Castle ruins of Thierstein, 2013.

4 CONCLUSIONS

The review of 80 interventions on historic buildings has revealed the characteristics that make structural membranes suitable for the refurbishment according to the principles formulated by ICOMOS, the International Council on Monuments and Sites. Because they are light, translucent, non invasive, differentiated, reversible and compatible, they can be integrated into the building layout and preserve its historic character and architectural configuration. And, most important for the designer, they enable the difficult balance between conservation and creativity that arises in refurbishment operations.

Three design strategies have been observed. If the intervention has to be overlooked, an option would be the symbiotic integration that causes the ETFE foil. But if additions or replacements are needed, a tailored tensile surface specifically designed to fit in the place may dialogue with the pre-existences. More appealing would be the juxtaposition of an outstanding different shape despite the difficulties of integration and compatibility.

Several applications have been identified, specially the protection of ruins and archaeological sites and in recent years, structural membranes cover large existing open spaces such as stadiums and arenas promoting the updating and recycling of existing buildings.

REFERENCES

[1] J. Llorens & A. Zanelli, 2016: “Structural membranes for refurbishment of the architectural heritage” in Procedia Engineering 155 (2016) 18-27, doi:10.1016/j.proeng.2016.08.003

[2] M.Barozzi et al. 2015: "Design of novel covering system for archaelogical areas" in "Structural Membranes 2015 - VII International Conference on Textile Composites and Inflatable Structures", E.Oñate, B.Kröplin & U.Bletzinger (eds.), CIMNE, Barcelona, p.105-114.

[3] P.Beccarelli et al. 2010: "Textile shelters for archaeological areas: a change in the preservation of cultural heritage" in H.Bögner-Balz & M.Mollaert, ed. "Tensile Architecture: Connecting past and future". TensiNet Symposium 2010, Sofia, p.165-175.

[4] S.Lombardi & R.Canobbio, 2010: "Covering for archaeological sites (few examples)" in H.Bögner-Balz & M.Mollaert, ed. "Tensile Architecture: Connecting past and future". TensiNet Symposium 2010, Sofia, p.339-349.

[5] A.Zanelli, 2015: "Architectural fabric structures in the refurbishment of archaeological and cultural heritage areas" in J.Llorens, ed. "Fabric Structures in Architecture", Woodhead Publishing, Cambridge, p.481-527.

[6] H.J.Schock, 1997: "Soft shells. Design and technology of tensile architecture". Birkhauser, Basel.

[7] J.Llorens, 2003: "Details in context. Case studies" in M.Mollaert et al.(ed) "TensiNet Symposium: Designing Tensile Architecture", Vrije Universiteit Brussel, p.84-94.

[8] *http://www.designboom.com/architecture/gmp-arkitecten-verona-arena-roof-cover-italy-02-01-2017/* (visited 17/06/2017)

[9] Von Gerkan, Marg &Partner, 2005: "Olympic Stadium in Berlin". DETAIL 9/2005, p.931-949.

[10] F.Krinzinger, 2000: "A roof for Ephesos". Österreichisches Archäologisches Institut, Wien

[11] *http://www.fernandovisedo.com/cubricion-casa-romana-del-anfiteatro-de-merida/* (visited 23/06/2017)

[12] J.Llorens, Ch.García-Diego & H.Pöppinghaus, 2003: "Tensegrity structures for textile roofs" in E.Oñate & B.Kröplin (ed): "Textile composites and inflatable structures", CIMNE, Barcelona, p.64-72.

[13] *http://www.kugel-architekten.de/* (visited 23/06/2017)