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Structural membranes for refurbishment of the architectural heritage

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Abstract

The characteristics that make structural membranes suitable for the refurbishment of existing buildings have been investigated by analysing 80 interventions in 24 countries. The cases have been classified chronologically, distinguishing them by fields of application, by countries, and by the type of installations, whether they are mobile or fixed. Several design strategies have been identified and contrasted with the principles set by the International Council on Monuments and Sites. The results are illustrated with examples chosen from the cases investigated, with the aim of highlighting how membrane structures can fulfil the most important principles of the preservation of architectural heritage.

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Keywords: Structural membranes, architectural heritage, historic buildings, industrial heritage reuse, building preservation

1. Introduction

Structural membranes are particularly suitable for refurbishment of existing buildings and urban spaces, especially historic ones, when the needs of enlarging the floor space or retrofitting existing areas arise. While in the past, structural membranes have been used principally as a covering system, a wider range of requirements is emerging nowadays and thus, a multiplicity of diverse textile architecture solutions can significantly fulfil many nuanced needs dealing with protection and valuing of the cultural heritage.

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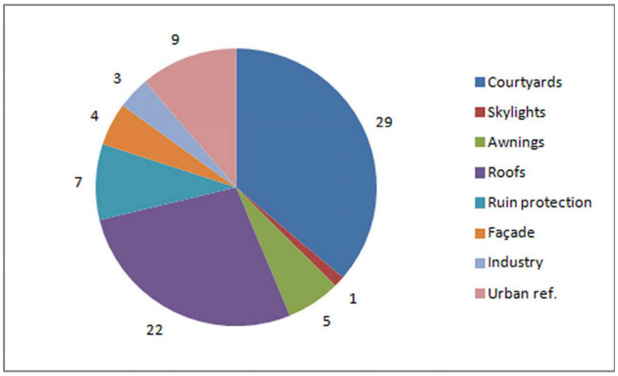
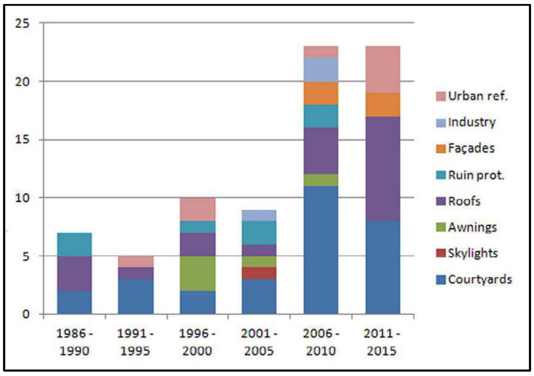
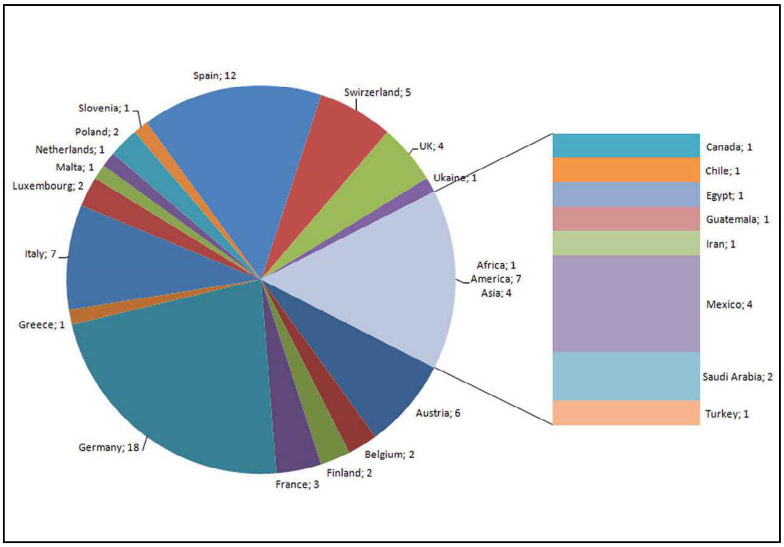
To determine how the characteristics of structural membranes adapt (or fail to adapt) to the demanding requirements of heritage restoration, a detailed analysis of 80 interventions has been conducted, drawn from our own designs, the documentation kindly provided by the designers, including visits to the sites and literature. Some of these examples are particularly significant and deserve to be elaborated further to show the way they achieve integration or dialogue with the existing building and the contacts between such diverse construction systems.

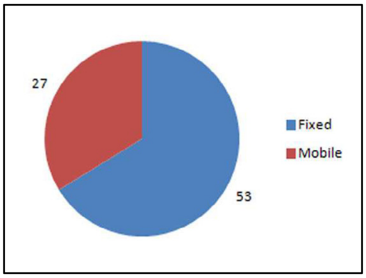
2. The sample

3. Eighty cases have been chronologically classified, distinguishing them by countries and fields of application: courtyards (29), skylights (1), awnings/canopies (5), roofs (22), ruin protection (7), façades (4), Industry (3), and urban refurbishment (9) (fig. 01). An increase in the use of membranes over the last 30 years is clearly observed, led by applications in courtyards and roofs (fig. 02). Referring to the 24 countries represented, two of them (Germany and Spain) top the list with more than 10 interventions. Furthermore, Europe accounts for 68 cases, America for seven, Africa for one, and Asia for four (fig. 03). In addition, mobile roofs have been distinguished from fixed installations (fig. 04). The complete list of interventions and links is available at:
http://sites.upc.es/~www-ca1/cat/recerca/tensilestruc/REFURBISHMENT_web.pdf









Left to right and top to bottom:

Fig. 1. Fields of application.

Fig. 2 Chronological development of fields of application.

Fig. 3. Countries where interventions are located.

Fig. 4 Fixed or mobile.

4. Principles of intervention in existing buildings

Textile architecture and structural membranes potentially offer several advantages, such as high flexibility, low visual impact, natural shapes, modularity, suitability for any geometry, reusability, light supporting structure, easy transportation, low maintenance requirements, and fast installation or dismantling. Nevertheless, the performance of the technical textile materials needs to be investigated, as well as the design methodology in order to assure the quality of the solution in the specific context, which has a very close relation to the peculiarity of the existing buildings.

According to the principles of the International Council on Monuments and Sites (ICOMOS), interventions on historic buildings and sites should:

1. preserve their historic character and particular significance
2. be non-invasive and compatible with the existing size, scale, and architectural values
3. be differentiated from the historic parts and be reversible

The first principle refers primarily to the *approach of replacement*, seeking to re-create a missing section or component (most often the roof) of the building that has been passed down to us from a previous era. This approach requires the highest level of accuracy throughout the design phase, in order to: 1) preserve to the extent possible, the historic character of the heritage; 2) avoid any future problems (e.g., condensation, excessive light shadows) and 3) allow for the exchange of air and the optimal ventilation under the renovated area.

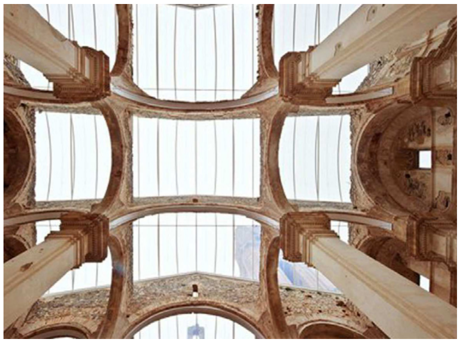
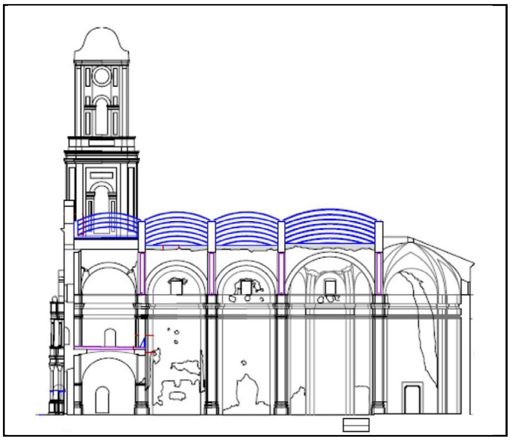
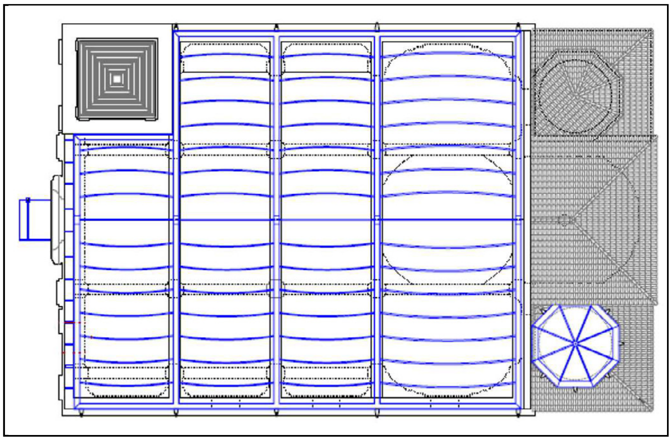
The second principle has to be taken into account mostly in the *approach of integration*. Adding functions to an ancient building requires additional space, and this leads to a review of the entire structure, and to find a dialogue between new and old building components. It becomes a meticulous work, with the objective of finding: 1) the linguistic coherence; 2) the structural compatibility and 3) the feasible connexion between different materials and techniques.

There are fewer other occasions when project designers want to highlight as much as possible the temporal difference between what previous centuries have bequeathed us and what is being added. This approach ensures a clear distinction between the volumes, and allows the viewer to interpreter the dynamics or contrasts between such structures. This kind of intervention has been led by the approach of juxtaposition between historic and new elements, where the textile material becomes a light medium between the environments of the past and the present. Little guidance can be generally assumed from the *juxtaposition approach*, which requires a different strategy every time, finding the right balance between two opposite requirements: 1) how to differ the new elements from the old ones and 2) how to minimize the visual impact of new buildings in order to guarantee to the visitors, at least from the perspective of the perception of the ancient elements. The reversibility of the new intervention is the most important aspect that designers have to take into account to the greatest possible degree in the adoption of the juxtaposition approach.

In spite of the large number of case studies considered, the authors are aware that is not possible to establish an exact number of best practices in the application of membranes in architectural heritage. Thanks to the few examples that follow, the authors aim to emphasise that not only does the juxtaposition approach seem to be compatible with the outstanding aesthetics of membrane structures, but the approaches of replacement and of dialoguing integration are also most often preferred and technically feasible. From the following case studies, some guidance should be inferred for broader textile application in the construction environment of the future.

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



Left to right and top to bottom: Fig. 5: Church and village of Corbera d'Ebre (Spain). Fig.6: Ruins of the church. Fig.7: ETFE transparent roof. Fig.8: Section. Fig.9: Plan.

The completion of the ruins of the Corbera d'Ebre hilltop roofless church (fig. 5) is an outstanding example of recovering the use of a building while preserving its architectural character. The roof was destroyed during the Spanish Civil War (1936-1939) and its ruins remained as a memorial of the events that strongly affected the village and its habitants (fig. 6). Nevertheless, the lack of protection exposed the church to 75 years of deterioration, which severely limited its use for cultural, social, or religious activities.

For this reason, a new transparent ETFE roof was envisaged (figs. 7 to 9). The idea of the roof being transparent came from the need to maintain as far as possible, the character of the ruins, preserving the feeling of being outdoors, keeping the church open to the sky and illuminated by the sunlight. The idea of the roof being light (made of ETFE instead of glass) was the intent to affect as little as possible the existing walls that were topped with a reinforced concrete ring (fig. 10). In this way, a series of gusset plates (fig. 11) could be anchored into the ring, which could support the structure of the roof that consists of a frame made of cold-formed U-steel channels subdivided by tubular arches and valley cables. The membrane rests on the tubular arches, and the valley cables stretch it and provide double curvature (fig. 12). In addition, confusion between the added elements and the old ones is prevented by the gap left between the frame and the supporting walls, alongside with the steel being painted white.

In summary, a transparent, simple layer of ETFE roof was added to enable returning the old church back to the townspeople, transforming it into a new and secure multifunctional public space (figs. 13 and 14). The cost was 303,993 € for 678 m^2 (448 €/m^2).

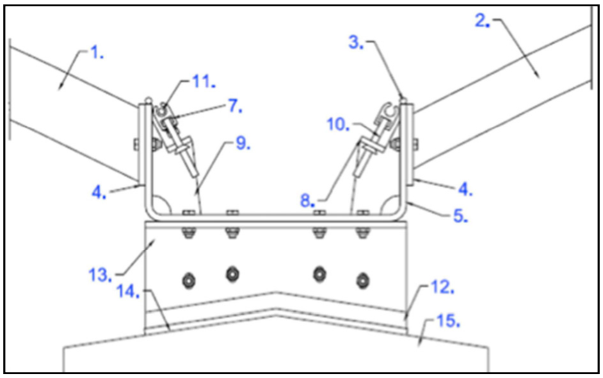


Fig.10: Reinforced concrete ring on top of the walls. Fig.11: 1 CHS 101.6x3.6; 2 CHS 76.1x3.25; 3 Ø10; 4 Cap; 5 Channel 400x180x6; 7 Keder rail; 8, 10: Tensioning system; 9, 12, 13 Gussets; 11 Polymer edge bead; 14,15 Ring.

Fig12: Valley cables stretch the membrane and provide double curvature.

Fig.13, 14: The transparent roof maintains the character of the ruin and transforms it in a multifunctional public room.

5. 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.

Fig.15: Palacio de Minería

Fig.16: The roof over the courtyard

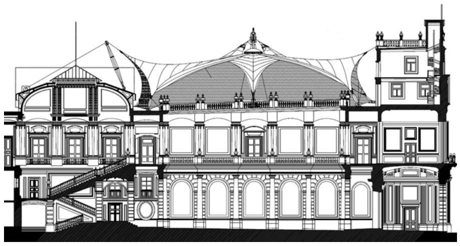
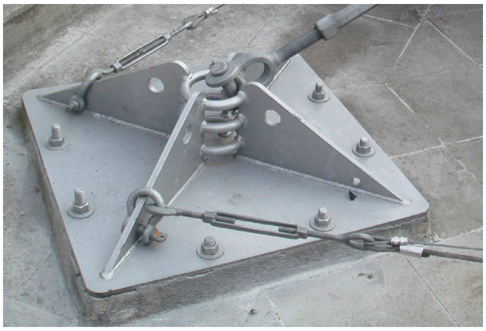
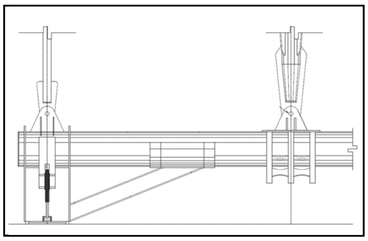


Fig.17: The roof does not alter the external look.

The "Palacio de Minería" in old downtown Mexico City was designed by the Architect Manuel Tolsá, and was built between 1797 and 1813 (fig. 15). It is considered a masterpiece of Latin American neoclassicism that must be preserved. It houses several institutions, and its 26 x 26 m courtyard is often used for diverse social, cultural, commercial, and academic events such as book fairs, conferences, concerts, courses, exhibitions, and fashion shows. To provide shade and protection from the rain, a cover was designed and built in 2002 that became an icon of textile architecture in Mexico (fig. 16). After nine years of use, the structure was still in good mechanical condition, but its appearance was strongly affected by the high level of pollution and by the lack of regular maintenance. Therefore, the cover was replaced in 2011, taking the opportunity to improve the material from PVC-coated polyester Précontraint 705 by Serge Ferrari to the dirt-resistant, 100% recyclable and durable 1102 T2 by the same material producer.





Left to right and top to bottom: Figs.18, 19, 20: Plates anchored in the concrete slab pored during a previous restoration. Figs.21, 22: Prestressed masts. Figs.23, 24: Masts are pinned on CHS acting as beams between plates.

The schedule included the requirement of not altering either the existing structure or the external look, meaning that no structural elements of the roof might be seen from the streets. This requirement implied that the intervention had to be very light and that the height of the masts would be limited (fig. 17). Additionally, in order 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. 18 to 20). Masts are 9 m high and are prestressed with ties to reduce buckling and their cross-section (figs. 21 and 22). They are pinned-on CHS, acting as beams spanning between plates (figs. 23 and 24).

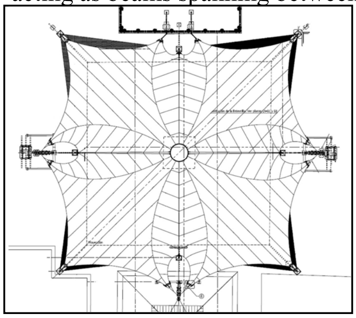
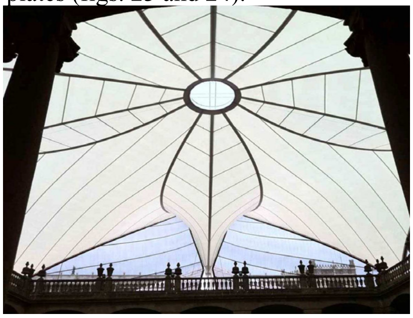
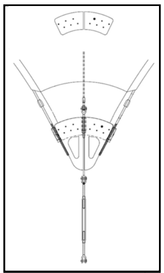
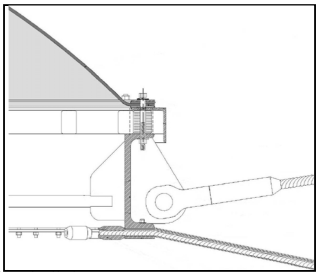




Fig.25: Plan. Fig.26: The radial scheme maintains the central symmetry Fig.27: A memory of Candela

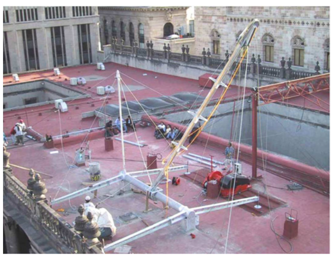
The 35 x 35 m translucent membrane cover was patterned with the software "Easy - TechNet GmbH" and was manufactured by "Carpas y Lonas El Carrusel SA" in one single piece in order to avoid joints on site, to reduce labour, and to minimise leaks. Its radial scheme defines four hyperbolic paraboloid surfaces separated by four V-shaped forms (fig. 25). It maintains the axes of the building, emphasizing its central symmetry (fig. 26). The overall double-curved and thin, white shape recalls and honours the shells of Félix Candela that make up other landmarks in the city (fig. 27). Detailing of the membrane is reduced to the corners (figs. 28 and 29) and the joint around the skylight.



Figs.28, 29: Detail of the corners. Figs.30, 31: Detail of the skylight.

The skylight is 2.5 m in diameter and rises 23 m above the floor level. It is composed of a ring made of galvanized channel and angular steel sections, enclosing a translucent, thermoformed, highly impact-resistant-acrylic surface (figs. 30 and 31). The skylight was envisaged to provide overhead lighting in the courtyard, contributing to the easy assembly and dismantling of the roof, given that one of the principles on which the roof was based was that it could be removed if required to leave the courtyard of the building as it was originally designed.




Figs.32 to 35: Installation process.

For the installation, the membrane and skylight were extended on the floor, and the masts on the roof were raised (fig. 32). The lifting was assisted by electrical motors, cables, and pulleys in a manner that the different stages of the mounting process could be considered works (figs. 33 to 35).

In summary, the historic building has been enhanced by the functionality of the membrane, which was designed taking into account the formal guidelines of the Palacio de la Mintería in order to preserve its architectural configuration. The membrane was easy to erect and will be easy to dismantle, it is light enough to rest on the existing structure without special reinforcement, and is flexible so as to admit the irregular sinking of the site (a former lagoon). In addition, if the roof is removed, all of its elements would disappear, and the courtyard would return to its original state.

6. Retractable roof at Salzburg Residence, designed and manufactured by Kugel Architects

The following case study presents a contemporary *velarium* as a heritage intervention pertaining to an integration design strategy. The retractable roof in the courtyard of Salzburg Residence cannot be strictly considered as a replacement, since the presence of an older *velarium* is not documented, but it seems to be a notable example of integration for two reasons: 1) it represents a different approach in protecting an open-air area enclosed into the built blocks and 2) the result is significantly coherent with that precautionary principle, which prefers reversible and seasonal structures, in spite of permanent ones.

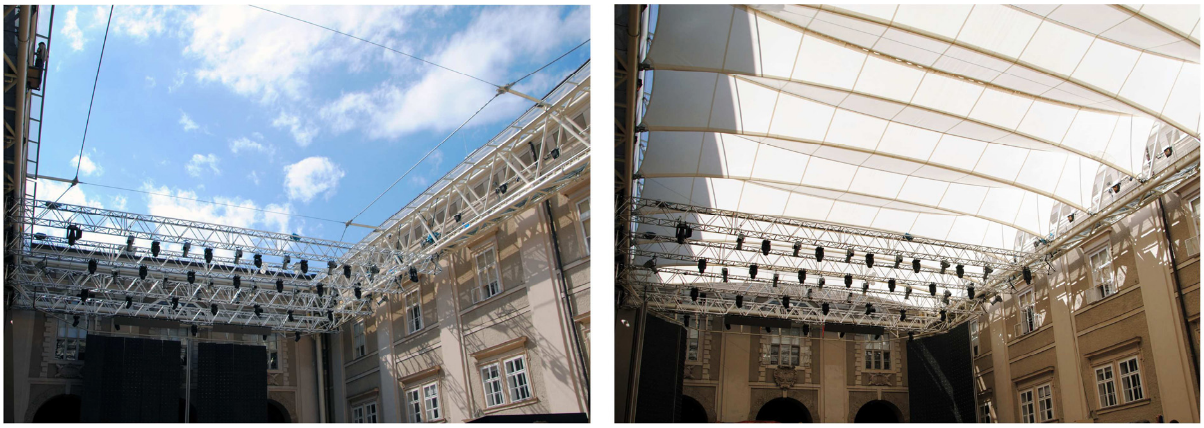


Fig.36: the seasonal retractable membrane structure at Salzburg Residence; view of the folded and opened velarium.

As the Salzburg Residence has been hosting the Salzburg Festival in its inner courtyard for several years, a retractable membrane protects the courtyard, opening and closing automatically within minutes (fig. 36). The whole roofing structure, designed by Kugel Architects in 2012, will be assembled and disassembled for many years into the future. By adopting this measure, no alternative indoor venue needs to be provided as a contingency for bad weather conditions. The protected buildings remain unaffected, as only minor horizontal forces are transferred to the facades (figs. 37, 38).

The steel framework, supported by four steel columns, serves as a catwalk for lighting technicians, situated 14 m above the ground level (fig. 39). The rectangular covering surface, 22 m by 37 m, can be closed by a parallel, foldable-textile membrane, moving alongside the framework girders. Ridge-and-valley cables carry the textile fabric. While opening the roof, the membrane becomes pre-stressed in both directions in order to bear the wind loads. Whenever the roof is opened, the membrane is folded under a textile membrane shelter at the east side (fig. 40), which closes the irregular part of the courtyard as well.

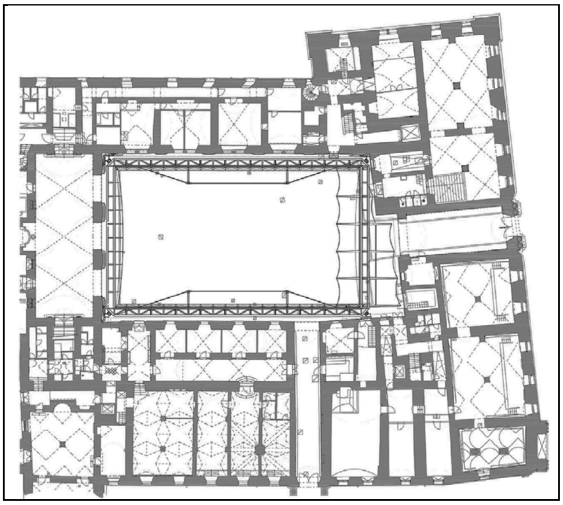


Fig.37: The temporary structure inserted in the building in a horizontal view. (Courtesy of Kugel Architects).

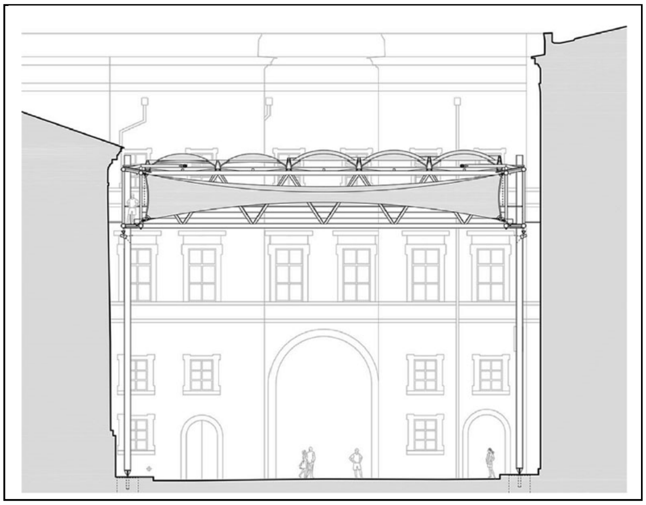


Fig.38: The relation between old and new intervention in a section view (Courtesy of Kugel Architects).

Our heritage cities are full of open-air courtyards, which have been hosting several functionalities during different seasons. Thus, well-designed and durable membrane structures are preferable to poor and provisional solutions. Similar approaches should be taken into account in a wide range of applications in the constructed environment.

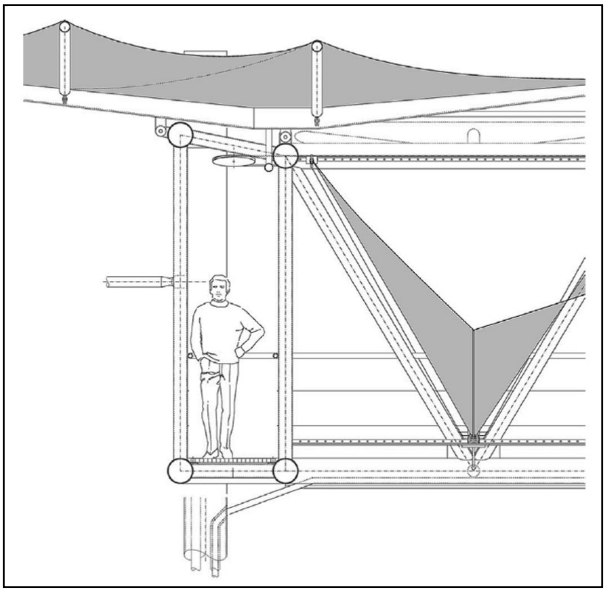


Fig.39: Construction details in vertical section. (Courtesy of Kugel Architects).

Fig 40: View of the east side shelter protecting the whole membrane when folded. (Courtesy of Kugel Architects).

More information on the construction, design, manufacturing and assembly, including a video display of the operation is available at: http://www.kugel-architekten.com/content.php?n=1&d=24

7. Conclusion

The world's leading bodies for protecting global heritage have been endorsing more and more the development of quality textile constructions as a protection system of endangered architectural heritage, following high standards of protection, flexibility, and reversibility, which is something structural membranes can guarantee.

As fabric structures are by nature on the one hand, essentially made of the minimum number of building elements, and on the other hand, sinuous and translucent to natural light, they can perform many different and complex solutions, fulfilling the need to protect the constructed environment. Both the provided sampling of 80 interventions and the following selection of case studies aim to show the wide range of possible uses of structural membranes in refurbishment and to highlight good practices in their current application. Nevertheless, textile materials and structural membranes are still generally underused in refurbishment, in comparison to other building materials.

In order to optimize the conservation and the visibility of the cultural heritage, the selection of appropriate materials for sheltering and protecting old buildings and ancient monuments is one of the most crucial issues that requires further study, and to be updated to include the wider range of new materials and construction technologies that are available nowadays. Further comparative studies on lightweight materials - textiles included - will allow structural membranes to cover an increasingly significant role in preserving and passing down our constructed legacy to future generations.

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