

NEW LIGHTWEIGHT STRUCTURES AND HISTORICAL HEAVYWEIGHT STRUCTURES IN CONSERVATION

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Abstract. *The field of lightweight structures becomes an important field of activity, not only in the built environment. The relevancy of this field to the conservation of the historical built environment is also very high. One of the most important and innovative issues is the integration between lightweight structures and historical heavyweight structures. But in the current situation, many of the practice and the research activities in this field are relatively specific and local. The activities are in many cases even done using different kinds of terminologies. This in addition to the fact that in general most of the research in conservation focuses mainly on historical heavyweight structures. In the current situation there is a need to create a wider and more integrated body of knowledge in order to explain and guide the existing activities as well as the future research and developments. The present research lays the foundations for a conceptual framework and a theoretical basis for the integration of new lightweight structures and historical heavyweight structures; reviews the recent theoretical and historical background; and defines an initial scheme of intervention design strategies for integrating lightweight structures with historical heavyweight structures. The basic implications of those strategies, in relation to the architectural – structural visual language, are presented and discussed, while other implications will have to be developed in future research. These efforts are part of an overall activity for developing a body of knowledge dealing with lightweight structures and conservation.*

1 INTRODUCTION

The conservation process of the built environment deals with a large gamut of structures. The richness of structures is continuously growing in the last centuries and nowadays it includes as well many structures with advanced technologies. These structures become more and more relevant to the conservation field. One important group of structures is the one of lightweight structures, in their contemporary meaning.

Lightweight structures always existed in the history of the built environment and different examples like tents, canopies, and other lightweight shelters can be brought. In parallel, designers and builders invariably aspired to lighten the weight of structures even when dealing with heavyweight structures. But in the last eras, different scientific engineering and technological developments enabled to lighten the weight of structures outstandingly, creating great challenges to the conservation field.

Despite the importance and relevancy of lightweight structures to the field of conservation, most efforts of research and practical activities focus on historical heavyweight structures, since naturally, many of the historical structures are still heavyweight structures. In the current situation, there is a great necessity to concentrate more on lightweight structures in the conservation field, in parallel to historical heavyweight structures.

This research deals with the use of new lightweight structures in a historical heavyweight conservation context, which is one of the challenges in the field of lightweight structures and conservation. The present research lays the foundations for a conceptual framework and a theoretical basis for the integration of new lightweight structures and historical heavyweight structures; reviews the recent theoretical and historical background; and defines an initial scheme of intervention design strategies for integrating lightweight structures with historical heavyweight structures. The basic implications of those strategies, in relation to the architectural – structural visual language, are presented and discussed, while other implications will have to be developed in future research.

The term "architectural-structural visual language" is used since in lightweight structures, very often, it is nearly impossible to separate between the architectural and the structural language. In addition, the focus in this research is on the intervention design strategies in which there is a clear visual distinction between the new lightweight structures and the historical heavyweight structures. The term "historical heavyweight structures" relates not only to historical structures but also to old existing structures.

2 LIGHTWEIGHT STRUCTURES AND CONSERVATION – THEORETICAL BACKGROUND

2.1 Lightweight structures – General background

The issue of lightweight structures is an interdisciplinary issue, which gets a special focus in a wide range of fields as: mechanical engineering aeronautical engineering, industrial and product design, architecture, civil engineering, materials engineering, morphology science, and other fields including art (for example, in connection to the possible relations between lightweight structures and sculptures[1]). Indeed, many objects surrounding us, such as laptops, cars, air-planes, etc., have a strong connection to the issue of lightweight structures. But "lightweight structures" is a relative and dynamic term. Accordingly, what we consider today as "lightweight" in the built environment can be considered heavyweight in the future. This relativity, beside additional reasons, makes it sometimes difficult to determine which buildings and structures have to be included in this category of lightweight structures. The borders can change with time and are not always clear. Generally, lightweight structures can be identified nowadays with the topics of minimal structures, minimum use of materials, natural structures and others. Yet, lightweight structures are connected especially with tensile structures like membrane structures, cable net structures, cable domes etc., as well as with other kinds of structures [2] like lightweight grid shells [3]

In the architectural language, lightweight structures are connected, in many cases, with transparency, and weightless appearance. Lightweight structures are special structures, not only due to their lightness, but also due to the fact that within them, little, if anything, is dividing between the configuration and the formal expressions. This topic deals with the question whether a structure can be beautiful by itself [4] and other issues dealing with the connection

between science and art in lightweight structures. There are many ways to lighten structures and different strategies can be identified to reduce the structure's weight, addressing aspects such as materials, overall geometry and other characteristics [2]. In general, all these strategies to lighten structures are continuously in a process of evolution, towards more lightness of the structures.

3.2 Lightweight structures and conservation

The field of lightweight structures can be strongly connected and relevant to conservation engineering and architecture in different facets, and is especially important since the modern era. Lightweight structures, many of which are from the recent past, contribute to the unique diversity of the modern heritage. The study of those structures, can contribute to understanding the philosophy of lighter structures along history and it is also relevant to the field of conservation engineering and architecture. Different mutual benefits can derive from connecting lightweight structures to the field of conservation.

Various examples of the challenges in the field of lightweight structure and conservation can be brought: the conservation of aging lightweight structures from different periods, the integration of new lightweight structures with historical heavyweight structures, lightweight strengthening intervention in historical heavyweight buildings, pedagogical issues of lightweight structures and conservation, etc. [2]. All these, in addition to the challenge of understanding the history and the philosophy of lightweight structures and their connection to conservation. As mentioned, this research focuses mainly on the challenge of the integration between new lightweight structures and historical heavyweight structures. It is important to stress that especially today, in the digital era that enables the application of very innovative technologies, those new lightweight structures can be designed as outstanding and unique ones. The results can be a mixture of new complex geometries, new advanced materials, in different variations together with the historical heavyweight structures. It is emphasized in this paper that researchers, engineers and architects who deal with conservation of the built heritage, should also concentrate on lightweight structures, generally and also specifically, on issues like integration of lightweight structures with historical heavyweight structures.

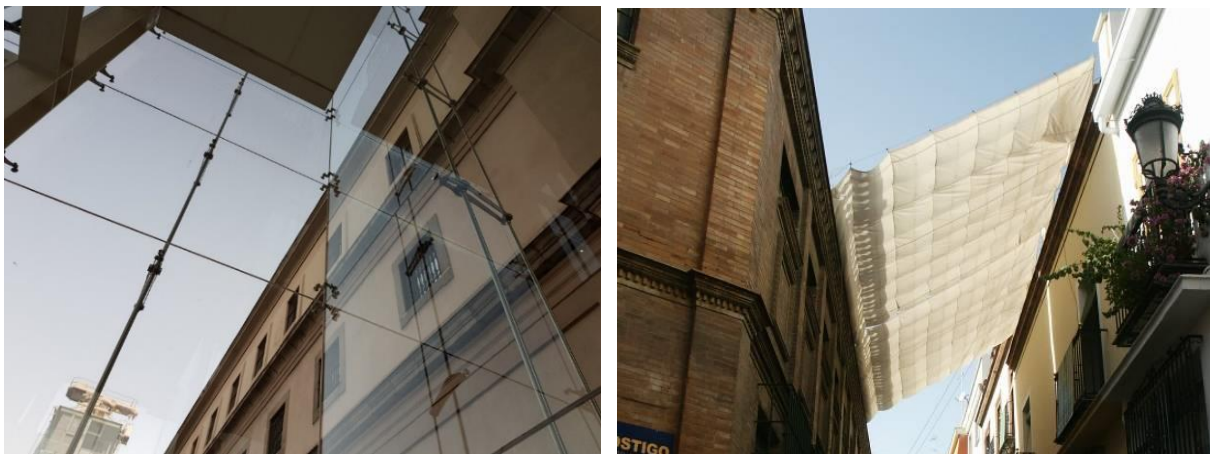


Figure 1: Examples of integration of lightweight structures with historical heavyweight structures
(Photographs by the author)

2.3 Relations between new lightweight structures and historical heavyweight structures

The issue of the relations between new and old-historical in conservation is a complex and multi-dimensional issue, dealing with many subjects. It can have cultural, social, aesthetic, economic, environmental and other aspects. Indeed, different strategies and approaches to those relations can be developed. The focus in our research is on the cases where the new structure integrated with historic heavyweight structure is lightweight, and there are relations which create a clear visual distinction between the old and the new. In the new situation the old historical entity is not the same any more. The new and the old are now an innovative system with new specific and unique characteristics and features.

3 NEW LIGHTWEIGHT STRUCTURES INTEGRATED WITH HISTORICAL HEAVYWEIGHT STRUCTURES – HISTORIC PERSPECTIVE

3.1 General

Understanding the development of the field of the integration between new lightweight structures and historical heavyweight structures along history is an important and fundamental step in this relatively new field in conservation. Understanding its evolution and architectural and engineering expressions along time can help us to analyze the developments and the main trends in the past, but also to acquire a background for the future developments of new abilities and strategies of design in this field. Accordingly, in the next paragraphs different selected milestones along time will be introduced.

3.2 New lightweight structures and historical heavyweight structures in early days

Creation of new structures integrated with old structures always existed in the history of the built environment. From early days of history, many buildings were designed and erected on the same site, in different periods and by different people, in a process of evolution. Indeed, in this process numerous buildings were heavyweight and it is reasonable to assume that many of the integrations between new and old were done with heavyweight structures. In addition to heavyweight structures, lightweight structures were also erected from the early days of the human being, as tents, canopies etc. Between the more sophisticated lightweight structures, it is possible to find deployable lightweight structures, which were integrated in the Roman amphitheaters to provide protection against the sun. For example, In the Roman Coliseum, which is considered to be a heavyweight structure, there was a lightweight deployable fabric, which created an upper shelter [5]. In the Renaissance one can find the use of lightweight textile structures integrated with heavyweight structures for covering courtyards. This, in order to create ephemeral shelters for public events, as the covering of the courtyards in Medici Palace and Pitti Palace in Florence [6].

In parallel, also in vernacular architecture it is possible to find lightweight fabric structures. Those were used also for shading, integrated in heavyweight historic buildings or urban areas, as a cover for courtyards, streets, or other open spaces. In Sevilla, Spain, there is an old tradition called the "Seville awning" [7] and it can be seen even nowadays in Sevilla and in other places.

3.3 Lightweight structures in the industrial revolution and the modern era

In the industrial revolution, new materials and technologies, industrial production, advanced theories and other achievements facilitated significant improvements in the capacities to diminish weight and create much lighter structures. Especially, the new technologies using iron and steel allowed designers to lighten the weight of structures [4]. This process had a great impact also on the architectural language which became, in many cases, lighter, transparent, with new elements of visual lightness. The Crystal Palace, which was designed and erected with iron and glass [8], can serve as an example for this phenomenon, besides many other projects. In parallel, textile structures for tents, circuses and other purposes were created as well and can be brought as examples for lightweight temporary shelters in this era [6]. Those structures were erected in different environments, including in the historical built environment. Other developments in lightweight structures include activities of figures like Vladimir Suchov, Buckminster Fuller and other designers, who had new ideas and visions in different aspects like geometry, materials etc. [2].

3.4 Integration of new lightweight structures since Frei Otto and beyond

One of the most important contribution to the field of lightweight structures in the modern era is the work of Frei Otto. His fields of activities and projects include structures like fabric tensile structures, cable structures, pneumatic structures and other lightweight structures from different materials and with various geometries. One of the projects which deals with the integration between new lightweight structures and historical heavyweight structures is the open-air theatre roof for the Bad Hersfeld church - a retractable textile roof over the courtyard of the church, designed for a seasonal purpose [9].

As an outcome of the developments in the field of lightweight structures, more lightweight structures integrated with historical heavyweight structures were erected. For example, the retractable roof installed for the "Schubertiade" in the inner court of the Hohenems Castle. The roof consists of a white translucent inner membrane, plus a loosely tensioned outer membrane [9]. Other examples can be brought from the work of the architect Renzo Piano. The first is the Otranto urban regeneration workshop - a UNESCO-supported project aimed at the renovation of historic town centers, with the purpose of testing the feasibility of using local artisans to restore an ancient town center [10]. The project included a tent roof that sheltered a wide range of activities open to and inviting the participation of the local citizens [11]. The next example is the Schlumberger Renovation, Paris, France [10], which includes the usage of a lightweight structure – a membrane structure - in the rehabilitation process [12]. Schlumberger Renovation was the first of a series of projects aimed at reclaiming industrial sites. While extensive changes were made inside the precinct of the site, the original exteriors were conserved to keep the historical identity of this area in the outskirts of Paris [10]. This project is one of the earliest cases of using membrane architecture in the rehabilitation of a significant area of urban landscape [12]. Other examples from the work of Renzo piano are from the historical old port - Porto Antico, in Genova Italy. Here, new lightweight structures, like tensile membrane structure and others, were built in the historical context of the old port of Genova as part of the urban renewal plan [10].

In addition to the examples above, which are mainly membrane tensile structures, many other tensile structures were erected. Among them it is important to mention pneumatic

structures integrated in historic buildings. The pneumatic structure which was built to cover the historical heavyweight arena in Nîmes, France [13], can serve as an example.

3.5 Advanced transparency in lightweight structures integrated with historical heavyweight structures

In parallel to all the above developments with lightweight structures, great important advances took place during the 80's of the twentieth century, in the field of lightweight-transparent structures, mainly with glass. This advancement towards more transparent architecture happened thanks to different innovative figures like Peter Rice and Jörg Schlaich [14] and others. One of the main important milestones related to the integration of those lightweight-transparent structures with heavyweight ones is the Pyramid at the Louvre in Paris, France. The structure of the glass pyramid is an early example of structural glazing stabilized with the help of cables [15]. In this case the space grid structure was innovative at the time in its large use of tensile elements [16].

In addition to this important project, examples of other new lightweight structures integrated with historical heavyweight buildings, can be brought. The covering of the courtyard of the Museum of the History of Hamburg in Germany with a glass grid shell is one of them. According to Addis, only the utilization of a sophisticated three-dimensional structural analysis software, made available in the late 1980's, enabled to build such a structure [14]. Indeed, the influence of the digital revolution was significant to lightweight structures developments.

Other important examples for transparent structures are the Louvre Sculpture Courts - courtyards in the Louvre museum, which were covered with lightweight glazed roof [17] in addition to projects like the inverted pyramid in the Louvre, Paris [18]. Later, additional significant transparent structures were erected like the glass dome for the historical heavyweight Reichstag in Berlin [19], the new lightweight glazed roof for the Great Court in the British Museum redevelopment [20] and others.

3.6 High level of Complexity – materials, geometries, design, fabrication

In addition to lightweight glass structures advancements, various developments like design technologies, fabrication, materials, and others, had a great impact on the integration of lightweight structures with historical heavyweight structures. For instance, other materials like ETFE were also used in new lightweight structures which were integrated. Some examples are: the "Kleiner Schlosshof" – the central meeting place within the castle complex in Dresden – in which the courtyard was covered with a lattice shell, filled with ETFE cushions [21]; the HM Treasuries renovation project, in which new lightweight transparent ETFE roofs were integrated to cover the large light-wells punctuating the building [22]. In addition, printing abilities on ETFE were also developed. The Aarau Bus Terminal in Switzerland, which is a lightweight structure in an urban fabric with old and heavyweight buildings, includes a large cushion wrapped by an arbitrary net of steel cables [23]. A pattern of bubbles was printed on the blue upper and the transparent lower ETFE-foil [21]. In parallel to ETFE, a great diversity of other materials relating to lightweight structures can be brought as for example composite materials [24].

Beside more advanced materials, different advanced technologies, dealing with the creation of non-standard geometries, enabled new lightweight structures with complex geometry to be

integrated. An example for this case is the "Capital C" (De Diamantbeurs) in Amsterdam. Here, a new lightweight grid shell structure with a free form, was built on the roof of a historical heavyweight building. In this case an advanced design process with parametric design tools and a unique fabrication process [25] were part of the architectural and engineering creation of new with old.

4 NEW LIGHTWEIGHT STRUCTURES INTEGRATED WITH HISTORICAL HEAVYWEIGHT STRUCTURES IN THE CURRENT SITUATION

In the current situation, in the digital era, there are many types of new lightweight structures which can be integrated, in a great richness of configurations, with historical heavyweight structures. Examples of this richness include different structural strategies, advanced design tools, simulation abilities and advanced theories, different materials, textures and colors using advanced technologies, different kinds of geometries including free form, different fabrication abilities using traditional beside advanced tools and other abilities. All these achievements create great challenges in the integration of new lightweight structures with historical heavyweight structures. These can be used in innovative and creative manners, in different intervention design strategies which have to be analyzed and identified, as shown in the next paragraphs.

5 DIFFERENT DESIGN STRATEGIES FOR NEW LIGHTWEIGHT STRUCTURES INTEGRATED WITH HISTORICAL HEAVYWEIGHT STRUCTURES

5.1 General

Dealing with the issue of new lightweight structures, integrated with historical heavyweight structures, requests defining an initial scheme of intervention design strategies in the conservation process. This act is especially important as a vital step for the development of the theoretical body of knowledge of this unique field in conservation. Knowing the possible intervention design strategies can significantly improve understanding and analyzing existing situations. It can also help in the future to achieve successful synthetic and integrative design between new and old. In the next paragraphs, the focus is on cases where there is a clear visual distinction between the new and the old. Accordingly, the new lightweight interventions in these cases have also a visual lightness which can be expressed by different means such as light appearance, transparency, immateriality etc. The basic implications of those strategies, in relation to the architectural – structural visual language, are presented and discussed, while other implications will have to be developed in future research.

5.2 Addition of new lightweight structures to historical heavyweight structures

In this case there is a need to add new parts or elements, which in our scope are also lightweight, to the historical heavyweight structure. The additions can be external or internal and they can get different configurations and possibilities. External additions can consist, for example, of an enlargement of the existing old heavyweight structure with a new lightweight structure placed aside, above or in other positions. The new lightweight additions can fulfill different functions as additional floors, entrances, lifts, stairs etc. Internal additions can be different lightweight elements, used inside the original buildings for the separation of spaces,

internal lifts, stairs, etc. The additional lightweight roofs over many courtyards in historical heavyweight buildings are one type of addition. The new lightweight roof for the courtyard in the renovated “Palacio de Comunicaciones” – a single layer glass grid shell over the courtyard [3] – is an example of this type. This intervention design strategy enables to conserve the visual identity of the historical heavyweight structure as an independent historical entity versus the new lightweight structure. This distinction is especially important when dealing with the different architectural-structural languages of each period – the historical versus the new.

5.3 Replacement of historical heavyweight structures by new lightweight structures

In the conservation process there is, in some cases, a need to replace original elements or parts, like walls, ceiling or stairs, of the historical heavyweight building. This replacement can be needed as an outcome of destruction or deterioration of the original elements or of other reasons. In such situations one of the possibilities is to replace the historical heavyweight element with a new lightweight structure. The replacement of the original elements can be internal or external. The replacement of the original dome in Reichstag Berlin by a new transparent lightweight dome can serve as an example for this case. Other examples can be the replacement of original heavyweight elements by ETFE in Corbera d' Ebre church restoration in Spain [26] and the Speicherstadt Hamburg Chimneys Boiler House, Germany. In this later project two new filigree steel grid towers were erected, which remind the chimneys destroyed during World War II, and thus re-create the historic silhouette of the boiler house [27]. This intervention design strategy allows to understand visually which parts of the original buildings were destroyed and what was the real situation before the new intervention. The story of the deterioration process along time is not erased in this case and it even becomes an undivided part of the whole story of the building.

5.4 Completion of historical heavyweight structures with lightweight structures

There are cases when different parts or elements of the original historical heavyweight structure were not completed in the original construction process. Different reasons exist for this situation but in the conservation process it may be possible to complete the unbuilt elements or parts with a new lightweight structure. An example for this case can be brought from Lille in France - The Cathedral of Notre Dame de la Treille. Here one of the original façades was not completed during the historical construction process and a new lightweight façade was erected nowadays [18]. This way a clear visual distinction is seen between the new completed façade and the uncompleted historical heavyweight structure. This strategy allows to visually understand the building's uncompleted story and the completion act in the conservation process. This intervention design strategy requires a thorough understanding of the intentions of the original designers and builders of the historical heavyweight structure and to create an appropriate solution using new lightweight technologies.

5.5 Covering historical heavyweight structures with new lightweight structures

New lightweight structures can be used not only in cases of addition, replacement or completion, but also as a shelter or covering for historical heavyweight structures. In this case the new lightweight structure acts as a kind of canopy or envelope and not as part of the original building. One of the most common usages in this category is lightweight shelters above

archeological sites. Examples for tensile membrane structures covering archeological sites can be found in different places. Another outstanding example in this category, dealing with covering an historical building, is the initial scheme for the rebuilding of the historical Reichstag, Berlin. Norman Foster's initial scheme included a large canopy to cover the existing structure [20] of the historical heavyweight Reichstag. At the end, this proposal was not built, but in spite of that this proposal had a great exposure in the literature until nowadays. In relation to the visual language aspect, this intervention design strategy allows to create wide-span covering solutions, which enables relative visual freedom under the canopy. It can release the internal space and minimize visual disturbances. This in addition to the visual lightness of such covers that in many cases have a relatively large scale.

5.6 A new independent lightweight structure in vicinity to a historical heavyweight structure

A new lightweight structure can also appear as an independent structure in vicinity to or beside a historical heavyweight structure or structures. For example, in a case of two structures - the new and the old structures are not necessarily physically connected as one continuous element and they can act as two different objects, standing near each other. This category mainly focuses on the building scale - the relations between close buildings or structures. The space between the structures can act as a mediator between them, and they can behave as separated projects or as a united one. In addition, the new lightweight structure can be temporary or permanent, according to different circumstances and needs. An example for this strategy is the project of Zaha Hadid in Serpentine Gallery, London [21]. This design strategy allows a visual duality in the composition between two objects in space, standing one near the other. This duality is inherent to old versus new but can be expressed also by opacity versus transparency, static versus dynamic and other possible visual relations, which are enabled by lightweight technologies.

5.7 New lightweight structures within historical and large-scale built areas

The conservation process relates to different levels in the built environment. One of the most important levels is the urban level, which deals with the conservation of historical urban areas or other historical built places like big archeological sites that can also be in this category. In these areas or sites there may be a need to place structures which have an urban role, such as an urban landmark, or fulfill a specific function in the historic urban space. In such cases the use of a new lightweight structure can be relevant. The new lightweight structure can be easily identified in different public spaces like Piazzas, squares and it can act as a distinctive feature in the space, either temporary or permanent. Possible examples are: entrances to Metro stations, bus stops, structures for temporary markets and others. One example is the lightweight pneumatic structure erected in the historic urban environment of Berlin, directly in front of the Brandenburg Gate (for the Ecumenical Church Day in 2003) [27]. A second example is the tower including a membrane structure in Phänomena Science Centre in Lüdenscheid, Germany [28]. This intervention strategy enables to distinguish, in the urban scale, between the historical heavyweight environments and new lightweight structures in this landscape. In addition, the lightweight structure can, in some cases, act as a landmark in the urban context, that draws attention to the historical heavyweight structure.

5.8 Lightweight structures and artistic-design activities in historic environments

Historical buildings and historic urban fabrics can be in many cases a place where different artistic and design activities take place. Lightweight structures can take an important part in this unique activity. They may appear outside in historic public spaces or in internal spaces of historical buildings. The lightness, transparency, flexibility, and other properties of these structures allow them to serve in a wide span of possibilities in art and design. They can be used as sculptures, monuments, structures or for other artistic and design activities. An example of using lightweight elements for an outstanding art activity is the wrapping of the historical Reichstag building in Berlin as a temporary sculpture [29]. Another example which can be considered as a design creation with artistic values, integrated in a historic environment, is the Elytra Filament Pavilion. The pavilion was erected in the Victoria and Albert Museum in London, using advanced technologies which include a robotic fabrication process. The pavilion establishes a dynamic space and an evolving structure. The pavilion structure is also inspired by lightweight construction precepts found in nature – the fibrous structures of the forewing shells of flying beetles known as elytra. The cover forms a fibrous tectonic system that is as architecturally expressive as it is structurally efficient [30]. This intervention design with lightweight artistic structures, in historical heavyweight environments, requires in many cases a lot of scientific understanding beside visual-artistic abilities. In addition, the issue of an object or a figure and its background is especially important in many visual artistic creations, and here the historical heavyweight structures can act as a background for the new lightweight creation.

5.9 Lightweight strengthening intervention in historical heavyweight structures which create a new visual and architectural appearance

There are cases where new lightweight structures are used to strengthen historical heavyweight structures. For this purpose, one can use steel tie rods, steel ribbons and other lightweight components according to specific circumstances [2]. In cases where the new lightweight structures are visible, they can, together with the historical heavyweight structure, create a new system which has also an architectural-structural visual language. This system has its own unique visual and aesthetic properties, which were born as an outcome of the necessity to strengthen the historical ruins. Since many historical heavyweight structures are strengthened by lightweight elements and components, which are visible in many cases, it is very important for the designers to understand the integration of the new and the old also from this point of view. In this intervention design strategy, the functional aspects of the lightweight strengthening system within the historical heavyweight system are strongly connected to the architectural-structural aspects. Functional strengthening elements, which naturally are engineering oriented, can also have a visual architectural-structural contribution.

5.10 Other possible design strategies

The intervention design strategies, which were identified and analyzed above, are selected principal strategies. Each one of them can be a crucial element in the conservation process. In addition, it is also possible to search and create new different combinations between these strategies and, as a result, to have new design strategies, which can be called hybrid strategies. In parallel it is very important to continue to deepen the study and the research in each strategy and to enrich our knowledge about its main characteristics.

6 PEDAGOGICAL ASPECTS

The study and research in the field of integration between new lightweight structures and historical heavyweight structures can also bring pedagogical benefits. It can enrich the people who are involved in the conservation studies and open them to new horizons for future design. Since in many cases most of the attention is devoted to historical heavyweight structures, understanding the possibilities of using new lightweight structures within the historical conservation context can create new innovative solutions in the conservation field. This issue is especially important in this era which is characterized by richness of different advanced technologies and possibilities of design.

7 CONCLUSIONS

The field of lightweight structures in conservation is a relatively new field. The findings of this research show that there are many advanced developments in lightweight structures, such as complex geometries and new advanced materials in different variations, which can be integrated with historical heavyweight structures. It is also demonstrated that there has been a significant evolution along time in this field. The findings also indicate that, in the first stage, a wide span of intervention design strategies for integration of lightweight structures with heavyweight historical structures can be identified. In this research a discussion is started on the implications of the different strategies on the architectural-structural visual language.

In the current situation it is important to continue the development of the body of knowledge in this field. This paper is one of the efforts to enlarge and to deepen this field of activity. In the future it is important to continue the research dealing with lightweight structures and conservation. For example, it will be useful to further develop the database on different cases of intervention such as additions, replacement, completion etc., according to different criteria and to follow the performance of the new-old systems. More research in this field can focus on further understanding the implications of different strategies on the visual architectural-structural language, in addition to other performance and functional aspects like climatic, lighting, acoustic, and other aspects.

REFERENCES

- [1] Neurohr, T. and Pasini, D. Principles of lightweight structures in the sculptural conceptions of Naum Ga-bo, *Interdisciplinary Science Reviews*, (2009) 34:4, 366-380.
- [2] Mosseri, A. Lightweight Structures and Conservation - Engineering and Architectural Perspective. In: Aguilar R., Torrealva D., Moreira S., Pando M.A., Ramos L.F. (Eds.): *Structural Analysis of Historical Constructions*. RILEM Bookseries, vol 18. (2018) pp. 116-124. Springer, Cham.
- [3] Schlaich, M., Burkhardt, U., Irisarri, L. and Goni, J. Palacio de Comunicaciones – a Single Layer Glass Grid Shell over the Courtyard of the Future Town Hall of Madrid. In: Domingo, A. and Lazaro, C. (eds). *Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures*. Universidad Politecnica de Valencia, Spain (2009) pp. 1338-1348.
- [4] Kawaguchi, M. 1996. Forward by Mamoru Kawaguchi. in Berger H. *Light structures structures of light*. Birkhauser Verlag. (1996).
- [5] Berger H. *Light structures structures of light*. Birkhauser Verlag. (1996).
- [6] Campioli, A., Mangiarotti, A. and Zanelli, A. Textile Architecture in the Italian Context.

- International Journal of Space Structures*. Vol. 23 No. 4 (2008).
- [7] Hermeking, T. Msheireb - Heart of Doha, Qatar, retractable shade canopy. *TensiNews 2015, Newsletter of the European based network for the design and realization of tensile structures*. Nr. 29 September (2015), pp 14.
- [8] Curtis, W.J.R.(1982). *Modern architecture since 1900*. Phaidon Press Limited.
- [9] Mollaert, M. Retractable membrane roofs. *Transactions on the Built Environment* vol 21, (1996). WIT Press.
- [10] RPBW Architects. Renzo Piano Building Workshop. Available in: www.rpbw.com
- [11] Buchanan P. *Renzo Piano Building Workshop. Selected Projects: Part 3*. The Architectural League of New York (1992). Available in: <https://archleague.org/publications/renzo-piano-building-workshop>
- [12] Scheuermann, R. and Boxer, K. *Tensile Architecture in the Urban Context*. Butterworth Architecture. 1996.
- [13] Zanelli, A. Architectural fabric structures in the refurbishment of archaeological and cultural heritage areas. In: Ignasi de Llorence, J. (Ed.) *Fabric Structures in Architecture*. Elsevier Ltd. Chapter 15, pp. 481-527 (2015).
- [14] Addis B. *Building: 3000 Years of Design Engineering and Construction*. Phaido. 2008.
- [15] Bijster, J., Noteboom, C. and Eekhout, M. Glass Entrance Van Gogh Museum Amsterdam. *Glass Struct. Eng.* (2016) 1:205–231.
- [16] Patterson, M. *Structural Glass Facades and Enclosures*. John Wiley & Sons Inc. (2011).
- [17] Ian Ritchie Architects. Available in: <https://www.ianritchiearchitects.co.uk>
- [18] Rice, P. and Dutton, Hugh. *Structural Glass*. E & FN Spon. (1995)
- [19] Schulz, B. *The Reichstag*. Prestel. (2000).
- [20] Jodidio, P. *Sir Norman Foster*. Taschen. (1997).
- [21] Mollaert, M., Dimova, S. Pinto, A. and Denton, S. (2016). Prospects for European Guidance for the Structural Design of Tensile Membrane Structures. European Commission Joint Research Center, Institute for the Protection and the Security of the Citizen. (2016).
- [22] Foster + Partners. Available in: <https://www.fosterandpartners.com>
- [23] form TL. Available in: <https://www.form-tl.de/home>
- [24] L. du Peloux, F., Tayeb, O., Baverel. and J.F. Caron. Construction of a large composite grid shell structure: A lightweight structure made with pultruded glass fiber reinforced polymer tubes. *Structural engineering international*. Nr.2/2016.
- [25] Octatube. Available in: https://www.octatube.nl/en_GB
- [26] Llorens J. and Zanelli A. (2016). Structural membranes for refurbishment of the architectural heritage. *Procedia Engineering* 155 (2016) 18 – 27.
- [27] sbp, Schlaich Bergerm Partners. Available in: <https://www.sbp.de/en>
- [28] form TL. Phanomenta. In: *TensiNews 2015, Newsletter of the European based network for the design and realization of tensile structures*. Nr. 29 September (2015), pp 10. Available in: <https://www.tensinet.com>
- [29] Mollaert, M. Haase, J. Hollander, S. Designing Tensile Architecture TensiNet Symposium (2003).
- [30] achimmegnes .net. Available in: <http://www.achimmenges.net>