

# Dematerialization of the Ruins: Glass as a Promising Restorative Material for the Consolidation of Historic Structures

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This research investigates the potential of glass as a new design tool to highlight and safeguard our historic structures. Current restoration and conservation treatments with traditional materials bear the risk of conjecture between the original and new elements, whereas the high consolidation demands often result in visually invasive and irreversible solutions. Nowadays, aspects of materiality and aesthetics appear as integral parts of the restoration practices, indicating new materials and technologies in the form of ambiguous gestures rather than absolute and permanent manifestations that prevail over the historic structures. The inherent transparent properties render glass a distinct material that enables the simultaneous perception of the monument in both its original and ruinous state. The emerging technologies have set the ground for using glass in a structural way minimizing the need for substructure and maximizing transparency, while protecting the sensitive historic materials. The paper explores the feasibility of this concept addressing aspects of compatibility, reversibility and transparency, through a review of realized examples. Finally, a developed methodology relates the, available in the market today, glass products to the possible consolidation treatments in respect to the degree of intervention and representativeness, stressing the potential of using and considering glass as a promising restorative material.

**Keywords:** restoration, consolidation, materiality, structural glass, transparency, reversibility, compatibility, aesthetics

## 1. Introduction

The conservation of our built heritage, in other words the architectural conservation, is an inseparable part of our cultural and national identity and ensures its existence to the future. Structures that have survived over time are imbued with values (e.g. historical, social, aesthetical), which are shaped throughout the multiple layers of history and trigger our emotions to form what we acknowledge today as cultural significance. From castle ruins and vernacular architecture to archaeological sites, the aim is not only to preserve building stock, scientific testimonies of the past or “conserve material for its own sake” (Avrami et al., 2000, p. 7); but to maintain all those values embedded in heritage settings and create a sense of belonging and familiarity, as aspects of our collective memory which enrich our present life. Any physical interventions or treatments should only serve as one of the means to achieve this purpose.

### 1.1. Conservation and Restoration principles

The practice of conservation is an evolutionary process, forming itself through the centuries and the mindset of each era. Contemporary conservation philosophy, based on Williams Morris “Manifesto of the Society for the Protection of Ancient Buildings” in 1877 and later established with the Venice Charter (ICOMOS 1964), underlines the importance of authenticity and respect of the current state of a historic structure (as found prior of any restoration actions) as well as the truthfulness which should accompany any consolidation attempt. Compared to the stylistic (and often arbitrary) restoration treatments of Viollet-le-Duc during the late 19<sup>th</sup> century, who aimed to reveal the “true form” and revive the “former glory” of gothic architecture, today, we accept that the time of these building has long passed and we try to preserve as much as possible with the least possible intervention. After all, part of the value of a historic structure is all these accumulated layers of history encoded in its decay through time. Any actions taken should be distinguishable in order to reflect their era and avoid falsified interpretation of the original structures. On the one hand, the stratification of the building should by no means be concealed and on the other hand the new materials should not be disguised, enabling an honest dialogue between the old and new, the past and present. Reversibility is another aspect of the restoration concept that should not be neglected. Every intervention should give the possibility for removal in the future either due to the development of new technologies or in case it proves inadequate or fails.

### 1.2. Restore or preserve?

Nowadays, theory and practice are contradicting resulting in two opposing movements, an on-going debate between restoring and preserving. This conflict between safely restoring a historic structure and at the same time preserving its identity, according to the conservation guidelines, stems from the fact that repairing actions refer to modern materials, technology and process (D’Ayala and Forsyth, 2007, p.6). While historic structures were designed and built in a different era and with a different function, their consolidation today is based on the structural demands and building

or sustainability codes for contemporary structures showing the way for the use of modern materials. This becomes crucial in cases such as the rehabilitation of monuments for current use; the ambition to meet the desirable safety codes and structural performance of modern structures may be followed by invasive treatments that can permanently damage the historic fabric. At the same time, without careful attention, modern materials could impose on the historic buildings impairing their authentic image. Conservative treatments with traditional materials could result in less intrusive solutions, bearing, however, the risk of conjecture between the original and new elements (Fig. 1a and b). Consequently, the curators find themselves in an internal conflict, being asked to respect and leave the monuments “untouched”, but at the same time efficiently safeguard them for future generations.



Fig. 1a) The restoration of Knossos Palace in Crete, in Greece, is debatable as a lot of assumptions were made misrepresenting the original composition, which was recreated in the archaeologist's (Sir Arthur Evans) own modernist vision (<http://www.hansdewaele.com/?p=1989>) and b) The dolphin fresco, as other frescos, was reconstructed by the Dutch artist Piet de Jong based on just tiny original fragments (<https://www.ancient.eu/image/393/>).

### 1.3. Materiality matters

As materials are the main physical expression to maintain and revive the values embedded in a historic setting, a lot of attention is placed on the harmonic articulation between the existing and the new. Aspects such as the aesthetics, the physical and mechanical properties, the connections and especially the compatibility of the new materials with the historic ones are of vital importance. Any addition or reparation on the existing structure should not interfere with its internal or external natural actions<sup>1</sup>. Modern materials are a lot different than historic ones (regarding their physical, mechanical, chemical properties), however the emerging technologies allow for their implementation in a smart way in order to achieve a better relation between building materials and performance. As original materials were chosen to satisfy a purpose in a certain context, which no longer exists, the use of contemporary materials and techniques appears more pertinent reflecting our time, culture and society (Fig 2a and b). If architectural conservation is assumed to be the process of managing the change (Orbasli 2008), what better way to leave our trace as a society of continuous change, technological advancements and innovation?

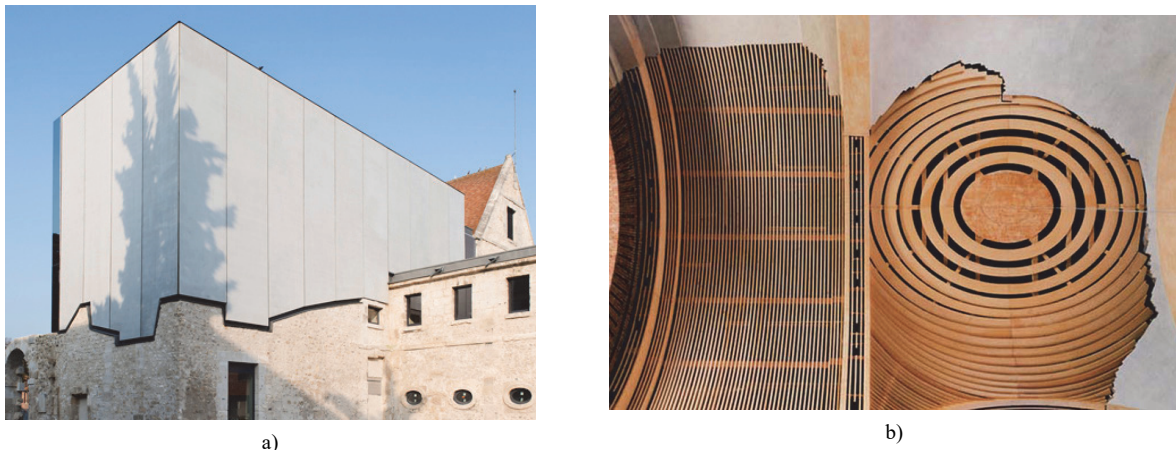


Fig. 2a) The new façade of Louviers Music School was restored using prefabricated reinforced concrete panels, cut out to follow the surface of the historic masonry showing the distinct boundary between the old and the new and b) The new roof of San Filippo Neri in Bologna uses wood, a traditional material, in a rather contemporary way to preserve the outline of the collapsed part due to Second World War bombings.

<sup>1</sup> Historic masonries should not be repointed using cement-based mortars that are impermeable and block the natural “breathing mechanism” of the walls, forcing moisture to evaporate through the historic materials and eventually deteriorate them.



#### *1.4. Inspiration from artistic restorations: Dematerialization of the ruins*

In the dawn of the 21<sup>st</sup> century restoration practice appears more extreme and bold than ever, targeting materiality as topic of discussion and questioning. However, what if we stopped trying to materialize and instead start dematerialize the bygone fragments of our built heritage? What if the demonstration of a compact form, could be replaced by vague gestures that appear visible and invisible at the same time? Transparency and translucency represent this idea of blur interpretation of materiality, a tool widely used by artists to create a sense of space continuity and juxtaposition between the existing and the new. Where architects are limited by building standards to efficiently consolidate the decayed materials, artists interpret the image of the historic structures in the present setting free of restrictions and regulations.

Artistic restorations and repairs show a trend towards any transparent means in order to complement the original volumes and give the “authentic image” without imposing it. One way to generate transparency is to give the outline of the general shape of the missing object using frameworks (Fig. 3a and b). The Basilica of Siponto (Fig. 3d), by the Italian artist Eduardo Tresoldi (2017), is one of the finest examples of conceptual transparent restoration. The use of wire mesh in his works creates a material and immaterial result that tricks the eye, while this transparency “narrates shape and space of the absent matter as a representation of something that was there and then disappeared”. The other way to generate transparency is with the actual use of transparent materials, as in the case of the artist Tatiane Freitas, who repairs old wooden furniture with acrylic elements to fill the form and give a simultaneous perception of its original and current state (Fig. 3c). Thus, inspired by artists, such ambiguous solutions could also be the answer to the current materiality dilemma, between restoring and preserving, by using materials, which appear existent and non-existent, visible and invisible.



a)



b)



c)



d)

Fig. 3a) “Reframe” illuminates the distinctive features of the space (Fleşeriu and Eszter 2016), b) Crypta Balbi’s structural elements are restored with metal mesh (<http://www.archidiap.com/beta/assets/uploads/2014/09/Crypta-Balbi-3-768x1024.jpg>), c) “New old chair” series by Tatiane Freitas using Plexiglas to repair broken wooden furniture (Freitas 2010) and d) Artistic restoration of Basilica of Siponto by Eduardo Tresoldi using wire mesh to revive the memory of the ruins (Tresoldi 2016).

## 2. Glass as restorative material: the potential

### 2.1. Why glass?

While artistic restorations can give the sense of transparency with any means, in architectural restorations the transparent elements should contribute to the consolidation of the damaged historic structure. This prerequisite can exclude the use of steel frames and meshes and encourage the use of materials with inherent transparent properties. When such materials come into discussion, glass and plastics are the first ones to come in mind followed by water, gemstones and some types of gases. However, in the fields of architecture and construction the latter categories can be simply omitted, while plastics are usually used as connective or complementary elements rather than main load bearing structure, due to their inevitable deterioration and relatively limited carrying capacity. Glass is the only material, which can create an almost dematerialized intervention due to its transparent properties, durability and high compressive strength. The latest technologies have turned glass into a competitive structural material, while the ability to see-through it converges with the demands for building skins that dissolve in the urban fabric. Advancements related to strength, safety and the declining need for supportive elements have led the way to all-glass structures of maximum transparency.

Historic structures make use of materials in large cross-sections and forms that are primarily loaded in compression, such as walls, arches and vaults. The high compressive strength of glass makes it a fitting candidate for the consolidation of such structures, while at the same time, the excellent resistance to the elements can offer indoor comfort or protect the sensitive historic fabric against corrosion. While from a conservation engineer's perspective, glass has a lot to offer as a durable restorative material its most valuable contribution to the conservation practice lies in its transparent nature. Restoring a damaged building by glass is the closest action of not restoring it at all; all traces of history are free to narrate their own story as "wounds that are healed but not hidden" (Frigo 2017, p. 25). Transparency can relate the structure to both its past and present setting, as it allows us to perceive the original volumes and, at the same time, the patina and natural ageing of our heritage, highlighting its unique and absolute character. Glass acts as complementary and contrasting, "bearing the contemporary stamp" as suggested by the Venice Charter, whereas it does not falsify the historic evidence. Furthermore, through this transparency, the monuments are related in a direct and honest way to their surroundings; the present setting and the way it has been shaped through the passage of time is what reflects their importance and values their cultural significance.

### 2.2. Franco Minissi's "Transparent Restorations"

The developments in the glass industry have rendered it a very popular and widely used material during the modern times as a means to dematerialize the, up-to-that point impermeable, facades and create a direct connection between the interior and the exterior. Consequently, it is not surprising that the first juxtaposition of transparent materials and historic buildings started around the middle of the 20<sup>th</sup> century, not always as a consolidation treatment, but rather as an attempt towards an open dialogue between the old and the new. The title of pioneer of this "transparent restoration" approach can be attributed to the Italian architect Franco Minissi (1919-1996), who created a novel architectural vocabulary in order to reveal the stratification of the monuments and reinstate their authentic image. For him, transparency was a variable element to invoke the heritage value and enable its narrative to the present (Vivio 2014). Loyal to the principles of compatibility, reversibility and minimum intervention Minissi proceeded either with conceptual or literal restoration projects using Plexiglas and glass (Fig. 4 a and b). However, due to poor maintenance, unsuitable bonding materials, the natural optical deterioration of plastic but also its "too modern" character, Minissi's work failed to meet the functional requirements and did not receive the attention it should have. Today, the new technologies can overcome and provide solutions to the technical challenges of the past and glass can once again be explored as a promising restorative material.



a)



b)

Fig. 4a) and b) Restoration of Villa del Casale, in Sicily, with a suspended transparent canopy made of glass and Plexiglas by F. Minissi (Vivio 2014)

### 3. Feasibility

In theory glass complies with the main conservation and restoration guidelines as a material that forms a legible intervention, respectful to both the stratification of the historic structure and the surrounding landscape. In practice, however, there are important parameters that determine whether a material should be part of the consolidation strategy. Factors such as compatibility of the historic and new materials, reversibility and aesthetic harmony (degree of resemblance or contrast) play an important role in the decision-making for the most suitable consolidation treatment and the chosen restorative materials.

#### 3.1. Material Compatibility

The monuments and historical buildings may be classified in two main categories regarding their structural form: hinged or articulated structures with dry joints (mainly classical temples and colonnades) and masonry buildings. Among the different materials used for their construction, such as cut stone or marble, rubble, bricks, tiles, mortars, timber, iron clamps, dowels, chains etc., only stones, bricks and mortars are called for co-operation with the new ones (Penelis 1996). When compatibility of materials is addressed, it is usually related to irreversible actions that permanently bond the historic and new materials together, so that their chemical, mineralogical, physical and mechanical properties match. Such actions involve grouting, deep rejoinings, reinforcement with steel bars, stitching of walls with pre-stressed bars, skins of reinforced concrete on masonry or strengthening of foundations (IHBC 2017). For reversible actions, such as rebuilding parts of the structure that have collapsed, properties related to strength, stiffness, thermal expansion permeability and durability are more relevant. Current restoration practices make use of traditional materials such as stone, marble, brick and timber, and modern ones, such as cast metals (iron, aluminum), stainless steel (for the connective elements), cast stone (cement-based), concrete, GFRC (Glass Fiber Reinforced Concrete) and FRP (Fiber Reinforced Plastic). In the case of glass, the term compatibility refers to the balanced engineering of the new elements in the historic structure, bringing to the foreground aspects related to the form, configuration, construction techniques, connections and post-breakage behavior. As glass is not used for the strengthening of the historic materials per se, but rather as a strengthening mechanism of the entire structure, it makes more sense to examine the critical points that result from a comparative study of the most common materials in a holistic approach regarding the aforementioned aspects. Table 1 presents the main properties of historic and other restorative materials compared to glass<sup>2</sup>, showing that the latter presents similar characteristics to the former and could cooperate successfully in consolidation practices.

Table 1: Properties of materials used in consolidation treatments derived from the Glass Construction Manual (Schittich et al. 2007) and CES Edupack 2017 Software (Granta 2017).

Property	Unit	Soda-lime Glass	Borosilicate Glass	Concrete	Marble*	Limestone*	Brick*
Density	10 <sup>3</sup> Kg/m <sup>3</sup>	2.5	2.2-2.5	2.2-2.6	2.72-2.85	2.55-2.6	2.1-2.5
Young's Modulus	GPa	68-72	61-64	15-25	50-70	35-55	30-35
Compressive Strength	MPa	300-420	260-350	13.3-30	55-105	30-200	45-150
Tensile Strength	MPa	30-35	22-32	1.1-1.3	6-10	8-22	5-15
Thermal expansion coefficient	10 <sup>-6</sup> K <sup>-1</sup>	9.1-9.5	3.2-4	5-12	3-5	3.7-6.3	5-8
Thermal conductivity	W/m°C	0.9-1.1	1.1-1.3	0.7-2.6	5-6	0.92-2.15	0.8-1
Porosity	%	0	0	0.1-0.15	0.002-0.004	0.006-0.12	0.06-0.2

\* The values of the historic materials may differ with the presented ones due to pathology and decay.

Glass is a much stiffer material than the traditional ones, which means that it does not require the same volume to carry the loads. Historic monuments employ relatively weak materials (compared to modern ones like steel) in massive forms, while contemporary structures use stiff materials and rigid connections to attain flexible forms (Feilden 1982). The greatest advantage is that as less new material is needed, the intervention does not burden the monument with redundant weight. Where a new stone masonry would cover the entire width of a damaged wall to structurally consolidate it, glass can be configured in plates and fins or cast glass masonry of minimum width with only using 25% of the equivalent original material (Barou 2016, p. 128). On the other hand, due to this stiffness difference, the weak historic structure could be damaged in case of overloading, as the modern structure would be strong enough to withstand the loads. The way these two parts of the consolidated structure are connected is a key element for the reinforcement strategy. The connection between the old and the new should be designed as the weakest link that will

<sup>2</sup> Soda-lime and Borosilicate glass show the greatest potential for architectural and structural applications

fail first and act as a warning mechanism, protecting, in such way, the historic fabric (Vacharopoulou 2006, p. 750, Barou 2016, p. 200, Oikonomopoulou et al. 2016).

A crucial aspect for the design of the connection is the difference in the thermal expansion coefficient of glass and the historic material. Most types of stone have a comparable to borosilicate glass thermal expansion coefficient, resulting to connections with small gaps for accommodating thermal movements. In the case of brick or soda-lime glass (with higher thermal expansion coefficient values), the connection has to allow for larger tolerances due to the different thermal behavior of the materials.

Moreover, glass is not a porous material, which means that it creates an impermeable filter against water, air, moisture etc. The connection to the historic materials should be designed in such way to retain the natural breathing properties of the walls, avoiding any trapped water, condensation or moisture. Likewise, any steel elements used to establish this connection, should not interfere or be affected by the particular climate of the area (Fig. 5).

Glass, unlike other restorative materials, poses a great risk of creating unwanted indoor conditions related to overheating of the interior space, threatening the historic materials especially in warm climates. Compatibility in terms of energy performance can be achieved considering the orientation of the glass structure, passive ventilation solutions and coatings on the glass surfaces to improve the thermal performance (Oikonomopoulou 2012, p. 95). On the other hand, the thick historic masonry walls present thermal mass properties, able to store heat and resist against temperature fluctuations. This facilitates the use of glass if the ratio between the glass and the existing surface remains balanced.

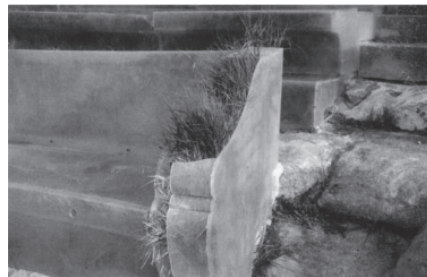


Fig. 5 Minissi's restoration in the Greek Theater of Heracleia Minoa failed due to the use of metal pivots to anchor the transparent Perspex encases, which eroded with the penetration of water and threatened the original stone.

### 3.2. Durability

A question that often arises when traditional materials are used<sup>3</sup> is how will they be detected years after their integration. With time, the contrast between old and new becomes obliterated and conjecture between the elements can occur without proper maintenance. Of course, the degree of weathering will vary in both the original and new members, but the original intention and selection of the material, its color and texture, collated to the existing ones seem to fade over time (Vacharopoulou 2006, p. 261). Natural stones and ceramic products appear to fall into this category and the present state of the monuments shows how these restorative materials will look like to the eyes of our posterity. The aspect of durability and decay is important and should be taken into account when we discuss about the lifespan of an intervention. The durability of glass can be observed in the ancient churches, where, unless broken by excessive loads, glass provides service through the centuries of use and remains distinguishable compared to the adjacent materials. Sudden temperature difference, unprotected edge finishes and mechanical stresses are some of the factors that affect the strength and consequently the durability (Pilkington 2018). When all these aspects, however, are taken into consideration in the design of the structure, the elements are not posing a huge threat to the surface quality of glass.

### 3.3. Reversibility

The aspect of reversibility lies in the connection between the structural elements and when it comes to glass there are three ways to do it: with adhesive, mechanical (bolted) or embedded connections followed by glass welding which is not applicable in buildings yet. Due to maintenance and ease of replace of damaged parts, mechanical and embedded connections are preferred compared to adhesives, offering the advantage of reversibility. In the context of restoration, adhesive bonding between the glass elements could be selected if maximum transparency is preferred, however, the connection to the historic materials should be achieved in a reversible way with dry connections (mechanical joints or soft interlayers). Current restoration treatments with traditional materials, could allow for the minimum damage of the original structure in certain cases and only if suggested by the restoration scheme after extensive research indicating that this is the only possible solution. A simple method, widely used today, is to insert tension rods by minimally penetrating the historic materials to prevent the structure from opening.

<sup>3</sup> Especially in the practice of anastylosis, where materials similar to the originals are preferred.



### 3.4. Aesthetic harmony – Degree of transparency

For traditional restorative materials, aesthetic harmony is a term to express how the color, texture and details of the new members co-exist with the historic ones in a non-intrusive way. Glass is assumed a “colorless” material and in architecture we use it to create simultaneous perceptions and sensations of the interior and exterior spaces. However, against the common belief, glass is not always transparent, colorless and flat, and when appearance is vital, as in conservation and consolidation treatments, aesthetics needs to be investigated in detail. Since transparency is the greatest benefit of using glass as restorative material, the degree of transparency and all the factors that can influence it need to be explored in order to highlight the challenges and potential. These parameters can be found on a micro, meso or macro-scale and are explained as follows:

- Micro-scale: Composition and surface treatment

At the microscopic level, the optical properties of glass highly depend on its chemical composition and the treatment of the surface, e.g. applied coatings. The basic glass recipe consists mainly of sand (silicon dioxide,  $\text{SiO}_2$ ), soda (sodium oxide,  $\text{Na}_2\text{O}$ ) and lime (calcium oxide,  $\text{CaO}$ ), while the presence of metallic oxides is responsible for a special tint that each glass type has. Soda-lime-silica glass used in windows usually has a green tint caused by the high percentage of iron oxide ( $\text{Fe}_2\text{O}_3$ ), while crystal glass, used for glassware, lenses and optical components, achieves higher levels of transparency due to the presence of lead oxide ( $\text{PbO}$ ), zinc oxide ( $\text{ZnO}$ ), barium oxide ( $\text{BaO}$ ) or potassium oxide ( $\text{K}_2\text{O}$ ). Other colorants, which can be used intentionally for customized products, are copper for blue, cobalt for dark blue, gold for dark red and manganese dioxide to decolorize colored glass (Corning 2011). In general, the density of glass, as a result of the combination of different chemical elements, affects the refractive index (how much the path of light is bent or refracted when entering a material) and consequently the transparency; the greater the density, the higher the refractive index and the more the distortion of the perceived image. Acid etching is a surface treatment used to attain a translucent glass surface, which emits scattered light and creates a hazy perception of the surroundings. Similar quality can be achieved by adding texture on the glass surface, using the methods of slumping, rolling or casting (Fig. 6a, b and c). Coatings applied as a thin layer on the glass surface can also change the optical characteristics. For example, anti-reflective glass, used in facades, showrooms, shop windows etc., offers a crystal clear result and sharp perception, by reducing the reflections to just a fraction of those seen with conventional glasses (SCHOTT 2018). For restorative applications, on a microscopic level, glass could be engineered to achieve a specific color, tint or texture that matches the historic materials<sup>4</sup>, while an anti-reflective coating could minimize the reflections from the sun taking into account that most of our historic sites are perceived in natural daylight. In archaeological sites, for instance, which often ask for moderate light conditions in the form of diffused illumination, is recommended to make use of translucent glass instead of crystal clear for the canopies in order to provide sufficient protection against the intense sunlight.

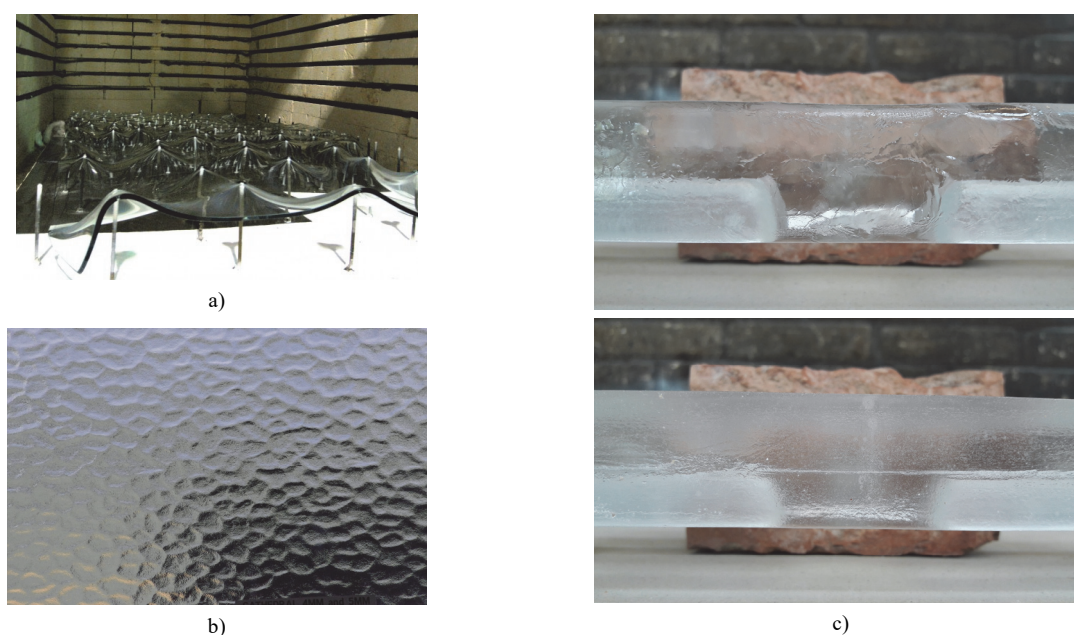


Fig. 6a) Slumped glass is produced by heating up float glass to its softening temperature so that it can bend along a patterned mold (BaseHEIGHT 2017), b) Rolled-plate, figured or “Cathedral” glass is formed between two rollers, one of which carries a pattern (<http://www.bowralglass.com.au/patterned-glass>) and c) Cast glass is produced by heating up the glass to its melting temperature and have it poured in a mold. Depending on the mold quality a more hazy or glossy result can be attained (Barou 2016).

<sup>4</sup> Suitable for the restorative treatment of anastylosis.

- Meso-scale: Geometry, configuration, scale and substructure

This category includes all those characteristics that affect the way we perceive the world and deal with how the glass elements are formed and arranged in space. The shape of the elements – flat, curved, round – is responsible for the faithful, or not, display of an image. Round elements, convex or concave surfaces create a distorted projected image as light rays are reflected in a different angle than the incident ones on the surface. Thicker elements can also create distortions compared to thinner ones; if we look a glass pane perpendicularly it appears transparent, while if we look at it longitudinally it appears translucent. This is more obvious when we stack glass panes on top of each other; they transmit light but prevent visual connection. Similarly, cast glass produced in larger thicknesses can create more distortion compared to thinner float glass, due to the larger distance the light has to travel through the medium. Given the fact that a flat glass surface can transmit, absorb and reflect the light, the more the layers the greater the optical illusions (Brzeziński 2017). This phenomenon is evident in cavity geometries, such as hollow glass, where the double panes create more reflections and alter the perceived image, or alternatively, in the overall configuration of the structure (Fig. 7c). A monolithic cast glass wall would create less distortion than a wall of the same thickness comprising of fins and plates under certain angles of view; the more the overlapping elements, the greater the optical phenomena. Scale and rhythm of a glass structure are important and in close relation to the necessity for substructure, which can undermine its transparency and simplicity. The size and number of elements determines the number of connections between them. The Apple cube in New York is a great example of how scale affects the degree of spatial perception. The 106 glass panels and 250 primary fittings of the first structure in 2006 were replaced by 15 panels and 40 fittings in the second improved version in 2011, with significantly less intrusive elements (Eckersley O’Callaghan 2018). Rhythm expresses the arrangement of the elements on the facade and the way we “read” it. The legible parts or modules can rely on the substructure that lies behind the glass, the sizes of the glass panes or the traces of connections. Depending on the restoration concept and the degree of transparency we want to achieve, distortions and translucency could be acceptable as long as the general feeling of the surrounding space is achieved.

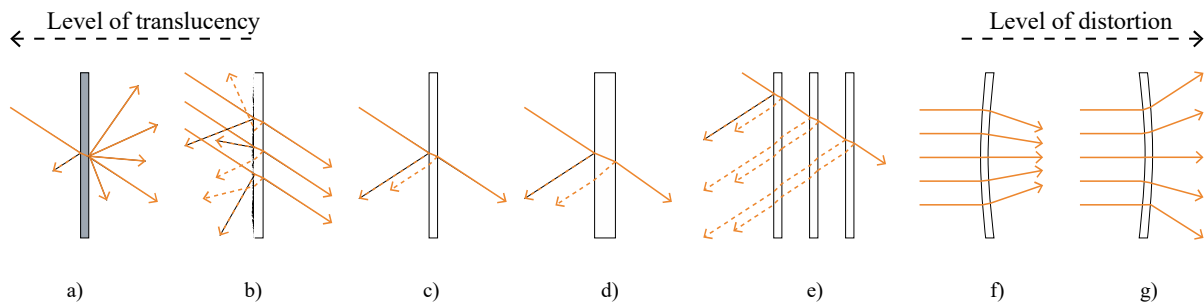


Fig. 7 Degrees of optical illusions related to the surface treatment, geometry and configuration of the glass elements: a) Translucent surface diffuses the light and allows for a perception of the surroundings in a certain distance, b) Textured surface allows for the perception of the surroundings with limited clarity, c) Thin flat glass has the maximum level of transparency and minimum distortion, d) Thick cast glass has a little lower level of transparency compared to thin glass, e) Configuration with multiple layers can create a great number of reflections distorting the perceived image, f) Convex curved glass results in barrel distortion of the perceived image and g) Concave curved glass results in pincushion distortion of the perceived image.

- Macro-scale: Lighting conditions

Since the term “transparent” expresses the property of “permitting the uninterrupted passage of light” (British Dictionary), the lighting and viewing conditions can influence the transparency of glass. Depending on “the time of the day, the angle of the sun and the weather conditions glass can be both reflective and transparent” and “material transparency is converted into material opacity” (Blau 2010). This reflection could result either in a great asset, enabling the continuity of space or a great threat over a historic monument creating an overwhelming opposition and imposition. The function of the historic building after restoration treatments with glass is also crucial as it determines its principal character and interaction with the visitors. In the case of Louviers Music School’s extension in France, the mirror finish of the new glass façade appears discreet during the day, reflecting its surroundings and allowing for space continuity and turns transparent during the night exposing its interior (Fig. 8a and b). However, most of our historic settings are visited during the day and under, sometimes, extreme daylight conditions. Too many reflective surfaces would create disturbance in our eyes, without being able to focus, as glass would prevail over the historic materials. Contrast is acceptable and encouraged for new materials as an evidence of the era, but at the same time, demands critical thinking taking all the variables into account.





Fig. 8a) and b) Louviers Music School glass façade creates different perception of the space depending of the time.

#### 4. Examples of glass in historic settings

All of us have encountered glass in close relation to historic artifacts; museum showcases usually use PVB laminated low-iron and anti-reflective glass to protect the sensitive materials against UV radiation and for security reasons (Lord and Piacente, 2014, p. 306). Glass floors on top of archaeological sites are often used to access and “walk through” the degraded ruins, as appear at the New Acropolis Museum in Athens, both indoors and outdoors. Although not frequent, there are a few more applications of glass for restoration purposes presented and discussed in this research. These can be divided in four categories according to the conservation aim of:

- Protection of the historic fabric

Glass can act as a protective element for the sensitive historic materials not only inside a museum. With the passage of time, buildings exposed to the elements are in risk as the materials become weak and consequently the structure loses its structural capacity. Glass can seal effectively these sensitive parts forming a durable protective layer against most harmful weathering conditions (e.g. sea salt in seaside areas or frost). In ancient buildings, roofs were made by lightweight materials such as wood, which have not survived until today, resulting in uncovered parts of monuments. A glass roof could serve as way to, not only invoke the authentic form, but also protect the interior form further degradation. Similarly, glass canopies can shelter archaeological sites creating a friendlier environment for the visitors.

- Reinforcement by filling of the form

Natural (e.g. earthquakes) or man-made (e.g. wars) factors are responsible for the collapsed parts of our historic buildings, changing the loading conditions and the stability of the structure. Filling of the form with glass walls, roof or floors preserves the original shape and enhances the diaphragmatic behavior of the whole.

- Adaptive re-use







Monuments are not only parts of our built heritage but also of our building stock and their re-use contributes to the sustainability of our available resources. Restorations aiming at the re-use of a historic building can employ glass elements either as a means to close the in-between spaces (colonnades, patios and arcades) or as part of an expansion structure, usually of abstract form, to create viable indoor conditions and accommodate new functions.

- Reproduction of craftsmanship

Decorative elements have always been part of the identity of historic buildings. From coats of arms to Corinthian rhythm columns, these special crafts or features are historic evidence of the time and the cultural, social, political, religious or architectural character of our monuments. The reproduction of such elements with glass can maintain this character and transfer it to the present time forming an open dialogue between the old and the new.

The selected case studies, presented in Table 2, match one or more of the aforementioned categories and show the potential and challenges of using glass and other transparent materials for the restoration of our historic sites.

Table 2: Overview and assessment of restoration case studies that employ glass and other transparent materials.

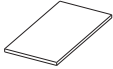
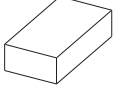

Case study	Purpose	Restoration element	Materials	Degree of transparency	Observations/Comments
 1. Abbey of St. Maurice, St. Maurice, Switzerland (2010)	Protection	Roof (new)	Polycarbonate + Steel substructure + Rocks	The translucent shelter creates a contemplative ambience. The presence of rocks decreases acts as filter for light regulation offering diffused illumination.	The shelter protects the ruins from the landslides from the adjacent cliff. The use of stones on the top part demonstrates a memory link and expresses the everlasting hazard that the site has been exposed to.
 2. Broerekerk, Bolsward, The Netherlands (2006)	Protection + Filling of the form + Adaptive re-use	Roof	Cylindrically shaped heat-treated laminated safety glass + Steel substructure	The steel substructure compromises the transparency of the glass roof but is essential as supportive element.	The shape of the original roof is preserved by the steel frames, which are part of the structural support for the glass panels.  During the assembly the glass panels failed due to the manufacture process of heat-strengthened curved glass.
 3. Fountain of Magdalena, Jaén, Spain (2009)	Protection + Adaptive re-use	Water container + Stairways	19mm stacked azure glass plates, laser-cut, and glued with transparent resin	The thickness of the stacked glass walls do not allow for transparency of the surroundings, while the upper part allows for the natural light to come in penetrating the layer of water.	The restoration entails a symbolic character in an urban environment, reinstating the historic cistern and stairways while using glass as a means to immerse oneself in the history of the place.
 4. Flourmill, Geraki, Greece (2007)	Filling of the form	Walls + Roof	Stacked float glass	The green tint of stacked float glass does not offer a clear perception of the surroundings, however, permits light to pass through.	The abstract reproduction of the collapsed part of the flourmill is a sculptural intervention where stacked glass resembles the existing masonry and construction technique.
 5. St. Francis convent, Santpedor, Spain (2011)	Adaptive re-use	Entrance (new) + Stairways (new)	Glass + Steel substructure	Due to the scale and the ration between glass and steel, the addition appears very transparent.	The addition, which accommodates the new entrance and staircase, complies with the conversion of the church into a multifunctional cultural facility. The modern, abstract form and the use of glass respect the historic fabric and distinguish from the existing building.
 6. Greek theater, Agrigento, Sicily (1963)	Reproduction of craftsmanship	Seats	Perspex + Metal pivots	The level of transparency is high allowing for the unobstructed perception of the form (before the Perspex turns yellow after long exposure in UV lighting).	The metal pivots eroded and threatened the historic materials and later were replaced by aluminum ones.  Perspex is a material that degrades after long exposure to UV light and turns yellow, decreasing the overall transparency.

## 5. Methodology

Having discussed all the considerations that influence the use of glass in conservation of historic buildings – compatibility, transparency, reversibility – one aspect remains to be investigated: what are the available glass products today and how can we exploit them according to our needs? The fabrication techniques pose a major driving force for the implementation of the material in restorative practices and determine the degree of harmonization with the historic setting. The available glass used for architectural and structural applications today is limited to float, cast or extruded components. Each of them has different qualities regarding the possible configurations, scale and degree of transparency and, therefore, meets a specific range of possible restorative applications. Multiple glass configurations are briefly presented in the case studies review of chapter 4, showing the application of glass types according to the priorities of the corresponding restoration scheme and in respect to the degree of intervention. An overview of the general characteristics and applicability of the glass types is shown in Table 3.

An efficient design tool, which can indicate the most appropriate glass type is the level of representativeness; how much the new structure will resemble to the existing one. This critical decision-making depends, to a large extent, on the evaluation and interpretation of the monument based on the available documentation but also the requirements related to the pathology and degree of intervention. An analytical values-based approach can determine the social, spiritual/religious, educational, symbolic and aesthetic values and finally the cultural significance of a place of memory. Kerr (2004, p. 16), Worthing and Bond (2008, p. 91) add that age, vulnerability, rarity, influential impact or representativeness of their kind is equally important in this equation. A rule of thumb is to treat older monuments with greater respect and sensitivity depicted in their conservative restoration strategy, such as the practice of anastylosis. In these cases the accurate representation of the missing elements and the revival of the original form is preferred. On the contrary, recent historic structures could tolerate a more abstract and flexible form in terms of design, especially when they are combined with the adaptive re-use of the space and are part of a branding strategy.

Table 3: Assessment of the different types of glass in respect to configuration, scale, transparency and applicability in restoration practices.

Type of glass	Scale	Configuration	Transparency	Applicability
 <p>Float</p>	<p>Thickness: 2-25 mm (Thicker elements can be achieved by laminating or stacking) Size: 3210x6000 mm (Bigger elements can be achieved with splice-lamination)</p>	<p>Plates + steel substructure Plates + Fins Curved (single, double) Stacked (vertically, horizontally)</p>	<p>Matte Translucent Transparent Optical quality Textured Tinted  The more the supportive elements (cable net, frame etc.), the larger the visual impact Stacking results in light-permeable but not transparent structures</p>	<p>Abstract representation to give a rough impression of the form and size: Floors Walls Shells  Functional additions: Stairs Showcases</p>
 <p>Cast</p>	<p>Size: max 10kg is recommended for repetitive elements of mass production. Bigger elements are possible but need more time and are expensive.  Geometry: symmetrical shapes are recommended for structural elements (The annealing process affects manufacture time and cost)</p>	<p>Freedom in shape and forms  Stand-alone elements or assemblies</p>	<p>Matte Translucent Transparent Textured surface Tinted  Larger thickness gives the sense of depth  More distortion of the image compared to float glass</p>	<p>Accurate representation: Masonry walls Hinged columns Vaults Decorative elements of complex shape  Ideal for the practice of anastylosis</p>
 <p>Extruded</p>	<p>Thickness: 0.9-460 mm Length: 0.3-1000mm (SCHOTT) (The size varies according to the profile, however the connection of multiple profiles can create larger elements.)</p>	<p>Cluster of extruded profiles for linear elements of increased thickness Array of extruded profiles for 3-dimensional elements</p>	<p>Matte, translucent, transparent  The curvature degree and number of elements combined multiplies the optical illusions and the faithful perception of the image</p>	<p>Abstract representation: Truss structure Column  Accurate representation: Clustered columns of Gothic style Linear decorative elements</p>



- Float glass

Float glass appears as a good candidate for abstract restorative solutions as its small thickness and 2-dimensional nature create a well-defined geometry that easily distinguishes from the one of historic structures. All the configurations generated using float glass can give a rough impression of the building, outlining its main shape and proportions without details of the workmanship or the construction techniques. Interventions aiming to the protection of historic materials, as well as, those that give a new adaptive character to the monuments can tolerate a higher degree of freedom for the design of the new glass structure. Solutions with abstract forms are a rather suitable approach as an indirect treatment, which can safeguard our built heritage and simultaneously stand out as iconic additions. The glass shell of the Canadian Museum of Nature stands for the memory of the original part in a completely contemporary form, which respects, however, the original volume and scale (Fig. 9).

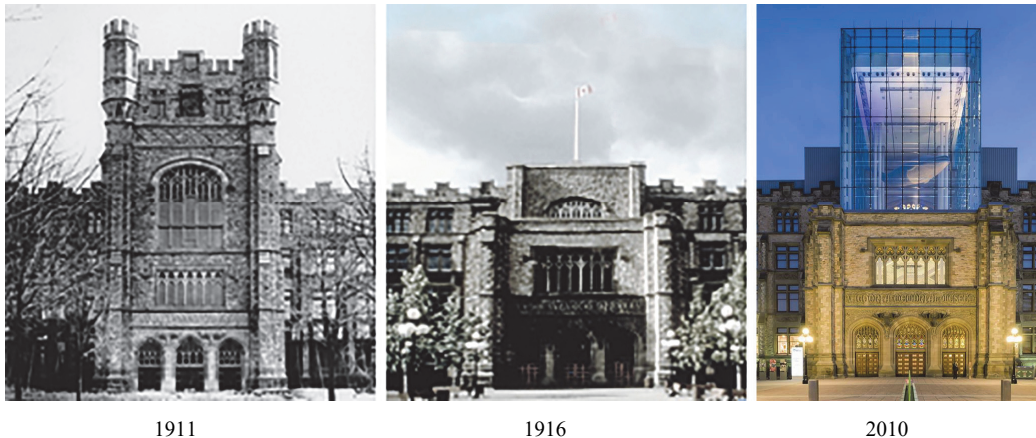


Fig. 9 The original tower of the Victoria Memorial Museum had to be removed due to unstable soil conditions and its massive weight and was replaced by a glass lantern after the rehabilitation of the monument into the Canadian Museum of Nature in 2010 (<https://nature.ca/en/about-us/history-buildings>).

Abstract solutions with float glass can also be the answer for monuments of later eras in order to fill the form and strengthen the collapsed parts of a building (Fig. 11a). As glass is in close proximity to the historic materials, the new design should preserve the rhythm and aesthetic quality of the existing one in a harmonic coexistence. Float glass can be articulated in a way to follow the grid and main lines of the historic structure either with the right dimensioning of the elements or the position of the substructure.

- Cast glass

The flexibility in forms that can be achieved using cast glass is the best solution for restoration treatment aiming to resemble the original shape as faithfully as possible. Glass casting offers is the sense of depth, the 3<sup>rd</sup> dimension that float glass lacks, and can produce complex volumes with thicknesses similar to the historic elements. Fig. 11b illustrates a proposed restoration for a decayed bastion in Greece with cast glass masonry. The masonry consists of interlocking units, which are translucent and textured in order to match the appearance of the existing historic masonry and at the same time retain their distinct character. In a similar way cast glass monolithic elements would be ideal for the practice of anastylosis, placed in-between the remaining structure, which appears to float in the air. Moreover, ornamental or other elements, responsible for the unique identity of a historic setting, could be reproduced in cast glass, with a high level of precision and details (Fig. 10).



Fig. 10 Glass sculptures, by the artist Karen La Monte, demonstrate the level of detailing that glass casting can achieve (La Monte 2007).

- Extruded glass

In specific cases, the use of extruded glass could be adequate for the restoration of linear structural elements of standard cross-sectional area, such as gothic columns (Fig. 11c). In a smaller scale, glass profiles could also be used as ornamental elements of very small thicknesses that cannot be achieved by cast glass. Special thermal treatment could be considered to add flexibility and freedom in the shape. A modern and abstract configuration of extruded glass profiles is also possible in the form of truss structures, to create lightweight horizontal components.



Fig. 11a) Abstract interpretation of Corinthian style column using float glass fins (Gnosis Architettura and Bardeschi 2017), b) Glass masonry that consists of interlocking cast glass units (Barou 2016) and c) Restoration of Gothic columns with extruded glass tubes (Van den Broek 2017).

In general, a good indication of which glass type is suitable for each restoration scheme highly depends on the state of the monument, namely its age and rarity. These are the drivers, which decide towards a more realistic or abstract approach. The assessment of applicability of the different glass types shows that cast glass should be preferred for a realistic representation of the historic elements, while float glass should be preferred for more abstract representations and treatments. Extruded glass could be used in exceptional cases for both approaches, depending on the context (Fig. 12). Nevertheless, in reality a combination of more than one glass types should be considered, as multiple parts of the same structures could ask for different actions.

Other factors that affect the choice of the glass is the loading conditions and constraints, as well as the cost. The position of the glass element suggests different glass configurations according to the consolidation demands. For instance, a collapsed roof is more likely to be restored by a lightweight glass structure with float glass than a cast glass masonry, in order to burden the historic materials as less as possible. Furthermore, cast and extruded glass are significantly more expensive than float glass and it is not coincidence that the latter monopolizes the contemporary glass structures of our time. Post-processing, such as surface or thermal treatment, and time-consuming construction also contribute to expensive structures.

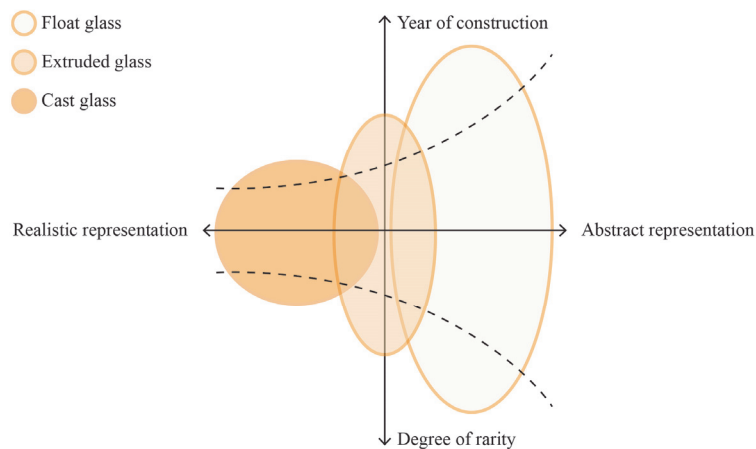


Fig. 12 Relation of age and rarity of a monument to the restoration concept of an abstract or realistic approach and the range of applicability for float, extruded and cast glass respectively.

## 6. Conclusions

The introduction of glass elements for the restoration of our monuments appears as an elegant solution to attain the tangible and intangible character of historic structures; an attempt to revive the original form, but at the same time respect the stratification and all the layers of history, including the present time and the surrounding landscape. Glass offers a contemporaneity to the historic materials and demonstrates the spirit of our era and the dominance of cutting-edge technology and innovation as part of our everyday life. Today, it is of vital importance to treat our historic heritage with honesty and apply materials and techniques that leave no room for conjecture. The unique transparency of glass gives a sense of immateriality; the volumes and shapes dematerialize and the perception of our ruins turns into a trick of the spatial acuity of our eyes.

The feasibility of the concept is explored through a study on the compatibility, reversibility and durability aspects, as prerequisites for any consolidation practice, and relies on the proper engineering of the glass structure in terms of connectivity, structural and climate performance in respect of the historic fabric. The aesthetic quality of glass and transparency can be interpreted in different ways; transparent surfaces allow for a clear, distorted or blurry perception of the surroundings or merely permit light transmission, concealing any peripheral views. Each glass structure can achieve different qualities depending on the geometry, configuration or treatment, and should always match the restorative concept, degree of intervention and level of representativeness. Nevertheless, the lack of any delineated principles of how to restore a decayed structure leads to tailor-made solutions, as there is no universal cure to heal various illnesses.

The state-of-the-art technology and continuous progress on glass fabrication, processing and assembly brings transparent materials to the foreground for applications of strengthening our decayed historic structures towards the sustainable exploitation and preservation of our built heritage for future generations. Based on the above, a methodology is developed as a toolbox of design possibilities regarding the existing glass products and their applicability, in order to highlight the aesthetical and engineering value of using and considering glass a restorative material.

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*Dematerialization of the Ruins: Glass as a Promising Restorative Material for the Consolidation of Historic Structures*

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