Challenging Glass Conference Proceedings – Volume 10 – June 2026 – Louter, Bos & Belis (Eds.)
International Conference on the Architectural and Structural Application of Glass
Challenging Glass Conference 10 – 15-17 June 2026 – TU Delft – The Netherlands

Historically Manufactured Glass in Actual Applications

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Abstract

Historically manufactured glass is also nowadays often used in listed buildings due to its special optical properties. Occasionally, they are used for artistic applications. Since the properties of non-industrially manufactured glass deviate from the harmonised European standards, special considerations must be made to verify its usability. Glass manufactured using the cylinder blowing process is part of an artistic lamp installation in an overhead situation. Securing the glass shards in the event of glass breakage is particularly challenging due to the uneven glass surface. In another project, coloured antique glass is laminated and mounted with point fittings in drill holes. The load-bearing and residual load-bearing behaviour of laminates with different degrees of thermal treatment was investigated using calculations and tests. In existing building projects, some of which are listed, the question of further usability is important, especially in the case of wired glass applications in overhead areas or as fall protection. This is illustrated by various practical examples.

Keywords

Historic Glass, Testing, Wired Glass, Drawn Glass, Art in Architecture

Article Information

- Digital Object Identifier (DOI): 10.47982/cgc.10.774
- Published by Challenging Glass, on behalf of the author(s), at Stichting OpenAccess.
- Published as part of the peer-reviewed Challenging Glass Conference Proceedings, Volume 10, June 2026, 10.47982/cgc.10
- Editors: Christian Louter, Freek Bos & Jan Belis

1. Introduction

The number of applications involving historic glass panes is increasing, and building in existing structures is becoming more important. This leads to the question, on the one hand, of how these types of glass and constructions can be integrated into current building regulations and standards. There are now very few manufacturers who still use the old methods, for example, to replace broken panes with ones that look identical. On the other hand, the imperfect surfaces of historically manufactured glass are increasingly being used for projects in the field of “art in architecture”.

Fig. 1: Historic glass construction.

2. Historical developments in flat glass manufacturing

In the past, flat glass was manufactured using a variety of processes depending on technical progress; over the centuries, even tried-and-tested methods fell into oblivion and were reinvented several times.

Historically, the production of flat glass has developed in several steps:

- Blowing process (blown hollow bodies such as spheres or cylinders are cut open and formed flat).
- Casting process (molten glass is poured and rolled)
- Drawing process (glass is drawn from molten glass by lipstone, Libbey-Owens e.g.)
- Float glass process (molten glass floats on liquid tin, standard since the 1960s)

The cylinder stretching process (known since the 1th century AD) is based on cutting and reshaping blown glass cylinders, while in the moon glass process (known since the 4th century AD), circular surfaces are created from blown balls by rotation.

In the casting process, the molten glass is poured onto surfaces and stretched or shaped by water-cooled rollers or pairs of rollers. Cast glass achieves a clear surface only through grinding and polishing.

With the invention of machine drawing processes, glass could be produced in larger quantities and of better quality. Drawn flat glass is produced as flat, transparent, clear or coloured soda-lime silicate glass in a continuous, initially vertical drawing process in standard thicknesses and with fire-polished surfaces on both sides. It has a characteristic waviness, which is particularly common in glass found in historic buildings – and is at least worth discussing when renovating the glazing of listed buildings, for example. In addition to drawn flat glass with a minimum of visible defects, the European standard also recognizes variants with other typical defects, such as so-called new antique flat glass and drawn flat glass for renovation. Depending on the respective production facilities, different maximum dimensions and thicknesses are manufactured.

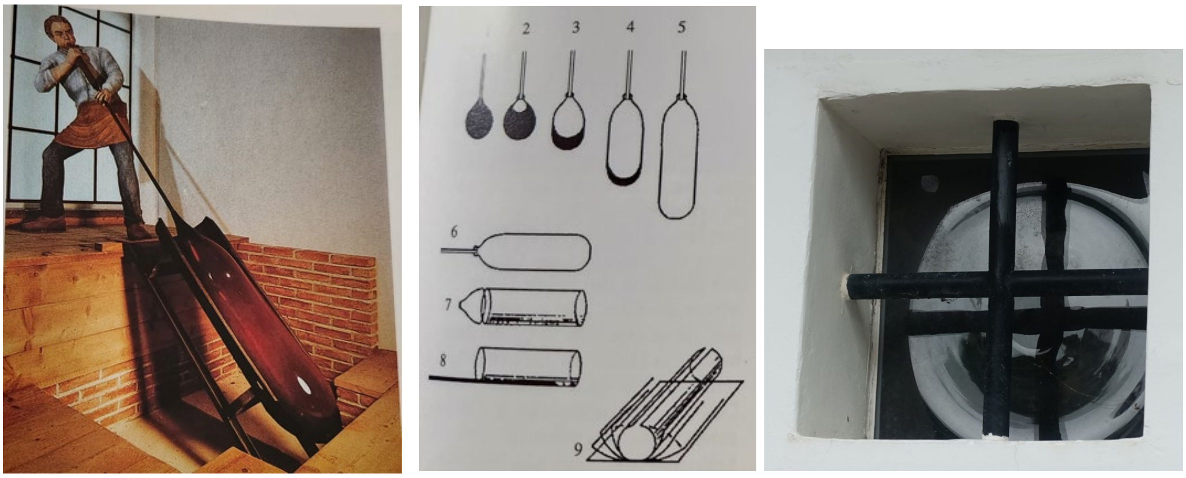

Fig. 2: cylinder stretching process, Source: Technikgeschichte im Deutschen Museum. Glas and historic glass in Japan.

Fig. 3: Typical surface of drawn sheet glass.

Manufacturing processes are constantly being improved. Functional glass is already being produced using rolling and drawing processes. In 1891, Siemens launches wired glass on the German market in Dresden. The embedded wire mesh improves residual load-bearing capacity and service life.

Perfectly flat, parallel surfaces can be created by “floating” the molten glass mass on a liquid metal bath. This principle is mentioned in two patents filed as early as 1902. William E. Heal received a patent in 1902, whereby the flat glass passes through a pair of rollers after leaving the metal bath. Halbert K. Hitchcock did not receive his patent until 1905, dispensed with the pair of rollers, and adjusted the glass thickness by varying the pulling speed of the conveyor belt at the end of the production line.

In 1909, Edouard Benedictus produced the first laminated safety glass for the automotive industry by pressing two panes together with celluloid film. Today, a tough, elastic PVB film forms the binding layer.

Pilkington further developed the float process for manufacturing flat glass in the 1950s; it has been used for the automated industrial production of flat glass since 1959.

Old tables from the end of the 19th century (Schwering 1880, 1894) already contain E-moduli, tensile strengths, and compressive strengths for various types of glass.

Glasforte	Elaftizitäts-ziffer nach *Wertheim* und *Chevandier*	Zugfeftigkeit nach *Wertheim* und *Chevandier*	Zugfeftigkeit nach *Fairbairn*	Druckfeftigkeit nach *Fairbairn* für Zylinder	Druckfeftigkeit nach *Fairbairn* für Würfel [208]
Fenfterglas	791,7	176,3	—	—	—
Spiegelglas	701,5	140,0	—	—	—
Ungefärbtes bleifreies Kriftallglas	689,0	100,2	—	—	—
Weißes und farbiges Kriftallglas	517,7	66,5	—	—	—
Gekühltes Flintglas	—	—	161 bis 179	1940	923
Grünes Glas	—	—	203	2241	1421
Crown-Glas	—	—	179	2180	1531
	Tonnen für 1 qcm	Kilogramm für 1 qcm			

Fig. 4: Old tables with E-moduli, tensile strengths, and compressive strengths.

The drawing process enabled larger glass dimensions than the float process in current standard layouts (which was agreed on mainly for transport reasons), which only allows for maximum glass widths of 3.21 m, making it nearly impossible to replace old panes in the event of glass breakage. Advances in production technology mean that float glass plants with wider formats are now available, and the technical equipment for further processing such as tempering and laminating has also become available.

Table 1: Maximum glass sizes.

Production process and company	Width [m]	**Length [m]**
Historic Libbey-Owens	3,6	> 5,4
Actual standard float	3,21	6 (20)
Special float + processing JingJing/NorthGlass (China)	4,0	18
Special float + processing NN/SEDAK (Germany)	3,51	20

3. Legacy protection for structures

The use of glass elements has a long tradition, parallel to the application rules for design were developed. The concept of proper design was developed since mankind started to build structures: design and building always was (and still is) related to finding a good compromise between fulfilling safety requirements and meeting financial framework. After application of glass came more common one can see a shift of design by architects and engineers towards craftmanship, using developed knowledge and experience based "rules of thumb" for glass as a filling element of moderate size - and by this often regarded as "non-structural element", a better classification would be element of low consequences in case of failure. Since several decades, with enlarged field of application and sizes, the shift from craftsmanship back to (structural) design architects and engineers can be recognized.

In the historical literature - insofar as publications (Schwering 1880, 1894) from the 1880s can be considered historical - the design of glass for iron-glass-roofs like used for upcoming railway stations or exhibition halls like crystal palace or other impressing structures is described by means of linear equations using corresponding material tests and assumed safety factors. In addition to design for static loads, the load case of hail impact and even accessibility for maintenance purposes is discussed. Strength limit values for different types of glass (e.g., blown glass, cast glass) and mechanical strength equations are aligned, i.e., both are similarly "wrong" due to the consistent use of linear equations; strength values depending on the glass thickness may have their origin in the non-linearity that is present to varying degrees.

A complicated issue in building renovation is whether the historical structure can still be preserved and whether it offers sufficient structural safety and serviceability. An initial point of guidance here is whether the structure complied with the standards and regulations existing at the time of its construction. Since regulations for structural glass construction have only been in place for the last few decades, this is highly unlikely. In addition, it must always be clarified whether there is a risk to life and health according to current regulations.

4. Wired glass for overhead applications

4.1. General

Wired glass is often found in old glass dome constructions used to illuminate stairwells or foyers of buildings or railway stations. At the time, wired glass was considered “safe glass” due to the wire inserts and also “fire protection glass”. The most commonly used glass thickness was 7 mm. Negative aspects include glass breakage due to moisture and subsequent corrosion of wires on the glass edges. At that time, there was no construction system with two sealing levels for drainage, which means that the construction details no longer correspond to the current state of the art. Below are some examples and details.

Fig. 5: Historic glass roof with wired glass.

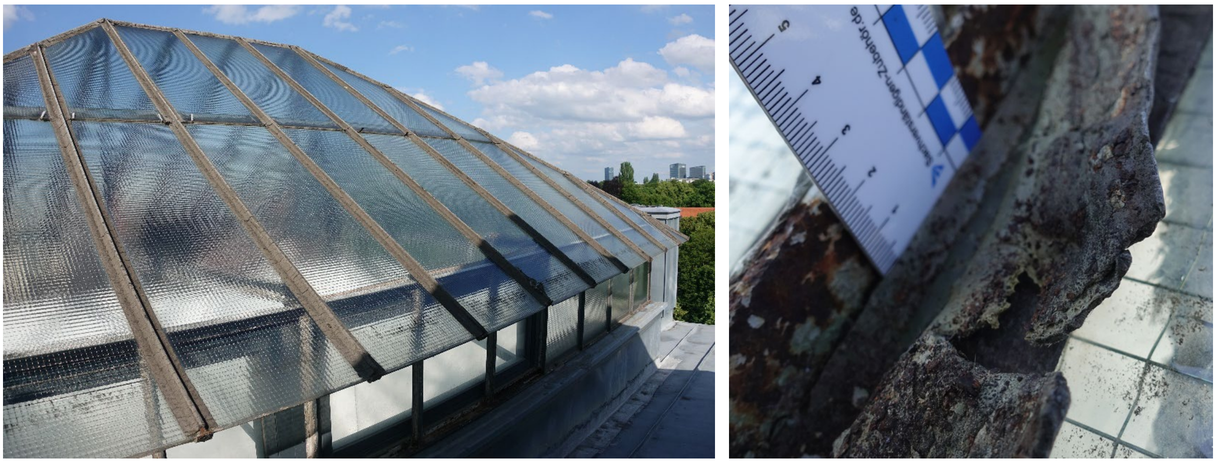

Fig. 6: Historic glass roof with wired glass.

4.2. Regulations DON 18008, Glass in building – Design and construction rules

In addition to DIN 18008-1 and 2 for static design and residual behavior (ULS + SLS + PFLS) , DIN 18008-6 (Additional requirements for walk-on glazing in case of maintenance procedures and for fall-through glazing) plays an important role for old glass roofs in Germany.

A distinction must be made between:

- Walkable glazing: Glazing that can be walked on for maintenance work, including cleaning, and that meets the relevant requirements of this part of the standard
- Fall-through-proof glazing: Glazing that cannot be walked on due to its design or intended use, but which is located near areas that can be walked on for maintenance work and meets the relevant requirements of this part of the standard

Both experimental verification and for all sided linear bearing elements also numerical verification is covered by the DIN-standard.

Fig. 7: Classification according to DIN 18008-6 and test-setup.

4.3. Example

A 60-year-old glass dome, which is a listed building, has to meet requirements in terms of statics, residual load-bearing capacity, and fall-through safety. Only a small proportion of the old wired glass was still original; over time, many panes had already been replaced by new glass. The static verification of the wired glass could not be fulfilled in accordance with current standards. The tests to proove residual strength carried out also led to instant failure of the glass-structure. Finally, in close consultation with the monument protection authority, a concept was developed using new glazing made of laminated safety glass with printed "mesh" to preserve the old appearance as much as possible.

The load-bearing capacity of the supporting steel structure is often is also not sufficient according actual design code (Eurocode), particularly due to the increased load caused by current snow loads and, in some cases, thicker glass.

The renovation is planned for 2027.

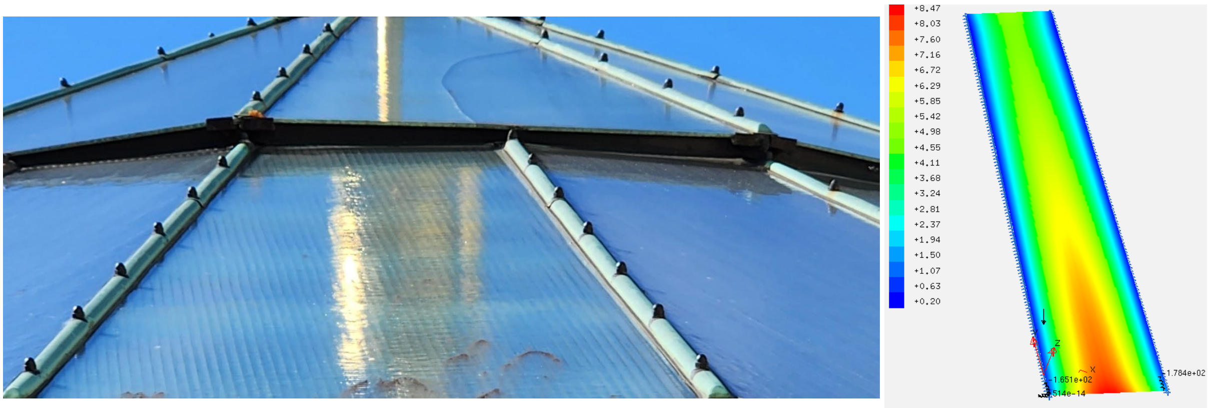

Fig. 8: Historic glass roof with wired glass, glass breakage and different surface structure and therefore age of the glass panes, structural analysis glass.

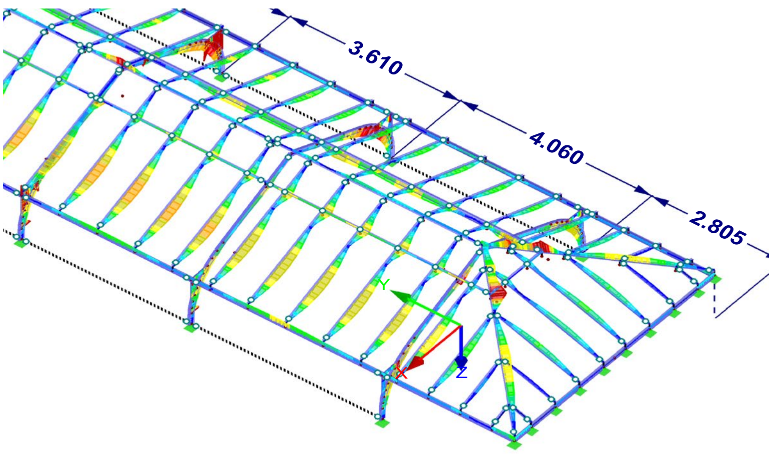

Fig. 9: Structural analysis steel-construction.

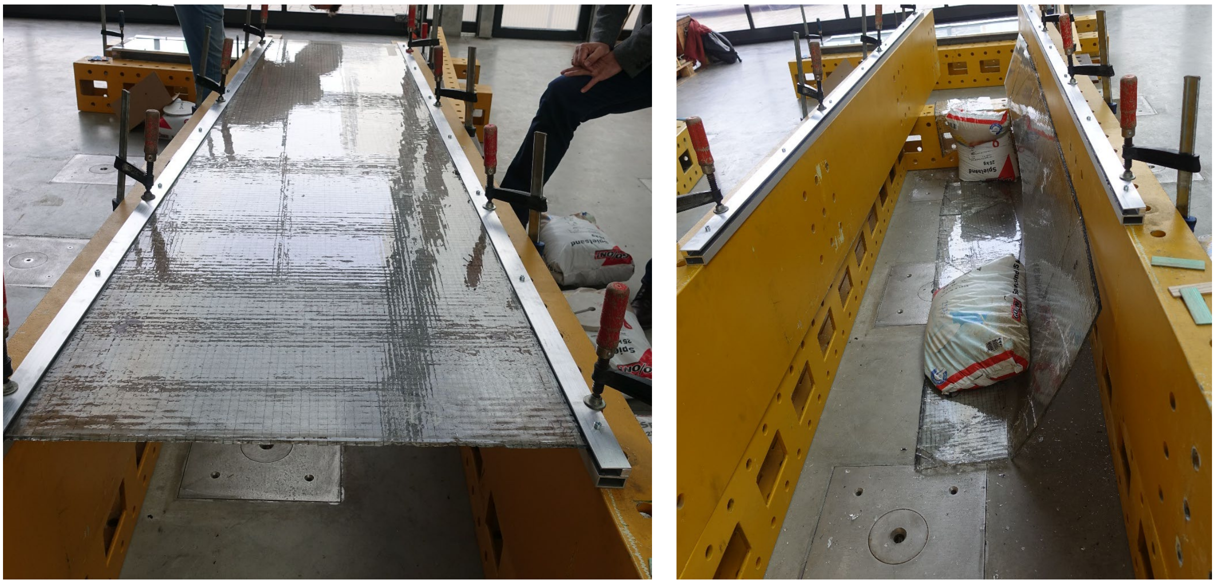

Fig. 10: Remaining load carrying capacity of wired glass, thickness 7mm.

5. Art in architecture

5.1. “Balloons”, Artist Sabine Straub, http://www.sabinestraub.com/

Mouth-blown balloons are to be hung in an intercultural family and community center in Kemnath. The balloons are not made of laminated safety glass, and the type and quality of glass does not comply with current product standards. In order to ensure residual load-bearing capacity overhead, various paints and coatings – to be applied on the inside of hollow bodies - were tested in advance to ensure residual load-bearing capacity even in the event of glass breakage.

Due to the overhead installation situation, the following requirements apply in accordance with the glass dimensioning standard DIN 18008:

- Residual load-bearing capacity: No danger from the glass balloons even in the event of glass breakage. Glass breakage caused, for example, by maintenance work on the roof or impact between bottles
- Sufficient functionality of the mounting plate, which is only loosely inserted
- Sufficient splinter binding ensured by plastic coating on the inside of hollow body
- Sufficient durability of the plastic coating

Fig. 11: Trial installation and test setup.

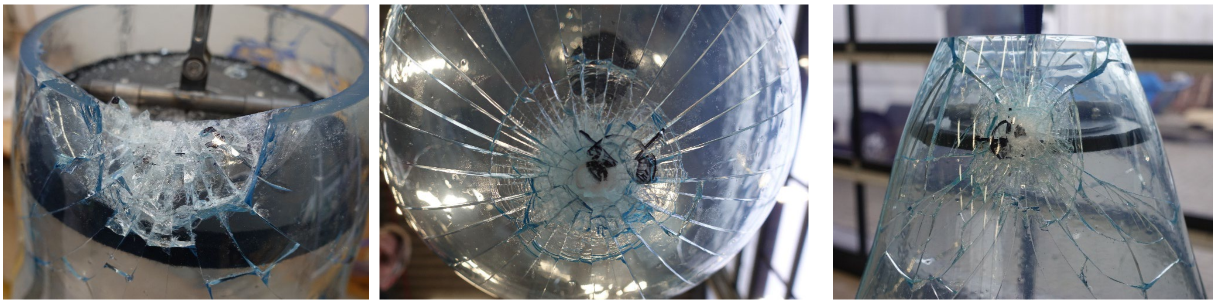

Fig. 12: Test Setup.

Finally, a material also used for upgrading plastic skylights was chosen as experience and proof for long term existed at least together with eg. PMMA.

5.2. “Antik-glass”, Artist Albert Weis, https://albertweis.com

The second “Art in Construction” project involves an art installation in a hospital. Here, laminated panes made of heat strengthened glass and genuine antique glass in various colours are to be suspended in a grid arrangement overhead.

The restoration glass and hand-blown genuine antique glass used can be manufactured in thicknesses from 2 mm and can also be thermally tempered according to individual requirements.

When it comes to antique glass and antique mirrors, a distinction must be made between:

- Original, historical glass
- New glass manufactured using old production methods (used for the project in the hospital)
- New glass manufactured using new production methods, which are only intended to give the impression of being old (e.g. by means of coatings)

According to current European technical assessments (e.g., ETA-12/0159), the tensile strength of antique glass is slightly reduced compared to flat glass.

Table 2: Tensile strength.

	Floatglass	"Genuine" antique glass
tensile strength, not tempered glass	45 MPa	30 MPa
tensile strength, tempered glass	120 MPa	105 MPa

The design deviates from the established technical building regulations in the following points, in this case the DIN 18008 series of standards and the harmonized European product standards for the various glass products, as well as the product standard for laminated safety glass DIN EN 14449:

- "Genuine" antique glass is an unregulated building product
- Due to the uneven surface the DOP (declaration of performance) cannot be transferred from glass with samples produced with even glass.
- 45 mm distance from the edge to holes do not comply with the specifications of DIN 18008-3
- The arrangement of the point holders (only two in a row and not three forming a triangel) does not comply with the specifications of DIN 18008-3

Due to the overhead installation situation, the following requirements apply in accordance with the glass design standard DIN 18008:

- Residual load-bearing capacity: No danger from the laminated glass panes even in the event of glass breakage. Glass breakage caused, for example, by maintenance work or impact between panes
- Adequate functionality of the fastening cables
- Adequate splinter retention by the PVB film (classification as laminated safety glass and not just laminated glass)
- "Safe" breakage pattern of unregulated glass

Fig. 13: Test Setup and breakage pattern.

By choosing thicker interlayer the waves of antique glass can be compensated.

- Variant 1 (V1, blue glass colour) made of laminated glass: "Genuine" antique glass (sollingglas) 1410 xx tempered / 4 x 0.76 mm PVB film / heat strengthened glass white glass 6 mm / 0.76 mm PVB film / heat strengthened glass white glass white glass 6 mm, total thickness: 18.80 mm.
- Variant 2 (V2, yellow glass colour) made of laminated glass: "Genuine" antique glass 68xx (sollingglas) tempered / 4 x 0.76 mm PVB film / heat strengthened glass white glass white glass 6 mm, total thickness: 12.04 mm.

The thickness of the antique glass was not consistent (due to manufacturing), with deviations from the average value (3 mm) ranging from several tenths of a millimeter to whole millimeters (individual measurements showed thicknesses ranging from 2.5 mm to 4 mm).

The breakage pattern shows heat strengthened glass with slightly finer pattern in some regions. There was no difference for blue or yellow glass. Finally, all tests were passed successfully.

6. Conclusion

Historically manufactured glass is increasingly being used in projects involving building renovation, monument preservation, and art in architecture. Fortunately, there are manufacturers who still produce glass using traditional methods, so that old broken panes can be replaced and the desired effects can be achieved in artistic projects. Due to the different manufacturing process, the glass does not necessarily have the same properties in terms of strength, fracture pattern, and residual strength, which must be taken into account during planning. If a structure is protected as listed monument, this can only be regarded to a certain (limited) extent, "safety" is non-negotiable.

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