INTRODUCTION
THE PRODUCTION AND USE OF GLASS IN ARCHITECTURE: A BRIEF HISTORY

Sophie Wolf and Laura Hindelang

Abstract

This introduction provides a historical overview of the production and use of sheet glass since its invention in Roman times and refers to the contributions in this edited volume. It focuses on the most significant technological and architectural developments in Europe and the USA and highlights the interaction between glass production, construction industries and architecture. It presents important manufacturing processes, outlines types of sheet glass and provides a basic glossary for technical terms in English, French and German. This text also touches on the challenges of conservation and restoration, as well as the life-cycle of historic glazing and windows. It ends by emphasizing the merits of interdisciplinary exchange and the necessity for a shared multilingual thesaurus for glass technology.

Keywords

Sheet glass, plate glass, glazing, window, glass technology, preservation, life cycle

Everywhere and Every Day: Glass in Architecture, Past and Present

Glass is omnipresent in our built environment, and it is impossible to imagine today's cities without it. Its diverse properties and its numerous possible applications make glass an indispensable building material. This is not a contemporary phenomenon. Glass has long been an integral part of buildings, and its production and use are intrinsically linked to the history and development of architecture. The material and its potential have always inspired architects, engineers and artists. History is rich with examples of the use of glass, and sheet glass in particular, on a monumental scale: the stained-glass windows of Gothic cathedrals, the *galeries des glaces* and lead glazing of 17th-century castles, the glass roofs of mainline railway stations and the large display windows of 19th-century department stores, as well as the glass façades of record-breaking high-rises such as Burj Khalifa in Dubai. Throughout the centuries, the growing demand for plate glass for windows, doors, walls and whole façades has fuelled production and led to technological innovations in manufacture and vice versa.

The availability and use of wood, coal and other fossil fuels as combustion material have had an enormous impact on the production of glass as a building material as well as on the environment.[1]

The aim of the conference *Glass in Architecture. From the Pre- to the Post-Industrial Era: Production, Use and Conservation* was to highlight and reflect on this fascinating history and on the interactions between glass, architecture and the construction industry. This book is the result of that international symposium, which was jointly organized by the Vitrocentre Romont, the Institute of Art History at the University of Bern and the Bern Acadamy of the Arts HKB; it was held in Romont (Switzerland) on 5–6 November 2021. The meeting was accompanied by the opening of the exhibition *Du précieux au quotitien. Le verre plat dans l'architecture* at the Vitromusée Romont (6 November 2021– 23 March 2022), which was dedicated to the history of the production and use of sheet glass. It showcased historical as well as modern production techniques and illustrated the almost immeasurable diversity and the many uses of this once valuable and now everyday material. One part of the exhibition was devoted to the Erie-Electroverre company in Romont, one of the world's last manufacturers of machine-drawn sheet glass, which unfortunately had closed its doors in 2020. The cover image of this volume, documenting the company's production process in the 1950s, is taken from the company's archive.

In this introduction, we will briefly summarize the history of sheet-glass production since its invention in Roman times and we will focus on the most important technological and architectural developments, referring to the contributions in this volume which discuss these topics in detail. Like the conference, the book is divided into three thematic sections. **Part 1** is dedicated to the production of sheet glass from pre-industrial times onwards and comprises contributions on the manufacture of crown glass, the development of the window-glass industry in Scotland and Belgium, and on innovative products for the flat-glass market. The articles in **Part 2** illustrate the diverse uses of glass and highlight its central rôle in architecture from the 18th century to the present day, from the Baroque glass architecture of the Dresden Zwinger to the glass façades of corporate headquarters of the 20th century. **Part 3** deals with the conservation of historic windows and glass façades and the importance of preserving this fragile heritage. The topics here range from the challenges of the *in situ* restoration of the original mid-18th-century glazing of Michelsberg Abbey in Bamberg (Germany), to the question of the repair, durability and reusability of insulating glazing today. In addition, we offer translations of key terms into French and German, thereby providing a basic glossary for the technical terms used in the English, French and German contributions gathered in this volume.

Cast or Blown: Early Production of Sheet Glass

The history of flat glass (French: *verre plat*; German: *Flachglas*) dates back to antiquity.[2] The fragments of flat glass found in Herculaneum, Pompeii and many other Roman

1 Fragments of window glass and wooden muntins from the legionary camp at Vindonissa (Windisch, Switzerland), c. 1st century CE.

cities, such as Aventicum (Avenches) and Augusta Raurica (near Augst and Kaiseraugst), prove that the Romans produced sheet glass and used it to close their window openings from the 1st century CE onwards. Initially, window glass was made by a casting process (French: *coulage*; German: *Gussverfahren*) that consisted of pouring molten glass onto a flat, heat-resistant surface and stretching the hot and viscous material into a rectangular shape.[3] The result was a relatively thick and translucent glass pane of pale-green or light-blue colour.

These more or less rectangular panes were held in grooved frames made from metal, marble or wood.[4] The windows were sometimes divided by wooden muntins (French: *croisillons en bois*; German: *Holzsprossen*), such as those unearthed at Vindonissa (Windisch) in the canton of Aargau (Switzerland) (Fig. 1).[5] The production of glass,

particularly the casting of sheet glass, was very challenging and expensive. For this reason, initially only windows in public buildings and the villas of affluent citizens were equipped with glass.

The invention of glass-blowing (French: *soufflage du verre*; German: *Glasblasen*) in the 1st century BCE and the use of the blowpipe (French: *canne à souffler*; German: *Glasmacherpfeife*) led to the development of new techniques that radically changed and greatly simplified sheet-glass production: the broad-sheet method and the crown-glass process.[6] The *Schedula diversarum artium* (c. 1100–1120 CE) by Theophilus Presbyter provides the earliest detailed description of the broad-sheet technique (French: *soufflage en manchon*; German: *Zylinderblasverfahren* or *Zylinderstreckverfahren*), which consists of blowing a pear-shaped bubble into an elongated tube shape, cutting both ends of the tube, and splitting and flattening the glass cylinder while hot.[7]

In the crown-glass process (French: *soufflage en couronne*; German: *Mondglasverfahren* or *Schleuderverfahren*), the molten glass is blown into a balloon shape. The bubble is then flattened; transferred to the glass-maker's pontil or punty, a solid iron rod (French: *pontil*; German: *Hefteisen*), and then reheated and rotated at speed, until centrifugal force forms a large circular plate known as a table (French: *cive*; German: *Mondglasscheibe*).[8] → **Alexandra Schmölder**

These new methods resulted in sheet glass of considerably better quality: it was much thinner and more transparent than the plate glass produced by casting.[9] From the 4th century CE onwards, mouth-blown window glass prevailed over cast glass.[10] The broad-sheet technique long remained the predominant method of sheet-glass production throughout Europe, while the crown-glass process prevailed in the Islamic world. It was not until the 14th century that the manufacture of crown glass became established in Europe.

Silica, Soda and Lime: The Materials of Early Glass Production

The Romans produced glass from calcium-rich beach sand and 'natron', a natural soda-rich salt that was mined, among other places, in the salt lakes of northern Egypt (for example, Wadi El Natrun).[11] The glass industry was divided into two branches: the primary production of glass, mainly located in the eastern Mediterranean, and the further processing of this raw glass into glassware, be it vessels or plate glass, in secondary workshops spread all over the Roman empire (Fig. 2).[12] Glass recycling, that is, melting down recovered scrap glass, was a common practice.[13] Early glass-makers already knew that the addition of this material (known as cullet) to a batch reduced the amount of raw materials and the melting temperature, and thus also the production costs for glass.

After the decline of the Roman empire, the production of glass in the eastern Mediterranean slowly decreased. The demand for glass was gradually met by the glassworks newly emerging in the forest regions of Central and Northern Europe.[14] In consequence, glass production changed from a two-stage to a single-stage industrial model: glass

2 Tank furnaces at the primary glass production workshop at Bet Eli'Ezer (Israel), late 7th – early 8th century CE.

was now made from local raw materials—sand, plant or wood ash, and lime—and processed in one and the same place. Glass recipes thus varied regionally and changed over time. The different natures and origins of the raw materials are reflected in the chemical and isotopic composition of the glass. The analysis of glass finds can thus shed light on the technology and the history of glass production in a region.[15]
→ Helen Spencer

Glass Windows in the Middle Ages: A Privilege of the Rich

The spread of Christianity gave a new impetus to glass production in Europe, especially that of plate glass: newly built churches were decorated with stained-glass windows made from pieces of coloured, mouth-blown sheet glass held together with lead cames (French: *baguettes de plomb*; German: *Bleiruten*).[16] Finds from the Merovingian and Carolingian period prove that early stained-glass windows had ornamental designs.[17] The first figurative depictions appeared from the 9th century CE onwards.[18] As the churches and cathedrals of the Gothic period grew taller, their windows took on monumental dimensions.

It was however not only the Church that could afford glass windows: secular rulers too glazed their windows, in castles and palaces.[19] Usually, only the upper portions of a 'cross-window' (French: *fenêtre à croisée*; German: *Kreuzstockfenster*) were glazed,

3 Chess-players, stained glass, c.1450, Paris, Musée de Cluny (Cl. 22422); detail showing a cross-window with lozenge glazing.

while the lower ones could be closed with wooden shutters (Fig. 3).[20] It was not long before the bourgeoisie and rich citizens of medieval cities followed this trend: by the 15th century, there was hardly a private residence, guild house or town hall in Central and Northern Europe without glazed windows. The increasing demand for sheet glass led to a steady rise in the number of private glassworks that produced and marketed their goods by land and water, partly over long distances.[21]

Because glass or glazing was very expensive, homeowners often looked for sponsors for their windows. In Switzerland, this led to a new genre of stained glass, the *Wappenscheibe.* These mostly small stained-glass panels, bearing a donor's coat-of-arms, were built into the glazing that embellished and closed the window openings of private houses, guild houses and town halls (Fig. 4).[22] Glass windows, however, remained a privilege of the wealthy in the medieval and for much of the early modern period.[23] The window openings of the dwellings of common people were still closed with hides, oiled parchment or wooden shutters.

4 'Bull's eye' window (crown glass) with stained-glass panel, 1636, Vitromusée Romont (VMR 699), on loan from Fritz Dold, Zurich.

From Quarries to Bull's Eye: The Transition from the Medieval to the Baroque Window

Gothic cross-windows had fixed lead lights (French: *vitrerie à resille* or *vitrage en plomb*; German: *Bleiverglasung*) that typically consisted of lozenge-shaped glass pieces known as quarries (French: *losange*; German: *Raute*) (see Fig. 3). These were cut out of broad-sheet or crown glass. The large circular tables of crown glass were thinner, more translucent and more brilliant than broad-sheet glass and therefore more popular, but also more expensive.[24]

From the 16th century onwards, and especially in German-speaking regions, lead lights made from either bull's eye panes, also known as roundels (French: *petite cive*; German: *Butzenscheiben*) or *Tellerscheiben* (French: *cul-de-bouteille*) replaced lozenge glazing (French: *vitrerie à losanges*; German: *Rautenverglasung*) (see Fig. 4).[25] Both forms are round, but manufactured in different ways, and are easily distinguished by the presence or absence of the 'bull's eye' (French: *boudine*; German: *Butzen*), a nodule in the centre of the crown-glass table where the pontil was attached. Lead lights could also take other forms; an example of this is the hexagonal glazing (French:

vitrerie à bornes hexagonales; German: *Waben-Verglasung* or *Sechseck-Verglasung*) of Michelsberg Abbey in Bamberg (Germany). **➔ Susanne Fischer and Josef Ganka**
A fundamental change in window architecture came with the introduction of symmetrical casement windows (French: *fenêtre à battants* or *fenêtre à la française*; German: *Flügelfenster*) in the Baroque period; these replaced cross-windows, which remained common until the late Renaissance. **➔ Ueli Fritz** The hinged sashes of these casement windows were subdivided by wooden muntins and glazed with small rectangular panes of broad-sheet or crown glass. These windows, often arranged in multiple rows, became a characteristic feature of the façades of Baroque castles and *hôtels particuliers*. The light streaming in through them was reflected by large wall mirrors and chandeliers, showing off lavishly decorated interiors to their full advantage. With its *Galerie des Glaces*—completed in 1682 and originally glazed with blown plate glass[26]—Versailles was the flagship example of the epoch and a reference point for other prestigious building projects, such as the Dresden Zwinger. **➔ Peter Heinrich Jahn**

Polished and Lustrous: Plate-Glass Production in the Early Modern Period

Developments in window architecture led to an increasing demand for particularly transparent glass, not least also to meet the new market for mirrors. Glass was supplied by the numerous glass-houses (French: *verrerie*; German: *Glashütte*) in the low mountain ranges of Central Europe (Bohemia, Silesia, Lorraine, Jura, etc.) that manufactured lustrous, highly fire-polished crown glass on the one hand, and blown plate, that is polished broad-sheet glass, on the other. Demand was so great that the glass industry also developed in regions away from those traditionally associated with glass production, for example in Scotland. **➔ Helen Spencer**
The clearest glass, however, came from Murano (Italy), which held a monopoly in the production of blown plate glass and mirrors until well into the 17th century.[27] France succeeded in breaking this monopoly with the foundation of the *Manufacture royale de glaces de miroirs* (which later became Saint-Gobain) in 1665. Jean-Baptiste Colbert, Minister of Finance to Louis XIV, recruited experienced glass-makers from Venice, and the import of blown plate and mirrors from Venice was eventually banned.
The manufacture of blown plate glass—used in windows and for mirrors—was a time-consuming and expensive business, since the streaky and often warped broad-sheet glass had to be ground and polished by hand. Sheets of cylinder-blown glass moreover had the disadvantage of being relatively small. With the invention of casting glass onto a table (French: *coulage* or *coulée sur table*; German: *Tischgussverfahren*) around 1688,[28] the French achieved a decisive technical breakthrough. With this new technique it was possible to produce large sheets of glass that could be used to glaze big window openings and to make tall continuous mirrors (Fig. 5). In order to obtain plate-glass quality however, the thick cast sheets had still to be polished manually on both sides. Smooth and lustrous plate glass was a luxury in great demand among the rich upper classes and was twice as expensive as blown plate or crown glass.[29]

5 'Manufacture des glaces' (manufacture of plate glass), Denis Diderot and Jean le Rond d'Alembert, *L'Encyclopédie ou dictionnaire raisonné des sciences, des arts et des métiers: Recueil de planches, sur les sciences, les arts libéraux, et les arts méchaniques, avec leur explication*, vol. 4, plate XXIV, Paris, 1765, Bibliothèque Mazarine (cote 2°3442).

Palm Houses, Train Stations and Department Stores: Mass Production and the Large-Scale Use of Sheet Glass in the 19th Century

During the 19th century, several developments had a significant impact on the glass industry and the cost of sheet glass: the introduction by Ernest Solvay (1838–1922) in 1864 of a new and more efficient process for the industrial production of soda, one of the most important raw materials for glass production; better transportation through the expanding railway network; and the switch from coal to gas firing. One ground-breaking invention however changed glass production in a particularly lasting way: the development of the continuously operating tank furnace by Friedrich and Wilhelm Siemens in 1861.[30] The furnace was no longer wood-fired but gas-fired, and the waste heat was recovered using the regenerative process. These developments made glass production much cheaper, more efficient and cleaner, and allowed the standardized mass production of sheet glass (Fig. 6). These innovations did not bring abrupt changes however, and the industry's success continued to depend strongly on craftmanship, an intimate knowledge of the material, and the transfer of this know-how.[31] → **Vitaly Volkov**

6 'Porteuses de canons', Verreries de Jumet, Jumet (Belgique), c. 1900, Musée du Verre de Charleroi, Collection iconographique (CP 118).

New construction methods and building materials (steel, cement) combined with lower prices for sheet glass opened up completely new paths and possibilities for architecture. An important field of experimentation was the construction of greenhouses and exhibition halls, which was promoted especially in England. The Crystal Palace built by Joseph Paxton (1803–1865) for the Great Exhibition in London in 1851 caused a sensation. Glass also became increasingly important in the construction of market halls, train stations, shopping arcades and department stores, with their large display windows.[32]

The invention of rolled plate glass by James Hartley (1810–1886) in 1838 led to the development of figured glass (French: *verre imprimé*; German: *Gussglas* or *Ornamentglas*).[33] This technology (English: *rolling*; French: *laminage*; German: *Walzglasverfahren*), which consists of passing the still-viscous cast glass sheets through a set of rollers engraved with negative patterns, allowed decorative glass to be applied in a wide variety of contexts in the second half of the 19th century, shaping the appearance of front doors, staircases and bathrooms until well into the 20th century (Fig. 7). **→ Emma Groult** The emerging hygiene movement, and the first efforts to build bright and well-ventilated homes, are reflected in the production of ingenious inventions such as *verre perforé* (English: *perforated rolled plate glass*; German: *perforiertes Walzglas*). **→ Anne-Laure Carré**

Glass by the Metre: The Invention of Drawn Sheet Glass and Its Manifestation in Modern Architecture

Architectural experimentation and technical innovation in glass production continued to stimulate each other.[34] At the beginning of the 20th century, the production of broad sheet glass was improved by the replacement of the human lung with compressed air; this allowed glass cylinders up to 12 m in length and 80 cm in diameter to be drawn directly from the melting tank.[35]

In Belgium and the USA, several men were already working on a new method that would allow a continuous sheet (or ribbon) of glass to be drawn from the melting tank and would—once again—significantly simplify production and reduce the price of flat glass.[36] Two patents for the new technique were filed almost simultaneously. In 1902, Émile Fourcault (1862–1919) obtained the first patent on a 'Method of and apparatus for drawing continuous sheets of glass' that he had developed with Émile Gobbe (1849–1915), but which soon became known as the 'Fourcault process'.[37] Two years later, Irving W. Colburn (1861–1917) and Edgar Washburn (dates unknown) filed a patent for a similar invention, which would go down in history as the 'Libbey-Owens process'.[38]

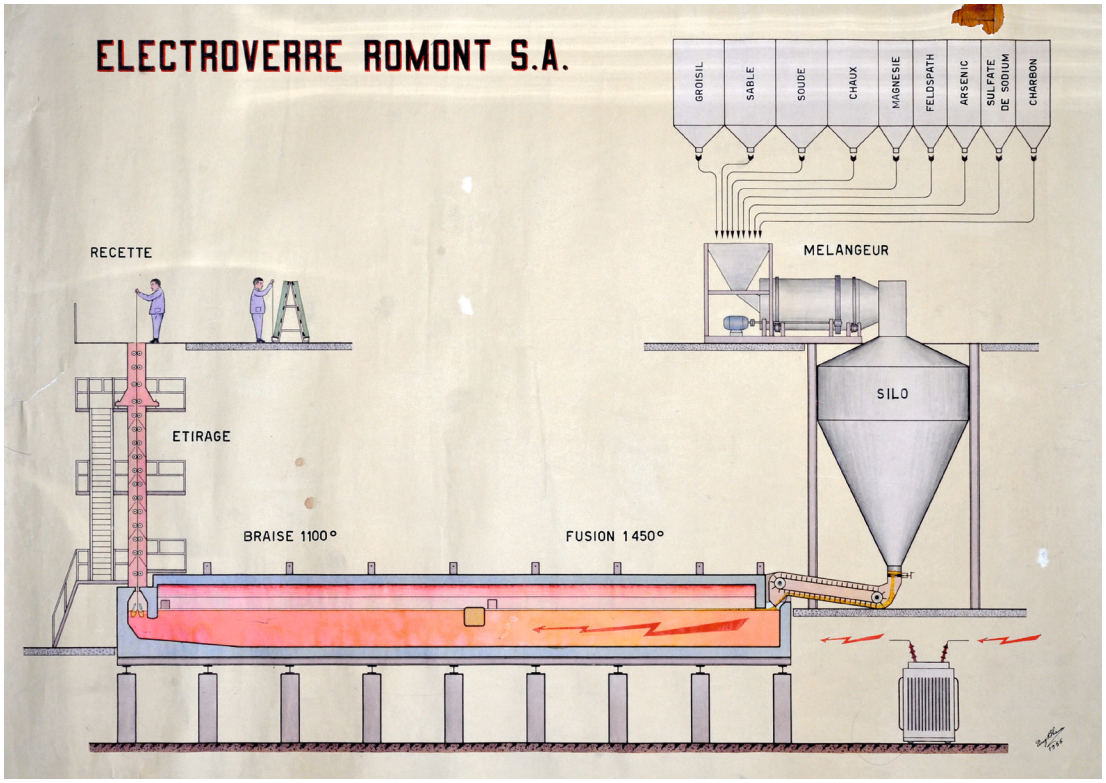
In the Fourcault process, liquid glass is pushed through an elongated clay nozzle known as a debiteuse (French: *débiteuse*; German: *Ziehdüse*) that sits in the melting tank, and is drawn vertically upwards between pairs of rollers; the ribbon cools on its way up to the top of the drawing line, where it is cut into rectangular sheets of the desired dimension (Fig. 8a). In the Libbey-Owens process, the glass ribbon is first drawn vertically and then horizontally over rollers into a lehr (annealing) oven (French: *four de recuisson*; German: *Temperofen*). In 1928, the Pittsburgh Plate Glass Company successfully combined the two drawing processes (the 'Pittsburgh process'). In 1935, Erie-Electroverre in Romont (Switzerland), switched from gas to electricity by installing the first *four électrique* (Fig. 8b).

Machine-drawn sheet glass began to be manufactured in the 1920s and dominated the market in the USA and Europe until the 1960s. The new process brought previously unimagined possibilities, as it liberated window glass from earlier size restrictions and made the fast production of large quantities possible. Thanks to the introduction of the Bicheroux process (1918), plate glass continued to be made on a large scale, for example at Saint-Gobain and in Pittsburgh.[39] It was more expensive, but of much higher quality than machine-drawn sheet glass, and used—among other things—for the windscreens of Ford cars.[40] Plate glass with an integrated steel mesh, so-called wired glass (French: *verre armé*; German: *Drahtglas*), also emerged as an early security glass.

The larger dimensions, the greater availability and the better transparency of machine-drawn sheet glass and plate glass stimulated new architectural designs.[41] Large horizontal bands of windows in thin metal-frame profiles became a characteristic of the *Neues Bauen*.[42] The use of glass became synonymous with modernist discourses on clean and healthy working and living conditions based on the circulation of fresh air, daylight and the sun.[43] → **Florin Gstöhl**

7 *Verrerie de Saint Gobain et de Jeumont, Album des principaux modèles de verre : Produits spéciaux en verre coulé*, around 1915–20, samples of rolled plate glass, cardboard, 28.4 × 17.7 × 8 cm, collection of the Vitromusée Romont (VMR 738).


Verre Cathédrale Teinté Jaune Armé (mailles carrées)
Epaisseur 3 à 5 m/m
N° 9
Verres Diamantés Teintés
Epaisseur 3 à 4 m/m
N° 11
N° 8
Verres Imprimés Teintés
Epaisseur 3 à 4 m/m
N° 10
N° 14

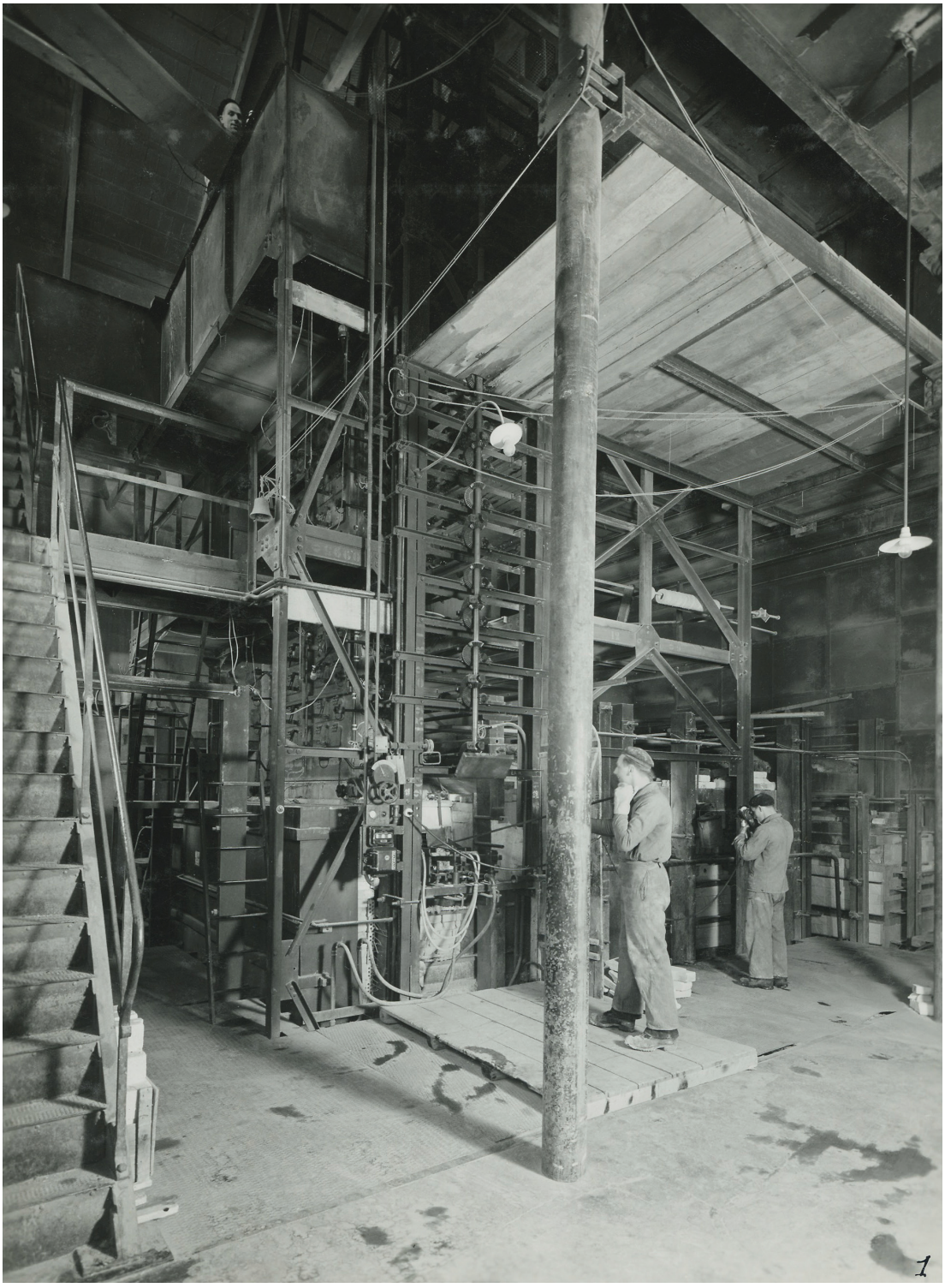


8a Schematic illustration of the Fourcault process at Electroverre Romont (Switzerland).

Moreover, the idea of the 'glass house' resonated widely with the avant-garde, and not only with well-known male protagonists but also with many female artists, architects and writers.[44] It resulted in innovative displays for glass companies, such as the 'Glass House' by Bruno Taut (1880–1938) at the Deutsche Werkbund exhibition in Cologne (1914) that showcased glass bricks and other products of the Luxfer-Prism Company;[45] or the glass-clad office towers as visualized by Ludwig Mies van der Rohe (1886–1969) in his designs for a high-rise building to a polygonal plan at Friedrichstrasse, Berlin (1921).[46] Others considered glass the material of choice not only for windows and façades, but also for entire interior designs; → **Logan Sisley** unearths the history of the spectacular glass house (1924) of celebrity hairdresser Antoine de Paris.

The Road to Float: Technological and Architectural Developments in the Post-War World

For much of the 20th century, the leitmotif was the total 'dissolution' of walls and windows into entire glass façades.[47] The curtain wall (French: *mur-rideau*; German: *Vorhangfassade*)—consisting of a non-load-bearing glass wall fixed to the outside of

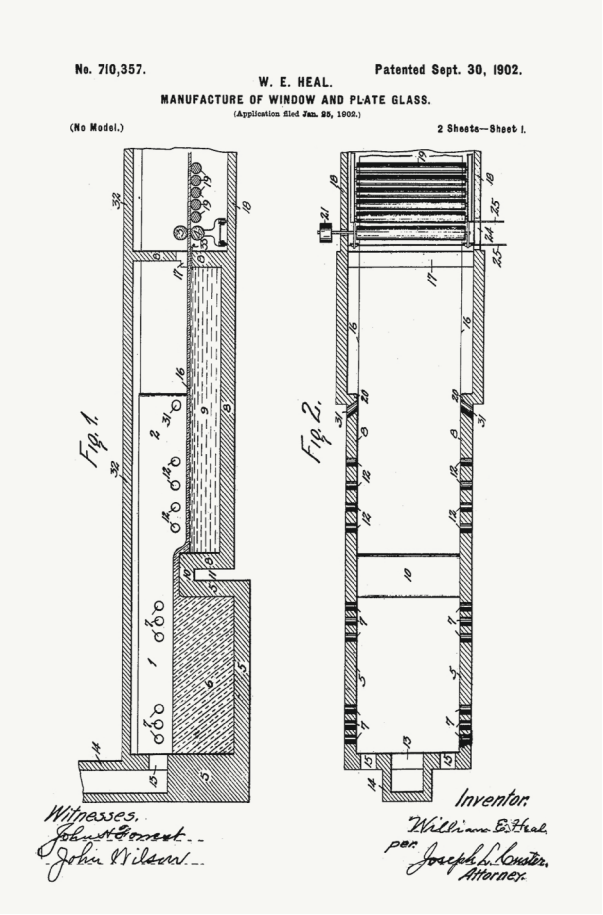


8b Manufacture of drawn glass at Erie-Electroverre, Romont, second quarter of the 20th century, gelatine silver print, 158 × 178 mm (EVR 22_1).

the structural framework of a building (skeleton)—converted this leitmotif into reality: the demise of the load-bearing function of façades enabled their opening-up and dematerialization into light and transparent surfaces.[48] Early iconic examples of curtain walls are the *Fagus Works* (1911–1925) designed by Adolf Meyer (1881–1929) and Walter Gropius (1883–1969) and the *Bauhaus* in Dessau.[49] Until well into the 1960s, machine-drawn sheet glass was the main architectural glass, with the market divided technologically (in 1950) into 70% Fourcault, 20% Libbey-Owens, and 10% Pittsburgh.[50] Curtain walling, often employing tinted sheet glass, went hand in hand with a new architectural aesthetic on the outside, and with the open floorplans on the inside that became popular in high-rise office buildings in the post-Second World War period in Europe, the USA and elsewhere. In 1952, New York's Lever House set the standard for the prestige architecture of large industrial corporations and their choice of glass façades to express 'symbolic transparency'.[51] **→ Hauke Horn**

The success story of glass-clad high-rises is not only linked to the curtain wall and capitalism, but also to the introduction of the float-glass process (French: *procédé de fabrication de verre flotté*; German: *Floatglasverfahren*). This is an endless process in which molten glass is continuously fed from one side onto a bath of liquid tin. The result is a flawless, transparent and completely smooth sheet glass more than 2.5 m wide. The glass does not need to be post-processed. Thanks to its relatively low production costs, the flexibility in thickness and length of the glass sheet, and its impeccable quality, float glass superseded more expensive plate glass and machine-drawn sheet glass and came to be used very widely for window glass as well as for mirrors, windscreens and many other applications. Alastair Pilkington (1920–1995) is usually credited with inventing the process in the 1950s, but in reality the basic idea goes back to William Heal, who was granted a patent for his invention as early as 1902 (Fig. 9).[52] Pilkington however had the courage and ability to develop and implement the process, thereby paving the way for the commercial production of float glass. Production started in 1966 at Pilkington Brothers in St Helens (England).[53] The company subsequently granted licences to other sheet-glass manufacturers around the world. Yet the production of colourless and transparent float glass was far from being the only field of activity among producers of flat glass: the industry also experimented creatively with the medium's aesthetics, launching products like the coloured-glass *Émalit*® panels produced by Saint-Gobain in 1958. **→ Catherine Blain and Océane Bailleul** Orange and bluish tinted sunscreen glass became ubiquitous in 1960s and 1970s European architecture and today poses many challenges regarding its long-term performance and renovation possibilities. **→ Giulia Marino**

Technical requirements and practical issues have also played a rôle in stimulating production and have led to the development of special glass-treatment techniques and a near-endless variety of glass types. New safety standards (to counter breakage and injury), for example, have been met through the development of toughened and tempered plate glass (French: *verre trempé*; German: *Einscheibensicherheitsglas* or *ESG*) and, from the 1950s onwards, of laminated safety glass, a composite of two or more



9 Figures 1 and 2 of Patent no. 710357, 'Manufacture of window and plate glass', by William E. Heal (issued 30 September 1902). The figures show a cross-section (left) and a top view (right) of a precursor of the modern float-glass tank furnace.

tempered glass sheets joined by an elastic polymer film (French: *verre de sécurité*; German: *Verbundsicherheitsglas* or *VSG*).

New Coating Techniques and Smart Glass: Developments Since the 1970s

In the second half of the 20th century, increasing requirements and tougher standards around building insulation and work safety led to the rapid spread of multi-pane insulating glass and safety glass, and accelerated the development of new techniques of glass processing and finishing intended to modify and enhance the thermal, mechanical and optical properties of sheet glass. Techniques include new approaches to heat and chemical strengthening (toughened and tempered glass), heat-bending (simple or double curved glass), tinting or colouring (tinted or coloured glass), and etching and sand-blasting (obscure glass). Decisive progress was made with the coating of glass with thin films of metals and metal compounds. Glass coating allowed the production of sheet glass with anti-reflection, anti-condensation as well as self-cleaning proper-

10 Headquarters of Qatar Central Bank (formerly Qatar Monetary Authority) on the Doha Corniche (Qatar), 2016.

ties and opened up many new applications, such as thermal insulation combined with solar control.

The latest invention is so-called 'smart glass', a term used to describe glass that can change certain properties, such as transparency or sound absorption. The generic term comprises various techniques and fields of application. Depending on the design, smart glass can, for example, be used as protection against the sun (with the glass remaining transparent) or take on the function of privacy protection (with the glass becoming opaque). Light transmission can be modified by applying an electrical voltage, by heating, or by changing external light conditions.

All these developments have led to an incredible variety of flat glass in terms of function and application, as well as to new forms of aesthetic expression. The diversity of sheet-glass products, in combination with new mounting techniques and synthetic seals substituting putty, promise seemingly unlimited design and application possibilities. Tinted and mirror-glass façades have spread across the world, becoming the face of a global building trend (Fig. 10).[54] New methods of fixing and suspending glass façades such as structural sealant glazing, point-fixing and cable net walls, to name but a few milestones, have become today's standard.[55]

Over recent decades, the number of safety regulations and energy requirements for building components has steadily increased and helped double and triple glazing

11 Disappearing hertitage: removal and destruction of the historic windows of a 19th-century house in Zurich (Switzerland), 2014.

achieve a breakthrough. The numerous norms for energy conservation and protection against sun, sound, fire and breakage, as well as the great variety of glazing types, not only represent a major challenge for architects and engineers, but also confront monument conservators and restorers with new problems.

Disappearing Heritage: The Challenge of Preserving and *in situ* Restoration of Window Glass

Today, we often consider glass a cheap everyday, 'throwaway' material; historically, glass was an expensive and much-valued building material, and each plate or sheet was unique. Glass has also defined our view of the outside world. We might see the world through wavy, bubbly or highly polished glass. The loss of the historically evolved diversity of flat glass should not be taken lightly from a historical or sociocultural perspective. Research and teaching should therefore also give a more prominent rôle to glass in architectural history.

In fact, much historical architectural glass is currently under threat owing to the renovation and conservation of architecture in line with new energy standards such as *Minergie*® or the changing lifestyles of houseowners and users. In the strong trend towards the thermal insulation of buildings, original windows are often the first thing

to be replaced (Fig. 11). At the same time, and somewhat paradoxically, 'new glass' has become the prime material in preventive conservation of entire or partial sections of historical buildings and monuments. **➔ Melchior Fischli**

The *in situ* conservation and preservation of historical architectural glass, whether medieval or modern, is very challenging.[56] The closure of many glassworks across Europe and the USA, the loss of knowledge and know-how regarding manual or mechanical glass manufacturing, and the rarity or rather the lack of appropriate historical glasses have rendered the restoration of architectural glass a difficult task. Practitioners in the field of architectural history, restoration and conservation have discussed and promoted best practices in the *in situ* handling of historical glass in the form of small handbooks or leaflets since at least the 1970s. **➔ Isabel Haupt** As one of the latest efforts in this regard, a research team at the University of Bamberg and the Fraunhofer Institute for Building Physics has been investigating practical solutions for improving the energy efficiency of historic glass windows. **➔ Paul Bellendorf et al.** Researchers from the Landesamt für Denkmalpflege Baden-Württemberg report here on their work at and the success achieved in preserving insulated glass panels with glass-paintings at a swimming pool in Stuttgart-Feuerbach (Germany) dating from the late early 1960s. **➔ Dunja Kielmann and Angelika Reiff**

Finally, from an ecological perspective, the reparability and recyclability of the ubiquitous post-1950s double glazing has become an especially pressing issue. **➔ Esther Geboes, Waldo Galle and Niels De Temmerman** show that insulated glazing (French: *double vitrage* or *vitrage isolant*; German: *Mehrscheiben-Isolierglas*) is almost never recycled, but instead downcycled or put into landfill. The authors therefore evaluate sustainable life-cycle approaches as potential alternatives to this throwaway practice.[57]

Looking Back and Ahead: In Search of a Common Terminology

'Glass in architecture' has already been the subject of several conferences and publications, but interest in the topic seems constant.[58] The high attendance and the lively and stimulating discussions at our 2021 conference in Romont made this clear once again.[59] It showed that this multifaceted topic can almost overcome the often still-deep-seated divide between the humanities and the natural sciences. The conference also revealed some deficits, especially regarding a common terminology in the field of (flat) glass technology. To date, there is no official online dictionary specific to glass technology and the glass arts. The various existing glossaries and vocabularies are not multilingual and usually not online. The desire to link the increasing number of online databases and other online resources only accentuates this problem, since this lack of standardization prevents the networking of platforms on a technical level. The problem does not only exist in the field of glass art. Indeed, with the digitalization and especially the pooling of resources in the field of conservation and cultural heritage (for example, Europeana), the need for common vocabularies becomes inevitable. In a pilot project initiated by the International Scientific Committee for the Conservation

of Stained Glass (ISCCSG) and the Vitrocentre Romont, the technicalities and various options for online publication of this multilingual thesaurus are currently being explored; publication via the online database of the Vitrocentre Romont (www.vitrosearch.ch) will also be discussed and tested.[60]

We hope that this publication will continue to stimulate exchange—as the conference did—not only across language and national borders, but also between the different disciplines of art history, architecture, the archaeological sciences, technology, conservation and restoration.

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1 Calder 2021.
2 For a good overview, see Komp 2009, 7–14.
3 Taylor/Hill 2002; Komp 2009, 30–33; Dell'Acqua 2004, 111.
4 Baatz 1991, 10; Dell'Acqua 2004, 115–18; Komp 2009, 18–19.
5 Fellmann 2009, 94, 97, and catalogue nos. 906–1054. The reconstruction of the glazed portico of the Roman town house Insula 39 in Augusta Raurica is a good example of what these multi-pane windows may have looked like; see Hufschmid/Tissot-Jordan 2013, 25–32.
6 Both processes are beautifully illustrated in the Recueil de planches of the Encyclopédie des arts et métiers by Diderot and d'Alembert (Diderot/d'Alembert 1765, vol. 4, pls. VII–XVI and pls. XXXIV–XXXVIII).
7 Schedula diversarum artium, book 2, chapter 6, 'QVOMODO OPERENTVR VITREAE TABVLAE'; see Theophilus/Dodwell 1986, 40. For a detailed study and recreation of the process, see Kaufmann 2010, 126–34.
8 Encyclopedia Britannica online 2003.
9 Foy 2005, 59.
10 Fontaine/Foy 2005, 19–20; Foy/Fontaine 2008, 430–31.
11 On the use of natron as a flux, see Shortland et al. 2006. On the transition from natron to ash-based glass, see Whitehouse 2002.
12 For example, Freestone/Gorin-Rosen/Hughes 2000; Gorin-Rosen 2000; Foy et al. 2003.
13 On early glass recycling, see for example Jackson 1997; Freestone 2015; Grünewald/Hartmann 2015.
14 See references in footnote 12 and Rehren/Freestone 2015, 236.
15 For example, Jackson 2005; Freestone 2006; Freestone/Wolf/Thirwall 2009; Brems/Degryse 2014; Degryse/Shortland 2020.
16 Strobl 1990.
17 For glass finds from the Merovingian period, see for example Balcon-Berry/Perrot/Sapin 2010. On early stained glass in Switzerland, see Kessler/Wolf/Trümpler 2005; Wolf et al. 2017.
18 Among the earliest surviving examples of figurative stained glass are the heads of Christ from San Vincenzo al Volturno (see Dell'Acqua 2010) and Lorsch (see Gast 2011, 179–84).
19 Lagabrielle 2009, 106.
20 Cross-windows are divided by a stone mullion and transom, forming a cross; see Curl 2006, 214.
21 Steppuhn 2016, 91, 96–98.
22 Oswald 1985, 433.
23 On the history of glass in the early modern period, see Cremer 2022.
24 Lagabrielle 2009, 109–10.
25 Gerber 2009, 187–88. To our knowledge, there is no specific term for 'Tellerscheiben' in English.
26 Hamon 2009, 139–40.
27 Verità 2013, 65–66.
28 The history of the invention of this new process, which is both complex and disputed, has been well summarized: Hamon 2009, 140–44.
29 Maxwell 2022, 40.
30 Krupa/Heawood 2002.
31 Savaëte 2013, 152–53.
32 See Schädlich 2015.
33 See Grace's Guide to British Industrial History 2022 based on James Hartley's obituary published by the Institution of Civil Engineers in 1886.
34 For a well-informed technical overview on modern glazing, see Pender/Godfraind 2011, 315–54.
35 The invention of machine-drawn cylinder glass is credited to P. T. Sievert and John H. Lubbers, US Patent no. 702013 (1902). Earlier patents, such as Vallin Patent no. 91781 (5 May 1871), paved the way for the technique. For a good overview, see Staib 2007, 11–12; Kutilek 2019, 41–43. For illustrations of the process, see Völckers 1939, 38–39.
36 Kutilek 2019, 43–46; Van de Voorde/Bertels/Wouters 2015 (section on glass and glazing).
37 See Hermès 1929, 2–7. From the invention of the Fourcault process to the production of drawn sheet glass is a complex story that stretches over nearly twenty years. It reads like a thriller; see Thomas 2018.

38 Irving W. Colburn and Edgar Washburn, 'Process and apparatus for the continuous production of sheet-glass', US Patent no. US876267A (7 January 1908). From 1916, the Libbey-Owens Glass Company in Charleston, USA, produced flat glass using this process. Since then, 'Libbey-Owens process' has become the accepted term for this method.
39 Kutilek 2019, 46–54.
40 Ibid., 46–50; Wigginton 1996, 55.
41 Stalder 2014; Jester 2014 (section on glass).
42 Turit Fröbe (2018) provides an excellent overview on reading architectural history by its windows.
43 Völckers 1939.
44 Gellai 2023.
45 Thiekötter 1993; Ikelaar 1996.
46 Riley/Bergdoll 2001; Bergdoll 2019.
47 Harrison 1950. On the use of glass in architectural façades in the first half of the twentieth century, see Korn [1929] 1999; McGrath 1961; Schulze 1929. For the second half of the century, see Wigginton 1996.
48 Herzog/Krippner/Lang 2004, 183–209.
49 Yeomans 2001.
50 Wigginton 1996, 63.
51 See, for example, Drexler 1979.
52 Heal's 'Manufacture of window and plate glass' was patented in US Patent no. 710357 (issued on 30 September 1902); see also Savaëte 2013. It was not until sixty years later that Alastair Pilkington ventured the first step in the production of float glass based on GB Patent no. 769692 (1954); see also Pilkington 1969.
53 For a historical overview of the Pilkington company, see Barker 1977; Bricknell 2009; and the company's website, https://www.pilkington.com/en-GB/uk (accessed 3 February 2023).
54 On postmodern architecture and mirror glass, see Martin 2010, 93–122; Drexler 1979.
55 For a good overview of contemporary glass types and construction technologies, see Herzog/Krippner/Lang 2004; Schnittich et al. 2007; Achilles/Navratil 2008.
56 See Mislik 2017; Pender/Godfraind 2018; Ayón/Pottgiesser 2019.
57 On building with material usually considered 'waste material', see Hebel/Wisniewska/Heisel 2014.
58 Most recently, *Mirror in Theory and Practice*, conference, University of Vienna and Alanus University of Arts and Social Sciences, 17–18 June 2021; *The Bauhaus Curtain Wall: 1926, 1976, 2026*, conference, Bauhaus Dessau Foundation, 6 June 2021; *Du miroir à la maison : Production, usage et restauration du matériau verrier dans l'architecture (XIX^e–XX^e siècles)*, Journées d'études, 20 November 2019, Institut national d'histoire de l'art, Paris; *Un rêve d'architecte : La brique de verre de Falconnier* (Jeandrevin 2018).
59 The conference was attended by more than 100 scientists and professionals working in the fields of architectural history, material science, glass technology, and glass conservation and restoration. They came from Austria, Belgium, France, Germany, Ireland, Italy, the Netherlands, Switzerland and the United Kingdom.
60 The project was funded by the Swiss Academy of Humanities and Social Sciences SAGW.

Bibliography

ACHILLES/NAVRATIL 2008
Andreas Achilles and Diane Navratil, *Basics. Konstruktion:* Glasbau, Basel: Birkhäuser, 2008, https://doi.org/10.1515/9783035612547.

AYÓN/POTTGIESSER 2019
Angel Ayón and Uta Pottgiesser, Reglazing Modernism: Intervention Strategies for 20th-Century Icons, Basel: Birkhäuser, 2019, https://doi.org/10.1515/9783035619348.

BAATZ 1991
Dietwulf Baatz, 'Fensterglastypen, Glasfenster und Architektur', in: Adolf Hoffmann (ed.), Bautechnik der Antike: Internationales Kolloquium, Berlin 15–17 February 1990, Diskussionen zur archäologischen Bauforschung 5, Mainz: Philipp von Zabern, 1991, 4–13.

BALCON-BERRY/PERROT/SAPIN 2010
Sylvie Balcon-Berry, Françoise Perrot and Christian Sapin (eds.), Vitrail, verre et archéologie entre le V^e et le XII^e siècle, Archéologie et histoire de l'art 31, Paris: CTHS, 2010.
BARKER 1977
T. C. Barker, The Glassmakers. Pilkington: The Rise of an International Company 1826–1976, London: Weidenfeld and Nicolson, 1977.
BERGDOLL 2019
Barry Bergdoll, 'Hüllen aus reinem Glas für einen neuen architektonischen Ausdruck. Mies van der Rohes Beitrag "Wabe" zum Wettbewerb Bürohaus Friedrichstraße', in: Bauhaus-Archiv / Museum für Gestaltung, Stiftung Bauhaus Dessau und Klassik Stiftung Weimar (eds.), Modell Bauhaus, Ostfildern: Hatje-Cantz, 2019, 115–18.
BREMS/DEGRYSE 2014
Dieter Brems and Patrick Degryse, 'Trace Element Analysis in Provenancing Roman Glass-Making', Archaeometry 56, June 2014, 116–36, https://doi.org/10.1111/arcm.12063.
BRICKNELL 2009
David J. Bricknell, Float: Pilkingtons' Glass Revolution, Lancaster: Crucible, 2009.
CALDER 2021
Barnabas Calder, Architecture: From Prehistory to Climate Emergency, London: Pelican, 2021.
CREMER 2022
Annette C. Cremer (ed.), Glas in der frühen Neuzeit: Herstellung, Verwendung, Bedeutung, Analyse, Bewahrung, Höfische Kultur interdisziplinär – Schriften und Materialien des Rudolstädter Arbeitskreises zur Residenzkultur 6, Heidelberg: Heidelberg University Publishing, 2022, https://doi.org/10.17885/HEIUP.821.
CURL 2006
James Stevens Curl, A Dictionary of Architecture and Landscape Architecture, 2nd edition, Oxford/New York: Oxford University Press, 2006.
DEGRYSE/SHORTLAND 2020
Patrick Degryse and Andrew J. Shortland, 'Interpreting Elements and Isotopes in Glass: A Review', Archaeometry 62.S1, August 2020, 117–33, https://doi.org/10.1111/arcm.12531.
DELL'ACQUA 2004
Francesca Dell'Acqua, 'Le finestre invetriate nell'antichità romana', in: Marco Beretta, Giovanni Di Pasquale and Istituto e Museo di Storia della Scienza (eds.), Vitrum: il vetro fra arte e scienza nel mondo romano, Florence/Milan: Giunti, 2004, 109–19.
DELL'ACQUA 2010
Francesca Dell'Acqua, 'The Christ from San Vincenzo al Volturno. Another Instance of "Christ's Dazzling Face"', in: Valérie Sauterel and Stefan Trümpler (eds.), Les Panneaux de Vitrail Isolés. Die Einzelscheibe. The Single Stained-Glass Panel. Actes du XXIV^e Colloque International du Corpus Vitrearum Zurich 2008, Bern: Peter Lang, 2010, 11–22.
DIDEROT/D'ALEMBERT 1765
Denis Diderot and Jean Le Rond d'Alembert, L'Encyclopédie ou dictionnaire raisonné des sciences, des arts et des métiers: Recueil de planches, sur les sciences, les arts libéraux, et les arts méchaniques, avec leur explication, vol. 4, Manufacture des glaces, Paris 1765, http://enccre.academie-sciences.fr/encyclopedie/ (accessed 3 February 2023).
DREXLER 1979
Arthur Drexler, Transformations in Modern Architecture, exhibition catalogue (Museum of Modern Art, New York, 23 February–24 April 1979), New York: Museum of Modern Art, 1979.
ENCYCLOPEDIA BRITANNICA ONLINE 2003
The Editors of Encyclopedia Britannica (eds.), 'Crown glass', in: Encyclopedia Britannica online, last revised 17 January 2003, https://www.britannica.com/technology/crown-glass (accessed 3 February 2023).
FELLMANN 2009
Rudolf Fellmann, Römische Kleinfunde aus Holz aus dem Legionslager Vindonissa, Veröffentlichungen der Gesellschaft Pro Vindonissa 20, Brugg: Kantonsarchäologie Aargau, 2009.
FONTAINE/FOY 2005
Souen Fontaine and Danièle Foy, 'La modernité, le confort et les procédés de fabrication des

vitrages antiques', in: Conseil Général Département du Nord (ed.), De transparentes spéculations. Vitres de l'Antiquité et du Haut Moyen Age (Occident-Orient), Bavay: Musée et site archéologique de Bavay, 2005, 15–24.

FOY 2005

Danièle Foy, 'La suprématie du verre soufflé en cylindre : panneaux et vitraux du Ve au IXe siècle', in: Conseil Général Département du Nord (ed.), De transparentes spéculations: Vitres de l'Antiquité et du Haut Moyen Age (Occident-Orient), Bavay: Musée et site archéologique de Bavay, 2005, 59–64.

FOY/FONTAINE 2008

Danièle Foy and Souen Fontaine, 'Diversité et évolution du vitrage de l'Antiquité et du haut Moyen Âge. Un état de la question', Gallia 65, 2008, 405–59.

FOY ET AL. 2003

Danièle Foy, Maurice Picon, Michèle Vichy and Valérie Thirion-Merle, 'Caractérisation des verres de la fin de l'Antiquité en Méditerranée occidentale: l'émergence de nouveaux courants commerciaux', in: Danièle Foy and Marie-Dominique Nenna (eds.), Echanges et commerce du verre dans le monde antique. Actes du colloque de l'Association Française pour l'Archéologie du Verre, Aix-en-Provence/Marseille 7–9 June 2001, Montagnac: Editions monique mergoil, 2003, 41–85.

FREESTONE 2006

Ian C. Freestone, 'Glass Production in Late Antiquity and the Early Islamic Period: A Geochemical Perspective', Geological Society, London, Special Publications 257.1, 2006, 201–16, https://doi.org/10.1144/GSL.SP.2006.257.01.16.

FREESTONE 2015

Ian C. Freestone, 'The Recycling and Reuse of Roman Glass: Analytical Approaches', Journal of Glass Studies 57, 2015, 29–40.

FREESTONE/GORIN-ROSEN/HUGHES 2000

Ian C. Freestone, Yael Gorin-Rosen and Michael Hughes, 'Primary Glass from Israel and the Production of Glass in Late Antiquity and the Early Islamic Period', in: Marie-Dominique Nenna (ed.), La Route du verre: Ateliers primaires et secondaires du second millénaire av. J.-C. au Moyen Âge, Travaux de la Maison de l'Orient Méditerranéen 33, Lyon: MOM Éditions, 2000, 65–83.

FREESTONE/WOLF/THIRLWALL 2009

Ian C. Freestone, Sophie Wolf and Mathew Thirlwall, 'Isotopic Composition of Glass from the Levant and the South-Eastern Mediterranean Region', in: Patrick Degryse, Julian Henderson and Greg Hodgins (eds.), Isotopes in Vitreous Materials, Studies in Archaeological Sciences 1, Leuven: Leuven University Press, 2009, 31–52, https://doi.org/10.2307/j.ctt9qdx40.

FRÖBE 2018

Turit Fröbe, Alles nur Fassade? Das Bestimmungsbuch für moderne Architektur, Cologne: DuMont, 2018.

GAST 2011

Uwe Gast, Die mittelalterlichen Glasmalereien in Oppenheim, Rhein- und Südhessen, Corpus Vitrearum Medii Aevi. Deutschland 3.1, edited by Hartmut Scholz, Berlin: Deutscher Verlag für Kunstwissenschaft, 2011.

GELLAI 2023

Szilvia Gellai, Glass Scenographies: Notes on Spaces of One's Own, with a response by Sina Brückner-Amin, edited by Center for Critical Studies in Architecture CCSA, Weimar: M BOOKS, 2023.

GERBER 2009

Christophe Gerber, 'Production de cives et de manchons dans le Jura central suisse au début du XVIIIe siècle. L'exemple de la verrerie de Court-Chaluet', in: Sophie Lagabrielle and Michel Philippe (eds.), Verre et fenêtre: de l'antiquité au XVIIIe siècle. Actes du premier colloque international de l'association Verre & Histoire, Paris-La Defense/Versailles, 13–15 October 2005, Les Cahiers de Verre & Histoire 1, Paris: Verre & Histoire, 2009, 407–12, http://www.verre-histoire.org/colloques/verrefenetre/pages/p407_01_gerber.html (accessed 3 February 2023).

GORIN-ROSEN 2000

Yael Gorin-Rosen, 'The Ancient Glass Industry in Israel: Summary of Finds and New Discoveries',

in: Marie-Dominique Nenna (ed.), La Route du verre: Ateliers primaires et secondaires du second millénaire av. J.-C. au Moyen Âge, Travaux de La Maison de l'Orient Méditerranéen 33, Lyon: MOM Éditions, 2000, 49–63.

GRACE'S GUIDE TO BRITISH INDUSTRIAL HISTORY 2022
Anonymous, 'James Hartley', Grace's Guide to British Industrial History, last edited 14 March 2022, https://www.gracesguide.co.uk/James_Hartley (accessed 3 February 2023).

GRÜNEWALD/HARTMANN 2015
Martin Grünewald and Sonngard Hartmann, 'Überlegungen zum Glasrecycling der Antike im Bereich des heutigen Deutschlands', in: Peter Henrich, Christian Miks, Jürgen Obmann and Martin Wieland (eds.), Non solum sed etiam: Festschrift für Thomas Fischer zum 65. Geburtstag, Rahden/Westfalen: Verlag Marie Leidorf, 2015, 153–64.

HAMON 2009
Maurice Hamon, 'Les commandes de glaces pour Versailles aux XVIIe et XVIIIe siècles', in: Sophie Lagabrielle and Michel Philippe (eds.), Verre et fenêtre: de l'antiquité au XVIIIe siècle. Actes du premier colloque international de l'association Verre & Histoire, Paris-La Defense/Versailles, 13–15 October 2005, Les Cahiers de Verre & Histoire 1, Paris: Verre & Histoire, 2009, 402–06, http://www.verre-histoire.org/colloques/verrefenetre/pages/p402_01_hamon.html (accessed 3 February 2023).

HARRISON 1950
Donald Dex Harrison, 'Window into Wall', The Architectural Review 108, 1950, 113–22.

HEBEL/WISNIEWSKA/HEISEL 2014
Dirk Hebel, Marta H. Wisniewska and Felix Heisel, Building from Waste: Recovered Materials in Architecture and Construction, Basel: Birkhäuser, 2014, https://doi.org/10.1515/9783038213758.

HERMÈS 1929
Hermès, 'La fabrication mécanique du verre à vitre. Le procédé Fourcault', Revue Glaces et Verres 11, August 1929, 2–7.

HERZOG/KRIPPNER/LANG 2004
Thomas Herzog, Roland Krippner and Werner Lang (eds.), Fassaden Atlas, Basel/Munich: Birkhauser, 2004, https://doi.org/10.11129/detail.9783034614573.

HUFSCHMID/TISSOT-JORDAN 2013
Thomas Hufschmid and Lucile Tissot-Jordan, Amphorenträger im Treppenhaus: Zur Architektur und Wanddekoration der Gebäude in Insula 39 von Augusta Raurica, Forschungen in Augst 39, Augst: Augusta Raurica, 2013.

IKELAAR 1996
Leo Ikelaar (ed.), Paul Scheerbart und Bruno Taut: Zur Geschichte einer Bekanntschaft Scheerbarts Briefe der Jahre 1913–1914 an Gottfried Heinersdordff, Bruno Taut und Herwarth Walden, Kölner Arbeiten zur Jahrhundertwende 10, Paderborn: Igel, 1996.

JACKSON 1997
Caroline Jackson, 'From Roman to Early Medieval Glass: Many Happy Returns or a New Birth?', in: Annales du 13e Congrès de l'Association internationale pour l'histoire du verre, The Netherlands, 28 August–1 September 1995, Lochem: The Association, 1997, 289–302.

JACKSON 2005
Caroline Jackson, 'Making Colourless Glass in the Roman Period', Archaeometry 47.2, 2005, 763–80.

JEANDREVIN 2018
Aline Jeandrevin, Un rêve d'architecte: la brique de verre Falconnier, Bern: Till Schaap Edition, 2018.

JESTER 2014
Thomas C. Jester (ed.), Twentieth-Century Building Materials: History and Conservation, Los Angeles: Getty Conservation Institute, 2014, https://www.getty.edu/conservation/publications_resources/books/20th_cent_building_materials.html (accessed 3 February 2023).

KAUFMANN 2010
Verena Kaufmann, Archäologische Funde einer spätmittelalterlichen Glaserwerkstatt in Bad Windsheim: Handwerk, Handel und Geschichte, Schriften und Kataloge des Fränkischen Freilandmuseums 59, Bad Windsheim: Fränkisches Freilandmuseum, 2010.

KESSLER/WOLF/TRÜMPLER 2005
Cordula Kessler, Sophie Wolf and Stefan Trümpler, 'Die frühesten Zeugen ornamentaler Glasmalerei aus der Schweiz. Die frühmittelalterlichen Fensterglasfunde von Sion, Sous-le-Scex', Zeitschrift für Schweizerische Archäologie und Kunstgeschichte 62, 2005, 1–30.
KOMP 2009
Jennifer Komp, Römisches Fensterglas: Archäologische und archäometrische Untersuchungen zur Glasherstellung im Rheingebiet, Berichte aus der Geschichtswissenschaft, Aachen: Shaker Verlag, 2009.
KORN [1929] 1999
Arthur Korn (ed.), Glas: Im Bau und als Gebrauchsgegenstand, reprint, Berlin: Gebr. Mann, [1929] 1999.
KRUPA/HEAWOOD 2002
Mick Krupa and Richard Heawood, 'The Hotties': Excavation and Building Survey at Pilkington's No 9 Tank House, St Helens, Merseyside, Lancaster/Oxford: Oxford Archaeology North, 2002.
KUTILEK 2019
Luke Kutilek, 'Flat Glass Manufacturing Before Float', in: S. K. Sundaram (ed.), 79th Conference on Glass Problems, Ceramic Transactions 267, Hoboken: John Wiley & Sons, 2019, 37–54.
LAGABRIELLE 2009
Sophie Lagabrielle, 'Les fenêtres des rois et des princes (XIV^{e}–XV^{e} siècles)', in: Sophie Lagabrielle and Michel Philippe (eds.), Verre et fenêtre: de l'antiquité au XVIII^{e} siècle. Actes du premier colloque international de l'association Verre & Histoire, Paris-La Defense/Versailles, 13–15 October 2005, Les Cahiers de Verre & Histoire 1, Paris: Verre & Histoire, 2009, 17–24.
MARTIN 2010
Reinhold Martin, Utopia's Ghost: Architecture and Postmodernism, Again, Minneapolis: University of Minnesota Press, 2010, https://doi.org/10.5749/minnesota/9780816669622.001.0001.
MAXWELL 2022
Christopher Maxwell, 'People in Glass Houses: The Polite and Polished in Georgian Britain', in: Elisa Ambrosio, Francine Giese, Alina Martimyanova and Hans Bjarne Thomsen (eds.), China and the West: Reconsidering Chinese Reverse Glass Painting, Arts du verre. Glaskunst. Glass art. New research by Vitrocentre Romont 1, Berlin/Boston: De Gruyter, 2022, 33–46, https://www.degruyter.com/document/doi/10.1515/9783110711776-004/html.
MCGRATH 1961
Raymond McGrath, Glass in Architecture and Decoration, revised edition, London: The Architectural Press, 1961.
MISLIK 2017
Manfred Mislik, 'Fensterglas', *Restaurator im Handwerk* 9.4, 2017, 22–25.
OSWALD 1985
Gert Oswald, Lexikon der Heraldik, Mannheim/Zurich: Meyers Lexikonverlag, 1985.
PENDER/GODFRAIND 2018
Robyn Pender and Sophie Godfraind (eds.), Glass and Glazing, English Heritage: Practical Building Conservation 5, Abingdon/New York: Routledge, 2018; first published 2011.
PILKINGTON 1969
LAB Pilkington, 'Review Lecture: The Float Glass Process', Proceedings of the Royal Society of London 314.1516, 1969, 1–25.
REHREN/FREESTONE 2015
Thilo Rehren and Ian C. Freestone, 'Ancient Glass: From Kaleidoscope to Crystal Ball', Journal of Archaeological Science 56, 2015, 233–41, https://doi.org/10.1016/j.jas.2015.02.021.
RILEY/BERGDOLL 2001
Terence Riley and Barry Bergdoll (eds.), Mies in Berlin. Ludwig Mies van der Rohe: die Berliner Jahre 1907–1938, exhibition catalogue (Museum of Modern Art, New York, 21 June – 11 September 2001), Munich: Prestel, 2001.
SAVAËTE 2013
Bernard Savaëte, 'Entre légendes et réalités. Contribution à l'étude des innovations dans l'industrie du verre plat, des origines à aujourd'hui', in: Anne-Laure Carré, Sophie Lagabrielle, Corine Maitte and Michel Philippe (eds.), Les innovations verrières et leur devenir. Actes du deuxième

colloque international de l'association Verre & Histoire, Nancy 26–28 March 2009, Les Cahiers de Verre & Histoire 2, Paris: Verre & Histoire, 2013, 301–11, http://www.verre-histoire.org/colloques/innovations/pages/p305_01_savaete.html (accessed 3 February 2023).

SCHÄDLICH 2015
Christian Schädlich, Das Eisen in der Architektur des 19. Jahrhunderts, Firmitas 1, Aachen: Geymüller Verlag für Architektur, 2015.

SCHNITTICH ET AL. 2007
Christian Schittich, Gerald Staib, Dieter Balkow, Matthias Schuler and Werner Sobek (eds.), Glass Construction Manual, 2nd edition, Basel/Boston/Berlin: Birkhäuser, 2007, https://www.degruyter.com/document/doi/10.11129/detail.9783034615549/html?lang=en.

SCHULZE 1929
Konrad Werner Schulze, Glas in der Architektur der Gegenwart, Stuttgart: Wissenschaftlicher Verlag Zaugg, 1929.

SHORTLAND ET AL. 2006
Andrew Shortland, Lukas Schachner, Ian C. Freestone and Michael Tite, 'Natron as a Flux in the Early Vitreous Materials Industry: Sources, Beginnings and Reasons for Decline', Journal of Archaeological Science 33, 2006, 521–30.

STAIB 2007
Gerald Staib, 'From the Origins to Classical Modernism', in: Christian Schittich, Gerald Staib, Dieter Balkow, Matthias Schuler and Werner Sobek (eds.), Glass Construction Manual, Basel/Boston/Berlin: Birkhäuser, 2007, 11–29.

STALDER 2014
Laurent Stalder, 'Glas 1930–1970', in: Susanne Hauser and Julia Weber (eds.), Architektur in transdisziplinärer Perspektive von Philosophie bis Tanz: Aktuelle Zugänge und Positionen, Architekturen 23, Bielefeld: transcript, 2014, 19–42.

STEPPUHN 2016
Peter Steppuhn, 'Flachglasproduktion und Flachglashandel vom Hochmittelalter bis zur Frühen Neuzeit in Deutschland und den Niederlanden', in: Simone Bretz, Carola Hagnau, Oliver Hahn and Hans-Jörg Ranz (eds.), Deutsche und niederländische Hinterglasmalerei vom Mittelalter bis zur Renaissance, Munich: Deutscher Kunstverlag, 2016, 90–99.

STROBL 1990
Sebastian Strobl, Glastechnik des Mittelalters, Stuttgart: A. Gentner, 1990.

TAYLOR/HILL 2002
Mark Taylor and David Hill, 'An Experiment in the Manufacture of Roman Window Glass', Bulletin of the Association for Roman Archaeology 13, 2002, 19.

THEOPHILUS/DODWELL 1986
Theophilus Presbyter and C. R. Dodwell, The Various Arts: De Diversis Artibus, Oxford Medieval Texts, Oxford/New York: Clarendon Press/Oxford University Press, 1986.

THIEKÖTTER 1993
Angelika Thiekötter (ed.), Kristallisationen, Splitterungen: Bruno Tauts Glashaus, Basel/Berlin: Birkhäuser, 1993.

THOMAS 2018
Catherine Thomas, 'La société anonyme Brevets Fourcault: victime de guerre?', in: Stéphane Palaude and Catherine Thomas (eds.), Composer avec l'ennemi en 14–18. La poursuite de l'activité industrielle en zones de guerre, Brussels: Académie royale de Belgique, 2018, 223–33.

VAN DE VOORDE/BERTELS/WOUTERS 2015
Stephanie Van de Voorde, Inge Bertels and Ine Wouters, Post-War Building Materials in Housing in Brussels, 1945–1975 = Naoorlogse Bouw-Materialen in Woningen in Brussel, 1945–1975 = Matériaux de construction d'après-guerre dans l'habitation à Bruxelles, 1945–1975, Brussels: Vrije Universiteit, 2015, http://postwarbuildingmaterials.be/material/glass-and-glazing/ (accessed 3 February 2023).

VERITÀ 2013
Marco Verità, 'Venetian Innovations in Glassmaking and Their Influence on the European Glass History', in: Anne-Laure Carré, Sophie Lagabrielle, Corine Maitte and Michel Philippe (eds.), Les innovations verrières et leur devenir. Actes du deuxième colloque international de l'association

Verre & Histoire, Nancy 26–28 March 2009, Les Cahiers de Verre & Histoire 2, Paris: Verre & Histoire, 2013, 201–11, http://www.verre-histoire.org/colloques/innovations/pages/p201_01_verita.html (accessed 3 February 2023).

VÖLCKERS 1939

Otto Völckers, Glas und Fenster: Ihr Wesen, ihre Geschichte und ihre Bedeutung in der Gegenwart, Berlin: Bauwelt-Verlag, 1939.

WHITEHOUSE 2002

David Whitehouse, 'The Transition from Natron to Plant Ash in the Levant', Journal of Glass Studies 44, 2002, 193–96.

WIGGINTON 1996

Michael Wigginton, Glass in Architecture, London: Phaidon, 1996.

WOLF ET AL. 2017

Sophie Wolf, Cordula Kessler, Jürg Goll, Stefan Trümpler and Patrick Degryse, 'The Early Medieval Stained Glass Windows from St. John, Müstair: Materials, Provenance and Production Technology', in: Sophie Wolf, Anne de Pury-Gysel and Association internationale pour l'histoire du verre (eds.), Annales du 20e congrès de l'Association internationale pour l'histoire du verre, Fribourg/Romont 7–11 September 2015, Rahden/Westfalen: Verlag Marie Leidorf, 2017, 660–67.

YEOMANS 2001

David Yeomans, 'The Origins of the Modern Curtain Wall', *APT Bulletin* 32.1, 2001, 13–18, https://doi.org/10.2307/1504688.