4 Overview of realized examples in architecture using structural cast glass blocks

Overview of the current state of the art as well as the investigated in this thesis building systems employing cast glass components[36]

In view of the meticulous and lengthy cooling process discussed in the previous chapters, in architectural applications solid cast glass components have been commercialized up to the size range of standard masonry bricks. Owing to their large cross-sectional area, solid glass bricks are promising structural components that can fully exploit glass's compressive strength. By forming repetitive components, self-supporting, 3-dimensional all-glass structures of undisturbed transparency can be achieved. Nonetheless, at present, little and rather sporadic exploration has been made in the use of casting as a manufacturing method for structural glass in architecture. To a degree, this is attributed to the existence of only a few realized examples of self-supporting structures made of solid cast glass elements. The, so far, limited demand has in turn led to the absence of a standardized manufacturing process, to a lack of consistent engineering data and to a general unawareness of the potential of cast glass in structural applications in architecture. Currently, including the contribution of this dissertation, there are 3 structural systems employed for creating self-supporting structures out of cast glass components: (a) with a metal substructure, (b) adhesively bonded blocks, (c) interlocking glass blocks. The former two have been applied in real structures, whereas interlocking glass blocks are for the first time introduced as a building system through this dissertation. In this chapter, the 3 concepts are briefly presented, analyzed and

36 This chapter has been published as part of the review article: Oikonomopoulou F., Bristogianni T., Barou L., Veer F., Nijsse R. *The potential of cast glass in structural applications. Lessons learned from large-scale castings and state-of-the art load-bearing cast glass in architecture*. Journal of Building Engineering, vol.20, 2018.(Oikonomopoulou et al. 2018c)

evaluated in terms of manufacturing, structural system, level of transparency, ease of assembly and disassembly.

4.1 Introduction

At present the non-standardized, virtually manual, manufacturing process of solid glass blocks and the lack of substantial research on their assembly and structural performance have limited their structural application in only a few built architectural examples. To ensure the desired stability and stiffness of the glass assembly, such envelopes currently employ either a supportive substructure or a rigid structural adhesive (Fig. 4.2). The most characteristic case studies are the envelopes of the *Atocha Memorial* (Schober et al. 2007), the *Crown Fountain* (Hannah 2009), the *Optical House* (Hiroshi 2013) and the *Crystal Houses* (Oikonomopoulou et al. 2017a) (Fig. 4.1). Table 4.1 contains a summary of each project's characteristics. The research, development and realization of the *Crystal Houses* façade forms an integral part of this work and is extensively discussed in Chapter 5 and Chapter 6. The research, development and realization of the adhesively-bonded system triggered the design of a third structural concept, comprising dry-assembled, interlocking cast glass components. The principles and experimental validation of this proposed system are presented in Chapter 7 and Chapter 8. The interlocking system is yet to be realized in construction. This chapter, aiming to give a broad overview of all the current systems, therefore provides a synopsis of the realized systems, as well as of the systems developed in this dissertation.

Finally, it should be noted that structures employing hollow glass blocks or solid glass blocks that are, in essence, non-load-bearing remain out of the scope of this research. Thus, architectural projects where cast glass has been applied as façade cladding will not be analysed, yet, some inspiring projects in this field worth mentioning here are the *Ice Falls* and the *Periscope Window* by (James Carpenter Design Associates Inc 2018) and the art installation *Qwalala* by artist *Pae White (Domus 2017).*

FIG. 4.1 Characteristic examples of structures employing cast glass blocks: The *Atocha Memorial* (left), *Crystal Houses* (centre), and the *Crown Fountain* (right).

TABLE 4.1 Overview of the characteristics of realized self-supporting envelopes using solid cast glass components.

Project	Optical house	Crown fountain	Atocha memorial	Crystal house
Location	Hiroshima Japan	Chicago Illinois, USA	Madrid Spain	Amsterdam The Netherlands
Envelope dimensions [m]	8.6 x 8.6	12.5 x 7 x 4.9	8 x 11	10 x 12
geometry	Flat envelope	Cube	Elliptical cylinder	Flat envelope
Structural system	Supportive substructure	Supportive substructure	Adhesively bonded	Adhesively bonded
Number of blocks	6000	22500	15600	7500
Size of blocks [mm]	235 x 50 x 50	127 x 254 x 51	300 x 200 x 70	210 x 210 x 65 210 x 157.5 x 65 210 x 105 x 65
Number of different blocks	1	1	1	3
Weight of block [kg]	2.2	4.5	8.4	7.2 / 5.4 / 3.6
Total weight [t]	13	50.6	130	40.5
Type of glass	Borosilicate	Low-iron soda-lime	Borosilicate	Low-iron soda-lime
Annealing time	unknown	unknown	20 h	8-38 h (size dependent)
Type of mould	Press steel mould	Open steel mould	Press steel mould	Open steel mould
Post-processing	no	Polishing in one side	no	Polishing 2 faces to ±0.25mm precision

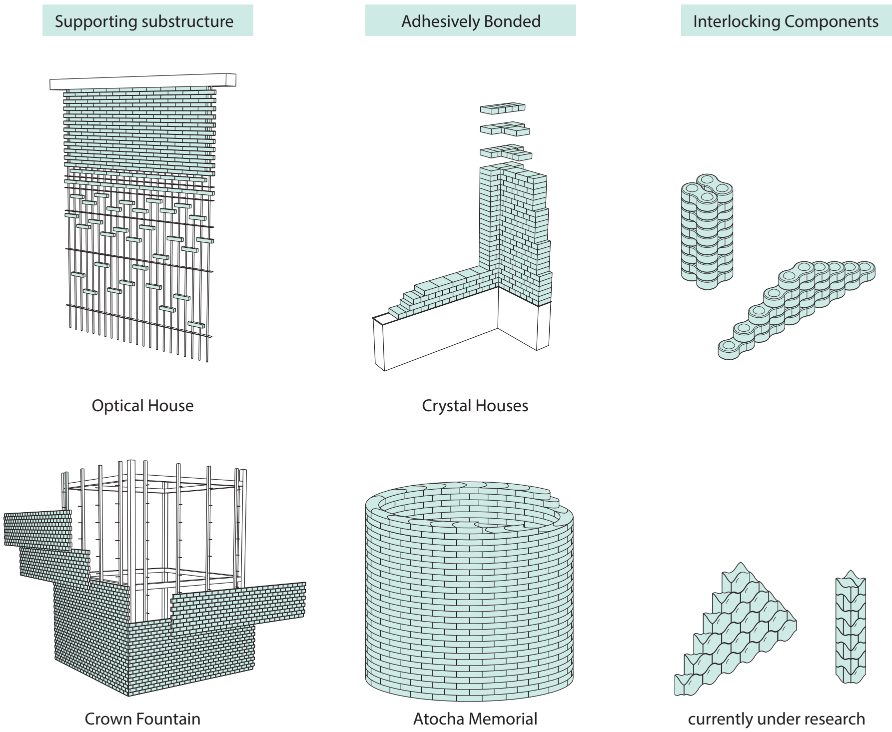


FIG. 4.2 Illustration of the structural systems currently developed for structures using cast glass components.

4.2 Principles of structural system employing solid cast blocks

4.2.1 Solid glass vs hollow blocks

Glass blocks are commonly produced in a hollow form, fabricated by thermally fusing two shallow rectangular cups along their open faces. A sealed interior air chamber is formed that gives the glass block its thermal and acoustic insulating properties (Murray 2013). Regarding transparency, hollow bricks can be completely colourless. However, the block's multiple layers (glass – air – glass) result in severe optical distortion of objects observed through it. Fig. 4.3 illustrates how each light ray passing through a block is reflected and redirected within every media, producing a visual obscuration dependant on surface texture and angle of view. Hollow glass blocks are further considered unsuitable as load bearing components due to their relatively low stated resistance to compressive load (given as 6 MPa in *ISO 21690:2006*). While ceramic masonry bricks with comparable failure loads are used as load bearing elements, the low wall thickness of hollow glass blocks risks internal buckling and failure from the vertical load of the stacked wall; hence the increased risk renders them unsuitable as load bearing components for solid load bearing walls. Accordingly, a separate supporting structure is required if hollow blocks are used. Usually, in small structures the blocks are embedded in a steel rod reinforced cement-based mortar. In large-scale structures, elaborate metal systems are required to carry the loads of the structure. Good examples include the *Maison Hermes* (Murray 2013) and the *Maastricht Academy of Arts* (Wiel Architects 2014). Hollow glass blocks are considered non-loadbearing and therefore will not be further discussed in this research.

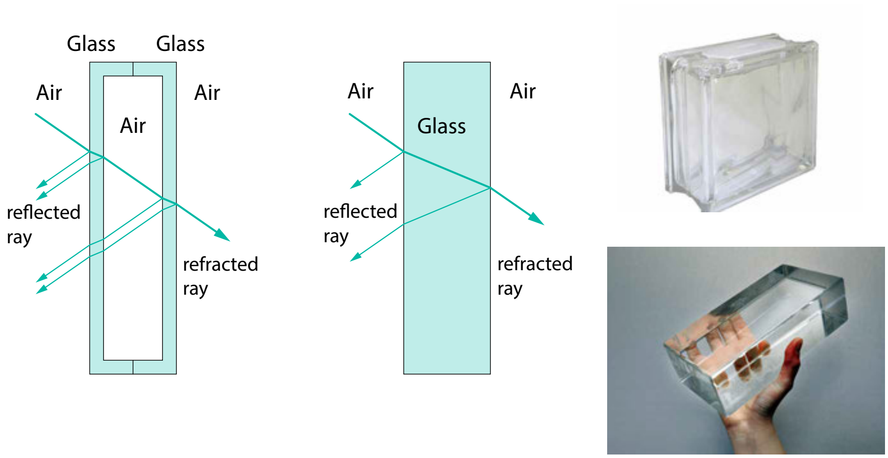


FIG. 4.3 The transition of the light rays through multiple media in a hollow glass block results in much more distortion compared to a solid glass block.

In contrast, solid glass blocks present a much higher compressive strength, typically over 200 MPa, which allows them to be used as loadbearing components. Solid glass blocks are produced by pouring liquid glass into a steel mould. Each block is then cooled down controllably for many hours – duration depending on the dimensions of the block – to avoid cracks due to unequal temperatures between the surface and the core (Christoph, Knut 2008) and to prevent the development of any pre-stress in the block. In comparison to hollow blocks, solid blocks have similar transparency but significantly less optical distortion. Their monolithic mass implies a constant refraction index that results in the redirection of the light rays only at the two external surfaces and hence, causing less distortion of objects projected behind them (Fig. 4.3). Solid blocks, however, exhibit a reduced thermal resistance compared to hollow ones. Owing to their inferior thermal insulation properties, as well as to a noticeably higher manufacturing cost and a non-standardized manufacturing process, solid glass blocks have, so far, rarely been employed for exterior glass walls, despite their load-bearing capacity.

4.2.2 Structural systems employing cast glass blocks

As previously mentioned, a supporting structure is required when hollow glass blocks are used in a facade of considerable dimensions because of their low load-bearing capacity. Due to the lack of standardized structural specifications and strength data on transparent adhesives, the majority of projects using solid glass blocks are also dependent on pre-tensioned steel reinforcement to ensure rigidity and prevent buckling. Nevertheless, to obtain an entirely transparent visual result, opaque reinforcement elements should be avoided. This can be achieved either through the use of a transparent, structural adhesive or through an interlocking geometry of the blocks in combination with an intermediate medium that prevents peak stress concentrations due to glass-to-glass contact.

The overall geometry of the structure can further contribute to its stability and stiffness. For example, in the *Atocha Memorial* solid glass blocks bonded by a transparent UV-hardening adhesive form a cylindrical tube which contributes greatly to the structure’s stiffness, eliminating the necessity of additional steel elements for its support (Christoph, Knut 2008).

In summary, there are currently 3 structural systems employed for creating self-supporting structures out of cast glass components:

1. With a metal substructure
2. Adhesively bonded blocks
3. Interlocking glass blocks

Prior to this research, the prevailing solution was the first one, employing a metal substructure, and there was only one example of an adhesively bonded glass block structure. This thesis has contributed to the field of structural cast glass by developing and experimentally validating the lateral two solutions: Adhesively bonded and interlocking glass blocks. All three concepts are briefly discussed in the following sub-chapters.

4.3 Solid glass block envelopes with supportive substructure

In this system, a supportive metal substructure carries the tensile forces and ensures the desired stiffness and buckling resistance, allowing the glass assembly to perform mainly under compression. The most characteristic realized examples using this principle are the *Crown Fountain* and the *Optical House*. In specific, the 8.6 m x 8.6 m envelope of the *Optical House* (Fig. 4.4) consists of 6000 solid blocks, with through holes between top and bottom sides (Fig. 4.5), whereby pass the rods of a pre-tensioned vertical mesh, consisting of 75 stainless steel rods suspended from a steel beam (Fig. 4.6) encased in reinforced concrete (Hiroshi 2013). The mesh withstands the lateral forces, while the glass carries its own weight. Two vertical steel fins further serve against wind loads. In this way, a façade of high slenderness is obtained. The rods are connected with stainless steel flat bars (40 mm x 4 mm) that seat within the 50 mm thick glass blocks at 100 mm intervals, to reduce lateral stresses directed to the glass blocks (Fig. 4.6 and Fig. 4.7). The resulting structure is mortar-free (Hiroshi 2013). Borosilicate glass was opted for the glass blocks, due to its increased optical qualities compared to soda-lime (The Architectural Review 2012).

The *Crown Fountain* (Fig. 4.8) employs a different system, a combination of pre-assembled glass block grates connected to a stainless steel internal frame, which carries both vertical and lateral forces (Hannah 2009). Each of the 2 towers of 12.5 m x 7 m x 4.9 m employs a total of 11250 cast glass blocks, pre-assembled in grates of approx. 250 units, stacked and welded together. All forces are transferred by an embedded steel T-profile frame to the base via a zigzag pattern. The lateral stability of the tower is enhanced by Ø13 mm rods anchored to the structure and triangular corner brackets. The blocks were made using melt-quenching and an open, high-precision steel mould. This resulted in blocks that needed to be polished only on one side. Approximately 350 blocks were produced per day over a period of 4 months.

FIG. 4.4 The *Optical House*. Source: *Koji Fujii / Nacasa & Partners Inc.*

FIG. 4.5 Cast glass block unit of the *Optical House*. Source: *Hiroshi Nakamura & NAP.*

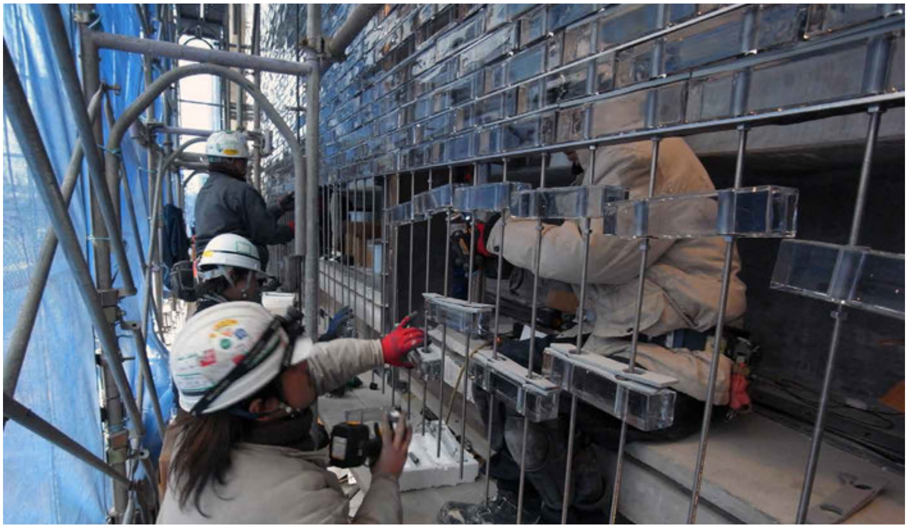


FIG. 4.6 Assembly of the *Optical House*. Source: *Hiroshi Nakamura & NAP*.

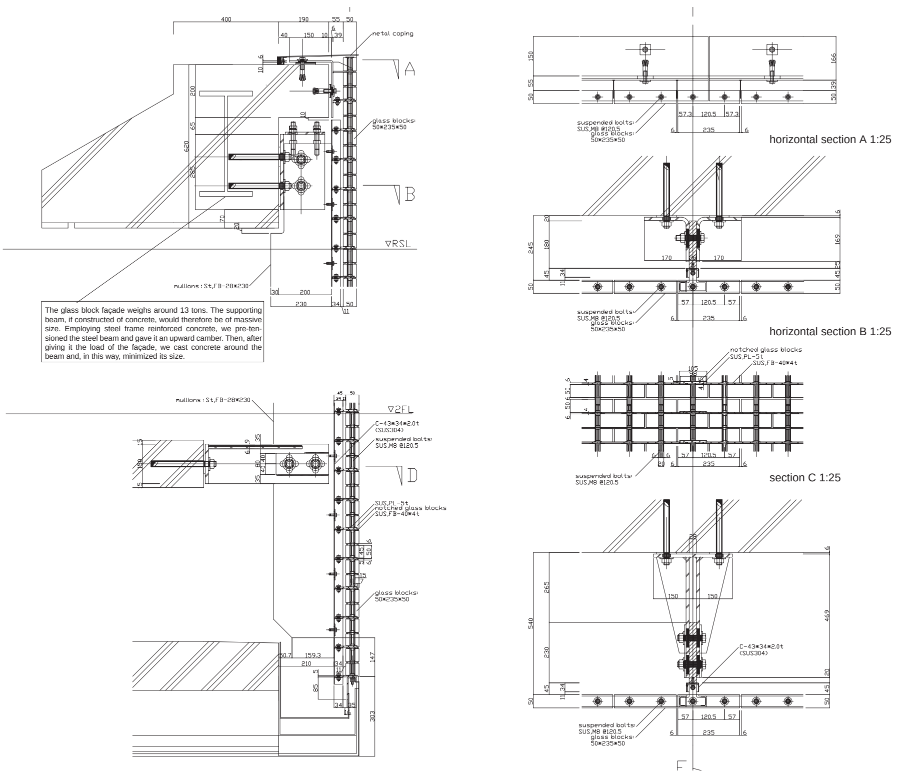


FIG. 4.7 Detail drawings of the *Optical House's* glass block system. Drawing courtesy: *Hiroshi Nakamura & NAP*.

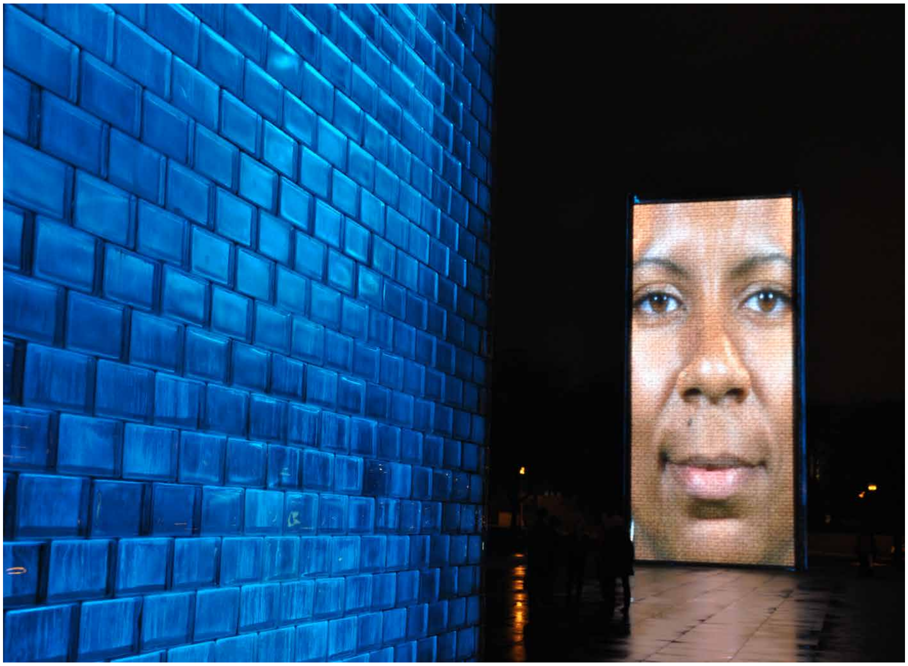


FIG. 4.8 The two *Crown Fountain* towers at night.

4.4 Adhesively bonded blocks

An entirely transparent cast glass structure can be built by bonding the glass blocks together with a colourless rigid structural adhesive. In this way material-compatible, low-stress and permanently resistant connections are established. In such a system, the mechanical properties of the adhesive are equally critical to the ones of the glass blocks; it is their interaction as one structural unit that defines the system's structural behaviour. The most favourable structural performance is when adhesive and glass fully cooperate and the assembly behaves as a single rigid unit under loading, resulting in a homogeneous load distribution (Oikonomopoulou et al. 2017a). Thus, rigid adhesives, such as acrylates and epoxies are necessary to ensure the desired bond strength. Two good examples of adhesively bonded glass envelopes from cast glass components are the *Atocha Memorial* and the *Crystal Houses*.

The *Atocha Memorial* (Fig. 4.9), approximately elliptical in plan and 11 m high, is built from 15600 glass borosilicate blocks bonded together with a 2 mm thick transparent UV-curing adhesive (Schober et al. 2007). To obtain the cylindrical shape of the monument (Fig. 4.10) by a single block geometry, a customized cast glass component was designed, convex on one side and concave on the other (Fig. 4.11). The curvature turns the glass wall into a shell structure of increased stiffness, sparing the necessity of a substructure. The glass roof is connected to the glass block structure in a rigid way to constrain the upper free edge and prevent the ovalisation of the section (Goppert et al. 2008).

FIG. 4.9 The *Atocha Memorial*. Source: *Esaú Acosta (FAM Arquitectura y Urbanismo)*

The glass elements are subject to high temperature fluctuations in Madrid, resulting in high surface tensions. Therefore, borosilicate glass was opted for the fabrication of the blocks due to its comparably lower thermal expansion coefficient than soda-lime. By casting borosilicate glass in high precision press steel moulds, the required ±1 mm tolerance was met, guarantying the applicability and uniformity of the selected adhesive without the need for post-processing (Goppert et al. 2008). The annealing time for each brick was 20 h.

The special characteristics of the adhesive required the construction of an envelope using a UV-filtering tent for protection against solar radiation, dust and adverse weather conditions (Fig. 4.12). Both temperature and humidity levels were controlled. Prior to construction, various tests were performed to validate the structural performance of the adhesive-glass assembly. According to the structural calculations, almost the entire contact area of the blocks had to be bonded. At the same time overflow had to be minimized. A special bonding method was developed, to distribute the adhesive in the right amount and prevent the trapping of air bubbles.

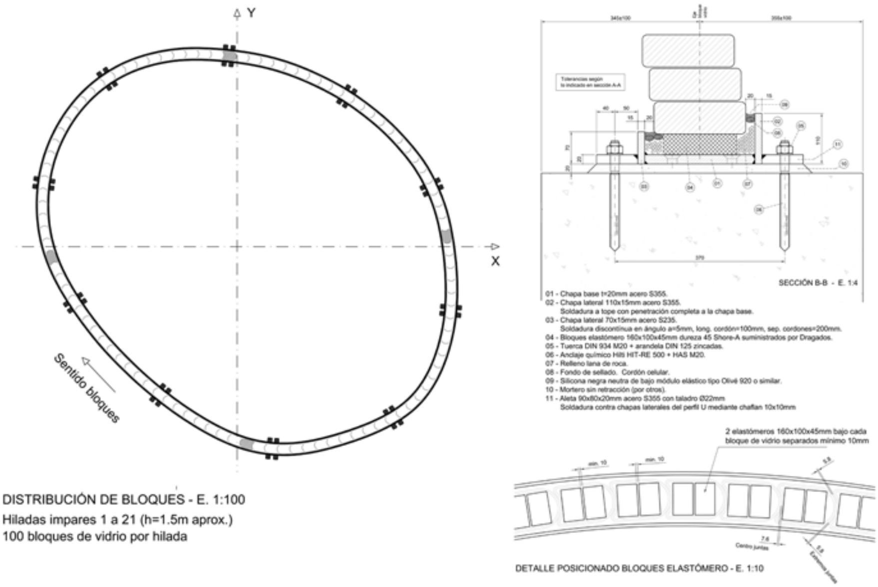


FIG. 4.10 Plan and details of the *Atocha Memorial* glass structure. Source: *Bellapart.*

FIG. 4.11 Glass block unit of the *Atocha Memorial.*

TOC

Logistics of the project were also challenging. Two 10 h shifts were established with 11 specialized workers per shift, 6 days per week, for the cleaning, bonding by UV-curing and external sealing of the blocks one by one, resulting in 500-600 glued blocks per day (Goppert et al. 2008).

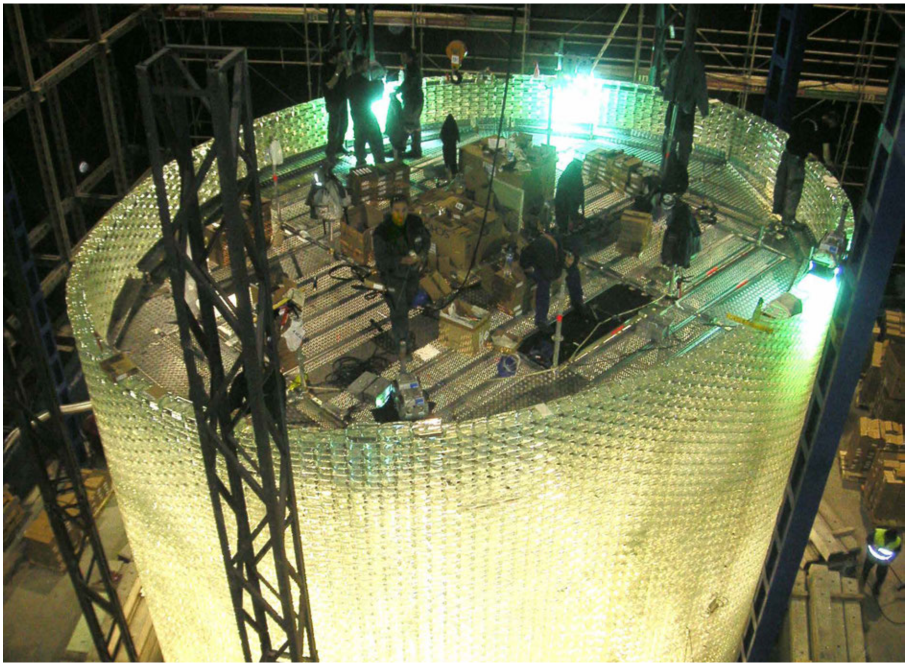


FIG. 4.12 Construction of the *Atocha Memorial*. Source: *Bellapart, SAU*.

The *Crystal Houses* is another characteristic example of an adhesively bonded, highly transparent glass bock envelope, made as an accurate yet completely transparent reproduction of the previous, 19th century masonry brick façade (Oikonomopoulou et al. 2015a). The research and development of this adhesively bonded system is part of this dissertation and is discussed in detail in Chapter 5 and Chapter 6. Based on the brick modules of the original façade, the 10 m x 12 m transparent elevation employs more than 6500 solid glass bricks, of 3 different sizes (Table 4.1), reinterpreting the traditional brickwork; while massive cast glass elements reproduce the classic timber door and window frames. Towards the top, terracotta bricks intermingle with glass ones, gradually transforming the glass elevation to a traditional brick façade (Fig. 4.13 and Fig. 4.15). The architects' desire for unimpeded transparency, rendered as sole solution the creation of an entirely self-supporting adhesively-bonded glass brick system (Oikonomopoulou et al. 2015b).

Research and testing of various adhesive types by (Oikonomopoulou et al. 2015b) led to the eventual selection of *Delo Photobond 4468;* a colourless, UV-curing, one-component acrylate, designed for high strength bonding between glass components.

FIG. 4.13 *Crystal Houses* façade, Site elevation. Source: *MVRDV* architects

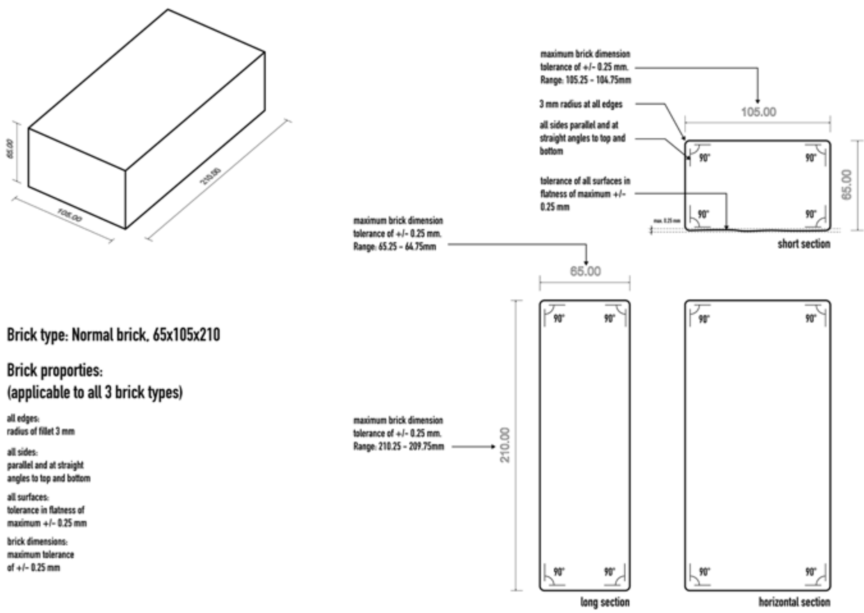


FIG. 4.14 Diagram indicating the properties and dimensional accuracy of a normal-size glass brick for the *Crystal Houses* façade project. Source: *MVRDV architects*.

FIG. 4.15 Left: 3D visualization of the *Crystal Houses* façade by *MVRDV* Architects. Right: The realized façade.

Structural experiments indicated the application thickness of the adhesive layer for an optimum bond strength to be between 0.2-0.3 mm. In addition, the construction of 4 architectural wall mock-ups by (Oikonomopoulou et al. 2015b) with tolerances ranging from ±0.25mm to ±0.5 mm in the height and flatness of the bricks indicated that tolerances above ±0.25mm result in an uneven spread of the adhesive that can greatly affect the structural performance. Moreover, the visual result of the transparent wall is disturbed due to induced air gaps in the adhesive layer. The relatively low viscosity of the specific glue allowed a homogeneous bonding only at the horizontal surfaces of the glass bricks; the vertical joints, approx. 1 mm in width, were left open, allowing as well for thermal expansion. Accordingly, it was determined that the glass blocks' top and bottom surfaces should be flat within ±0.25 mm (Fig. 4.14 and Fig. 4.16) (Oikonomopoulou et al. 2015b).

The thickness of each construction layer had to be confined within the same dimensional accuracy, as any accumulated deviation larger than the required bonding thickness could lead to uneven and improper bonding. The demand for this remarkably high level of accuracy and transparency, introduced various challenges in the engineering and construction of the façade. The required ±0.25 mm tolerance influenced the selection of glass recipe and mould as well. Soda-lime glass and open high precision moulds were chosen to prevent an unnecessary increase in production costs as the high required accuracy would necessitate the mechanical post-processing of the block's bonding surfaces anyway (Oikonomopoulou et al. 2017a). Depending on the block's size the annealing time ranged between 8–38 h. The 65 mm thickness of the blocks hindered an accurate stress measurement by a *Scattered Light Polariscope* stress-meter; instead a qualitative analysis of strain concentration was made using cross polarization (Fig. 4.17).

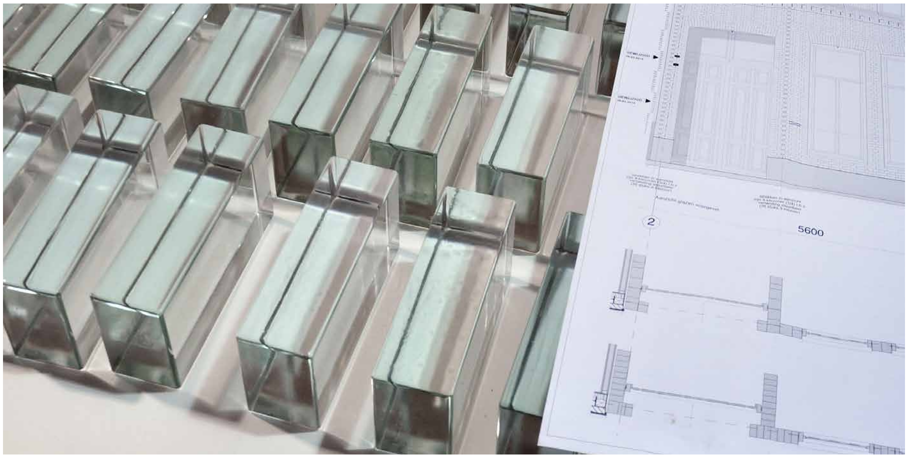


FIG. 4.16 Solid glass blocks used for the construction of the *Crystal Houses* façade.

Eventually the horizontal, bonding surfaces of the blocks were CNC polished to meet the desired precision. Structural tests and architectural mock-ups by (Oikonomopoulou et al. 2015b) suggested the bonding of the complete contact surface between blocks. Through the uniform application of the adhesive both a homogeneous load distribution and maximized transparency are attained. To eliminate defects in the adhesive layer that would deeply affect the final visual result, a customized bonding method was developed, using custom-designed self-reinforced polypropylene forms for controlling the flow, spread and amount of the adhesive (Fig. 4.18).

(Oikonomopoulou et al. 2017a) discusses the complex logistics of the project, which are similar but more stringent as for the *Atocha Memorial* project. The 8 times less allowable thickness of the adhesive, introduced a significantly higher complexity level of the manual bonding process that called for a highly skilled crew and a strictly controlled construction. A 12 h working schedule was established, 5 days per week. 7-9 highly skilled workers bonded and sealed on average 80-100 blocks per day under the supervision of 2 quality control engineers and the construction site supervisor. The entire build-up of the façade took 7 months.

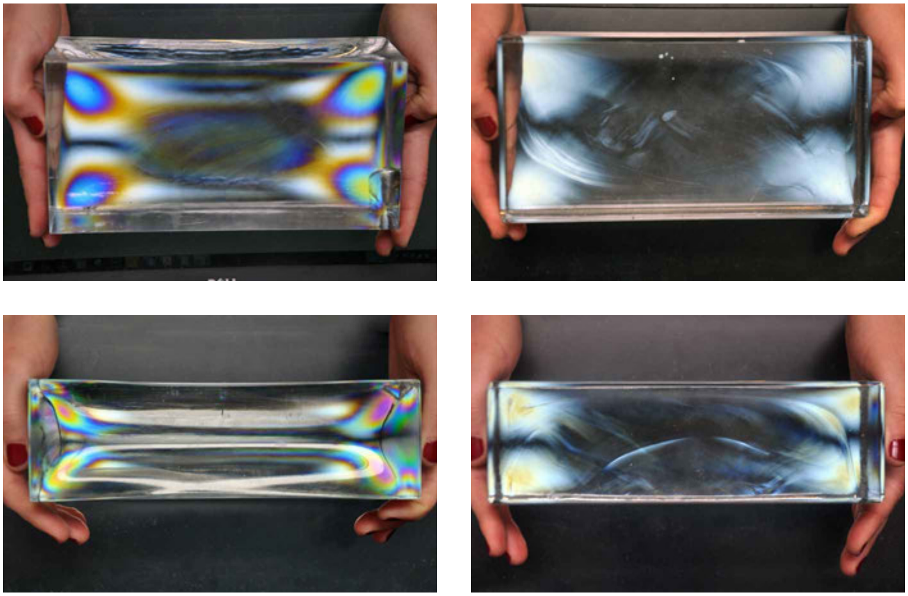


FIG. 4.17 Qualitative stress analysis through cross polarization. Bricks with clear indication of stresses (left) were discarded. Specimens with no visible strain concentration (right) were employed in the façade.

FIG. 4.18 Bonding and curing of the adhesive at the *Crystal Houses* façade.

4.5 Interlocking components

This third, new concept – that is an integral part of this dissertation and is yet to be realized in an actual construction – explores the potential of full-glass compressive structures, such as envelopes, walls and columns from interlocking cast glass components. The research and development of interlocking cast glass components is presented in detail in chapters 7 and 8 of this dissertation. In this system, the overall stability is achieved through compression provided by the construction's self-weight combined with the interlocking geometry that restrains lateral movements, resulting to a structure with minimal, if any, metal framing. The suggested system proposes the use of a dry, colourless interlayer, such as Polyurethane Rubber (PU) or Polyvinyl Chloride (PVC), as an intermediate medium between the glass units (Fig. 4.19).

FIG. 4.19 Prototype of a 3 mm thick, cast interlayer from PU70 (Oikonomopoulou et al. 2018).

This allows for a demountable structure that enables the circular use of the glass components: they can be retrieved intact and reused or, eventually, recycled as they are not contaminated by foreign substances such as coatings or adhesives. Moreover, the dry interlayer prevents stress concentrations due to glass-to-glass contact and compensates for the inevitable dimensional tolerances in the cast units' size (Oikonomopoulou et al. 2018a). So far, various geometries, dry interlayers and structural applications have been explored and experimentally tested by the *Glass & Transparency Group of TU Delft*.In particular, (Aurik 2017; Snijder et al. 2016; Aurik et al. 2018) studied a dry-assembled arched glass masonry bridge interlocking in one direction (Fig. 4.20). All other research projects focus on systems that confine the movement in both axial and transverse direction. (Akerboom 2016) studied the realization of a glass column out of solid interlocking cast components. The column's cross-section was optimized based on its structural capacity and performance. (Barou et al. 2016) proposed an interlocking system for flat, self-supporting envelopes using a brick inspired by the *LEGO*® block (Fig. 4.21, left). (Frigo 2017; Jacobs 2017; Oikonomopoulou et al. 2018a) further developed the interlocking brick concept, suggesting more curved geometries and an equal mass distribution, in respect to the manufacturing process of cast glass and towards an increased shear capacity. Numerical modelling of the resulting osteomorphic block (Fig. 4.21, centre, right) presented in (Jacobs 2017) indicated that geometrical parameters such as amplitude and block height can have a significant influence on the system's failure mechanism and ultimate load-carrying capacity in shear.

FIG. 4.20 Visualization (top) and a tested glass block prototype (bottom) of the dry-stacked glass arch bridge concept developed by (Snijder et al. 2016).

Although there are not sufficient experimental results to derive statistical data, they suggest that interlocking cast glass components can be a promising solution for future structural applications. An important input from this research is the development of units featuring more organic shapes with curved geometries (Fig. 4.22 and Fig. 4.23), avoiding sharp edges to prevent residual stress concentrations, fitting the characteristics and peculiarities of cast glass as a construction material (Oikonomopoulou et al. 2018a).

FIG. 4.21 Evolution of interlocking cast glass blocks towards more curved geometries of equal mass distribution. From left to right: interlocking glass brick inspired by the *LEGO®* block by (Barou et al. 2016), osteomorphic block by (Jacobs 2017) and osteomorphic blocks by (Oikonomopoulou et al. 2018a)

FIG. 4.22 Physical prototypes of a two-component interlocking geometry by (Oikonomopoulou et al. 2018b).

FIG. 4.23 Physical prototypes of different interlocking geometries by (Oikonomopoulou et al. 2018b).

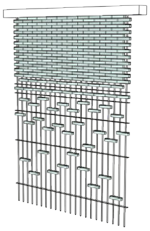
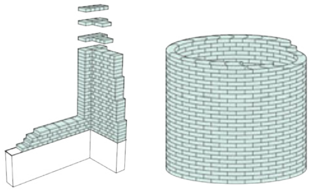
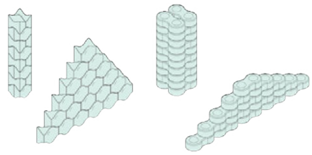
4.6 Discussion

The comparative charts of Table 4.2 lead to general conclusions regarding the applicability of cast glass in load-bearing structures in architecture. Due to the lack of sufficient and comparable technical data, the thermal and acoustic performance of the presented solid cast glass applications[37] have been excluded from this dissertation.

All realized projects have been made using primary casting, and typically employed a singular block geometry of simple rectangular form and less than 10 kg in weight. Either borosilicate or soda-lime glass are employed, depending on the weather conditions per location, and specifically the anticipated temperature differentials, and the required dimensional accuracy.

37 In general, solid glass blocks exhibit a reduced thermal and acoustic resistance compared to hollow glass blocks. The latter, due to the air cavity, exhibit an increased thermal resistance and can reduce sound transmission. On the other hand, due to the aforementioned air cavity, hollow glass-blocks are considered non-load-bearing and cannot be applied in structural applications.

TABLE 4.2 Design principles of the different structural systems employing cast glass components

1. Additional substructure	2. Adhesively bonded glass structure	3. Interlocking cast glass units
Tensile forces are carried by a metal substructure	Homogeneous load transfer in the glass assembly via rigid adhesive	Stiffness is obtained by the interlocking geometry
		
Dry-assembly/ adhesively bonded	Adhesively bonded	Dry-assembly
Interlayer accommodates size deviations	Adhesive's thickness requires high precision in unit size	Interlayer compensates for size deviations
Easily assembled	Meticulous, intensive labour of high precision	Easily assembled
Compromised transparency	High transparency	High transparency
Reversible	Non-reversible	Reversible

Although primary casting requires higher working temperatures, it is considered a more cost-effective method for the production of numerous identical units.

Also, as described in Chapter 2, the glass type, overall dimensions, form and volume of the object are key-factors for the total annealing time. Thus, smaller-sized and simple-shaped objects are preferred. For example, the solid glass bricks of 3.6 kg weight used in the *Crystal Houses* façade required 8 h of annealing, whereas components of double the volume (and critical dimension) and 7.2 kg weight, required an annealing cycle of 36–38 h respectively (Oikonomopoulou et al. 2017a). The annealing time can be further reduced if borosilicate glass is employed instead of soda-lime due to its improved thermal expansion coefficient (table 2). A comparison between the 8.4 kg block of the *Atocha Memorial* and the 7.2 kg block of the *Crystal Houses* demonstrates this clearly. The former, although larger in dimensions and weight, required almost half the annealing time than the latter.

A limited mass also facilitates the transportation, installation and handling processes. Moreover, a repetitive component geometry is essential for simplifying the production and assembly and for limiting the manufacturing costs, owing to a limited amount of moulds and a standardized production process.

Regarding the overall shape, little exploration has been made of the forms that can be achieved by cast glass in the realized projects (Fig. 4.24). Only the research conducted in interlocking components (and included in this dissertation) shows a greater potential in developing non-orthogonal shapes matching the properties of glass.

There are currently, including the contribution of this thesis, 3 developed structural systems for making self-supporting cast glass structures, employing: (1) a supportive substructure, (2) a stiff, colourless adhesive and (3) an interlocking geometry and a dry interlayer.

Whereas the first solution compromises the overall level of transparency and the second solution results in an irreversible, non-recyclable and challenging construction of intensive and meticulous labour, the interlocking cast glass components can tackle the limitations imposed by both previous systems. Nonetheless, this solution has yet to be realized and be validated in practice.

Lastly, a crucial aspect that can greatly influence the performance of the structure is its overall geometry. Flat geometries or walls of high-slenderness have limited resistance to lateral loads and buckling and call for more challenging solutions than geometries with inherent stability such as closed shapes.

FIG. 4.24 Top left to bottom right: Glass block units employed in the *Optical House*, *Atocha Memorial*, *Crystal Houses* façade and the interlocking research.

Adhesively bonded soda-lime glass blocks at the *Crystal Houses* facade

Adhesive

A substance used for sticking objects or materials together; glue

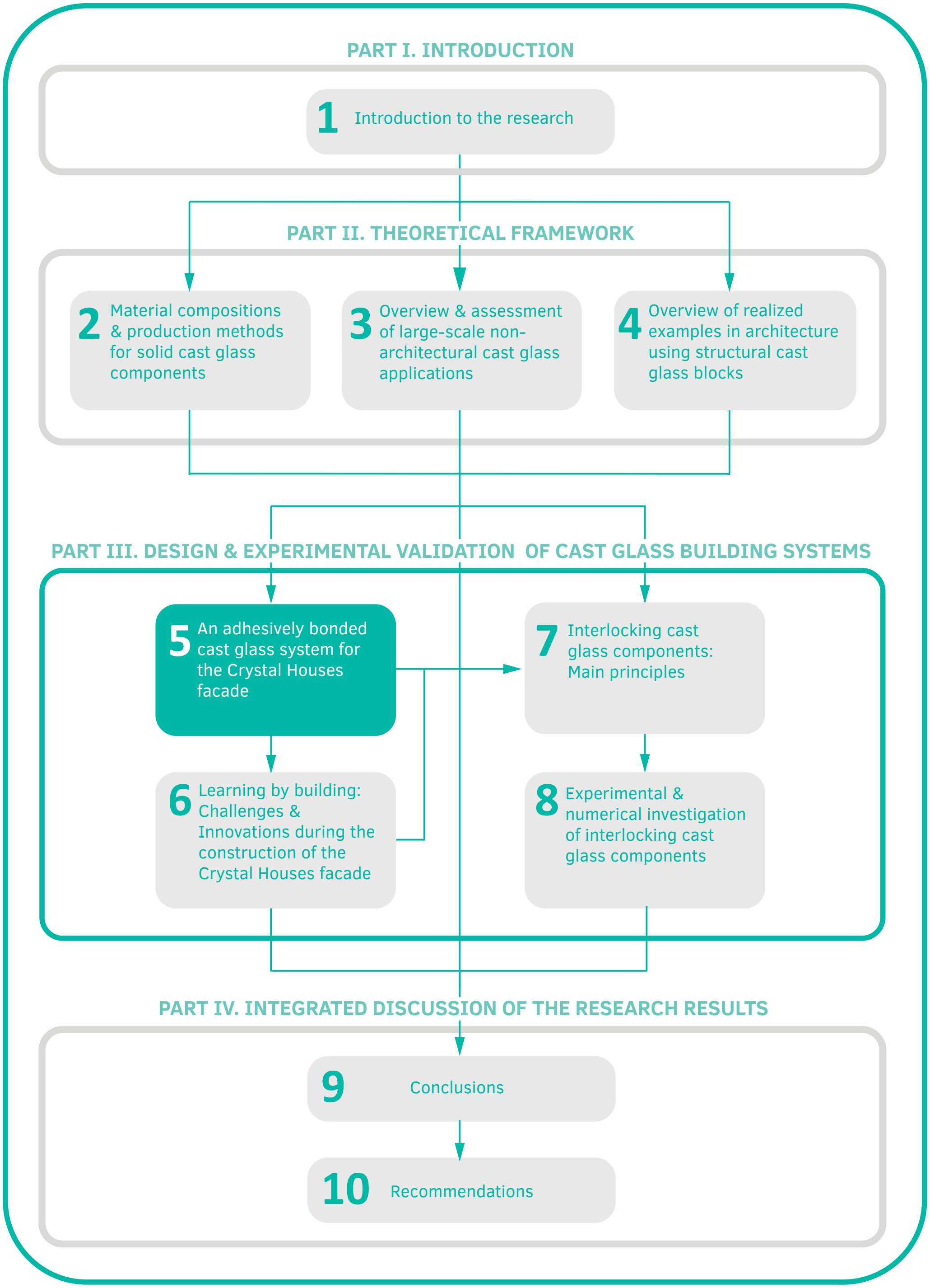
Definition by the Oxford Dictionary

Glue

A sticky substance that is used for joining things together permanently, produced from animal bones and skins or by a chemical process

Definition by Cambridge Dictionary

Exploring the third dimension of glass



Solid cast glass components and assemblies for structural applications

TOC