Conclusions from Defects on Glass Façades

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Abstract

In recent decades, more and more glass façades have been built, both elaborate iconic façades and simple standard façades. This paper is intended to provide an overview of common damage to glass and façade construction that we often see today after a few years in operation. This ranges from common glass damage (whether due to inadequate structural calculations or design errors) to maintenance and cleaning errors and the very common leaks in façades. The topics of maintenance, care, periodic building inspections of façades (with a new guideline as a supplement to VDI 6200) and the expected life cycle of façades are discussed. Façades make an important contribution to sustainable building and the need for optimization is highlighted. These points are therefore very important for frequently arising questions as to whether and how heritage-protected façades can be renovated. Examples from the work as a publicly appointed and certified expert and from the field of façade refurbishment will be shown.

Keywords

Facade, Damage, Maintenance, Sustainability

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1. Introduction

Nowadays built glass constructions are becoming more and more sophisticated and transparent. For these iconic projects like the glass-roof in Buffalo in Fig. 1, it is general practice that specialised designers from the glass and facade sector are consulted during the planning phases in order to obtain planning security.

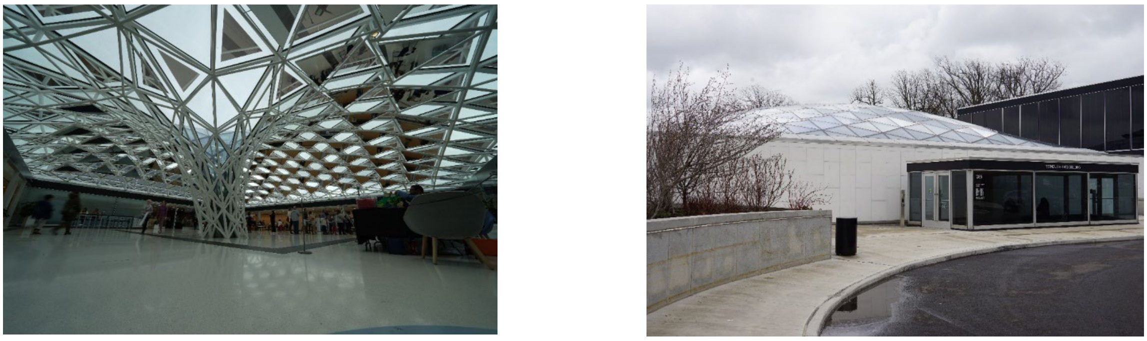


Fig. 1: Glass Roof in the AKG Art Museum, Buffalo, USA.

With “everyday facades” the often-seen procedure looks different. As part of a general contract, the planning is "passed on" to the façade execution company, which carries out the work with different levels of planning depth. In the tendering phase, it is very difficult to calculate the planning services still required. These and other open questions are basis for future discussions.

2. Planning process

The planning process and legislative boundary conditions differ from country to country, as an example the procedure in Germany including the obvious "gaps" are described here. According HOAI (fee schedule for Architects and Engineers), a subdivision of structural engineers’ tasks in the following different planning phases (so called Service Phases SPH) is made:

- Fundamental evaluation (SPH1)
- Preliminary design (SPH2)
- Final design (SPH3)
- Planning permission application (SPH4)
- Execution planning (SPH5)
- Preparation of contract (SPH6)
- Involvement in contract (SPH7)
- Project supervision (SPH8)
- Post-completion services (SPH9)

This fine subdivision ensures step-by-step planning that builds on one another. In this way, the planning becomes more precise and detailed with each planning step, performed in parallel by object design, structural design and building physics.

The façade analysis and the analysis of glass constructions are not included in this design process of the service phases, but do represent a so-called “special service”. Only façade design in the sense of “key details” is regulated by a separate guideline (AHO No. 28).

So, the practice in facade construction is different: in the run-up to an invitation to tender, at best a preliminary structural analysis is prepared, but usually only "a piece of facade including necessary calculation and permits" is put out to tender. Thus, it can happen that constructions are put out to tender which do not work at all. In this early stage it is hard to calculate the necessary budget for engineering work and eventually special "tasks" including tests, experimental report, time and eventually necessary authorities' approvals. And sometimes – especially for new and special applications like glued corners of bottom to ceiling glass elements (which in addition are acting as anti-drop device) or coating of glass in contact to interlayer of laminated safety glass (LSG) – an execution company is simply not aware of the need for additional design, calculation and permits.

Execution planning is done without the necessary basis in form of SPH3 and SPH4. Therefore, the contractor in fact is responsible not only for SPH5, but also for SPH3 and SPH4.

In Germany, a checking engineer usually checks static calculations – but only with regard to ULS (Ultimate Limit State), and not to SLS (Serviceability Limit State). There are no checking engineers specialized in the field of glass and façades, experienced "bridge engineers" are expected to be able to check facades; sometimes even the opinion exists, that facades are "non-structural" and by this of no interest for checking-engineer at all. Effect on the quality of the construction is obvious.

Thinking about this one concludes, that there is a need for optimization at various points in the design process. If this gets better with implementation of BIM is questionable: setting up a digital model with additional information does not necessarily include sufficient static design.

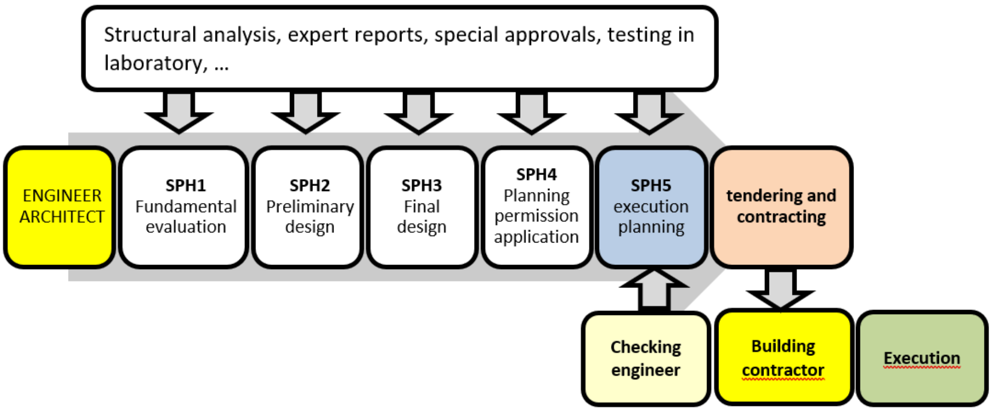


Fig. 2: Service Phases SPH1 – SPH5, "standard" construction (concrete, timber, steel,..) for buildings and bridges.

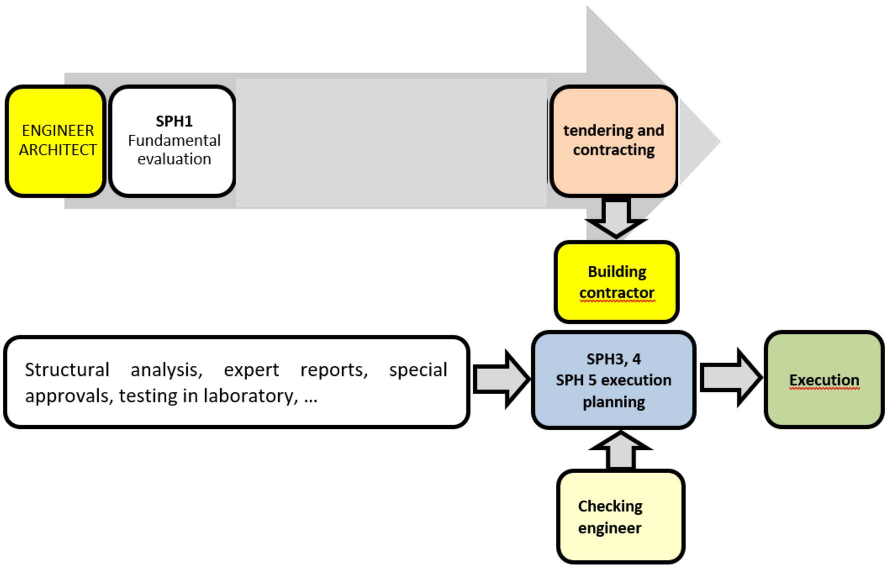


Fig. 3: Service Phases SPH1 – SPH5, facades current practice.

3. “Forensic” engineering versus structural monitoring and evaluation

Forensic engineering has been defined as "the investigation of failures - ranging from serviceability to catastrophic - which may lead to legal activity, including both civil and criminal". Evaluation of existing facades is done e.g. in case of conversion or rehabilitation of facades which are in service for longer times, even up to decades. It is assumed that the service life of an IGU is around 25-30 years, that of a façade around 25 years and that of the building structure 80 years, meaning that a building will have two to three façades over the course of its service life.

Also, in case of damages of facades or its elements often evaluation to identify the reason or responsibility for damage has to be done, e.g. as part of legal dispute. First of all, the question of inventory documents must be asked. Often these documents do not exist, are incorrect or do not match the built version.

- Execution drawings
- Structural Analysis
- Report of checking engineer
- corresponding approvals from building authorities

The opening of construction components often turns out to be very time-consuming, often a complete dismantling is necessary. Façade inspections will become increasingly important for sustainable construction in the future to extend the service life. This means that they must be easy to carry out.

4. Regulations for Inspection

After a significant number of tragic building collapses in Europe at the start of 2006, a new guideline has been introduced in Germany. With the guideline VDI 6200 (Structural safety of buildings – Regular inspections) a guideline for inspections of buildings was introduced. The bilingual (German and English) guideline VDI 6200 contains assessment and evaluation criteria and practical instructions for the regular inspection of the structural safety as well as recommendations for the maintenance of buildings of all kinds, with the exception of transport facilities and bridges. Building constructions are classified according to the possible consequences in the event of global or partial failure and their structural design. However, only few are aware of the fact, that the guideline VDI 6200 also has to be applied for facades. According guideline VDI 6200, facades are classified in to consequences class CC2 (see Eurocode 0), same class as e.g. high-rise buildings or public buildings. CC2 means medium consequences: Damage to life and health for many persons and serious environmental damage. Furthermore, robustness classes RC1 – RC4 are described in the guideline. The Consequence classes are basis of Eurocode. Depending on the Consequence class, intervals for periodic inspections are given as orientation values, see Table 1. This means that every 2 to 3 years it is recommended to do a surveillance by the owner or authorized representative for obvious defects or damages and the documentation thereof. Every 4 to 5 years an inspection by an expert shall be done and every 12 to 15 years a thorough examination by a special expert. This includes parts of the structure, which often are difficult or – without damage – impossible to access. It may be necessary to take material samples to determine the remaining strengths and rigidities. Furthermore, any found defects or damages must be assessed in terms of their relevance for the structural safety of the building and its parts. Looking to common façade constructions, especially the point “examination of parts of the structure, which are difficult to access” causes problems. E.g. the examination of the fixing points of an element façade means the complete dismantling of the façade – and by this opening existing moisture barriers. A special guideline for the periodic inspection of façade constructions was completed in 2024.

Table 1: Intervals for periodic inspections according to guideline VDI 6200.

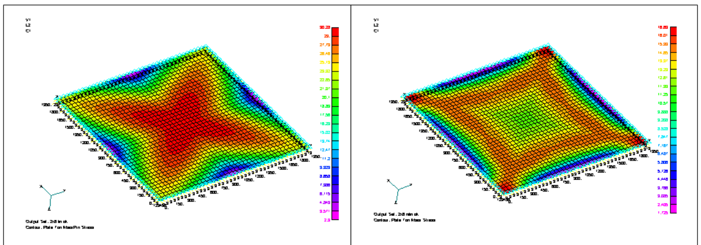
Consequences Class	Surveillance [years]	Inspection [years]	Thorough examination [years]
CC3	1 to 2	2 to 3	6 to 9
CC2	2 to 3	4 to 5	12 to 15
CC1	3 to 5	As required	As required

Table 2: Extract guideline for the periodic inspection of façade constructions, part 2.4 Glass.

(A) Checklist for Surveillance	(B) Checklist for Inspection	(C) Checklist for Thorough examination
2.4 Glass	2.4 Glass In addition to (A)	2.4 Glass In addition to (A) and (B)
a) Visual inspection for scratches, cracks, edge bond damage in the space between the panes with regard to waviness, blinding, clouding, moisture, etc. b) Visual inspection of the position of the glazing for possible displacements c) Visual inspection for edge damage to free glass edges, e.g. on glass corners, glass railings, etc.	a) Drainage opening suitable in terms of size and position / sufficient vapor pressure compensation available? b) All-glass corners and SSG façades: visual inspection of adhesions c) Visual inspection for delamination, incompatibilities, bubbles, detachment of coatings... d) If necessary, measure glass structure and check for basic suitability (e.g. glass with safe breakage behavior) e) Check of installation orientation f) If the requirement exists: Is the glazing fall-proof?	a) In the event of anomalies: Visually check removal of panes and adjacent rebate space and glass edges. b) Has there been any glass breakage in the past, and if so, is this related to structural alterations or changes of use? c) In the case of window sealant/cement, check for harmful substances if necessary

5. Structural analysis of glass

In the countries of Europe design standards for glass construction exists for many years (e.g. Germany, DIN 18008), at European level recently a draft version of a Eurocode for glass was published. Due to the brittle behaviour of glass, the static calculation – as all glass experts know – has to be carried out taking care of several specific aspects. Design of glass is often not done by glass experts. Supposedly conservative geometrically linear glass statics results in a safe design, but also an uneconomical one - which can also lead to expensive disputes.



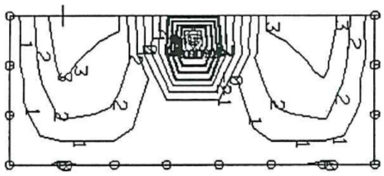
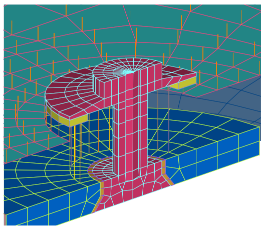
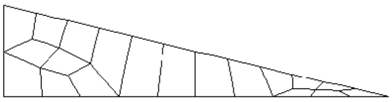
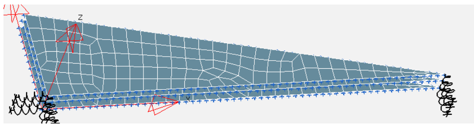
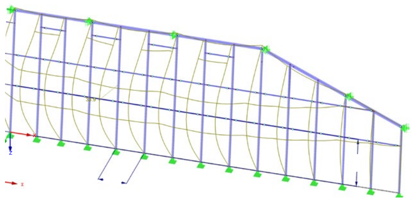
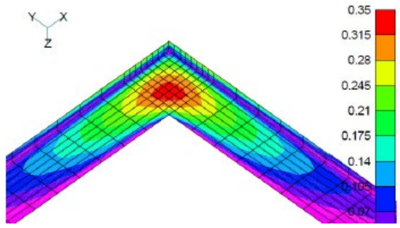
Linear analysis:
Max. tensile stress: 30,28 MPa
Max. deflection: 49,0 mm

Non-linear analysis:
Max. tensile stress: 16,69 MPa
Max. deflection: 19,2 mm

Fig. 4: Linear Analysis vs. Non-linear Analysis.

In façade constructions and even in simple windows various "pitfalls" exist such as: very restrictive deflection limits, bimetal effect in (thermally separated) window frames, unregulated connections (e.g. between mullion and transom or in the field of the screw channel). Table 3 gives an exemplary overview of "current" and "desired". Here, in the context of expert opinions, one can very often see "gaps" in design process of supposedly simple constructions. Even if these very simple calculations might be on the safe side, the result often is not economical and optically less transparent.

Table 3: Examples structural analysis.

Aspect	Current / often found	Desired / the way things should be
Point-Fixing		
Finite element analysis		
Façade	“q l²/8” 	• Calculation structure with posts, transoms and eccentricities, fixed and loose point • ULS and SLS • Proof of connection brackets • Verification of dowels • Proof of Pressure strips, screw connection, screw channels, post and rail connectors,... 
Window	No special design – hopefully the supplier did a rough check based on experience	• Structural analysis of IGU including climatic loading • Structural analysis of frame with Bi-Metall Effect • Structural analysis of dowels, drilling screws, rivets • if applicable anti drop device glass, frame and anchors
Structural sealing	Stress = force / area	

6. Examples of damages

6.1. Setting blocks

Very common errors are related to the field of setting blocks. According to the rules of glazing blocks, the blocks must be indented by a minimum block width, maximum 250mm (for very wide glass panes), minimum 25mm in special cases.

The blocks must support all panes of, for example, a multiple pane insulating glazing unit (IGU), at best even protrude by 2mm on the outer pane (which is usually not possible on facades). Blocks that are too deeply indented can be tolerated up to a maximum of 1/3 of the thickness of the outer pane.

In reality, blocks are often not in the right place, have slipped inwards so that either the outer pane of the laminated safety glass slides down on the PVB film or the outer glass pane slides along the edge seal. “Slippage" of up to 10 mm have been observed in some investigations.

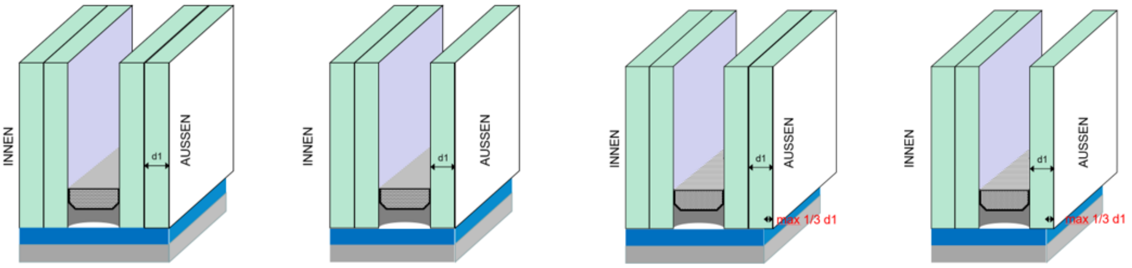


Fig. 5: IGU resting on setting blocks (blue), ideal and tolerated position.

Fig. 6: Setting blocks, not properly installed.

6.2. Grinding in the glass edge

In one case of damage, where more than half of the panes were broken, a so-called "grinding-in" system was used. In this case, emergency brackets were inserted into a grinding-in of the outer fully toughened safety glass pane. While the original system had the appropriate approvals and certificates, here the system was copied to save money, but unfortunately some things were overlooked. Since the breakage point was always in the area of the grinding-in, in addition to static considerations, the pane was also dismantled and the individual fragments examined more closely. As often in cases of defects, several critical points do exist:

- Questionable level of tempering
- The edge processing in the area of the incision was very bad
- From the point of static analysis, a larger incision is of course worse (with a punctual load by the emergency holder)

Fig. 7 system, breaking point, “Wallner” lines.

6.3. Incompatibilities of materials

Incompatibilities between the materials involved, such as silicones, edge bonding in IGU, adhesives and coatings, are a frequently observed defect that can also lead to load-bearing capacity problems if, for example, a load-bearing adhesive fails.

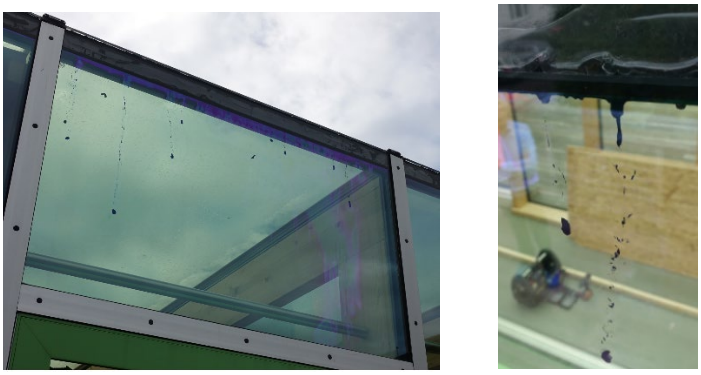


Fig. 8: Incompatibilities on an all-glass-corner.

6.4. Glass breakage

Glass breakage can have various reasons, the most common are:

- Thermal breakage of float glass due to partial shading or additional heat source through absorption
- Climatic load breakage occurred due to encapsulated glass expanding in the cavity
- Spontaneous failure due to nickel sulphide inclusions in tempered glass
- Mechanical damage, insufficient edge trimming...

The first two breakages can be avoided by doing a special stress analysis or sufficient static calculation, the risk of nickel sulphide failure by heat soaking or alternative glass products.

Fig. 9: thermal breakage / climatic load breakage IGU / Spontaneous failure nickel sulphide inclusion.

6.5. Construction details

A large proportion of cases of damage in structural glass engineering relate to leaking facades and glass roofs: this is caused by roofs with too low inclination, systems in which the screw connection penetrates the lower sealing level, faulty bonding of the seals, water accumulation in the drainage channel, filling of the glass rebate with silicone, a too small contact pressure and much more. Two examples are shown in Figure 10.

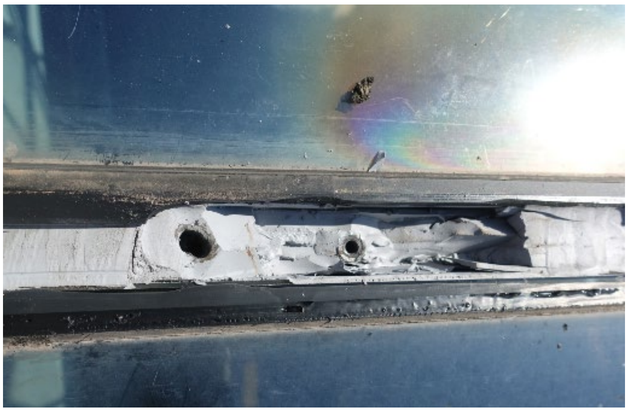


Fig. 10: Crossing point with blocked inner sealing level and destroyed edge bonding (left) and glass rebate filled with silicone and first damage on the coating of the IGU (right).

6.6. End of service life reached

The normal service life of multi-pane insulating glazing is 25 to 30 years. This means that over the lifetime of a façade, the glazing must be replaced minimum once. Over the lifetime of the building, the façade will also need to be replaced. The example of a 50-year-old heritage listed façade shows that important components of an energy-optimized façade are missing today (Figure 11, right). There is a conflict between an unsustainable new façade, an almost impossible energy-efficient refurbishment and the heritage protection. For the future, façades must become more modular (simple refurbishment), more durable and therefore more sustainable.

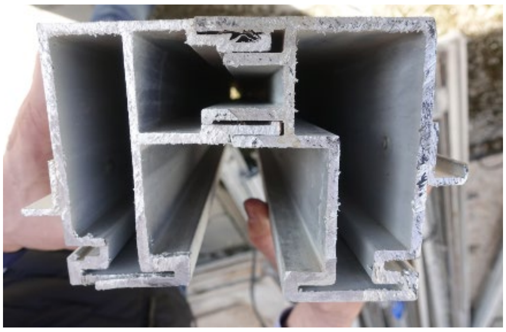


Fig. 11: End of service life of an IGU (left) and Cross-section of non-thermally separated old element façade (right).

7. Conclusions

Iconic Projects are usually designed and executed by specialists. With the "mass" of projects in the area of glass and facades, one often can see "sloppiness" in both, design and execution. Due to a missing understanding or awareness of the problems, a lack of checking engineers qualified in the field of glass and façade, these errors often are overlooked. One can conclued that there is a need for optimization, clarification and eventually changes in the design process. If an executing company has to take over the entire planning management, it will do so in a profit-optimized way. In addition, if there is not a consecutive maintenance contract, the interest of easy access for monitoring is less than if responsibility for the future exists. Therefore, if holistic planning is done in advance, a corresponding basis does exist and standards are set.

Experience from forensic engineering in term of expert reports lead to conclusion that a proper planning before tender results in

- more safety regarding time and money for execution company and building owner
- less risk for the executing company to make an inadequate offer
- less risk for the building owner for justified discussions and additional demands
- a better protected investment with less risk of unknown future cost

Unfortunately, the higher investment in design only pays off after a certain period of time. Property owners with a larger portfolio now seem to have learnt from various damage cases, while one-time investors and their planning team are not always aware of this - or are simply not interested.

For the future, façades must become easier to inspect and to maintain, more modular (simple refurbishment), more durable and therefore more sustainable.

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