Lucerne University of
Applied Sciences and Arts

HOCHSCHULE
LUZERN

Engineering and Architecture

Façade2010 – Conference on Building Envelopes

refurbishment. hightech – lowtech.

Symposium, 25th November 2010

FH Zentralschweiz

FAÇADE2010 CONTENTS

PREFACE

Daniel Meyer
DR. LÜCHINGER & MEYER
BAUINGENIEURE AG, ZURICH (CH)

Contributing to the establishment of a European Competence Network Centre, the half-yearly Façade symposium is being held in Lucerne for the first time. It is being hosted by the School of Engineering and Architecture – which is part of Lucerne University of Applied Sciences and Arts (Lucerne UASA) – in association with the Swiss Centre for Window and Façade Construction (SZFF).

The demands made of building façades, and thus of architects and engineers, are rising in line with global warming and the gradual depletion of fossil fuels. Buildings – their façades in particular – therefore need to be constructed in a more sustainable manner and tailored as closely as possible to the sensitivities of the environment and the needs of people. Today's modern, well-designed façades help save energy – but they can also help generate energy. The demand for increasingly complex building envelopes and the continuing trend towards highly transparent façades present structural engineers with immense technical, ecological and economic challenges. Moreover, remediating the myriad of existing façades that already clad our built environment calls for input from everyone involved in construction – including the client, the planner and the monument conservator – and for intelligent, sustainable and well-designed solutions. The symposium is taking place in the Hans Erni Auditorium, whose legacy façade (together with other buildings forming part of the Swiss Museum of Transport in Lucerne) has been skilfully remediated and renovated – architecturally no easy task.

The symposium is therefore exploring innovations in façade construction with the twin focus on new build and remediation.

It is one of a series of activities exploring the ins and outs of façades. A number of workshops are being held at Lucerne UASA in Horw either side of the symposium (23–24 and 26–27 November) for students taking the Façade Master of our network partners TU Delft (NL), TU

Ostwestfalen-Lippe (D), Universidad del Pais Vasco (E) und University of Bath (UK). The aim is not only to provide the students with the requisite training, but, perhaps more importantly, to offer them the opportunity to network in today's truly global façade market.

We would like to thank our organising partner SZFF and sponsors Wicona Hydro Building Systems AG, Glas Trösch Holding AG and Sika Schweiz AG for their generous donation of staff time, materials and/or funding. Thanks also to the partners of the European Competence Network Centre.

My special thanks go to Mr. Ueli Zihlmann, scientific assistant at Lucerne UASA, for the professional organisation of Façade2010.

SWISS MUSEUM OF TRANSPORT, LUCERNE

Caspar Bresch
GIGON / GUYER ARCHITECTS,
ZURICH (CH)

Situation, context: The current project is based on the 1999 competition. At that time the brief represented an urban design vision for the gradual renovation of the museum complex with its various buildings exhibiting the different means of transport, as well as a new building for the Road Transport Hall. During the first construction phase (2005 – 2009) a new entrance building (FutureCom) was built in addition to the replacement of the Road Transport Hall. This urban design strategy enabled the creation of an open central courtyard (Arena), which in the new scheme should remain undeveloped and creates space for temporary, themed exhibitions.

Entrance building: The new entrance building forms a bridge-like link between the existing buildings on Lidostrasse (the IMAX cinema, the Rail Transport Hall and the high-rise building). The ticket office, shop area and two restaurants are located on the ground floor – one restaurant offers table service and opens towards the lake, the other is conceived as a self-service restaurant that stretches out like fingers into the Arena. The exhibition areas for communication media, the new entrance to the Planetarium and also the services area are found on the first floor. The second floor accomodates the conference area, with a conference hall that seats 500 guests, a generous foyer and three smaller meeting rooms. A large opening in the ceiling of the entrance hall allows viewing through the entire building – into the exhibition level and up to the conference level.

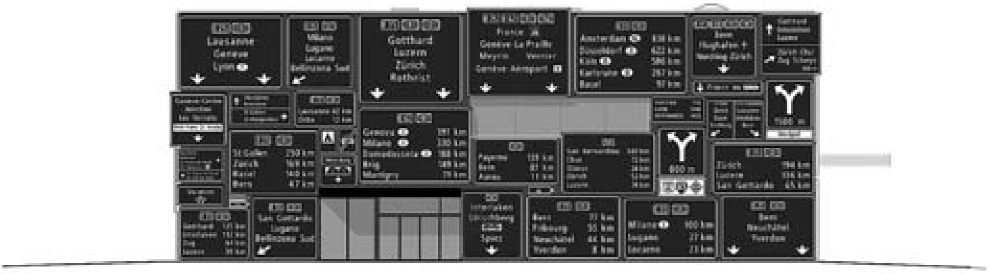
The Swiss Museum of Transport was looking for a new branding for its fiftieth anniversary. One key parameter of the commission was to design a new entrance for the museum that makes for a strong iconic image, an image easily recognizable. The stretched, low-rise volume was given by the spatial programme, leaving little range for a prominent volumetry. The same programme also implied only a very limited number of windows apart from the glazed ground floor and the conference centre, so most parts of the façade had to be closed. Therefore the design focuses

Pictures: Above and left Heinrich Helfenstein, right Gigon/Guyer this part of the façade. The concept reacts to this task with a rather narrative approach: The façades form roughly transparent «vitrines» for all kinds of wheels, propellers, wheel rims, turbines, cogs, steering wheels, etc. These mechanical parts are hung densely in front of the building insulation and behind the façade panes, forming a shimmering, shiny and in parts revolving façade «undergarment». The omnium-gatherum of the various manifestations of the wheel pays homage to this basic element of mechanical movement, the very heart of all transportation. The fusion of exhibits and architecture in one building element – the façade – results in a visual richness despite the rather limited overall budget.

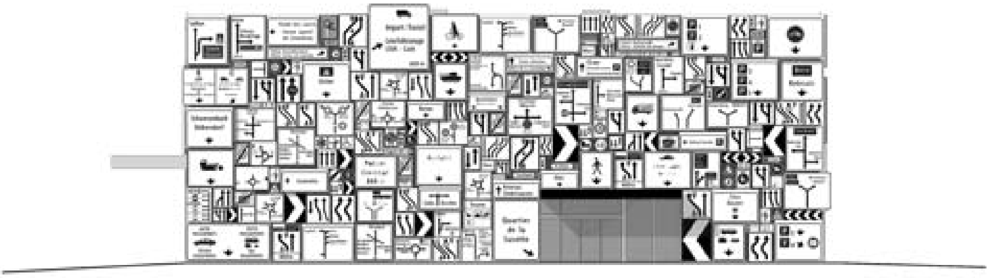
This was achieved by the use of low-priced materials and a rather low-tech construction. The double-layered skin is mostly made of industrial materials: the glass is a rolled, U-shaped channel glass, offering enough stability and at the same time not being fully transparent. This gives this outmost layer a materiality, a thickness that varies its aspect from different points of view. The closer you get, the more blurry the exhibits gleam behind the glass as from a distance the wheels become clearly visible. The 3,500 exhibits consist for the most part of recycled car wheel rims from the scrapyard. In their sheer number they become a pattern. To ensure a free and random position of these wheels at any place on the façade a grid acts as support. It is made of galvanised steel grids, used commonly for stairs and industrial purposes. The wheels are fixed with simple S-crooks allowing for a later repositioning if necessary. The larger exhibits like propellers, gears and turbines are surplus items from the museum itself and are fixed directly on the concrete wall. The thermal insulation made of mineral wool can be seen through the grid. With its double layer the «vitrine» acts as a thermal buffer. It is accessible for maintenance.

The large windows for the conference centre pierce through this «vitrine». Their frames are made of aluminium and contain the outer textile sun-protection. The small windows for the secondary rooms like kitchen and bathrooms are located within the double layered façade and remain covered by the channel glass.

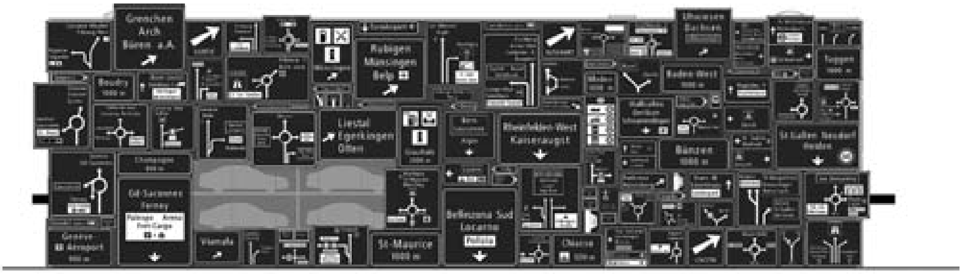
The ground floor façade is divided into two parts: on both ends of the stretched building it is made of metal panels, forming the basis of the bridge-like construction. This allows for a large opening for the rest of the ground floor. The structural glazing offers maximal transparency so the public can see through the building into the Arena. Both restaurants are fully glazed.



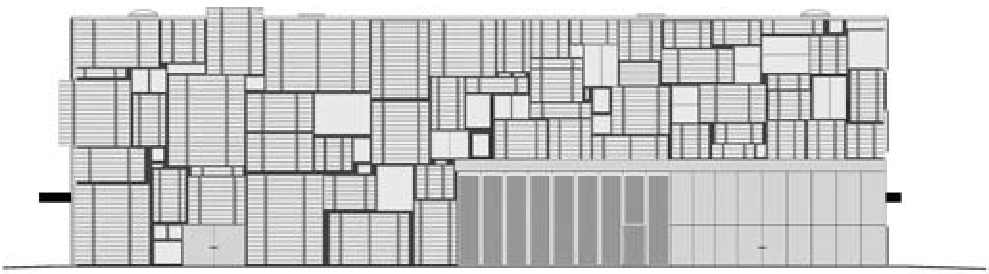
Road Transport Hall elevation south



Road Transport Hall elevation north



Road Transport Hall elevation west



Road Transport Hall elevation east

Plans: Gigon/Guyer

The roofing consists of an aluminium seam system on a mineral wool thermal insulation.

Road Transport Hall : The concept for the new Road Transport Hall differs considerably from the first design during the 1999 competition. Originally a three storey building was conceived with concrete shear walls, a load-bearing, glazed façade construction and bridge-like ramps on the exterior. The new building should have two storeys, it should be like a black box, more flexible and in particular more economical. It should be a structure that is reminiscent of those buildings countrywide that are designed for the storage and housing of cars, i.e. multi-storey car parks. Instead of negotiating the floors via ramps, an automated parking system is employed here; a shelf-like structure operated by a mechanical lift displays the collection of classic cars (or even new models) densely positioned one above the other and out of reach. At the touch of a button visitors can bring one of the cars closer to them and look at it close up. The connection to the open areas on the ground and first floors enables the possibility of running different themed exhibitions parallel to this. A workshop shows the visitors how the vehicles are maintained and repaired.

The façade cladding of the mainly closed building volume is composed of sheet metal in differing formats and colours. However, standard façade sheeting is not employed, nor metal from car bodies from the scrapyard (as envisaged during the preliminary project), but rather the façades are clad from the sheet metal boards that direct traffic – we are referring to traffic signboards: destination and orientation boards, instruction signs, mandatory signs, prohibitory signs and place name signs. The signboard walls, which spatially delimit the Road Transport Hall, indirectly refer to the great latitude of private transport, which is directed and regulated with the help of such boards. The signs also refer to numerous locations that are connected via different road networks. Amongst them might be the home towns and cities of the visitors, who arrived at the Swiss Museum of Transport via diverse traffic routes and with different means of transport and here can discover more about (their) mobility. On the rear façade, towards the neighbouring buildings, the signs are reverse mounted, which means that the printed side faces the building while the untreated, metal side faces outwards. Thus the neighbours see these boards just as road users would see those signs meant for the oncoming traffic – from the rear side.

The concrete structure of the building is clad with thermal insulation which is covered by horizontally mounted metal profiles. They act as support for the traffic signs. The construction of the traffic signs is dependent on their size: the small signs are made of sheet metal, while the large ones are composed of special aluminium profiles. These different construction principles lead to varying dimensions of the sub-construction. This results in different depths of the traffic boards.

INVOLVED IN THE PROJECT:

Site:	Swiss Museum of Transport Lidostrasse 5 CH – 6006 Lucerne
Spatial Programme:	Entrance building with restaurants, exhibition space and conference rooms Road Transport Hall (exhibition building for cars, motorbikes, trucks and bicycles)
Competition:	1999, 1st Prize
Planning/Construction:	2005 – 2009
Client:	Swiss Museum of Transport, Lucerne
Architecture:	Annette Gigon / Mike Guyer, Architects, Zurich
Collaborators:	Caspar Bresch (Project Manager), Mark Ziörjen, Damien Andenmatten, Gaby Kägi, Gilbert Isermann
Landscape Archit.:	Schweingruber Zulauf Landschafts-architekten, Zurich

THE CHALLENGES OF FUTURE FAÇADE RENOVATION

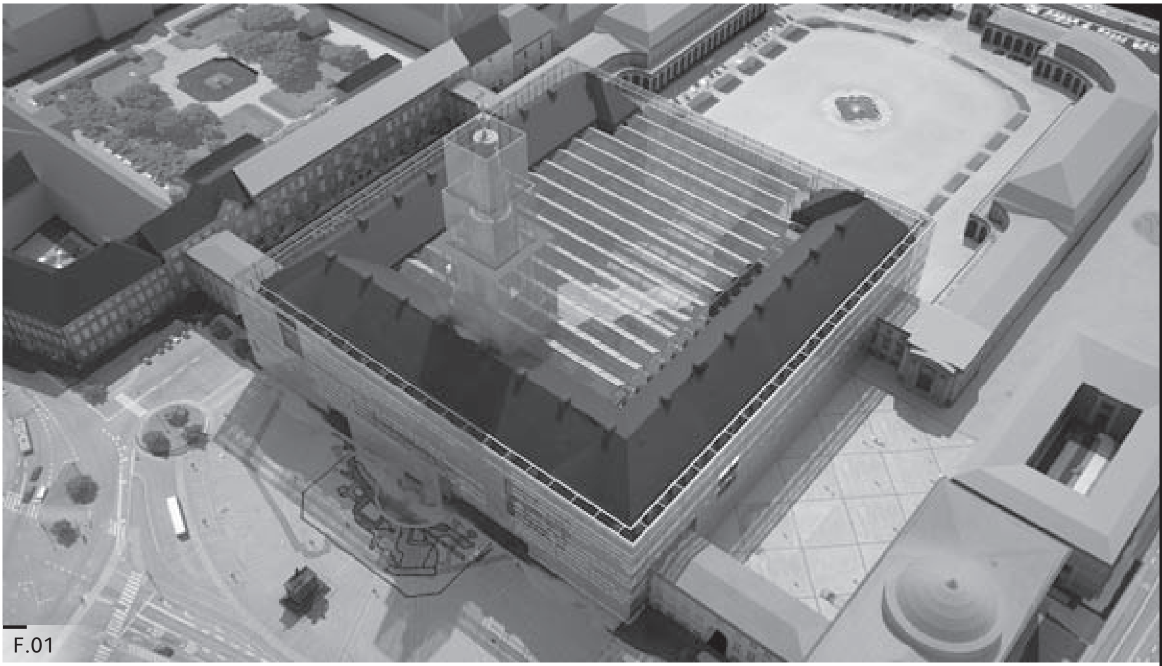
Thomas Henriksen

GUEST RESEARCHER, TU DELFT (NL)

In recent years there has been an increased focus on the energy usage of buildings. This has been incorporated into new legislation, i.e. the part L in the building regulation in the UK. The new part L sets stricter performance criteria for new buildings. However this does not solve the issue with existing buildings and especially listed buildings (historical buildings) where there are limitations regarding the possibility to change the appearance of the building. This paper highlights some of the problems which exist today and aims to start a discussion in relation to the topic and possible solutions to solve the challenges.

Introduction: Energy and usages of energy in buildings are becoming more and more relevant. In 2009 the COP 15 was centre stage in relation to discussing the current climate change, with a common aim to reduce the CO^2 emissions. The topic of climate change will not be covered in this paper, however one way of reducing the CO^2 is to improve the performances of façades in general and this is an issue which needs to be addressed. New regulations throughout Europe have been incorporated to lower the emissions. From the UK's point of view Part L of the building regulation was changed in October 2010.[1] This should ensure that the performance criteria for new buildings are much higher than previously.

However this does not cover existing buildings which have significantly higher allowable performance criteria for their façades. There is a problem with regard to listed buildings. If the building has a historical significance, it might not be possible to change the appearance of the building. In some cases, even the interior of the building could be listed, leaving very little room for improvement with regard to the performance of the building. *Figure 1* and *figure 2* show how a Danish architect[2] suggested the adding of a double skin to the Danish parliament. This was done in connection with the COP 15 held in Copenhagen in December 2009. The suggestion was made due to the sig-



F.01

F.02

F.01, F.02
Double skin added to the
Danish parliament,
rendering Vandkunsten[2]

nificant heat loss from the parliament building. The walls are not insulated according to current regulations.

Energy usages in buildings: To understand better the importance of reducing heat loss in buildings the U.S. Energy Information Administration recently carried out a survey on the total energy consumption for different sectors. In *figure 3* the relation between the different sectors can be seen.

Figure 3: In general, the residential and the commercial sectors consume 22% and 19% of the total energy consumption respectively. The remaining consumption is divided between the transportation and the industrial sector.

For the energy usage in the commercial building sector the energy usage is divided between space heating 36% and lighting 21% which represent the main consumption; the rest is divided equally between cooling, ventilation and water heating etc. The graph can be viewed in *figure 4.*

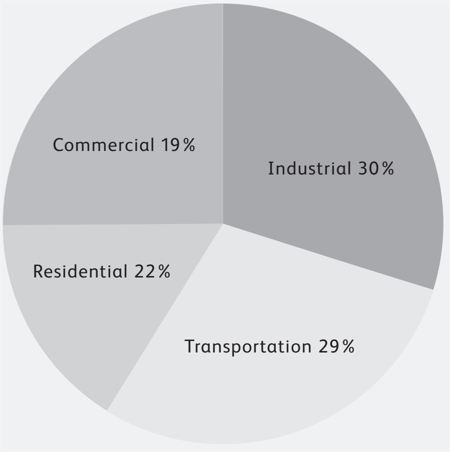
Figure 4: A similar survey has been made for private houses. Here the space heating consumes 41% and the lighting and other appliances 26%, which again is the dominant part of energy consumption. The graph can be viewed in *figure 5.*

Figure 5: From this it can be concluded that 16% of the total energy consumption is used for space heating in commercial buildings and private houses. Lighting represents 10% of the total energy consumption. Therefore there is still room for improvement with regard to reducing the energy consumption from space heating. A reduction in energy consumption can be achieved by increasing the performance of the façade, e.g. using better insulated materials, or other schemes.

Regarding lighting it is equally important to reduce the electricity consumption. This can easily be done by changing from conventional light bulbs to low-energy light or in the future LED lights. This is already legally required in Europe. At the same time movement sensors which switch off the light automatically can be installed throughout buildings. However, the movement sensors need to be sensitive or else they turn the light off when people are working without their movements being registered by the sensor. This can be very annoying. However the challenge with regard to lowering light consumption is not the aim of this paper.

F.03

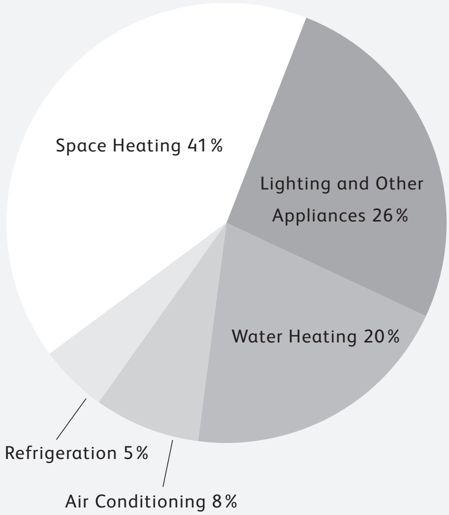
Share of Energy Consumed by Major Sectors of the Economy, 2009



Source: U.S. Energy Information Administration, *Annual Energy Review 2009.*

F.05

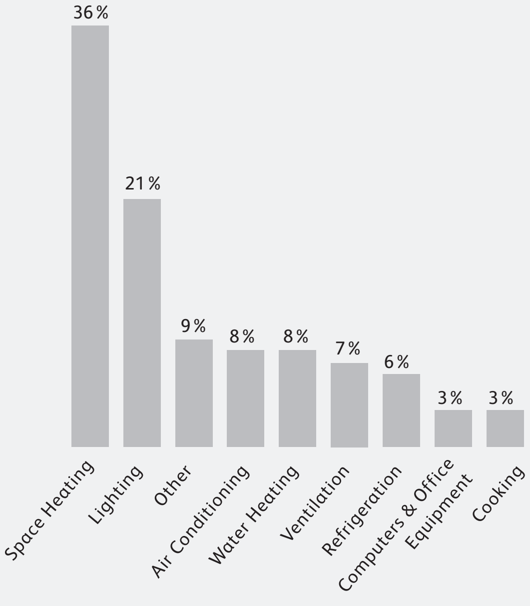
How Energy is Used in Homes (2005)



Source: U.S. Energy Information Administration, *Residential Energy Consumption Survey 2005.*

F.04

Energy Use in Commercial Buildings, 2003



Source: U.S. Energy Information Administration, *2003 Commercial Building Energy Consumption Survey*, Table E1A (September 2008).

Reduction of the energy consumption in new buildings can be achieved by changing the building regulations, i.e. through new legislation. This has been done in Europe and more strict rules are being implemented. However, this leaves out existing buildings in Europe and other parts of the world. However the American LEED system and the British BREAM system are being requested on more and more developments, which will lead to buildings with significantly better performances.

Existing and listed buildings: For existing buildings it is much more difficult to issue legislation which requires owners of buildings to lower the energy consumption of their buildings. Several issues come to mind. Possible solutions are often expensive, and often require reglazing of the entire building and adding external insulation which changes the appearance of the building. Changes which increase the performance of the façade are usually only incorporated in relation to bigger refurbishment schemes.

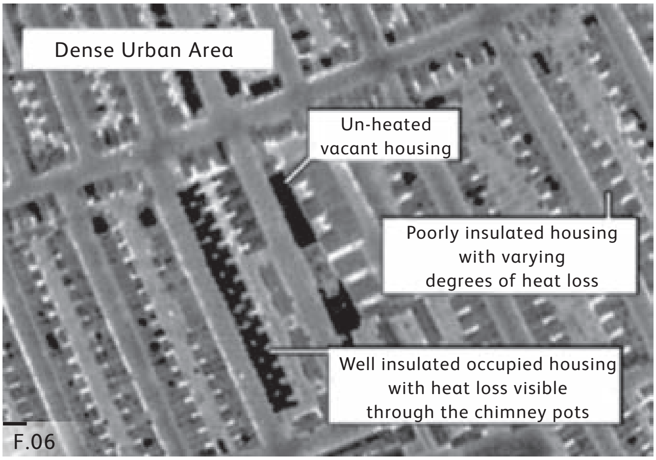
Haringey Council in London, UK, took a more unusual approach to the subject and published on the internet the energy performance of all the buildings in the council and gave them a colour from blue to red dependant on their performance. The pictures were taken from aeroplanes that were making surveys over London with infrared cameras. After colourisation of the pictures it is possible to see the difference in heat loss from adjacent buildings. *Figure 6* shows an example from London.

The purpose was to show which buildings have a significant heat loss compared to well insulated buildings, and to expose them to the public. However, whether this form of trying to shame people into upgrading their houses works or not needs to be viewed over a longer period.

For listed buildings this, however, is much more complicated, since there might be several restrictions with regard to changing the appearance of the building. However, the problem with the significant heat loss of listed buildings still remains. *Figure 7* shows a picture illustrating the Houses of Parliament in London. From the picture it can be clearly seen that the building has a significant heat loss.

The Houses of parliament in London are only one example. There are many more historical buildings with similar problems.

Renovated buildings with static façades: In Linz in Austria there exists an example of a conventional 5-storey residential house built in the 1950s. This building has been converted into a passive house, with a decrease in



F.06

F.07

F.06, F.07
Haringey Council heat map

energy usage by approximately 80 %.[3] The building before the renovation is shown in *figure 8.*

The renovation scheme is an add-on system where additional insulation is added on the outside of the existing building. In the case of Makartstrasse in Linz, Austria, the additional insulation was approximately 400 mm. At the same time the building appearance also changed to a more modern architectural style. *Figure 9* shows the building after the renovation.

The add-on system was made from prefabricated elements which were fixed on the outside of the old façade. The U-value of the windows was reduced from 3.0 W/m^{2}K to 0.85 W/m^{2}K. The walls' performance was reduced from 1.2 W/m^{2}K to 0.21 W/m^{2}K. The solution is relatively cost effective and the payback time is less than a decade with the current fuel prices. The concept of an add-on system is shown in *figure 10.*

Thick insulation between 300–400 mm is fixed on the outside of the existing walls and clad with durable material.

With the add-on system there will always be a problem with recessed windows. This has to be solved architecturally.

In Bolzano in Italy an old post office building has been converted into a passive house, following a scheme similar to the Linz project. Insulation has been added to the outside of the building, and the performance of the windows has been improved.[4] However the Bolzano project featured an architectural solution for recessed windows when using an add-on system. The refurbished building achieves a reduction in the heat loss of approximately 80%.

The building before the renovation is shown in *figure 11.* The building after the renovation in 2006 with the bevelled window recess is shown in *figure 12.*

The aesthetics have clearly improved, together with the performance. The payback time was calculated at 6 years.

Building with dynamic façades: An alternative to the add-on system with static façade is the dynamic façade. The terminology «dynamic façades» currently means façades with movable parts, i.e. movable louvres, Venetian blinds or fabric curtains. The movable parts are normally integrated into double skin façades. These types of façades can be added to existing buildings if the structure is sufficient to support the new outer skin. The double skins can act as a thermal flue, making sure that the air in the cavity between the inner and outer skin is ventilated. More advanced double façade schemes can have an air intake which in the summer uses the cold air from outside to cool down the building. The heated air from the building is then exhausted out into the thermal flue.

For the Plantation Place in London finished in 2004 the building received a double skin with movable Venetian blinds, automatically controlled depending on the orientation of the sun, as part of the original scheme. This is just one of many schemes which have recently been built. However the current financial crisis has a big impact.

A transparent double skin façade could be a solution for listed buildings. However it would still have an aesthetic impact. The question is whether we can afford to ignore the problem.

The future with regard to dynamic façades should be façades which would be able to change shape or performance depending on the surroundings, similarly to trees which can orientate their leaves towards the sun, and where the leaves fall off in the winter when they are no longer required, and grow back again in the spring.

Conclusion: Heat loss in buildings is an important topic, especially when space heating represents 16% of the total energy consumption and, as already mentioned, this has to be addressed. In this paper some of the issues and solutions have been shown.

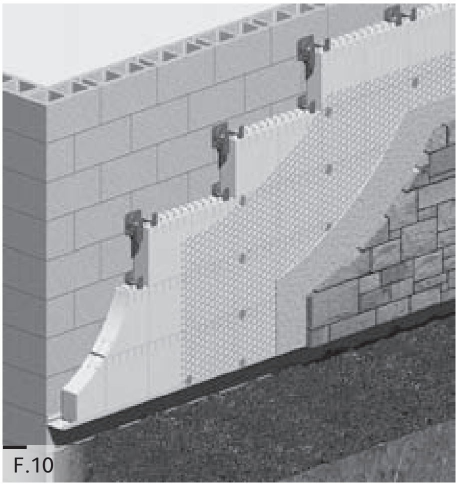
F.08
Makartstrasse in Linz before the renovation

F.09
Makartstrasse in Linz after the renovation

F.10
Schematic rendering of an add-on system


F.08


F.09


F.10

It should be noted that in most north European countries great efforts have been made with regard to the refurbishing of buildings with subsidised schemes. This has mainly resulted in changing windows to low EDGUs and adding insulation in the cavity between the inner and outer brick wall in brick buildings.

However, some countries are still behind in this process, for instance the UK. With new emerging economies this will also be relevant.

It is the small house owners who have to upgrade the performance of their houses in order to significantly lower the global energy consumption used for space heating.

In the future, it is important that new and better schemes for increasing the energy performance of existing buildings are developed. It might be necessary to introduce stricter regulations in order to push this issue further. Old listed buildings are problematic, but a consensus with regard to changing their appearance might have to be agreed upon in order to upgrade their façade performance to current standards.

Acknowledgement: I would like to thank Sigga Björnsdottir for her support in reviewing the paper, and Sören Pedersen from Passivhus.dk for his advice regarding passive house projects in Europe.

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1 UK building regulation, Part L, October 2010.
2 Vandkunsten A/S, Nörregade 66D, DK-2200, Denmark.
3 Bauforum, Oct 2006. Page 11.
4 Troi, Alexander et Al., *Towards Zero Energy Renovation: Ex-post Building in Bolzano/Italy,* Dublin, PLEA, October 2008.

F.11
The post building in Bolzano before the renovation

F.12
The post building after the renovation

SIMPLIFICATION NOT SIMPLICITY

Will Stevens
RAMBOLL, LONDON (UK)

Introduction – Unavoidable Complexity

Is there a real choice between simplicity and complexity? Certainly we are more often looking at a choice between levels of complexity with simplicity rather marginalised into historical constructions.

With the construction of buildings and in particular façades, there seems to be only ever increasing complexity. This has been driven by a desire for ever better performance along with tighter regulation. Both backed by the need to reduce the environmental impact of the manufacture and use of our buildings, whilst still maintaining the comfort and utility they provide. For example, at one time glass was simply that – glass – but like our food, our glazing has become ever more processed. The complexity and combinations of materials used to produce something that is simply considered as «glass» is quite staggering, yet still better performance continues to be demanded.

This environmental pressure is only likely to increase over the coming years. We are starting to understand the performance of our buildings better – although the amount of monitoring in use is still very limited. However the impact of the materials used is still way behind and as performance improves the environmental impact of production will become ever more significant. I believe we will soon be required by law to understand the true environmental impact of all the materials we specify – in detail. These regulations will be necessary to allow us to make educated choices in material selection by ensuring the information is available to specifiers. This information will only become available when it becomes necessary to assess and report on it.

The methods of construction and the manufacturing capabilities also drive complexity into the design, detailing and delivery of buildings, through both opportunity and economy. Bespoke unitised curtain walling is not simply bespoke because it can be, but also because being bespoke delivers value to the project.

Complexity is also driven by our natural «can do» attitude as designers. We enjoy exercising our hard won skills and extending our knowledge. With greater expertise be-

F.01

BBC Cyclorama

ing developed into design guidance, codes and testing requirements and with ever more specialists working with better design tools this has made what had been unachievable not only possible but, in some cases, even quite ordinary.

Further during this latest period of rapidly increasing property values where, in certain parts of the world, developers could sell even the most extraordinary constructions «off plan» to investors desperate not to lose out in the upwardly spiralling market, and the level of complexity demanded by some clients became extraordinary.

It would seem that, with performance, design and capability all acting to increase complexity in our buildings it is unlikely that we will see a run to simplicity – or is it?

The construction industry has already been hit hard by the economic downturn. All the unbelievable projects are now indeed unbelievable and will never be built. The additional onslaught of government spending cuts is not going to make things any easier. How will this affect the run to complexity we have seen? Does the age of austerity that we are being told we must have, mean the end of complexity, a return to the «simple» for façade engineering?

I do not believe so. It simply means refocusing on the complex issues needed to deliver buildings that really deliver.

Dealing With Complexity

To understand this more fully we will review three areas of complexity that occur within façade engineering: Systems complexity; Geometric complexity and Material complexity, and then determine how these aspects have been dealt with in a few relevant projects.

Systems Complexity: The façade of a building as the primary moderator of the environment is inevitably linked to the services systems and must work closely and in detail with those services, in order to result in an efficient overall comfort solution. However it is quite often the case that the building services and façades are designed in isolation with simple assumptions of other services being made in the design process throughout.

Although these assumptions are necessary during the early stages of the design process they should be replaced by the actual design criteria that are developed during the schematic design. This often seems not to be the case as there is some perceived design risk in assuming anything but the «standard» situations. The excuse of «robustness», «future proofing» or «standardised solutions» often being given, but this is really just an oversimplification which results in crude unintegrated solutions.

With a project where there is a requirement to integrate the façade and the building services together to an additional level of complexity this process has to be carried out in detail. The façade engineers have to understand how the services will respond to the changing energy conditions of the façades in different seasons and times of the day in order that they can develop the façade systems in a logical way. Further they need to understand how the façade results in «comfort conditions» within the building and how alterations to the façade performance directly affect those conditions. The building services engineers have to understand in detail what performance they will get from the façade during the different seasons and times of the day and what energy will be imposed on their systems by the façade, in order that they can design the services at all. Again a good understanding of «comfort conditions» is necessary in order for the engineers to understand what impact the façade performance will have on these.

Although these statements are true for all buildings, the development of simple standard solutions has meant that it is possible and even normal for standard assumptions to be used throughout the design development.

Developing projects that demand the integration of these two systems to a high level has illustrated that this integration will become much more necessary as we push for further reductions in energy consumption.

Geometric Complexity: Geometric complexity has always been part of the architectural language of principle cultural buildings. Religious buildings with their extraordinary arches, spires, minarets and domes illustrate this beautifully. These have always challenged the engineers involved and have given rise to significant advancements in building engineering by going beyond what was believed to be possible at the time.

The current increase in the use of complex geometric solutions in architecture should be seen as a simple extension of that tradition. We have seen an increase in the variety of the building types with complex geometry – we now have offices, car manufacturing and sales, as well as galleries and museums, concert halls and theatres, which probably reflect quite well the location of the economic wealth in our societies. The development of computing capacity which allows the design of these complex forms, has allowed a significant increase in complexity to be entertained. The forms can now be generated and manipulated with reasonable ease. The use of parametrically linked, three-dimensional modelling also allows the understanding of the impact of geometric alterations on the functionality of the building to be understood but it is still very time intensive.

The ability to understand, analyse and rationalise these forms in some detail is still being developed, as is the process of design development needed to deliver the best value to the clients in these cases.

The projects we have been involved in have all had shortened design programmes. This has reduced the design period available after the building form has been fixed to an absolute minimum. Inevitably this has pushed some of the form analysis and most of the rationalisation out to the contractor design period. This has made tendering difficult and often protracted, but with the introduction of a «pre-construction service agreement». As the design solutions preferred by each of the specialist cladding contractors differ significantly, bringing a single cladding contractor into the design process early allows the development of a single construction method, which is essential given the complexity of the solutions.

Although there are some tools available for the analysis of the complex geometries these are still relatively crude. They consist of panelisation tools and geometry analysis tools. The latter are still generic and have little inbuilt ability to accommodate the parameters needed to determine which specific manufacturing techniques are required for each panel. This relationship between manufacturing and geometry analysis is essential in order to deliver «economic» rationalised solutions to complex geometric architecture. We need to develop tools that are rapid enough to be part of the design process and sensitive enough to allow the development in manufacturing techniques to influence the solutions selected. This kind of design tool development is in progress and is very likely to be of use for other less complex situations.

Material Complexity: The materials we use to make façades, the processes that are used in their manufacture and the performance that these materials give, have to be understood in order to deliver façades that work and are durable. Materials have to be specified with the knowledge of how they are made and how they will be reused or recycled. This is is being extended to include the true environmental impact of the materials and assemblies we use. At least one manufacturer has already prepared this fully detailed information for one of their systems.

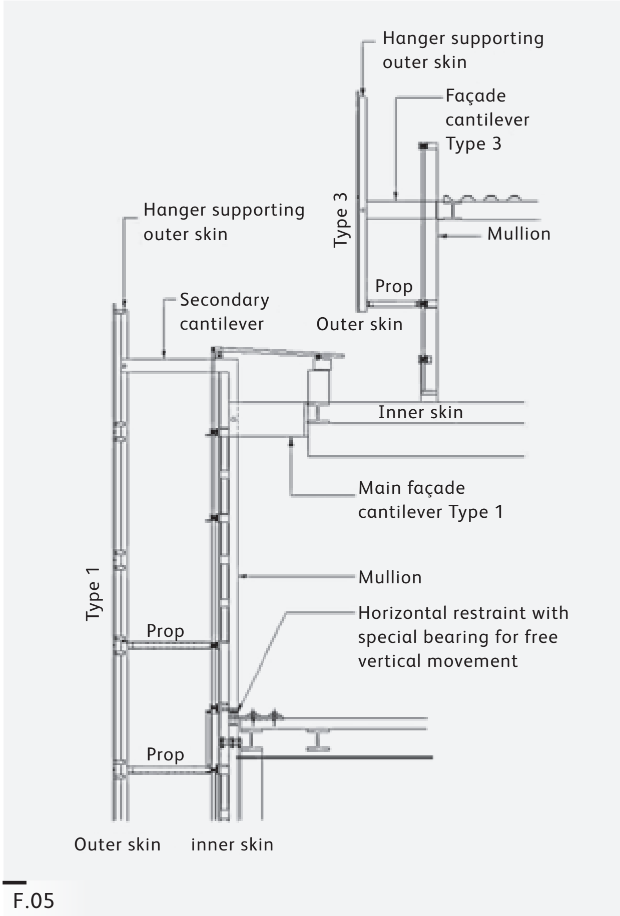
F.02
Egton House

F.03
BBC Broadcasting House

F.04
BBC Fritt and sand
blasted glass

F.05
BBC double façade diagram


F.02



F.05


F.03


F.04

The performance we demand from our materials is ever increasing. This is partly due to the advances in the materials available (we do because we can), but these materials are developed because improved performance is valuable. We need better performance to reduce energy consumption and give greater durability with less maintenance. All this can only be delivered through greater complexity in materials. Simple materials can no longer meet these demands.

Learning Through Complexity – Case Studies: The following two projects illustrate complexity and support the case that working on complex and demanding projects delivers knowledge that is reused in simpler projects making the simple better where it would otherwise not have advanced.

BBC Broadcasting house, Regent Street, London

We are just completing phase 2 of this project which we started working on in 1999. Much has changed in that time, but the example of the double façade that surrounds the main external space is worthy of note. Here, although a complex façade in many ways, we are focusing on system complexity – the relationship between the performance of the façade and the building services.

The building overall consists of the refurbishment and vertical extension of the existing Broadcasting House, a new building, Egton House, and a large new building known as BHX. Egton House and BHX are linked by an eight storey bridge wide enough to be used as an office floor plate.

These disparate elements are all linked by a double façade called the «cyclorama». This was predominantly an architectural device unifying the different parts of the building with their different storey heights and providing a backdrop to the grade I listed All Souls Church and its inclusion was a prime reason the architect, MJP Architects, received planning permission for this sensitive location.

In the upper level extension to Old Broadcasting House, restricted ceiling height and a requirement for the use of chilled beams for cooling, along with very high equipment loads, meant there was very limited cooling capacity remaining for the solar gain. It was necessary to carry out a detailed analysis of the double façade, which, although wide, was needed to provide shade. This included determining the shading performance of both the partial sand-blasted finish and the white fritt pattern in detail. This was quite novel at the time and required experimentation to determine the performance provided both individually and combined.

F.06
No. 1 Merchant Square – black / red fritt pattern

The shading performance requirement was determined through detailed thermal analysis of the spaces with the heating loads, including the solar incidence, for this east-facing façade, along with the maximum cooling capacity available. From an understanding of the material available and the performance requirement, the density of the fritt pattern and sand blasting required could be determined. This was followed by a further shading study to determine the location on the façade that the shading was needed, allowing vision areas out, but still shading the façade when required.

The acquisition of this knowledge and understanding of the performance of different colours of fritt have allowed us to use this information and method many times since to give accurate G-values for «simple» projects, delivering buildings with higher light transmission glazing than would otherwise have been the case.

National Holdings Headquarters, Abu Dhabi, UAE

With the National Holdings office building in Abu Dhabi by Zaha Hadid Architects, we were faced with all three areas of complexity outlined above. The geometry is undoubtedly complex. The material of the outer façade required new material development and the façade system was novel and completely linked to the building services. All of this was initially driven by the architectural vision, but detailed engineering was required to identify a workable solution. The concept was to separate the primary functions across a double façade solution. It was proposed that a single-glazed outer skin should deal with the geometric complexity and a geometrically simple, inner double-glazed skin should predominately deal with the thermal performance. This is rather a large simplification, but it helps to understand the ultimate reason for solution.

System complexity: With the wide cavity necessary to accommodate the variation in geometry, the system was developed to control the inevitable heat gain from the intense solar radiation and high external temperatures of the location. The system proposed was a solar controlled, single-glazed outer skin, wide cavity with automated blinds and double-glazed inner skin with super low e-coatings to give good insulating performance.

The outer glazing was required to be reflective gold and the solar control performance of this was key to understanding the overall system. Unfortunately the data on the coating we required was not determined for most of the design period (see material complexity below) and so estimates had to be used for a product that was still in manufacturing development. This added to the risk associated with the system during this period.

Although it would have been normal to externally ventilate the cavity of the double façade on a floor by floor basis, the proximity of the desert, resulting in high general dust levels, together with the local occurrence of sand storms, meant that this was not an option. It was thus necessary to ventilate the cavity through the building ventilation systems. Options were reviewed for this, including a completely separate system, a partially separated system and a system simply using the building ventilation systems. This investigation highlighted the loss of floor space due to increased core size from a separated system. This alone made the separated options non-viable. Knowing that the use of the building ventilation systems would inevitably result in lower efficiencies we had to investigate how to reduce the impact this would have.

F.07

F.08

F.07
NHHQ Night view

F.08
NHHQ Daytime image

After carrying out solar studies to determine the energy delivered to the outer façade, a single floor was modelled in detail through a typical year and maximum temperatures determined throughout the façade. This included surface and cavity temperatures to allow a review of materials and comfort levels. From this and further studies we found that the higher the temperature was allowed to go in the cavity the lower the energy consumption was. However the temperature did need to be limited to prevent the degradation of the materials in the cavity and so an upper limit of 60 deg. C was set. The surface temperature of the inner glass of the inner façade was then checked against the radiant heat comfort requirement for occupants adjacent to the façade.

The façade cavity was split into separate zones around the building to allow the control of the ventilation to the cavity by orientation. This resulted in the cavity remaining unventilated for most of the year and even, in the summer, only the zones in direct sunlight needed to be ventilated. This produced the best energy results for the system proposed.

Geometric complexity: The geometric complexity for National Holdings was one of the most extreme we have been involved in. Here the whole façade was complex and the complexity also ran through to the building structure as well, although not to the same extent.

There was no intention to base the geometry on simple forms and the variation in curvature was high and in places localised.

An analysis was carried out to identify the opportunities for simplification and, from our previous work on «Opus», also with Zaha Hadid Architects, it was decided that it was worth adopting four methods of producing the geometry in the glass outer skin: hot moulded; hot formed; cold formed and flat.

The prime effort was concentrated on reducing the extent of hot moulded glazing as the moulds are individual to the pieces and increase the cost of the panel by about a factor of 10 compared to cold formed glass and a factor of 5 compared to hot formed glass (without a mould). The adjustment to the geometry continued throughout the design period we had available, making rationalisation and simplification limited prior to the tender of the project pre-construction service agreement. This was targeted as one of the key outputs from the PCSA process.

Even with the limited design development period allowed by the client, geometric design and analysis tools were developed to assist in this process. These tools have been further developed and used on two further projects involving complex geometry. The interrelationship between manufacturing processes and geometric complexity on this project was also a prime motivation in the instigation of our ongoing research into the integration of the design-to-manufacture of façades with Cambridge University.

Material complexity: The material of the outer glazing added a further level of complexity to the whole process. The design requirement was for gold glass. This was not too bad for performance as the reflectivity gave us a reasonable g-value. However the glass needed to have a reasonable light transmission and to be curvable. After significant research and quite a few «red herrings» we found that this was not currently available on the market, but that there was a coating in development by Interpane which might well be suitable.

The client was supportive and the product development was monitored while the design was in development. The use of complex materials in complex unusual situations has inherent risk and, as soon as the glass was available, performance testing and curvature testing were carried out. This showed that we did have a curvable high performance gold coating available. The performance figures could only then be fed into the analysis, which required re-running to give the level of certainty required.

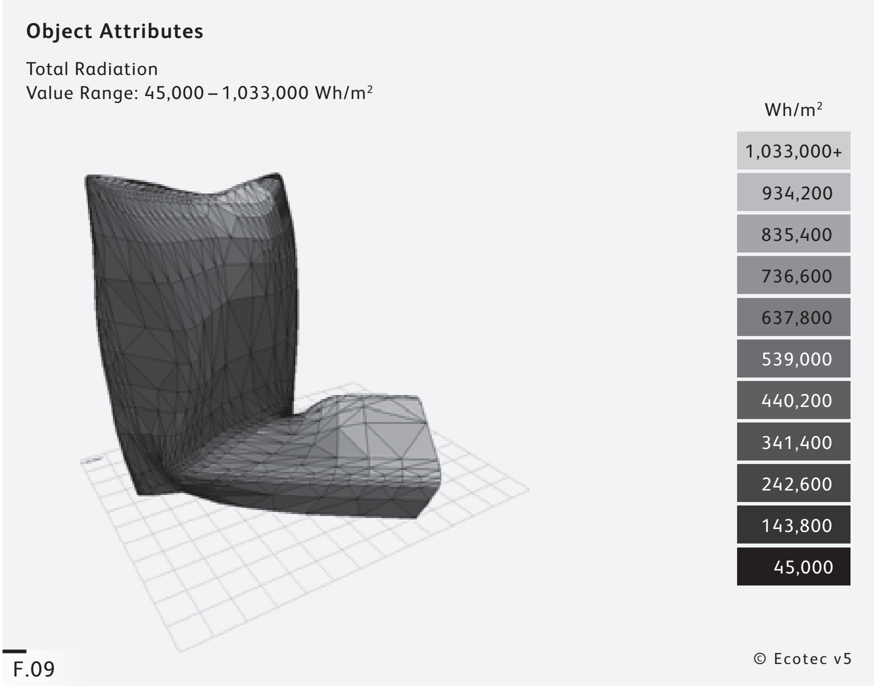
Although the project was not the sole driver for the development of this glass coating, it was certainly of great interest to the glass company developing the coating.

F.09
NHHQ Solar Study

F.10
NHHQ Double façade

F.11
NHHQ Double façade cut away detail

F.12
NHHQ Atrium trusses



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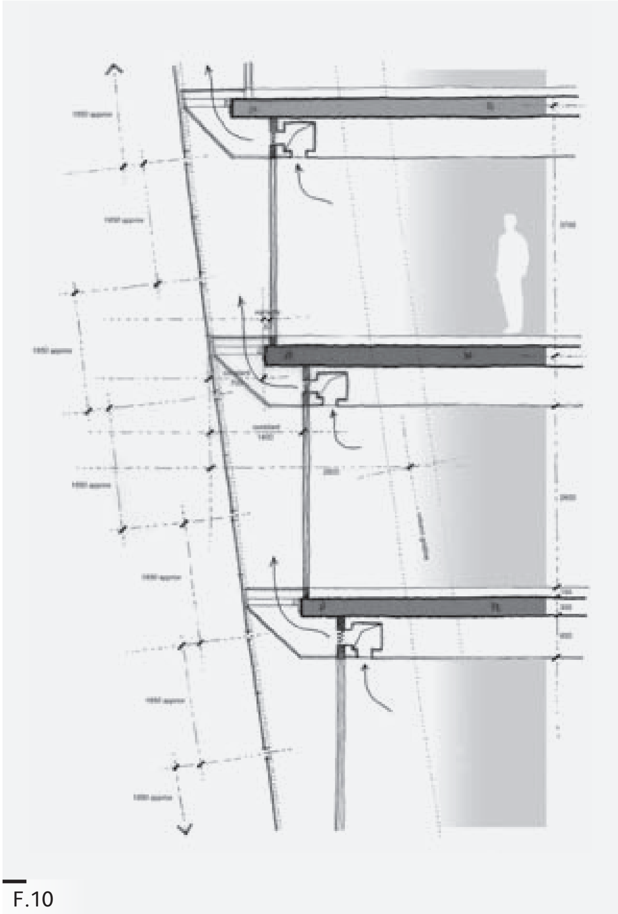

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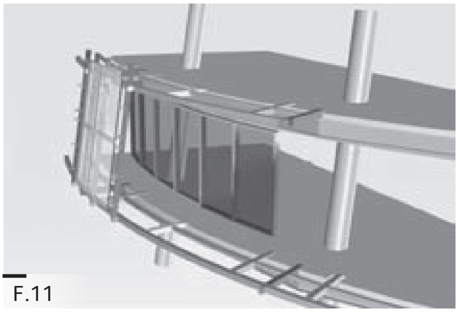

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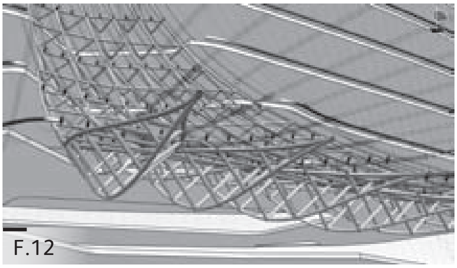


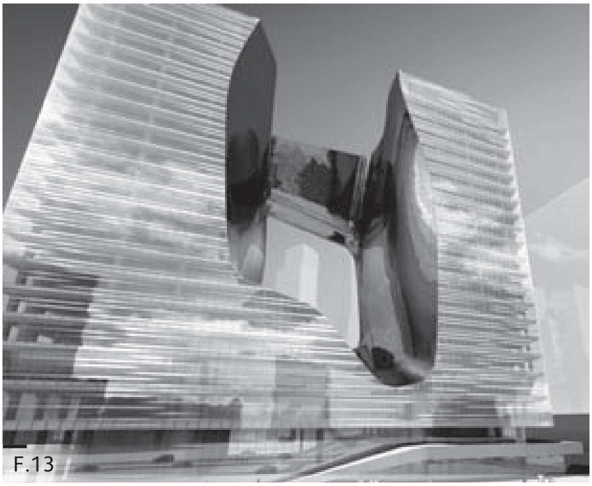
F.12

Conclusion

Complexity in the design and technology of building façades is not new. We will always have complexity in the design and manufacture of façades and this is only going to increase in the future as the pressure for greater performance increases.

The development of buildings with greater complexity pushes forward the development of design, manufacturing and materials, all of which can be used directly for the improvement of simpler buildings.

There always needs to be a desire for simplification during the design process. This delivers value in the making and the use of our buildings. This drive for simplification is one of the key areas where façade engineers can deliver value for our clients. The development of the design tools to enable us to deliver simplification – be it in material use, systems analysis or geometric analysis, in what is inevitably an ever increasingly complex design environment is critical to the development of the façades of tomorrow.



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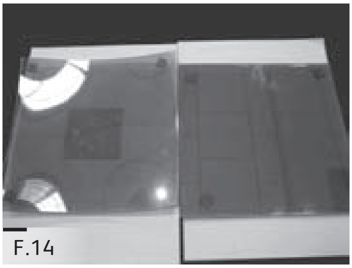


F.14

F.13
Opus

F.14
NHHQ hot bending trial

APPLE STORE, UPPER WEST SIDE, NEW YORK

Marcin Marchewka
MENG MRES, CENG MISTRUCTE,
ECKERSLEY O'CALLAGHAN,
LONDON (UK)

Introduction: This paper outlines the refurbishment of 1981 Broadway in New York to create the high-tech glass, steel and stone Apple Store, Upper West Side. The store is one of Apple's most recent «significant» stores situated a block away from Central Park on Broadway, New York. The structure creates a single uninterrupted 13 m high open space and 850 m^2 of sales area. 14 m high stone clad walls form a horseshoe on plan with a 20 x 20 m insulated glass roof supported by 5 No. tied arch trusses spanning between. The store is fronted by a wedge-shaped structural glass box where all visible structure is pared down to the bare minimum. A helical glass staircase leads into the basement where there is additional retail space.

The glass wedge is a wholly structural glass assembly which follows the 60° angle made between Broadway and 67th Street. Two glass façades, 30 m and 13 m wide respectively, rise to 13 m in height and follow the gentle radius of the barrel vault roof behind. The wedge is topped with a similarly curving roof which, supported vertically by the façade on two edges and steel trusses on the third, forms the only connection points between the all-glass wedge and the steel structure behind.

In an effort to increase the transparency of the glass roof the use of steel was limited to the 5 No. steel trusses, each 20 m long and spaced at 4.6 m and the purlins running from the rear to the front of the store.

The paper begins with the work carried out to re-use the existing building envelope to create the solid walls of the structure before describing the use of high-tech structural glass design and fabrication to create an envelope which maximises transparency and space while meeting energy requirements. The paper touches on temporary works and scheduling associated with refurbishment before looking at large uninterrupted spans, jumbo glass panels, and thermal requirements associated with large glass buildings. In short, this paper describes the approach taken to create a building with maximum transparency: The removal of as much opaque structure as possible and using in its place,

where possible, structural glass which would act as both the method of load transfer and envelope.

Temporary works and excavation: The original structure on the site was a braced steel frame with a concrete masonry unit (CMU) wall envelope running along the perimeter. To achieve city approval for a refurbishment project, 50% of the existing envelope was to be retained and re-used in the updated structure.

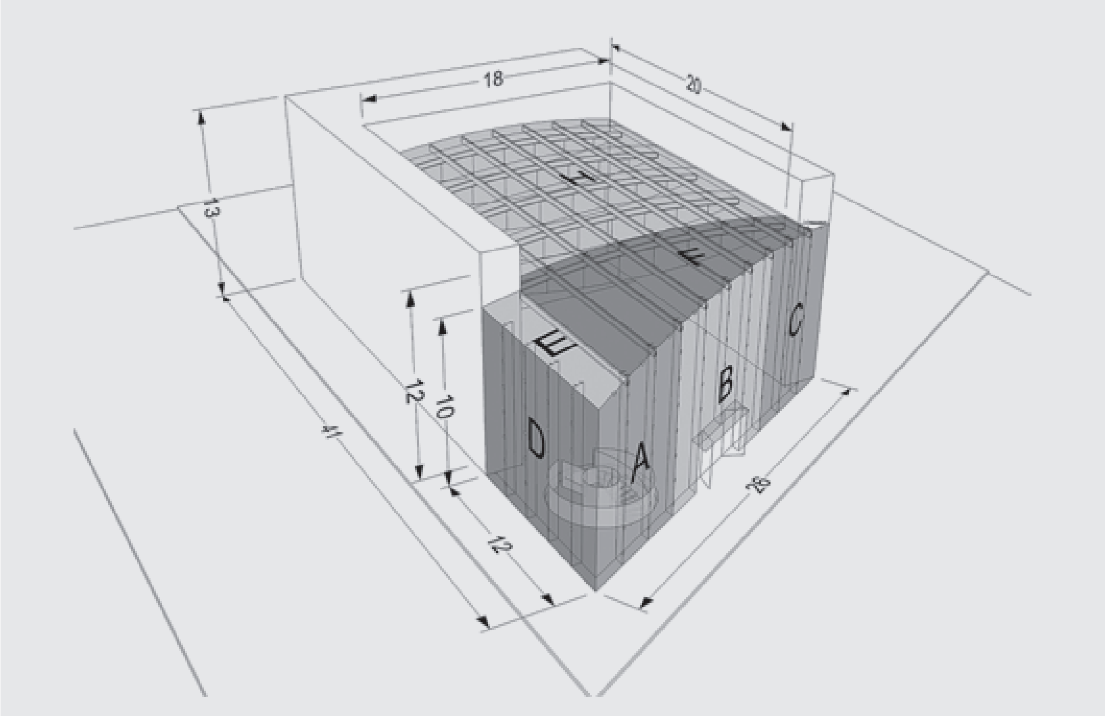
The additional requirement was to develop the basement further into the Manhattan granite to create a sub-basement. To achieve this, while maintaining the integrity of the re-used envelope, it was necessary to build an internal steel frame to form a series of storey-high trusses spanning the full 20 m width of the building. Once the trussing members were installed, the internal columns were cut from below to allow the excavation to begin.

Stone walls: With the excavation complete the support steelwork for the stone walls could go in. The stone walls are supported by a series of vertical steel cantilevers which sit on a similar series of portal frames spanning the whole ground floor. The result is sheer vertical stone walls and a completely uninterrupted retail area on two levels.

A key part of the energy rating of the building relied on these 1 m thick stone walls, which house the services and building insulation, the effectiveness of which offset the high percentage of glazed envelope.

High-tech façade: The use of glass in buildings is primarily to maximise the transparency of the structure which is a key part in the language of the Apple Stores. A corollary of this drive for transparency is the removal of the transparent opaque structure, which has the effect of turning the envelope into a key load-transferring part of the building. Further to this, the number and size of connections between glass elements is reduced to create what is as close to a pure glass envelope as possible.

The façade panels are full height and lamination-spliced from three layers of shorter panels, overlapped in a similar way to glulam or plywood. The use of SentryGlas interlayer allows the overlap in the splice to transfer all the loads applied to the glass as if it were a monolithic member. In this way, the need for additional visible joints running horizontally across the face of the building, as was necessary in the construction of the Cube on 5th Avenue, was mitigated.



Using the vertical continuity of these jumbo glass panels, the façade design led to the creation of 6 No. structural areas within the wedge and the lateral separation of the wedge from the rest of the structure. The motivation for this is the need to generate clear load paths through which external and internal forces are transferred: by selectively stiffening or loosening a single connection or series of connections, structural Zones A, B, C and D take lateral loads and transfer them to the roof and ground, as well as bracing the structure in lateral directions. The zones in the façade are summarised below:

Zone A: 3 No. adjacent full height splice-laminated glass panels mechanically stitched together form a vertical cantilever in the façade plane; full height fins span from ground to purlins in zone F; bolted to ground slab.

Zone B: 4 No. adjacent full height splice-laminated panels mechanically stitched together form a portal frame over the doorway; full height fins span from ground to roof; bolted to ground slab.

Zone C: 3 No. adjacent full height splice-laminated panels mechanically stitched together form a vertical cantilever in the façade plane; full height fins span from ground to purlins in zone F; bolted to ground slab.

Zone D: 5 No. adjacent full height splice-laminated panels mechanically stitched together form a vertical cantilever in the façade plane; full height fins span from ground to zone E.

As well as being tricky to deal with architecturally, a key structural issue is the angle between the two main façade areas. A typical perpendicular façade transfers forces as glazing panels simply span horizontally between fins which in turn span vertically between the restraining structure. Broadway runs at 60° to 67th Street which results in load paths more commonly associated with pinned truss systems where forces are resolved at connection nodes. This non-perpendicular arrangement results in interactions between in- and out-of-plane forces: the consequence is that perpendicular wind loads on Broadway generate in-plane forces within the façade panels themselves generating an additional racking load where one typically does not exist.

This geometry effect works in both directions: initial design ideas were to brace the wedge against the back of the horseshoe through the full-length purlins running from back to front of the building. However the thermal operation range and the length of the purlins meant a material thermal expansion of almost ±20 mm. In the case of a perpendicular fin/façade arrangement, this would be acceptable as the façade would push out with no ill effects except for a slightly eccentric dead load. However combined with the geometry effects of the 60° angle, expansion of the purlins would generate in-plane forces in the façade working the shear walls and their push/pull supports even harder.

The theoretical solution to fix this push-back from the main structure was easy – to break the continuity between the main roof and the wedge. The detailed design proved less straightforward: the wedge would have to be laterally free-standing and, with the ever present need for maximum transparency, with no visible bracing structure over the 18 m span between flanking walls.

Hi-tech roof: Wedge: However, before maximum transparency can be achieved, a viable structural solution is needed. Original concepts considered the roof glass working as simple infill glazing panels, with loads within

the roof and from the façades restrained by a grillage of steel and glass beams, similar to the roof in the Cube on 5th Avenue. This approach came from the need to insulate the entire roof with IGUs, however calculations showed the energy requirements would still be met by using a non-IGU roof over the wedge. This development was fortunate as it allowed the design of a structural glass roof which would span 18 m as a single horizontal beam or «diaphragm» between stone flanking walls.

The solution to the structural continuity of the roof is similar to that employed for the façade: by using jumbo panels half the mechanical connections, vertical support requirements and weather joints were immediately removed, leaving behind only a single direction of spanning structure in the form of the purlins. The design requirement was therefore simplified into splicing glass panels in one plane along the face of the building. Taking the analogy of a simply supported beam, shear and tension/compression connections were developed to create a continuous bending member from 8 separate sections.

The roof panels are vertically supported slender steel purlins made up of two parallel plates, each a flat plate section 15” x ¾” (380 mm x 20 mm) spaced 4” (100 mm) apart, the longest spanning 12 m. Again, in an effort to remove as much material as possible, these purlins are laterally braced by the wedge roof. Combined with this lateral bracing and with the dead load of the roof sufficient to resist wind uplift, buckling of the support structure is mitigated by the envelope. The zones in the wedge roof are summarised below:

Zone E: 1 No. splice-laminated cold-bent panel spans as a beam between stone parapet and zone A, resist wind load applied to zone D.

Zone F: 8 No. splice-laminated cold-bent panels mechanically stitched together form a horizontal beam spanning 60’ (18 m) between parapets, resist wind load applied to zones A, B, C.

Jumbo benefits: The use of jumbo-sized glass in façade and roof construction is a key factor in the creation of maximum transparency. Where smaller panels are used, more support structure is needed, creating the common grillage effect seen on most façades. The result is a steel structure which supports glass, much like the transom/mullion systems traditionally used. Even replacing these metal members with glass does not achieve the expected transparency as glass when viewed on edge is not as invisible as when viewed head-on. One can remove local support structure entirely, such as in cable-net façades, but this cannot work when free-standing transparent structures are needed. Jumbo panels, when used structurally, create something in advance of the two examples – there is no longer any distinction between infill and structure with the envelope supporting itself and resisting external forces while at the same time allowing maximum light to enter the building.

The use of jumbo panels, as well as the full width roof trusses which came to site as single partially pre-stressed pieces, helped deal with the tight site conditions and crane restrictions. On-site assembly was reduced while off-site fabrication helped carefully controlling quality and finishes.

Hi-tech roof: barrel vault: While the ideal for maximum transparency is to remove as much structure as possible, and where absolutely required to use glass as a load transfer material, such as in a clear 18 m span, sometimes steel is necessary. The roof behind the wedge is made up of 32 No.

7’ x 15’ (2.3 m x 4.6 m) curved glass units fully insulated with high-spec low E-coating, sitting on steel purlins which in turn span 15’ (4.6 m) between the 5 No. trusses. The detailing of these ostensibly simple arrangements was key to getting the clean lines and junctions – sprinkler pipes and head, electrical cabling and speaker systems are integrated into the steel purlins with all services hidden within the 100 mm gap between.

Final thoughts: While the use of glass in building envelopes allows for a large amount of transparency, there is always a balance between the opaque support structure and transparent glass infill. Even when used structurally, glass can require a large amount of connections, particularly when considering tall façades and large roof structures. The use of jumbo glass, as seen at the Apple Store, Upper West Side, allows the complete replacement of a structure and infill way of thinking on transparent envelopes with a building shell that is both an envelope and a load transferring structure, all the while pushing closer to 100 % transparency.

BUILDING SKINS

VISIONS FOR THE FUTURE

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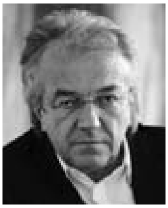


Innovations of building skins in recent decades have been dominated by the material glass. Double and triple glazing insulating units allow great portions of the façade to be clad with glass without dramatically impacting the overall energy performance of the building. Different coatings and prints on the glass can be used to further reduce heat loss or gain. At the same time, due to the transparency of the glass, daylight is provided for interior spaces – reducing the amount of artificial lighting required. While research advancements predominantly took place in the building science sector addressing climatic aspects, a student workshop at the ILEK (Institute for Lightweight Structures and Conceptual Design, University of Stuttgart) focused on the development of new glass design ideas.[1]

After introducing the students to the fundamental characteristics of glass, they were confronted with questions such as: Can glass elements be woven? Can a façade light up? Can glass be three-dimensionally deformed and can it be joined without visible connection material? Eager to come up with a solution, each student chose a topic and tried different techniques to achieve new design aspects.

In one study the effects of letting a plane glass pane rest on a supportive grid and subjecting it to a thermal treatment were investigated. Since the stiffness of glass is greatly reduced around a temperature range of 650°C to 750°C, the glass pane deforms between the fixed points. The deformed shape is retained after cooling, generating three-dimensionally deformed glass panes. Altering the temperature magnitude, the thermal exposure duration, the geometry of the supports (sharp, round, pointwise, linearly) and the grid spacing, a variety of objects were obtained. Each of them generates a unique aesthetic and recalls the design vocabulary of lightweight textile structures.

The creation of continuous glass elements from broken glass shards by thermally fusing them was studied in another project. A sequence of experiments was carried out using everything from regular float glass to thermally prestressed glass, from randomly arranged glass shards to intentionally laid configurations, from short to long thermal

F.01
Pointwise supported thermally deformed glass pane.

F.02
Linearly supported thermally deformed glass pane.


F.01


F.02

exposure durations, and from clear to colourful glass. A manifold of shapes with diverse haptic qualities was created, ranging from sharp-edged and fragile to smooth-edged and sturdy glass agglomerates. Compared to regular plane glass panes a controlled diffusion of light is achieved, while the appearance of colourless glass is maintained.

Another project sought to determine whether glass – commonly known as a brittle material – can be transformed to become flexible. One approach was to embed flexible yarns in between glass platelets which were then fused together. One difficulty was the temperature stability of the yarns. While most yarns became very brittle due to the high temperature exposure a thin multifilament steel yarn remained flexible. It eventually allowed the creation of a flexible glass-hybrid which can be deformed into a wide spectrum of shapes. Instead of exposing the glass to high temperatures another option was to use a laminate interlayer to create a flexible glass element. Glass elements of regular shapes were placed on the two sides of an interlayer foil and were laminated together. Since the interlayer of the laminate remained continuous, it formed a connected glass structure.

While flexibility of glass can be created by additional means, such behaviour is inherent to textiles which only obtain a certain out-of-plane stiffness by introducing curvature and prestressing. While still offering a certain degree of translucency, textiles are much lighter than glass elements and – if used as a façade element – allow thinner and lighter substructures. In the past the physical properties of textile building envelopes were almost always unsatisfactory. With the advancements in the field of technical textiles and smart materials (including new materials and coating developments) multi-layered arrangements can be designed providing good physical properties and these are a promising alternative for future building envelopes. An in-depth study of the physical properties of multi-layered façade systems was carried out during a research project at the ILEK.[2,3]

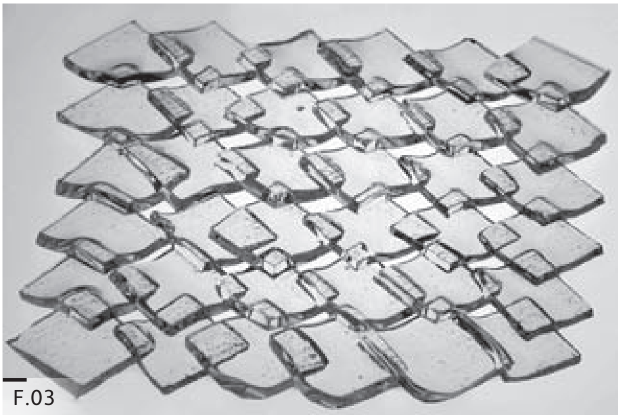
In the multi-layered arrangements the outer layer typically provides the structural stability and acts as a shield against outside loads and environmental conditions such as wind and rain. The layer facing the inside of the building provides structural stability against inside loads and has excellent haptic qualities. In between outer protective layers additional functional layers are integrated. By including high-performance ceramic insulators, aerogel-filled cushions or phase-change materials (PCM), these middle layers ensure the good physical properties of the overall system.

F.03
Fused glass shards – regular arrangement, short heat exposure.

F.04
Fused glass shards – irregular arrangement, long heat exposure.

F.05
Flexible glass hybrid with a flexible multifilament steel yarn.

F.06
Flexible glass hybrid using deformability of the laminate interlayer.



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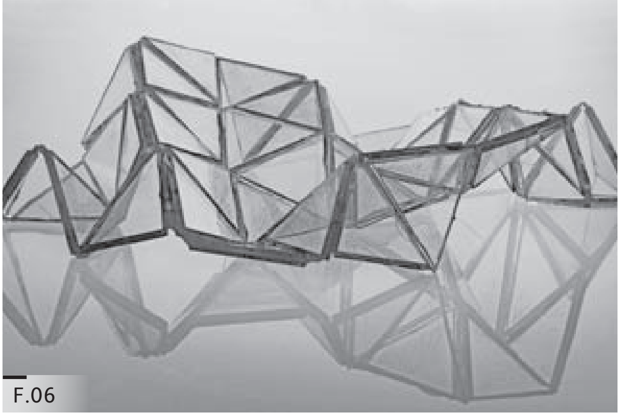


F.06

If the multi-layered compound is designed with a certain degree of adaptivity (for example changing thickness of the insulating layer or integrated openings), the physical properties of the whole system can be adjusted according to the prevailing outside conditions. This allows a direct interaction between the outside conditions, the building envelope and the users' comfort level.

In contrast to regular PV-modules, CIGS (Copper-Indium-Gallium-Selenium) cells can be applied onto flexible membranes. If these membranes are used as the outer layer of the multi-layered compound, electric energy can be generated. Then the building envelope not only acts as space enclosing element but also as an energy generator.

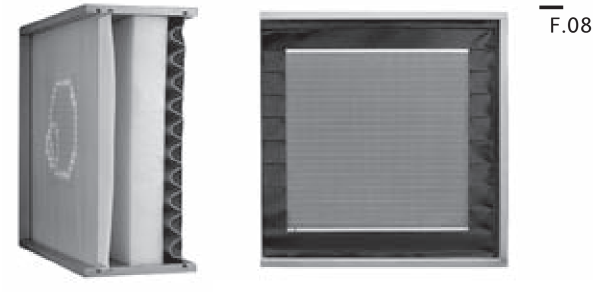
Figures F.07 to F.09 show small-scale functional prototypes of multi-layered building envelopes which were developed at the ILEK.[2, 3]

Another very promising approach for future building envelopes is offered by so-called vacuumatics systems.[4] The idea behind these systems is that the pretension – which is needed to obtain a certain degree of structural stability of a textile – is provided through the creation of a negative pressure difference between the exterior and the enclosed air volume. A textile fabric or a film encloses a supporting grid or a filling material and is then deflated until a high bond is achieved. At the ILEK the structural stability and the optical properties were examined for various filling materials.

One of the first structures for which this technology was applied was the exhibition stand for the Mero company at the Euroshop 2002 by Werner Sobek Stuttgart. A multicurved lattice grid composed of numerous Mero elements was encompassed by a sandblasted PE foil. The airtight PE-foil formed a cushion which was then deflated. This caused the PE-foil to contract and envelope the lattice structure. Subsequently the PE-foil was manually arranged on the grid to form a harmonic pattern of folds – haptically and optically resembling a draped silk cloth.

This technique was applied on a large scale for the first time world-wide to form a cover for one of the saddest places in German history. The memorial space of the Gedenkstätte Sachsenhausen (a former concentration camp) had to be covered to prevent further decay caused by environmental exposure. The architect HG Merz together with Werner Sobek Stuttgart proposed a very quiet and calm structure consisting of a steel frame with a smooth cover. After winning the competition it was decided to clad the steel frame with a PTFE-coated glass fibre fabric. Instead of glueing or clamping the membrane onto the grid, vacuum pressure was used. The technique of vacuumatics not only minimizes the amount of vis-

F.07



F.08

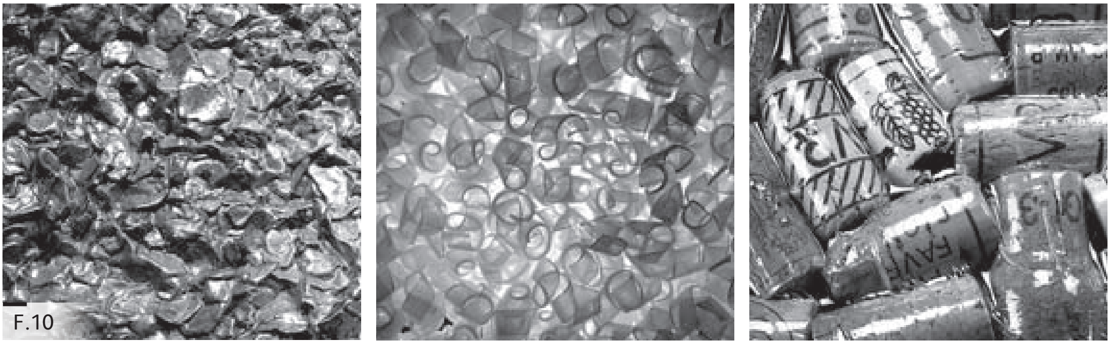
F.09

F.07
Multilayer prototype with variable-thickness insulation

F.08
Multilayer prototype with dual solar collector – thin-film PV on outer surface backed by air channels

F.09
Multilayer prototype with adaptive opening, PCM-layer and insulating layer.

F.10
Vacuumatics with various filling materials (from left to right: Vermiculit, spiral tubes, cork)



F.10

ible details but also ensures a complete recyclability of the structural materials, which is of extreme importance in a world with limited resources.

In summary, the appearance of a building skin is of indisputable importance – not only with respect to the building performance criteria but also to express the character of a building. While flat glass façades are dominating the current projects, new glass approaches offer tremendous design possibilities. Even though the objects created in experimental student workshops are not intended for direct architectural implementation, they give a glimpse on what might one day be possible. The applications of textiles in architecture have not been fully exhausted – new materials and coating techniques will give rise to previously unknown designs. The construction method of vacuumatics is one of the few methods which ensures complete recyclability – a design principle of undeniable significance. With all these developments, many promising building envelope designs are still to come.

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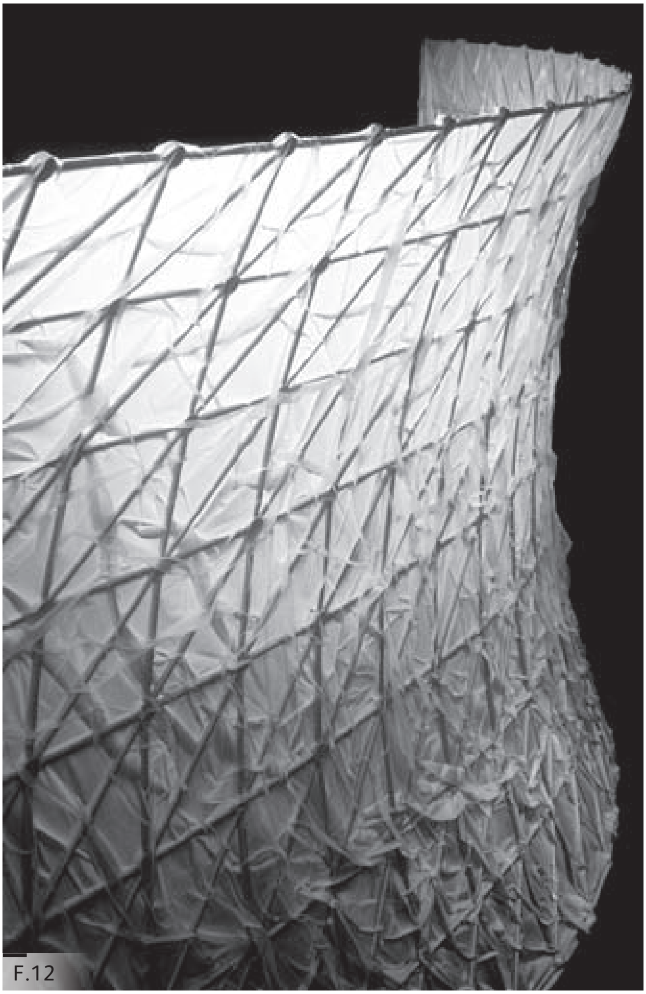
F.11
Gedenkstätte Sachsenhausen

F.12
Mero exhibition stand


F.11


F.12

THE WAY TO ZERO ENERGY BUILDINGS

ENERGY EFFICIENCY AND ALUMINIUM GLASS FAÇADES

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WICONA HYDRO BUILDING SYSTEMS AG,
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Zero energy buildings (ZEB) are the future of the building construction market. Many countries in Europe have adopted the Energy Performance of Buildings Directive and plan to make zero energy buildings mandatory from 2018 onwards for public buildings and from 2020 onwards for all new buildings. There are more than 20 definitions as to how a ZEB should be designed and laid out. The most appropriate way of significantly reducing the energy demand of buildings during the use phase is to design buildings with a zero net energy consumption AND zero carbon emissions. The design principle is to become autonomous from the energy grid supply – energy is produced on site.

Multi-functional buildings of tomorrow

The main focus today and in the future is to save energy by keeping materials to the minimum and by reducing the energy demand for use in buildings (heating, cooling, ventilating and lighting). When that is achieved and the annual net energy demand is in the range of 50 kWh/m²a, then additional measures to integrate energy gain into the building concept are possible (assumption is European climate). These solar gaining measures can be passive (e.g. double skin façades, coupled windows) or active (e.g. PV modules, solar thermal collectors).

Future materials must also focus on 100 % recyclability and be designed for recycling. This means a minimum amount of compound materials, which must be non-harming to the environment and the users.

The most important parameter for zero energy buildings is the user. The level of comfort of the user will determine the level of energy reduction in buildings. Comfort is composed of thermal, acoustic, visual and air quality parameters and must be integrated into the building automation of a zero energy building. This implies an increased demand for mechatronics and sensors within the building envelope.

Impact of the building envelope

Recent research has shown that with a holistic layout and design of the building, the optimized envelope can reduce energy demand by 50% or more compared to today's building standards.

In the future, the focus will be increasingly placed on the building envelope. Here, ongoing improvement of the thermal insulation is only one aspect to be considered. Other factors that should be considered are:

Ability to ventilate the building naturally: Here, the choice of envelope opening is a determining factor. When raising the ventilation efficiency of a tilt window to 100%, other window openings such as parallel outward openings will have 10% more air exchange. Horizontal pivot windows allow up to 28% more air exchange and vertical sliders with openings up to 82% more. On the other hand, the air exchange in window designs such as horizontal sliders is reduced by 6%, and top hung, outward-opening windows have 26% less air exchange in rooms. In addition, with a double skin construction the overall air exchange rate may be reduced by more than 50%.

Shading device position and absorption: A comparative measurement was conducted, measuring the inner surface temperature of the insulation glass unit and comparing several curtain wall designs. At outside temperatures of 20°C and inside temperatures of 20°C, the results varied from 31°C for an interior shading device to 23°C for a curtain wall with exterior shading device. Double skin solutions reached temperatures of 24°C, whereas double insulation glass units with integrated shading devices reached up to 29°C. Further measurements on the HBS test containers tested the impact of the shutter coatings on surface and room temperatures. Here, HBS tested two exterior shutter systems with identical design and RAL colour. The difference on one shutter was that the coating had a material formulation which did not visibly change the colour aspect, but in the near infrared (NIR) spectrum of the sunlight. This low absorption coating results in up to 10 K reduced surface temperatures of the shutter systems.

Breathing façade system WICLINE 215 and passive solar gains: The research and projects conducted over the past few years gave rise to window development that resulted in a product called Wicline 215. This window is designed as a double skin window with the ability to open the exterior glazing unit via a parallel opening mechanism and to use inside a turn and tilt window. All in all, such a double skin window has a construction depth of 215 mm.

Overheating in double skin façades occurs mostly because either the shading device system is positioned too close to the inner window and/or the openings of the outer skin are not big enough to guarantee a sufficient ventilation of the window cavity. Both risks are minimized by the new design, as the shading device can be moved away from the inner window, since it is mounted at the outer, parallel opening sash. By opening the outer sash, the ventilation rate of the cavity is increased, so that hot air or condensation can be extracted fast.

A joint project between the European Aluminium Association and the German Fraunhofer Society has investigated the impact of glazed building envelopes on the energy demand in buildings and has defined a calculation model as to how this can be linked to the glazed area. This new model is called equivalent U-value and includes passive solar gains via the glazed units. With this model the Wicline 215 including the glazing unit shows a decrease from 1.0 W/m²K (acc. To EN 10077) to 0.1 W/m²K for north-orientated windows or even –0.3 W/m²K for south-orientated windows. So here, windows become passive solar collectors.

This effect can also be measured during the year, as shown by the R & D results from HBS. Installed at the HBS test containers, the temperatures within the entire window construction and inside a room were measured under real climate conditions for more than one year.

On a selected reference day (a September day with max. exterior temperatures of 24°C and up to 800 W/m² solar radiation), the Wicline 215 window had a closed exterior and interior window. The temperatures measured on the surface of the integrated shading device went up to +90°C and the room temperature reached +32°C. By opening the exterior skin and thus increasing the cavity ventilation AND moving away the shading device from the inner skin, the temperature on the surface went down to +42°C (from +90°C) and the inner room temperature reached +24°C (down from +32°C).

Energy Storage in Buildings: Present and future trends to achieve flexible room layouts reduce the probability of heavy wall constructions inside buildings. Thus the heat storage capacity of the building is reduced, which leads to a faster conditioning of rooms, but also to higher cooling loads, as these loads must be removed from the building, when they occur. With increased heat storage capacity, cooling load peaks can be minimized and removed from the building via night ventilation, thus reducing cooling energy consumption.

To compensate this, HBS has investigated the possibility of using the aluminium profiles of the envelope and inserting into these Phase Change Material (PCM). A 3 m high aluminium profile can contain 30 kg or more of PCM and can thus store 100 W or 1,000 Wh of heat. Moreover, measurements under real climate conditions have shown that this effect works. During the daytime, the room temperatures (see boundary conditions of the room tested) were 2°C less inside the room with PCM filled aluminium profiles. Night ventilation was used to get rid of the heat stored during the daytime.

Building information modelling and numerical simulations

All aspects of zero energy buildings require an early and intense interaction between the stakeholders: investors, architects, engineering experts, metal builders and system suppliers.

With the collaboration models used today – mainly based on 2D paper printouts – these complexities cannot be managed rapidly and cost efficiently. Thus, the data models of the stakeholders must become the same, so that all experts can work with the same data set to optimize costs, performance and delivery time. The backbone of this data set will be an IT/IS system able to link 2D and 3D data, as well as information on performance (e.g. U-value, environmental impact, static values) of the building components to enable a holistic optimization from the very beginning. During this project phase potential changes have no critical impact on the financial aspects or time scope.

When it comes to the curtain wall, HBS is linking 2D (AutoCAD), 3D (Inventor) and Architectural Software (REVIT) with the HBS software solutions-Wictop (window and curtain wall design and calculation solution), Wicplot (CAD add-on solution to make faster designs on junction-to-structure), Wictip (online based catalogue with the latest update on system solutions) and Wictop 3D Master.

Wictop 3D Master is a numerical simulation software of the latest generation in industry. It enables the rapid energy performance calculation of a whole building with a user interface allowing all stakeholders to optimize the design of the building: U-values of components, glass performance, insulation layers, HVAC systems, lighting systems and parameters, shading devices etc.

This software solution enables energy simulations at an early stage of the building process, optimizing all the building components simultaneously. It avoids sub-optimization of single performances but can optimize the overall building performance.

Wictop 3D Master integrates active solar gaining systems (e.g. PV or solar collectors) into the early design process, getting immediate feedback on efficiency, energy gains and payback time.

The latest example – an office building located in Doha (Qatar) – shows that a building which demands ~640 kWh/m² today can become «0» thanks to lower glass g-value, higher thermally performing curtain wall, increased air tightness of the curtain wall, shading devices with low solar absorption, optimized heat pumps, artificial lighting strategy and the use of efficient heat exchangers in the ventilation system. These measures reduced the energy demand to 107 kWh/m²a. The additionally planned PV generator, composed of monocristalline modules, can offset this energy demand and the result is 0 kWh/m²a. The surplus energy cannot be used directly as it is produced, but it is possible to adopt the European approach and feed in the PV generated electricity and take back electricity from the public energy grid when needed.

A NEW FOLDING GLASS ROOF FOR THE HISTORIC CITY SWIMMING HALL, ZURICH

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DR. LÜCHINGER & MEYER
BAUINGENIEURE AG, ZURICH (CH)

In 1941, the City of Zurich swimming hall was the largest architecturally designed space in Switzerland, hosting the first 50 metre swimming pool. Today, these records have been broken many times. However, the exceptional architectural quality of the city swimming hall still stands.

The architect Hermann Herter and the engineer Robert Maillart started developing the original project in 1934. The earlier built Stadtbad Gartenstrasse Berlin-Mitte was an important reference project for the architect and for the engineer. Hence, it has been noted with interest that on early drawings, the roof structure was thought to be in concrete, and the interior glass roof was flat like the glass roof in Berlin. During the project development, the interior glass roof was developed into an angled glass roof, and the roof structure changed from concrete to mild steel.

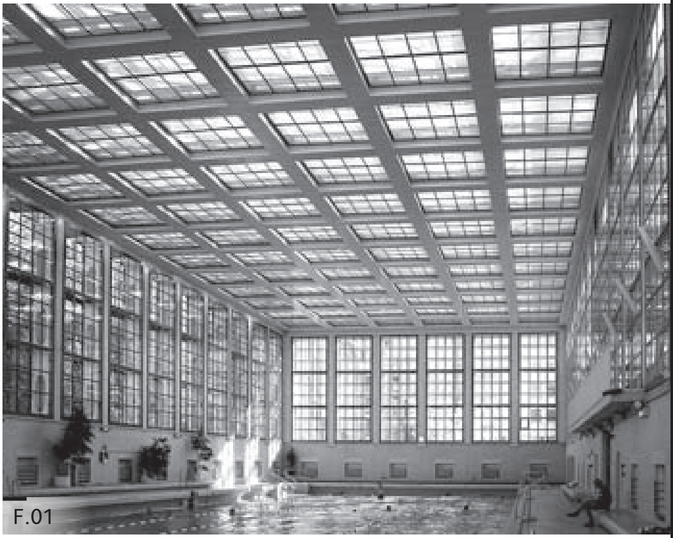
The finished project, with the swimming hall as the main space and the adjacent «service» units such as changing facilities, entrance or gymnastics hall, is a building moderately inspired by modernism. Symmetries were still clearly kept, the light and bright spaces as well as the exercise facilities satisfied the aspirations of health and strength of the period, the pure design was reflected down to the details and even the «backstage» technique was greatly celebrated much.

The city swimming hall completed in 1941 stayed unchanged and in service until the 1970s. With the refurbishment work taking place, new functions such as a children's pool were introduced. Due to the «overloading» of functions within the defined parameters of the thirties and forties, the clear architectural layout and design became partially lost. Most unfortunately, the glass roof was removed, the ceiling was boarded up and a part of the steel roof structure was removed.

Today, after more than sixty years of service, the city swimming hall is being completely renewed. In accordance with the main refurbishment work, the removed glass roof will be rebuilt as well. The Architects Ernst Niklaus Fausch are in charge of the project. They will focus on the original architecture while reinterpreting details, materials, functions, etc. and will sharpen the architectural expression again.

F.01
Stadtbad Gartenstrasse in
Berlin-Mitte 2008

F.02
City Swimming Hall Zurich



F.01

F.02

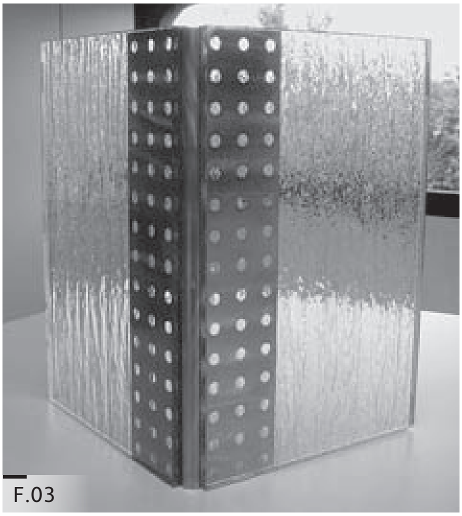
Pictures: Courtesy of Ernst Niklaus Fausch Architekten

The New Folding Glass Roof: The original angled glass roof consisted of a single spanning line supporting glass panes. In the seventies, the supporting profiles at the apex were removed, involving a change in the significant engineering boundary conditions for the new glass roof. Furthermore, the architects Ernst Niklaus Fausch were keen to take the design a step further. Instead of the ordinary equilateral angled glass corner of the old glass roof, the new «folding» glass roof transforms the shape dynamically along the lines of the Thales Circle. The 90° angles remain but the length of the glass panes has changed. At the centre of the swimming hall, the glass elements of the folding roof are symmetric. Towards each end of the swimming hall, the glass elements fold as described above to one side.

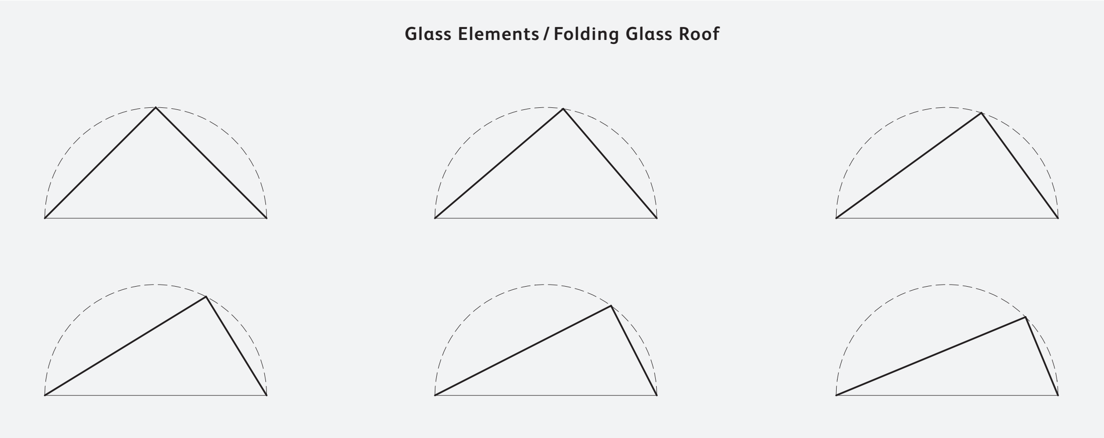
As the service zone between the interior folding glass roof and the outer insulated glass layer should not be fully visible, only a translucency is aspired. Shadows due to sunshine or artificial lighting in the service zone will be projected on the folding glass roof. To achieve the desired translucency, laminated cast glass was chosen.

Dr. Lüchinger & Meyer Bauingenieure AG have taken on the challenge of designing these glass elements. They soon realised that, even though the single glass elements and glass angles are tiny, and that the forces and stresses are small, nevertheless the remaining supporting profiles are able to take vertical loads only. Due to the fact that the new folding glass roof is not equilaterally angled, horizontal reaction forces occur, unless the glass-to-glass corners are fully connected. Ernst Niklaus Fausch architects and Dr. Lüchinger & Meyer Bauingenieure AG developed a broad range of corner connectors or alternative framing, in order to avoid the undesirable horizontal reaction forces.

The architectural criteria that the visible dominant lines occurring in or on the glass roof must run parallel to the swimming pool, eliminated most of the proposed mechanical corner connectors or additional new supporting profiles. Adhesively bonded corner details could not provide the required long-term bending resistance.


F.03


F.04



F.05

F.03
Prototype

F.04
Supporting condition

F.05
Schematically drawn
glass element rotation in
the Thales Circle

In order to get as close as possible to the original architectural design intention, laminated glass elements have been developed within the metal strips embedded in the interlayer. These metal strips couple two laminated glass units together. After the lamination process, the coupling metal strips are to be bent along a pre-perforated line. Thereafter, the glass elements are shaped and can be installed on site. The bending resistance of the coupling metal strips is calculated generously enough to provide the required resistance during service. This connection detail that was eventually chosen gives the opportunity to reduce the opaque line to a minimum. Therefore, the anchorage length of the metal strip is further reduced. Furthermore, the section which is laminated in the glass is densely perforated. Only the metal sections between the glass panels remain opaque as a thin line.

Prototypes are currently being produced. On the building site, a mock-up is due to be finished shortly. According to the preparation work, the visual optimisation is still on going and to be finalised. The folding glass roof is due to be installed during spring 2011. The city swimming hall reopens in 2012.

INVOLVED IN THE PROJECT:

Client:	Stadt Zürich, Immobilienbewirtschaftung
Client Representative:	Amt für Hochbauten
Architecture:	Ernst Niklaus Fausch Architekten, Zurich
Façade Engeneering/ Folding Glass Roof:	Dr. Lüchinger & Meyer Bauingenieure AG

SPORTS ARENA (THE KOI PROJECT)

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MARQUES AG, LUCERNE (CH)

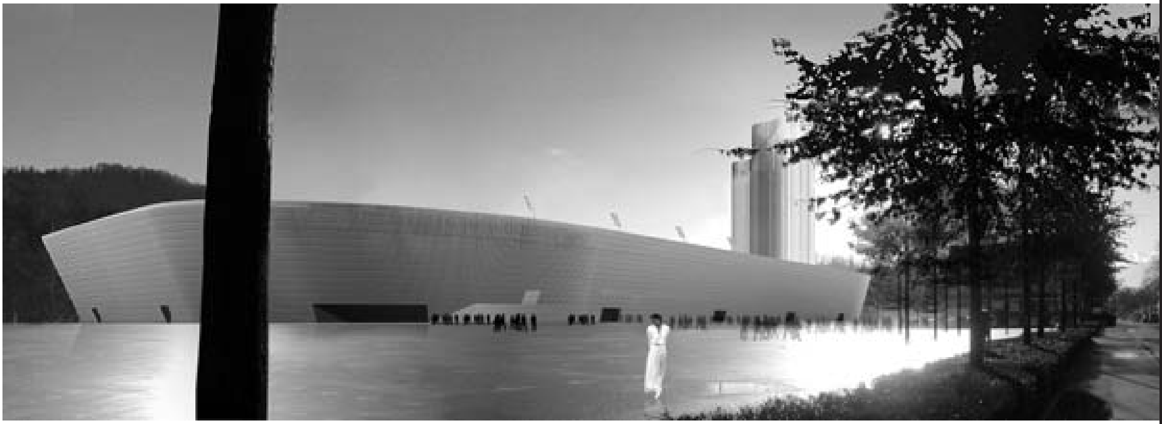
The situation: The project sees common land as a large open space which serves the public for a variety of different needs: recreation, sports activities and events.

In the residential area of Lucerne it provides an important and attractive green space. The KOI project proposes an open development whereby the various building complexes are placed on the common land in such a way that the open space can still be experienced as a single entity.

The complexes are grouped together by function and as ensembles, placed at various locations with their relevant infrastructures. The trade fair grounds and the stadium are situated on Horwerstrasse. The building complex with indoor swimming pool, fitness centre, sports hall and sales area is located at the corner of Horwerstrasse / Zihlmattweg, whereas the residential buildings are on Zihlmattweg. The generous dimensions of the outdoor spaces between the buildings ensure a smooth and independent use of the various components with their different functions.

Despite their different functions, the buildings are characterised by architecturally simple structures. As a solitary building with typological features, the stadium is emblematic in its effect. From a distance, the ensemble is first seen via the two high-rise buildings. Together with the sports arena and the building complex with indoor pool, fitness centre, sports hall and sales area they constitute a powerful redefinition of the common land as a venue.

Architecture: The shape of the buildings is dominated by soft forms without sharp corners. The external areas which are determined by these constructions flow into each other and outwards into the common land. Conversely, the open space of the common land is given a dense appearance in the vicinity of the buildings, before leading to the park-like areas near the entrance. The references for the suggested architectural language are to be found in classical elements of parks such as fences, iron gates and arches. The aim is for the filigree appearance of the architecture derived from these references to make a connection to the atmosphere of the park landscapes and outdoor sports



grounds. In this context, an important issue of public space, especially in connection with football, is the question of safety, both in terms of visitors and the facilities. The external public area is open to everybody and must at the same time be demarcated and made safe. The repetition of vertical lines at equal distances for the façades implemented by the use of vertical metal profiles on the façade emphasises the three-dimensional form of the proposed buildings. Despite their common initial position in the use of façade elements as well as differently defined façades developed in line with their function and the construction necessary for the various buildings, each building group is given its own identity.

The buildings: The football stadium is conceived as a concrete construction with steel beams for the roof. The exterior façade consists of golden anodised aluminium profiles of a strength of 8 times 15 cm and an axis distance of 22.5 cm. The actual arena is clad on the outside with blue aluminium sheets, the colours of the Football Club Lucerne (FCL). Within the gallery, a dialogue emerges between the air-permeable aluminium façade with a view of the surrounding landscape on the one hand and the closed blue cladding with isolated passageways to the arena on the other. At the same time, the gallery, on account of its overlapping oval forms, is a flowing and pulsating space with exciting dynamics. On the inside of the stadium, concrete steps are equipped with blue foldable seat shells. The eaves of the arena roof are clad with golden anodised aluminium profiles. The lawn of the playing field is visually elongated with artificial lawn up to the railing. At night, the stadium, i.e. its exterior shell and the aluminium profiles, is illuminated all around by a lighting strip mounted at ground level. During a football match, the FCL blue of the arena from the inside illuminates the common land area.

The sports centre with indoor swimming pool, fitness centre, sports halls, and sales area is a simple, rectangular building with a complex interior life. Differently designed rooms with differing special concepts are interleaved, thereby enabling synergies. The softness of the organic form in the interior gives rise to a special atmosphere for the baths areas of the fitness centre and the indoor pool. On the outside, this softness is manifested solely in the corners of the building and its entrances. The interplay of vertically arranged aluminium profiles with varying distances on the façades results in a rhythmised expression which refers to the movement and materiality of the interior. The dimensions of the aluminium profile are 8 x 15 cm and have an axis distance of 45, 90 and 180 cm.

The residence towers feature a rolling form which is developed out of the square. The grid of aluminium profiles with an axis distance of 90 cm offers wall connection possibilities for a flexible floor plan. The circular shape enables interior spaces with room segments opening towards the outside with minimum site development and an optimal aperture angle towards the light and the views, despite relatively small living areas. The golden colour of the metal construction of the façades enhances the currently very mundane impression of the common ground as a sports venue by creating a stylish and celebratory atmosphere that can be seen from afar and which is in keeping with the horse races, athletics events and football matches held there.

The new heights of the towers: The boldly designed, slender slender 134/107 metre high towers are replaced by strong, calmly proportioned towers with heights of 77 and 88 metres. The difference in height of only two storeys permits an exciting perception game. Depending on the viewpoint, the differences in height are, in terms of the perspective they offer, either significant or negligible and in some cases eliminated altogether. The overall effect of the two towers accommodates vastly differing impressions, from a curved entity formed by the two towers to two different-looking individual towers, underscored by the effects of light and shade.

Open space: The generous dimensions and vast openness of the common land provide the inspiration for the uniform design of the overall development area. As a given theme of the common land, existing rows of trees are continued and grouped together to form a park. This park unites the numerous individual buildings such as the clubhouse and bicycle shelters as well as the little bus and cashiers’ building and leads visitors across the forecourt to the football stadium. In the area of the residence towers, the regular tree structure is overlaid with a plant carpet. Near the access points to the stadium, the continuous asphalt areas constitute generously organised functional spaces, whereas in the residential section they form small paths which lead visitors through the park and to the entrances to the houses.

At night, numerous standing lights illuminate the paths and squares of the facility in an arrangement which forms a deliberate contrast to the tree structure. The large form of the arena in the background which either appears golden or is illuminated in blue completes the nocturnal atmosphere.

Functions: The development concept with individual buildings shows itself to be advantageous in terms of staged implementation, functional partition and emission levels. The proposed development concept involving individual buildings easily permits a staged implementation, should this be necessary. Due to an intelligent division by functional uses, the development of individual buildings is simple and problem-free. Mutual emissions are thereby reduced to an absolute minimum, and smooth operation of the various functional entities is guaranteed.

The sports arena is principally a football stadium with the additional possibility of organising concerts and events. In this arena, there are rooms for VIPs, visitors, athletes and organisers. On the east side, the complex features its own covered grandstand for the spectators of track-and-field events. Through this combination, the various functions and their mutual relations are grouped together in a straightforward manner and guarantee smooth operation to fulfil individual needs.

The indoor pool, the fitness centre, sports hall, and 2,600 m^2 sales area are all housed in the sports centre, thereby enabling synergies between these functional units. However, the functions are clearly separated to ensure that each division within this building complex can individually unfold and develop.

To make use of the shell area, living space is offered. Being a recreational area close to the city, the common land provides a unique opportunity to

create high-quality living space. As a result of the project concept of safeguarding the extent of the common ground, the dwelling units are located in two residence towers of different heights with 336 apartments.

Traffic model: As part of the traffic model, it is planned to control streams of visitors primarily via public transport. In this connection, the extension of the suburban railway station at the Moosmattstrasse / Horwerstrasse intersection will be of significance. The route of Bus No. 4 will be altered to include Zihlmattweg / Horwerstrasse, thereby making possible new bus stops at the stadium and clubhouse as well as at the indoor pool and the residence towers. The system of developing the entire site incorporates the idea of creating separate and independent entrances and exits for each functional area. Thus the area of the stadium faces Horwerstrasse, the indoor pool is located at the Horwerstrasse / Zihlmattweg intersection and the residence towers on Zihlmattweg. A car park for private transport is situated south of the restaurant serving the clubhouse, the indoor swimming pool, and the sports hall. A bicycle shelter is also provided there. For parking private cars in the stadium, in the sports centre and in the residential units, underground car parks with a ramp from Zihlmattweg are provided. The position of visitor entrance points to the stadium as well as the layout of the entrances and exits for cars and the parking facilities reduce any conflict potential for football fans to a minimum. Deliveries by lorry for trade fairs, the stadium, and the track-and-field complex can be made via the Moosmattstrasse / Horwerstrasse intersection as one-way traffic, with outgoing traffic using Horwerstrasse.

FAÇADE REFURBISHMENT

NEW STRATEGIES FOR OLD LIGHT FAÇADES

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Introduction: focusing on the problem

Building façades have developed – and still do – up to the point that the thin line that separates the inside from the outside is almost immaterial. The application of new technologies and construction materials has made the envelope lighter and lighter until it has become what we call today «light façades» and «curtain walls», which are considered to be the easiest way for a building’s inhabitant to directly participate in the exterior environment by permeating his home, workplace, or any other activity container’s physical limits with the purpose of improving quality of life.

Historically, through building, mankind has succeeded in controlling atmospheric agents and temperature, through regulating light and heat from the sun’s radiation, inside-outside views, the outer noise and the quality of the air as well as increasing our intimacy and security. Learning from this experience, knowing construction materials and their characteristics, the function of every component and the fabrication systems, we develop methods and evolve architectural concepts correctly to further satisfy our needs.

Knowing how to construct means knowing our market. In order not to limit our projecting capacity, the process has to follow its course. Innovation has to be directed to improve envelope features obtaining better value for money, always being at people’s service and attempting to make our environment age with dignity.

However, this is not a smooth process. Some materials and technologies used only a few decades ago are of inferior quality to the newest ones and become technically obsolete even if their appearance is still good and valid.

The most important energetic exchanges in a building take place through the façade. A façade is a complex combination of elements and materials whose performance, which deteriorates as the years pass by, is not always harmonious.

More than 30% of light-façade buildings are more than 30 years old, which is the average age at which most buildings have to be refurbished in one or another way. There-

F.01

F.02

F.01
Avinguda de Josep
Tarradellas 133 before
(Case Study #4)

F.02
Avinguda de Josep
Tarradellas 133 after
(Case Study #4)

fore we have to keep on considering the problem we talked about at the beginning in order to see the background, the present situation and the best future strategies.

Why refurbish?

We have to consider several different issues such as performance and comfort loss, improvement of the building appearance, regulations update, reducing energetic consumption, etc. Bearing in mind the nuances that geographical situations impose, in Spain just as in other southern countries in Europe, we consider six evaluation parameters for a building's energy use:

a) Energy production on façades and roof
b) Energetic consumption of the general services (security, elevators, toilets, maintenance, hall or façade lighting, etc.)
c) Workplace lighting
d) Air conditioning
e) Heating
f) Ventilation

As we can see, most of these parameters are related to the building envelopes' features. It is true that the aspects related to energy factors are determinant when taking decisions about the building's refurbishment strategy. However, these are not the only points to be considered. The renovation has to be focused as a global problem: if the façade image and comfort is not improved, market opportunities may be lost, rental income may fall and investment in maintenance and repair will be negatively affected.

Some of the refurbishment operations are exclusively evaluated in economical terms and are refused basically because of the construction cost. This decision is often taken without considering whether the investment is somehow retrievable: through the increase of the building's value when opening to market, the reduction of exploitation costs or the cost of the necessary energy to maintain the building in use.

The operation costs must be analyzed in detail after re-asking the question backwards: «What happens if the building is not refurbished?» or «What is the future of this edifice if it is not refurbished?»

The answer is obvious: We must update and upgrade the appearance of a building (or maintain the old one because of the cultural heritage) in

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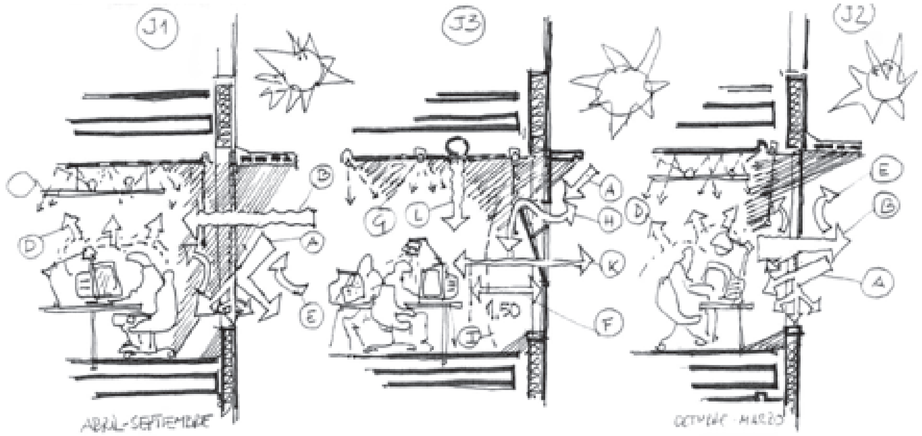


F.03
Principal Exchanges with the Outside through a Façade

order to improve the user's comfort, reduce energetic consumption and put the edifice in accordance with regulations.

Strategies

It is necessary to study the constructive solutions for the building by thoroughly analyzing the façade condition in order to define the possible pathologies affecting the façade and see the possible interventions that will improve the building's performance. Just to clarify our ideas, it is also important to study the future of the façades and the building itself if nothing is done to it, that is, think of what would occur to the edifice if it wasn't refurbished or its façade wasn't repaired or changed.

The decision must be taken at the right moment: if the building has habitability problems will it be out of market? Do consumption problems make the building non profitable? Will the improvements to the building compensate the distortions of the normal use of the building?

The next step is proposing alternative options or complements for the actual façade or the building. These changes will improve the building features at 4 different levels:

Level 1: Intervention on the minimum features: improvement of the water- and air-tightness and sound insulation of openings.

Level 2: Minor intervention: Adaptation of the profile system, improvement of the glazing and opaque insulation performance, plus improvement of the water- and air-tightness and sound insulation of openings.

Level 3: Medium intervention: besides the points treated previously, intervention on the fireproofing, fireman access, security of the ledges, improvement of the energetic performances, maintenance and cleaning systems. An integral treatment of the façade is developed, sometimes using as a base the present façade's configuration and, in other cases, using an over-cladding system.

Level 4: Major intervention: in this case the façade must be totally substituted. Apart from the improvements previously defined by re-cladding, this type of intervention will help to update and upgrade the whole building's appearance and architecture. This kind of intervention usually means an integral rehabilitation of the building, a refurbishment of all of its components, facilities, elevators and, in some cases, the building's structure or parts thereof.

Examples

Case Study #1, level 1. Reparation.

Office building at Barcelona's Rambla de Catalunya:
This project only required a change in the building's sealing gaskets (glass-aluminum profile on the vision and panel glazing, sealing gaskets between the frame and the operable window and the gasket between aluminum profiles) and the reparation of the window hardware. It was all about reducing the air and water filtration, increasing the acoustic insulation and restoring proper window functionality to make fresh air intake possible and enable ventilation at any time in the year or day, which meant an overall reduction in energy consumption. All this was achieved by making a minimal intervention on the building.

Case Study #2.
Features' improvement maintaining the façade's appearance.

Office building at Passeig de Gràcia, also in Barcelona:
Apart from the repositioning of the gaskets between the fiberglass panels it was necessary to replace the vision monolithic glazing with high performance double glazing without altering the appearance of the building, all

this improving the thermal and acoustic insulation, solar factor and security features.

The fixing system of the glazing initially consisted of an extruded EPDM gasket with water tightness problems. The proposal meant the complete change of the gasket to enable double glass units which have solar control and low emission coating, held by curtain wall profiles with thermal break. One of the most important improvements was the optimization of the office's inner space since it was possible to recover the area next to the façade and eliminate the non-comfort zones that are caused by direct solar radiation in summer or the cold-wall effect in winter.

Case Study #3. Over-cladding.

«Nutrexpa» office building, Lepanto street, Barcelona:

This case was developed in 1992. The modernization of the building meant the construction of a newer façade on the outer part of the existing one, that is, an over-cladding process. The over-cladding operation here involved putting a new insulation system on the outer face of the bearing wall. The air conditioning vertical conducts were put in the gap between both façades' skins so that they didn't take up space inside the building , thus optimizing the ventilated façade gap.

This radical change in the appearance of an industrial building of the 1950's was carried out while the building was being used by workers and the normal activity of the offices was only affected when the old windows had to be dismounted and the new ones were mounted by working on their pre-frames.

Case Study #4. Re-cladding.

In this case we re-clad a residential building at Barcelona's Avinguda de Josep Tarradellas, which is the most usual of the interventions made.

The intervention meant the complete change of a façade that was obsolete in all aspects: its profiles were inadequate and insufficient; the façade had no thermal break; there were difficulties with the operability of the windows; glasses were monolithic; all sorts of leakages, etc.

Apart from the renovation of the building appearance, this work by Wortmann-Bañares architects, has the particularity that all the works, even the structural reinforcement of the slab edges, were carried out while the building was in use. In order to do this a provisional cladding was mounted in every floor so that the normal activity of the residents wasn't disturbed.

Depending on the inner use of the building, the façades were treated with new aluminum profiles special for curtain walls, regular windows, with DGU with solar control and low-e coating and many opaque with ventilated façades were treated with a panel for new work and rehabilitation: Euronit® cement-fiber panels.

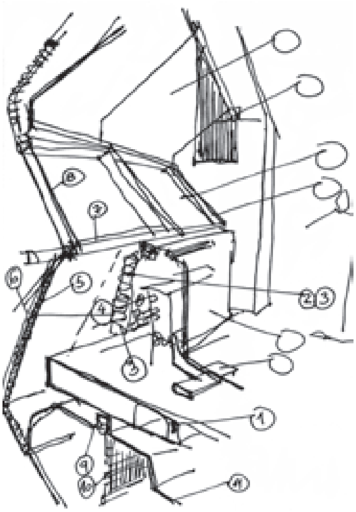
Case Study #5. Preserving the appearance.

There are very few rehabilitation processes in which preserving, as far as possible, the original appearance of the building has been tried. After years of degradation due to lack of maintenance, a work by Francisco Mitjans, an office building on Bacelona's avinguda Josep Tarradellas 123, was completely remodelled in 2007, keeping the original façade's configuration dating from the 1970s but using new materials.

This time, Fermín Vázquez and b720 architects proposed a renovation that meticulously recovered the original volumes and details, reinterpreting and updating the façade with modern technology and materials. For the process steel profiles with thermal break and minimal sections were used as well as DGUs with high light transmission selective layers and resin panels that concealed the supporting water- and air-tightness and isolation components. The final result is also an interesting model of process and management since the work was finished with most of the floors being used.

Case Study #6. Respect the shape and appearance.

The peculiarity of this case is that the creator of the original work and of the integral rehabilitation project is the same. The building in this case is located on Madrid's calle de Génova. Estudio Lamela carried out the new project 30 years later. This building was originally conceived as an answer to the petroleum crisis (early 1970s) with a light façade system. A re-styling of the section using the same materials, a radical change of proportions and opaque-glazed ratio resulted in a transparent building with lower consumption than the older one, due to the inclined angles of the façade and modern glazing. All this was made possible by using today's materials and technical solutions. Moreover, apart from the quality and comfort of the working spaces the architects incorporated firebreaks on every single floor of the building and got rid of the asbestos insulation systems and its hazards.



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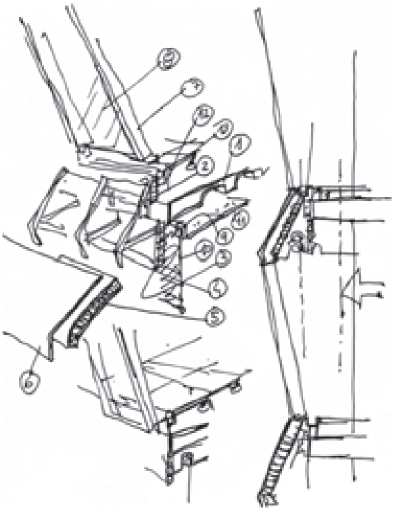

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F.04
Génova before
(Case Study #6)

F.05
Génova after
(Case Study #6)

Case Study #7. Changing the appearance.

This office building in Barcelona's avinguda de Diagonal is the rehabilitated 1998 version of a 1982 construction: 16 years is a poor survival record. The construction is part of a 3-building complex initially designed to be residences, of which only one is a residential building. The other two were turned into offices and only one conserves the original façade. That is, we have three different solutions: residential building with the original façade; office building with a façade made in the 1990s; and a building that was integrally rehabilitated by TAC-Eduard Gascón in 1998. On this last building, three façades were resolved with a conventional curtain wall. The main façade features a curtain wall system between slabs and an opaque cladding to conceal the building's installations, slab edge and firebreaks and to integrate the lighting system in the building's façade.

We must think about the durability of the model as well as the constructive solution. The fact that, out of two buildings that had initially been equally presented, one of them still has the original light façade 28 years later and the other updated its cladding leads us to think that the energetic efficiency, new materials, user comfort, life-cycle…, arguments aren't valid to overcome the difficulties in the management of an operation that has to be agreed between a community ownership as against a sole owner or 20 different tenants as against a sole occupier.

How to evaluate

Considering all of the above, the strategies for refurbishment can be grouped according to different criteria: constructive solution, type of improvement, over-cladding or re-cladding, new image or old image improved, level of change always considering the different variables exposed.

Using Thiemo Ebbert's graphs from his PhD thesis, recently published in a book, we can begin to evaluate different strategies according to four fundamental aspects: Economic, Architecture and Function, User Comfort and finally Material and Energy.

This evaluation can be adapted and expanded to specific cases adding variables such as profile systems, net energy savings, maintenance facilities, etc. In any case, the evaluation process must be made several times during the refurbishment project, to consider the building as it was originally constructed, in its present state, and different retrofit options which may be considered. In the end, we must obtain an overall vision of the objectives to be achieved, to be able to compare results and finally decide how to upgrade the building.


F.06


F.07

F.06
Diagonal 682 before
(Case Study #7)

F.07
Diagonal 682 after
(Case Study #7)

Economic aspects
- a) Construction cost
- b) Interference with use
- c) Operation cost
- d) Additionalbenefits

Architecture & Function
- a) Architectural design
- b) Functionality
- c) Design for future use
- d) Health & safety

Comfort
- a) Visual comfort
- b) Acoustic comfort
- c) Thermal comfort
- d) Individual influence

Material & energy
- a) Material of components
- b) Building process
- c) Period of use
- d) End of life

Think of the future, learn from the past

When we think of improving a façade, we must analyse how it has aged and how it has degraded with time, what has happened and if it is because of materials or because of the systems. In general, there are two different causes which sometimes combine: one is the lack of maintenance, cleaning and repair, which causes not only a visual degradation but also the loss of performance of components such as thermal insulation and (most commonly) the loss of water- and air-tightness. This turns in an immediate loss of value.Second is the loss of performance due to obsolescence, usually poor insulation and poor solar protection in relation to current standards. «Old» glazing has a high U-value, sometimes only single glazing was used, or solar control layers have a poor g-solar factor/ light-transmission ratio. This means changing the glass composition, increasing opaque insulation thickness and sometimes improving or changing the profile systems.

Thinking of the future, in new buildings and in retrofit work, systems should be made as flexible as possible to be able to easily add on new features such as solar shading and integrated windows or to make component changes in a cost-effective manner: for example new insulation, metallic or composite panelling, or even re-coating of profiles. Reflecting upon the use of double-skins, it may be useful to oversize anchors and profiles to be able to update the image of a façade without an expensive overhaul and from the outside of the building so as to not interfere with a building's normal use.

I think that light-façade technology does not evolve as fast as is desirable. For example, unitised curtain-walls were already successful about 50 years ago, thermal-break profiling was developed in the 1970s and double-skin façades started being built in the late 1920s and early 1930s. High selective glazing has been available now for almost 15 years. This means that from a performance point of view the application of new technologies in the façade industry is slow, and although the evolution from a materials point of view has indeed been fast, the same cannot be said of systems. We have to think of the possible evolution and adaptation capacity within the next 15 years to increase the flexibility of multiple combinations.

How to proceed

At this point, we must address the problem of refurbishment. For this, I propose the following step-by-step strategy:

1. Rigorously evaluate the current state of the building, comparing it with the benefits of several possible courses of action.
2. Establish the limitations of light façade systems and ensure the results and benefits of the intervention on the building when retrofitting its envelope.
3. Technically and economically evaluate different strategies from a basic minimal level to a complete re-cladding.
4. Think of the building as a whole: use, structure, HVAC, envelope, construction and materials.
5. Make sure performance improvement, as a fundamental design criterion, takes into account ecology, clean energy, energy savings, optimization of systems and resources (sustainable approach) without forgetting of user comfort.
6. Investigate systems, materials and products on the market or develop specific ones for each project to obtain the maximum possible quality during the design process and construction.

7. Make time and allocate resources during the design process and before construction for samples, prototypes, lab tests and simulations to reduce uncertainty.
8. Integrate clients and users in the process, especially during the planning of the construction work.
9. Ensure that, in future, correct use and maintenance are applied on the envelope and in the building, with adequate means to provide cleaning and repairs.

Conclusion

The examples shown here bring into focus the refurbishment of façades in Spain, which I think is not too different from Europe as a whole. It is always more sustainable to retrofit than to demolish and build again; even when considering a change of use, a façade adaptation or re-cladding may be an answer. This is so because architecture, engineering and technology are nowadays able to solve complex problems and develop specific products and systems for each case. Still, from a construction industry point of view, there is a long way to go when it comes to providing good answers in a market which has been growing for many years and will continue to do so at an increasing rate.

We have to work on reducing the difficulties of putting into practice refurbishment projects and the economic and planning effort involved. The most convincing arguments are: reducing operational costs, increasing user comfort and enhancing architectural quality of building's façades of our streets and cities.

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LIGHT-FLOODED LANDSCAPE OF HILLS

THE NEW ROLEX LEARNING CENTRE OF THE ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE (EPFL) IN LAUSANNE

Steffi Neubert
EMMER PFENNINGER PARTNER AG,
MÜNCHENSTEIN (CH)

In February 2010, the Rolex Learning Centre, designed by the internationally renowned Japanese architects SANAA, was opened. The Learning Centre was built on the campus of the Swiss Federal Institute of Technology (ETH) in Lausanne. The unusual architectural concept posed complex and exceptional challenges for both the structural and the façade engineers engaged in the project.

Designed as an educational establishment, featuring a library of some 500,000 volumes, the Rolex Learning Centre forms the cultural node of the campus, which will not only be accessible to students but also to the public. The 20,000 m^2 floor space offers a network of services, libraries, reading rooms, auditoriums and workstations for individuals and groups as well as restaurants, cafés and parks.

Architectural Challenge: With an avant-garde touch, the low-rise building has a wavy shape like a hilly landscape and includes a number of light-flooded courtyards. The supporting structure of the pre-stressed concrete slab required a new technology in order to achieve an almost invisible construction.

Those passing under the imposing concrete vaults and through the central entrance will find themselves in an artificial landscape without any partition walls, so that the building appears to have no limitations. When passing the entrance area with coffee shop and information point, the visitor experiences surprising surroundings.

The library is located on a kind of commander's viewpoint leading the visitors through the electronic barrier with direct access to almost all of the 500,000 books as well as the numerous electronic journals in the basement. Next to the library, pathways lead to a recess containing some of the total of 860 student workstations. Those visitors taking the opposite direction from the entrance will find a multi-functional forum after an ascent.

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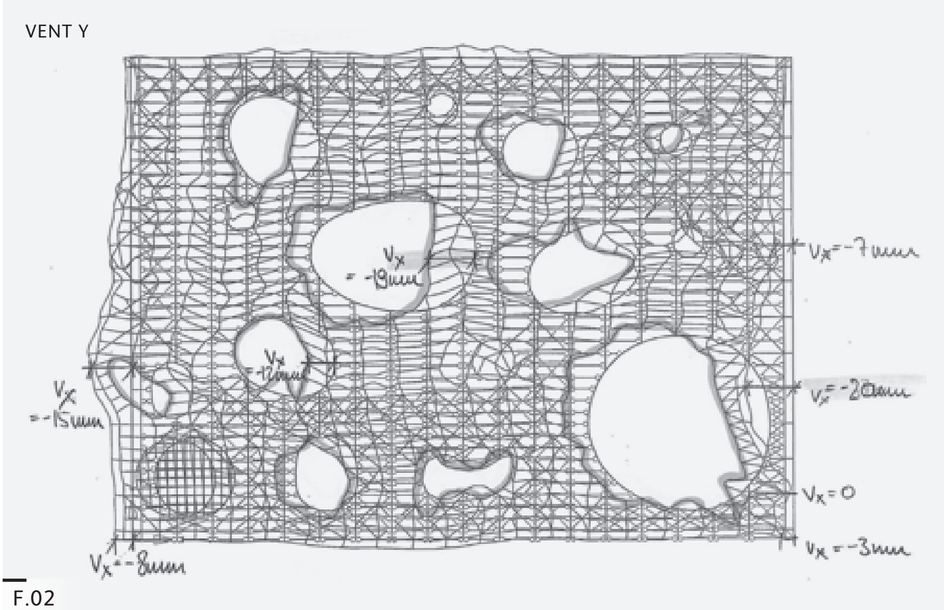


F.02

F.01
Internal view (computer simulation by SANAA)

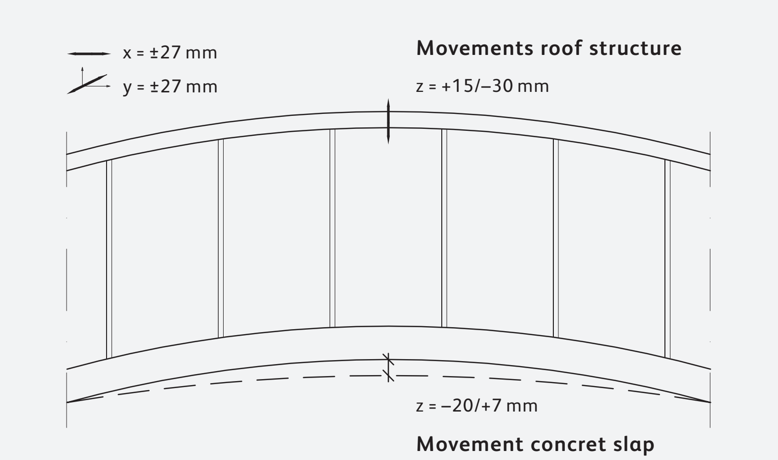
F.02
Deformation of the roof structure under wind loads, exaggerated – the roof structure reacts like a sponge (Bollinger Grohmann)

Complex engineering tasks: The engineering performance regarding this building has met with unanimous praise. The large building complex is supported by two concrete shells and eleven pre-stressed arches which are up to 90 m in size. The 1,400 formwork panels had to be laser-cut to size in order to achieve the required precision. For the 4,700 square metre external envelope, 90 % of the glass elements consist of individual shapes which were manufactured in China and Spain. Despite the large percentage of the glass areas for the external envelope, ventilation and heating requirements were calculated by means of sophisticated computer simulations in order to meet the required Minergie standards.

For the most part, the building is illuminated by daylight. In addition, it features carefully controlled natural ventilation systems (with the exception of the restaurant and the multi-media library which are equipped with cooling ceiling systems). Thanks to high-quality insulated double glazing, 20 cm of insulation at roof level and up to 35 cm of insulation at floor areas, the use of external blinds, natural lighting and ventilation as well as the thermal pumps that were installed 25 years ago using lake water for cooling of the entire campus, the overall energy consumption only amounts to 38.5 kWh/m^2 (139 MJ/m^2). With the assistance of digital models for air flow, lighting and thermal simulations, it was possible to increase the energy efficiency of the new building to a technical maximum standard whilst ensuring the safety of users in case of fire.

Design and construction of the façade of the Rolex Learning Centre: The Rolex Learning Centre of the EPFL was designed as a one-storey wavy rectangle with sides of 121 m and 166 m respectively. The building comprises round and amoeba-shaped patios with diameters of 7 m to 50 m protruding at variable distances. The façade stretches between the floor and the ceiling like a membrane. The flush exterior façade consists of rhomboid-shaped glass panes, whereas the patios typically require concave and in a few places convex diamond-shaped glass panes. The façade comprises a total amount of 700 glass panes having mostly individual shapes, although each glass has a grid measurement of 2.25 m in width and 3.30 m in height, with the exception of the 4.80 m high multi-purpose hall.

The computer simulation *(Figure 1)* illustrates the architectural intention with a high transparency and fluidity of the façade. This was achieved by means of using curved patio glass panes for the flush exterior façades without protruding capping profiles, filigree mullions and minimum joint sizes between the individual glass panes. For the external glazed envelope,



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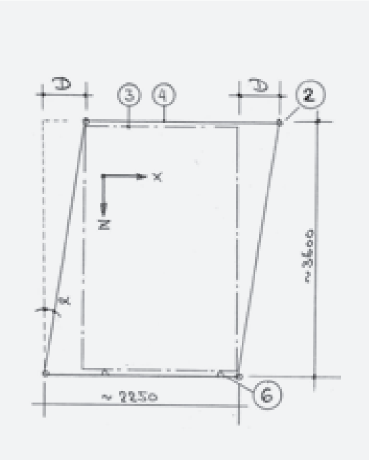

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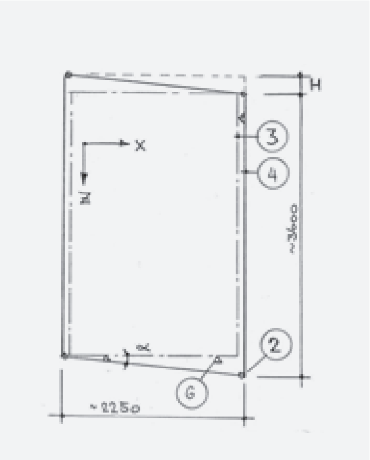

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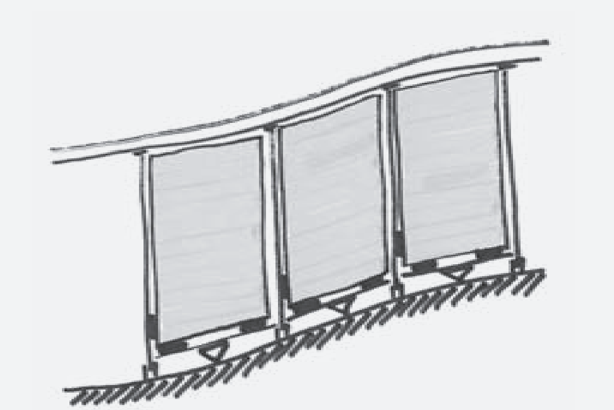

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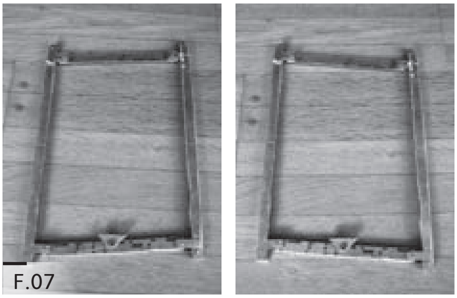


F.07

F.03
Movements to be compensated by the façade (EPPAG)

F.04
Sketch illustrating impact of slap movements on the façade (EPPAG)

F.05
Sketch illustrating impact of roof structure movements on the façade (EPPAG)

F.06
Support system with two setting blocks placed on balance beam (EPPAG)

F.07
Working models with articulated transoms and balance beam (Alain Ruetsch, EPPAG)

a low U_{cw} value of 1.6 – 1.7 W/m²K, retractable electrically operated solar shading devices and a large number of motor-operated opening window sashes for natural ventilation were thus required.

The main challenges of the façade, and hence to the façade engineers involved, were the structural and fixing details of the glazed screen to take up the large deformations of the building structure.

F.08
Vertical section of guide line detail (EPPAG)

F.09
Floor plan with global coordinate system

F.10
Conversion of global deformation vectors into local deformation vectors at right angle to glass pane (Sketch EPPAG)

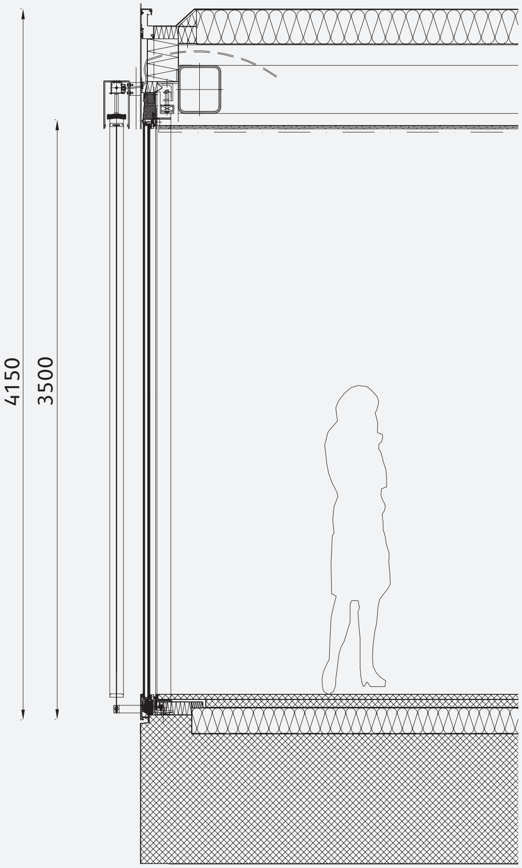
F.11
Impact of global deformation on local movements (EPPAG)

Incorporation of building deformation: in close cooperation the façade engineer and the structural engineer defined a vertical deformation for the concrete floor structure of –20 mm and +7 mm under creeping, shrinkage, dead load, thermal loads (caused by wind, snow, and temperature expansion/contraction) and life loads as limitation requirements. The deformations of the steel and timber roof to be taken up by the façade were limited to –30mm / +15mm vertically and ±27 mm horizontally *(Figure 3).* In between these two large deforming structural surfaces, rigid insulated glass panes were installed *(Figures 4 and 5).* Despite all deformations of the building structure, the glass units have to resist against breakage and must constitute a water- and airtight façade.

How was this solved? To be able to take up the movements of the concrete structure, it was decided not to support the glass directly by the bottom transom but by a balance beam which rests at the centre of the transom. The variable inclination of the deforming floor structure is thus taken up. As a result, the glass panes are always supported by both glass setting blocks and the movements occur only in the up and down direction. The vertical edges of the glass panes remain vertical and thus prevent them from touching each other *(Figures 6 and 7).* For trapezoid-shaped glass panes with an inclined supporting edge, the setting blocks on the side take up the dead load of the glass pane and prevent the glass contacting the mullion.

Deformations from the roof are taken up with the specially designed upper connection detail *(Figure 8),* which was constructed as follows:

- A sliding u-shaped glass setting block permits free movement between the roof structure and the glazed façade (x direction).
- Deformations at right angles to the façade (y direction) resulting from the structural movements of the roof are taken up by tilting the entire façade surface.
- Vertical deformations (z direction) are taken up either via a vertical sliding bolt or an elongated hole.



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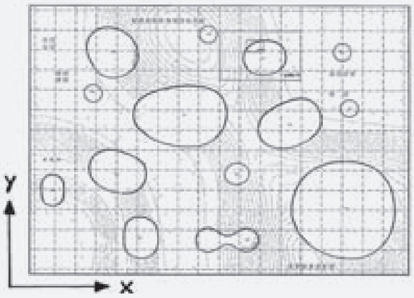

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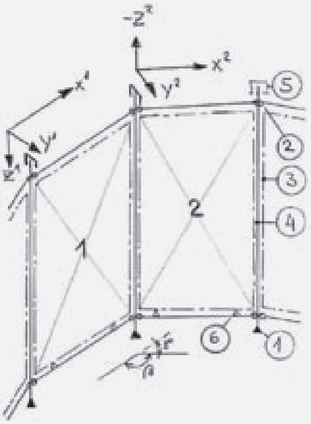

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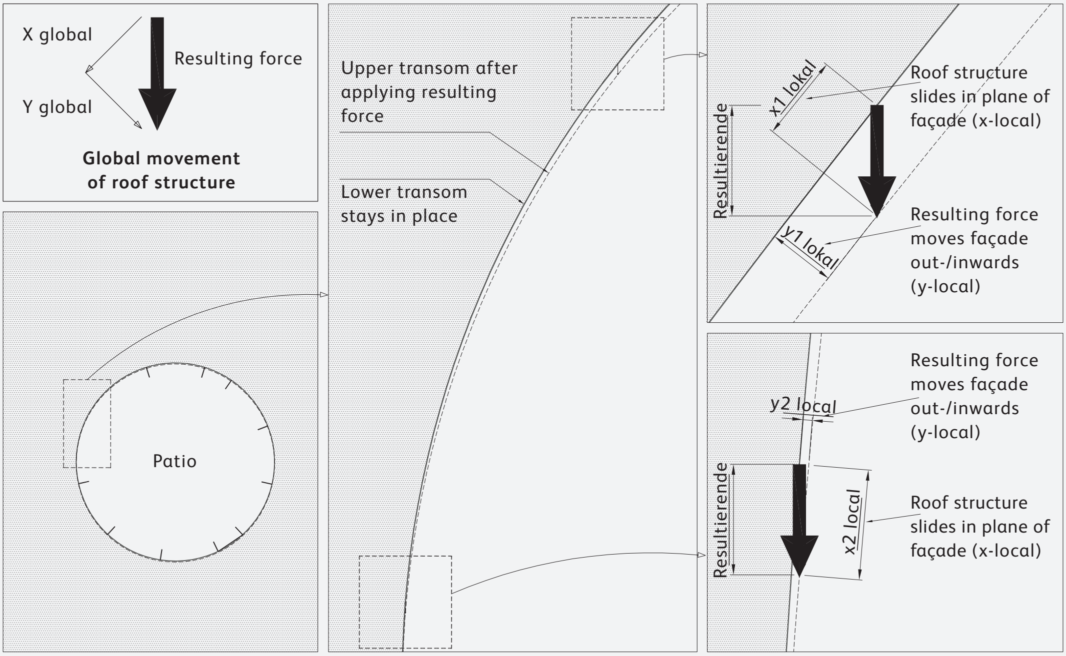


F.11

Effects on the curved patio façades: For the flush external façades, the designed principle works without any problems. But when it comes to the curved patio façades, the glass panes may move towards each other due to the angle of their position in plan. The deformation values of the building structure are indicated in a global coordinate system *(Figure 9)* and must be converted into a local vector at right angles to the pane for each patio glass *(Figure 10).* A global deformation vector (bold arrow) arising from a global x and y movement then causes, depending on the point of action on the patio, a local x and y deformation. The x_{local} vectors run parallel to the façade surface whereas the y_{local} vectors run at right angles to it *(Figure 11).*

Not only the bending across the diagonal of a curved glass pane investigated, but also the behaviour of glass panes moving towards and away from each other. Tilting of the individual glass panes results in opening or closing of the joints *(Figures 12a and 12b).*

The path of a glass edge towards the middle of the joint is mathematically represented in *Figure 13* and is determined directly by the following three parameters:

- the glass pane radius,
- the deflection of the façade surface y_{local} and
- the element width.

This means:

- the greater the inclination from the façade surfaces, the larger the required joint size.
- the wider the element, the larger the required joint size.
- the greater the radius, the smaller the required joint size.

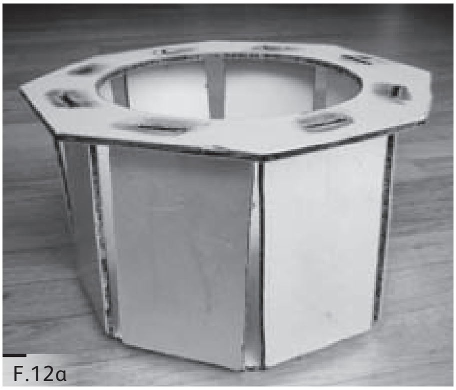
Since the glazed element width is predefined at 2.25 m, it was possible to calculate the path E in dependence of the radii and to present it in a table *(Figure 14).* Looking at the eleven radii which are entered horizontally at the top of the table and the inclination y_{local} which is listed vertically, one can read the horizontal movement x_{local} of a glass edge. To warrant an overall joint width of 24 mm, a permissible E ≤ 10 mm was defined. This means that the values highlighted in green represent permissible inclination. Each pane of the patio façades was then checked to ensure that the calculated inclination was within the permissible spectrum. For this purpose, the colour code of the maximum inclination occurring, depending on the given load, was applied to the individual floor plans. Instances where the limit values were exceeded were easily recognisable due to the yellow colouring and these were subsequently analysed in more detail. In the larger patios

F.12a, 12b

Working model under different deformation conditions. The upper ring of the model is rigid with elongated holes permitting movements in x_{local} direction. The movements in y-direction, perpendicular to the façade result in an inclination of the façade and therefore the joints open or close up. (Alain Ruetsch, EPPAG)

F.13

Horizontal section with formula to calculated the width of the joint between the glazing (EPPAG)



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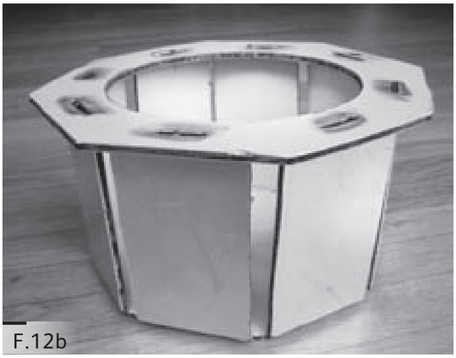

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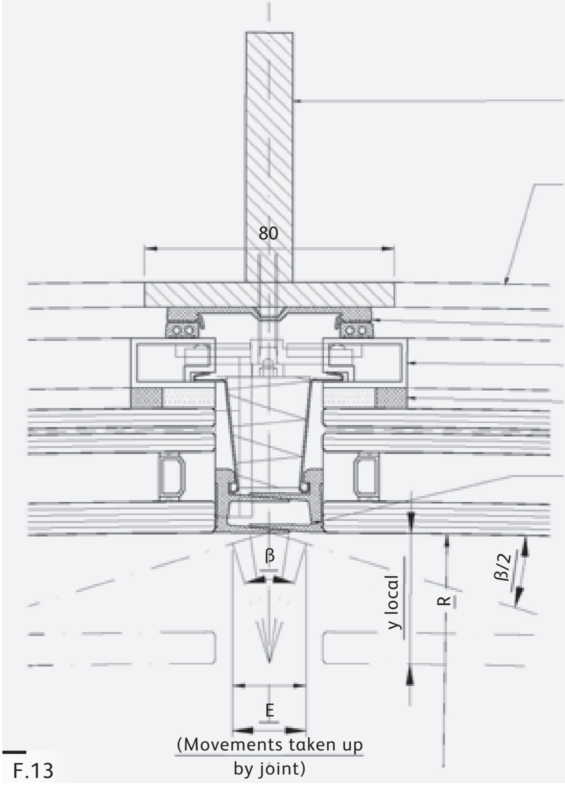


F.13

The component of the roof structure movement, perpendicular to the façade, causes an inclination of the façade. It translates into a closing or opening up of the joints between elements.

The required width of that joint can be defined depending on the glass radius and the occurring movements. Whereby the path of the glass edges towards each other is indicated by E.

$$E = 2 * y\ local * \sin \beta/2$$

$$\beta = 180 * b\ (\text{width of element}) / \pi * r\ (\text{radius})$$

The path E will reduce

- if the radius is increased
- if the width of the element is reduced
- if the roof structure movements are reduced

Built-up of the façade:

1 Steel mullion, T-section, powder coated
2 Steel transom, bend, T-section, powder coated
3 Neoprene gasket
4 Aluminium frame permitting structural silicone glazing
5 Insulated glazing, curved, outer pane toughened, inner pane laminated
6 Water barrier, silicone gasket with spring clip

there were individual cases, where local reinforcements within the roof structure were necessary in order to reduce the movements to the acceptable values.

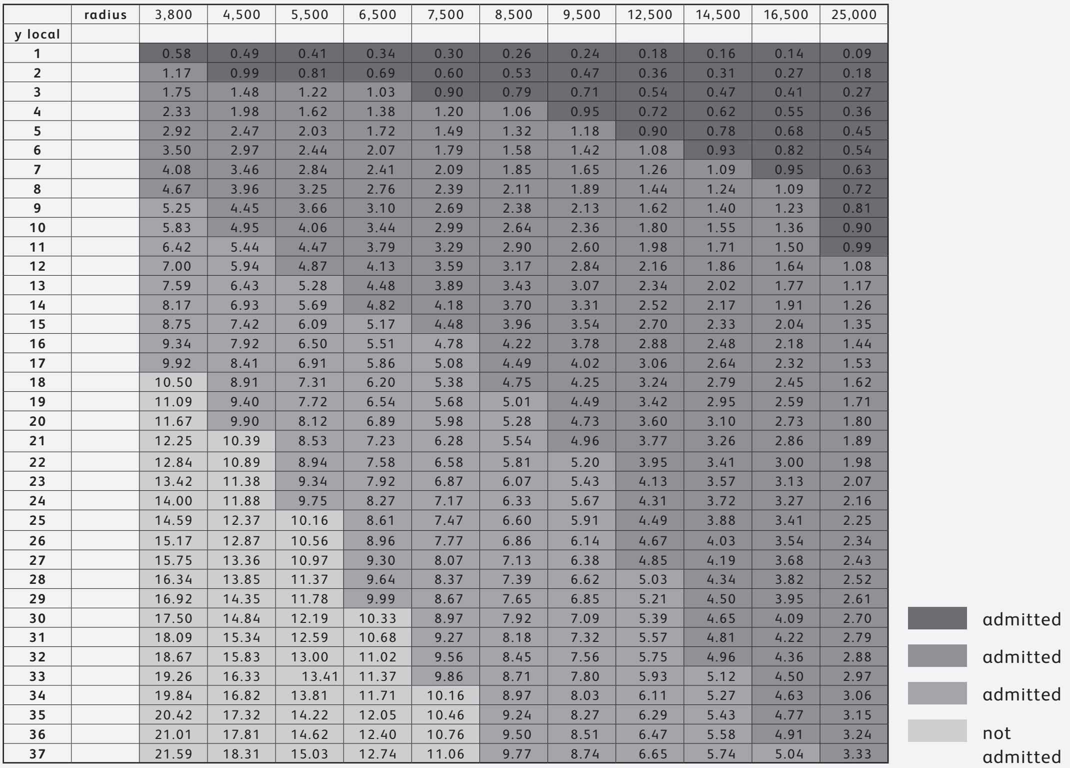
In particular, the small patios with a radius of 3.80 m presented problems. Due to their narrow radii, they cannot accommodate the inclinations that occur. Since a reduction of width of the panes, i.e. doubling the joint frequency, was out of the question for architectural reasons, the only viable solution was to diminish the allowable movements. All supporting mullions were executed as steel tubes so that they could carry a second ring beam, to which the façade was attached. Having its own ring beam, the roof can now move freely and no longer applies any forces onto the façade.

F.14
Excel sheet indicating the movement of the glass panes towards each other, depending on radius and movements perpendicular to the glass pane (EPPAG)

F.15
Support system where the glass tilts from one side to the other, in each case only supported by one setting block (EPPAG)

The executed mullion/transom/stick system construction: These limit values were established during the tender phase and were included in the contract requirements for both the façade and the building structure. Based on these specific constraints, the selected façade company Roschmann took the responsibility during execution to allow the glass panes to take up the relevant movements by tilting from one side to the other, following the movements of the mullion/transom/stick system *(Figure 15).* During a test period lasting several weeks and involving maximum deformation, the behaviour of the curved façade, supporting the glass on one side, was successfully tested on a full scale prototype at the manufacturing facilities *(Figures 16 and 17).* Based on this test and all glass panes being toughened or heat-strengthened safety glass, the design team approved the modified support system.

As part of the planning process, different profiles and fixing systems were investigated. For the execution, a mullion-transom-stick system with vertical mullions made of welded T profiles (flange 70/10 and web 90/15) was selected. The mullions consist of asymmetrical T profiles which are fixed to the ceilings and floor construction. The glass panes of the external façades are mechanically held within the vertical edge seal without any capping profiles being visible from the outside, thereby achieving a flush appearance without any protrusions. In contrast, the glass panes of the patio façades can never be viewed flush to the façade and thus capping profiles were acceptable. The double insulated glass panes consist of an external 10 mm toughened safety glass, a 14 mm cavity with argon gas filling and a 2 x 6 mm internal laminated glass pane to achieve fall-out protection. The double insulated glazing units have a U_g value of 1.1 W/m^{2}K and a g-value



	radius	3,800	4,500	5,500	6,500	7,500	8,500	9,500	12,500	14,500	16,500	25,000
y local												
1		0.58	0.49	0.41	0.34	0.30	0.26	0.24	0.18	0.16	0.14	0.09
2		1.17	0.99	0.81	0.69	0.60	0.53	0.47	0.36	0.31	0.27	0.18
3		1.75	1.48	1.22	1.03	0.90	0.79	0.71	0.54	0.47	0.41	0.27
4		2.33	1.98	1.62	1.38	1.20	1.06	0.95	0.72	0.62	0.55	0.36
5		2.92	2.47	2.03	1.72	1.49	1.32	1.18	0.90	0.78	0.68	0.45
6		3.50	2.97	2.44	2.07	1.79	1.58	1.42	1.08	0.93	0.82	0.54
7		4.08	3.46	2.84	2.41	2.09	1.85	1.65	1.26	1.09	0.95	0.63
8		4.67	3.96	3.25	2.76	2.39	2.11	1.89	1.44	1.24	1.09	0.72
9		5.25	4.45	3.66	3.10	2.69	2.38	2.13	1.62	1.40	1.23	0.81
10		5.83	4.95	4.06	3.44	2.99	2.64	2.36	1.80	1.55	1.36	0.90
11		6.42	5.44	4.47	3.79	3.29	2.90	2.60	1.98	1.71	1.50	0.99
12		7.00	5.94	4.87	4.13	3.59	3.17	2.84	2.16	1.86	1.64	1.08
13		7.59	6.43	5.28	4.48	3.89	3.43	3.07	2.34	2.02	1.77	1.17
14		8.17	6.93	5.69	4.82	4.18	3.70	3.31	2.52	2.17	1.91	1.26
15		8.75	7.42	6.09	5.17	4.48	3.96	3.54	2.70	2.33	2.04	1.35
16		9.34	7.92	6.50	5.51	4.78	4.22	3.78	2.88	2.48	2.18	1.44
17		9.92	8.41	6.91	5.86	5.08	4.49	4.02	3.06	2.64	2.32	1.53
18		10.50	8.91	7.31	6.20	5.38	4.75	4.25	3.24	2.79	2.45	1.62
19		11.09	9.40	7.72	6.54	5.68	5.01	4.49	3.42	2.95	2.59	1.71
20		11.67	9.90	8.12	6.89	5.98	5.28	4.73	3.60	3.10	2.73	1.80
21		12.25	10.39	8.53	7.23	6.28	5.54	4.96	3.77	3.26	2.86	1.89
22		12.84	10.89	8.94	7.58	6.58	5.81	5.20	3.95	3.41	3.00	1.98
23		13.42	11.38	9.34	7.92	6.87	6.07	5.43	4.13	3.57	3.13	2.07
24		14.00	11.88	9.75	8.27	7.17	6.33	5.67	4.31	3.72	3.27	2.16
25		14.59	12.37	10.16	8.61	7.47	6.60	5.91	4.49	3.88	3.41	2.25
26		15.17	12.87	10.56	8.96	7.77	6.86	6.14	4.67	4.03	3.54	2.34
27		15.75	13.36	10.97	9.30	8.07	7.13	6.38	4.85	4.19	3.68	2.43
28		16.34	13.85	11.37	9.64	8.37	7.39	6.62	5.03	4.34	3.82	2.52
29		16.92	14.35	11.78	9.99	8.67	7.65	6.85	5.21	4.50	3.95	2.61
30		17.50	14.84	12.19	10.33	8.97	7.92	7.09	5.39	4.65	4.09	2.70
31		18.09	15.34	12.59	10.68	9.27	8.18	7.32	5.57	4.81	4.22	2.79
32		18.67	15.83	13.00	11.02	9.56	8.45	7.56	5.75	4.96	4.36	2.88
33		19.26	16.33	13.41	11.37	9.86	8.71	7.80	5.93	5.12	4.50	2.97
34		19.84	16.82	13.81	11.71	10.16	8.97	8.03	6.11	5.27	4.63	3.06
35		20.42	17.32	14.22	12.05	10.46	9.24	8.27	6.29	5.43	4.77	3.15
36		21.01	17.81	14.62	12.40	10.76	9.50	8.51	6.47	5.58	4.91	3.24
37		21.59	18.31	15.03	12.74	11.06	9.77	8.74	6.65	5.74	5.04	3.33

■ admitted

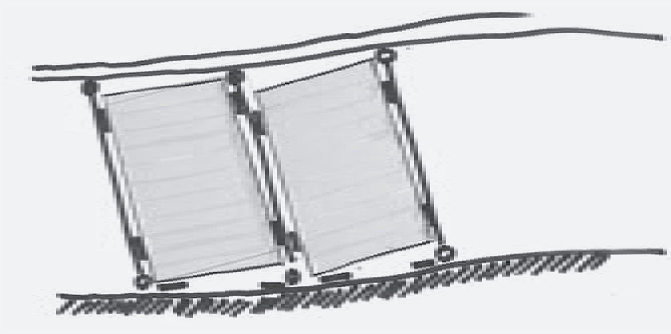
▩ admitted

▨ admitted

□ not admitted

Movements in the joint between two glass panes depending on the radius and the local movements in y-direction (perpendicular to glass pane)

F.14



F.15

of 57% which can be reduced to 15% when using external venetian blinds in cut-off position. The venetian blinds follow the angle of inclination and the geometry of the façade. Each set of blinds is straight, however, resulting in a faceted layout within the patios *(Figure 18).*

If you compare the photo (*Figure 19)* to the computer simulation *(Figure 1)* from the planning phase, it is pleasing to see that the architectural objectives have been implemented very well, despite many adjustments during the planning and execution stage.

F.16

F.16
Test of the prototype at Roschmann (EPPAG)

F.17
Screws to simulate the deformation on the prototype (EPPAG)

F.17

INVOLVED IN THE PROJECT:

Client:	Ecole Polytechnique Fédérale de Lausanne
Architects:	Sanaa (Tokyo) and Architram (Renens)
Civil engineer:	Bollinger und Grohmann GmbH (Frankfurt) and Walther Mory Maier (Basel)
Façade planning:	Emmer Pfenninger Partner AG (Münchenstein)
General contractor:	Losinger Construction SA (Bussigny)
Steel constructions:	Sottas SA (Bulle)
Façade engineering:	Roschmann Konstruktionen aus Stahl und Glas GmbH (Gersthofen)

SANAA

The world-renowned Japanese architecture firm SANAA (Sejima and Nishizawa and Associates) was founded in 1995 by Kazuyo Sejima and Ryue Nishizawa. Their leading-edge constructions combine a minimalist aesthetic with highly complex technology. SANAA's latest major project is the New Museum of Contemporary Art in New York. In 2009, they designed the Serpentine Gallery Summer Pavilion in London. Among their other most important constructions in recent years are the 21st Century Museum of Contemporary Art in Kanazawa (Japan) and the Dependance of the Louvre in Lens in the North of France which is to open its doors in 2012.

F.18
Internal view with external venetian blinds (EPPAG)

F.19
Internal view before opening (EPPAG)

F.20
The rolex learning center

F.18

F.19

F.20

INNOVATIVE MATERIALS AND EMBODIED ENERGY

Ulrich Knaack

FAÇADE RESEARCH GROUP,
TU DELFT (NL) / HOCHSCHULE OSTWEST-FALEN-LIPPE (D)

Summary: Architecture is mainly driven by materialising ideas – be it with focus on the creative or on the technical development – the search for innovation is always the driving force.

This contribution discusses tendencies in the building industry that originate in material development and are now applied to architecture. The main focus hereby lies on an experimental development of technical and creative possibilities for façade applications, research topics and design parameters.

As one example, this paper presents the «Façade Research Group», a group active both at TU Delft and the Detmold School of Architecture and Interior Design, working on developing new façade technology and structural principles. In addition to research activity in the areas of product development, tools, strategies and technologies, the group introduces solutions for free-form façades, considerations in the area of grey energy as well as «Future Façade Principles».

Energetic necessity and material-related innovation as the driving force in architecture: Besides formative and societal approaches, the necessities of energetic considerations as well as new technological developments have significant influence on architecture.

Considering the impact of energy on the design, it is apparent that, due to an ever increasing understanding of the energy flow in buildings, this impact has increased; as reflected in that part of a design called «Climate Design». Hereby, the energy gains and losses of a building are optimized to provide sensible constructional and technical installations for a specific use or user with the goal of achieving maximum performance with minimum energy consumption. However, this needs to encompass an evaluation of the energy needed for the production process and recycling after use – the energy embedded in the materials caused by their production and utilisation – in order to be able to accurately evaluate the function «a building's use for a certain period». During the past few years several

F.01

F.02

F.01
Kew Garden / London – English greenhouse dating from the 19th century

F.02
Van Nelle Fabrik / Rotterdam – the suspended façade as a step on the path to glass architecture from the beginning of the 20th century

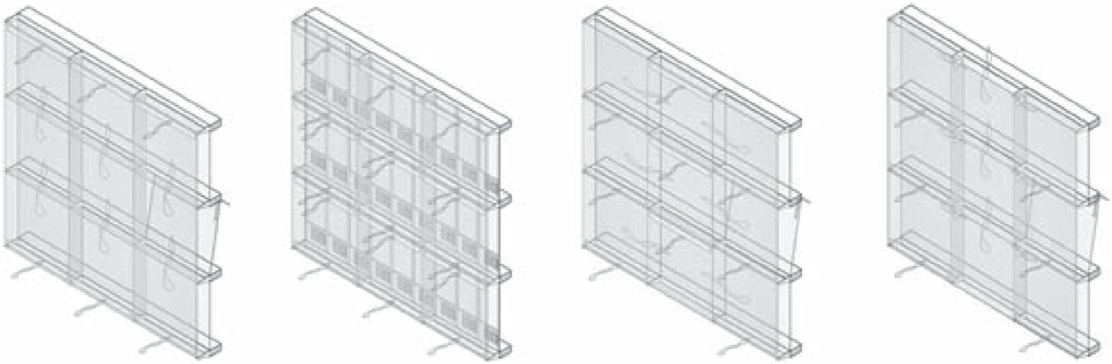
tools have been developed that help us in examining and evaluating the entire life cycle of a building. However, these evaluation tools (LEED, DGBN, BREEAM, HQE a. o.) are all flawed by the fact that they are not applied during the design process but only provide means to evaluate a building at the end of this process and thus only examine the results. The design process is not influenced in terms of choice of construction method or material; rather these factors are left to the designer's experience.

Another factor influencing the design concerns material-related technical innovations. Two parallel trends can be seen: on one hand designers today place a strong focus on choosing certain materials and surface finishes to realise their designs. This includes linking known materials in new contexts and / or changing their surface characteristics such that this creates new impressions. Alternatively, known materials are further developed or new materials, possibly from other industry segments, are used. Often, interior design leads the way for these trends because it has fewer technical requirements such as load-bearing capacity or the necessity to permanently withstand climatic conditions. If a material fulfils the demands and its performance proves successful in architecture as well, it is most often first applied to pioneer projects, the particularity of which is to be highlighted for various reasons.

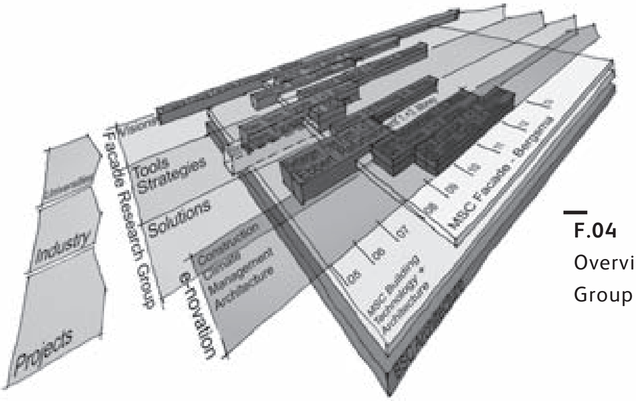
Besides the potential to affect the appearance, alternative technical parameters as well as cost considerations and new manufacturing methods typically drive such developmental lines.

Glass as an example for material development in architecture: Against the background of the often discussed and illustrated examples from the 19th and 20th centuries, the end of the 20th century saw a boom in fully glazed constructions that, for architecture, provided the opportunity to realise the desire for completely transparent constructions. Innumerable structural variations, slowly extending existing technical boundaries, created a knowledge pool of structural and creative possibilities that is still driven by projects today.

While trying to realise transparency that fulfils aesthetic as well as energetic requirements, fully glazed façades have, over the past twenty years, developed into double façades and, in a current development, into component façades, whereby building services with mechanical and natural ventilation form an integral part of the – partially pre-manufactured – façade. The goal is to have the façade react by opening and closing depending on the season, by being able to naturally control the ventilation and by providing sun protection with shading located between glass panes.



F.03
Principles of double façades – Second-skin façade, box window, corridor façade and shaft-box façade



F.04
Overview Façade Research Group TU Delft

F.05
Apple Store / New York – Current status of high-end technology for fully glazed constructions, realised without a steel supporting structure.

F.06
Sainsbury Centre for the Visual Arts / Norwich – Fully glazed façades are the logical consequence of the search for transparency

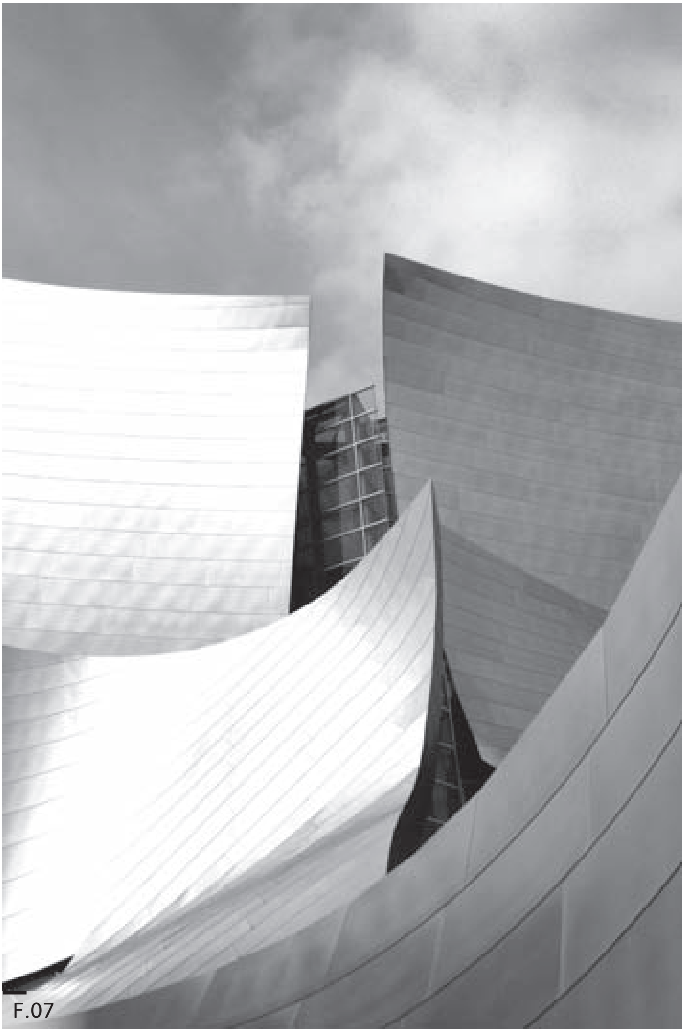
The result is an integral product in the form of the component façade, made possible only by combining the technically sophisticated material glass, which reached the limits of its performance capability, with other technologies to fulfil the formative desire for transparency.[1, 2]

Façade Research Group TU Delft: During the course of working with the parameters influencing the planning and building processes, as well as developing the necessary research, the topics energy, efficiency and individuality (as technical corner points of a tension field encompassing the advancement or new conceptualisation of façades) were isolated reaching beyond aesthetic trends: energy as the motor of all actions, efficiency in the sense of performance expected of the façade as a technically sophisticated building component, and individuality as a part of architecture that, in every building, reflects the expression of a particular urbanistic, spatial and aesthetic conception.

Against this background, the Façade Research Group was formed at TU Delft in 2005. It focuses on several topics within the field of façade technology: problem / solution oriented research with the goal of providing solutions to issues requiring short-term solutions. This involves questions about façade refurbishment or manufacturing processes of free-form façades. The group also works on developing working methods and tools to standardise planning processes and technology transfer. PhD's and the author link the group to the research focus Construction Lab at the Detmold School of Architecture and Interior Design.

New material technologies in the building envelope: The possibilities of free-form architecture and its technical realisation can be used to describe the development of material technologies within the Façade Research Group. Driven by the possibilities that planning software offers today's architects, there is a desire for freely formed, homogenous building envelopes that accommodate as many functions as possible. Corresponding to the engineering strategy of dissecting problems into individual questions, solving them individually, and to then reuniting them, current free-formed building envelopes typically consist of a layered system with an underlying steel support structure that creates the raw geometry. This is then complemented by an additional construction system until the desired free-form surface is realised.

In order to develop an alternative to this method, the Façade Research Group has examined different possibilities of free-form construction – with



F.07

F.08

the goal not only to create free-form surfaces but to include the functions of load-bearing and insulation.

One example hereof is a folded free-form shape based on a fibre-glass reinforced epoxy structure that, combined with a foam core, acts as a load-bearing sandwich. The desired shape was achieved with a cut and fold technique. The sandwich construction provides the load-bearing and insulating properties.

In order to advance the development to create a «true» free form, Daan Rietbergen / TU Delft in his PhD thesis worked on a system for controllable formwork onto which curable materials can be applied in liquid form. As a result, different materials such as fibre-glass reinforced concrete or plastics can be cast into any shape using a formwork table under consideration of system-immanent radii of curvature, and thus serve as elements for a free-formed building envelope.

F.07
Walt Disney Concert Hall – Los Angeles / Frank Gehry Architects

F.08
Structure of the free-formed façade of the Walt Disney Concert Hall

With his PhD thesis on translating rapid-prototyping and rapid-tooling technologies into architecture, Holger Strauss / Detmold School of Architecture and Interior Design makes a step towards «digital» production. This involves working out these principles – already in common use for modelling and prototyping – for the areas detailing and component development as well as producing complete building parts, against the background of new material developments and an elimination of the limits of building space.

Grey energy and the building envelope: As previously described, the energetic considerations of a building's operation have shifted towards looking at the entire life cycle. Due to the necessity to evaluate the design of a building with regard to the energetic performance of the materials used and the resulting support needed for the design process, Linda Hildebrand / Detmold School of Architecture and Interior Design is working on an accordant planning tool as part of her PhD topic. This involves examining various building types and their building envelopes to generate a gene pool that aids in early identification of «right» or «wrong» or, put differently, «good» or «bad» construction types for particular uses and life cycles.

F.12

Future Façade Principles: Another focus point that the Façade Research Group works on collaboratively is to develop visions for future conceptualisations of the façade – the «Future Façade Principles». For this, the group employs traditional development tools to guarantee a traceable and controlled process, even if the results can not be predicable. The goal is to create potential developmental paths in order to identify and put at the designer's disposal creative, production-related and structural opportunities through discussion and evaluating technical possibilities. The work is not aimed at solving specific technical issues but rather at reversing the working method into a methodology that offers opportunities and possibilities as a starting point for design developments.[3, 4, 5, 6]

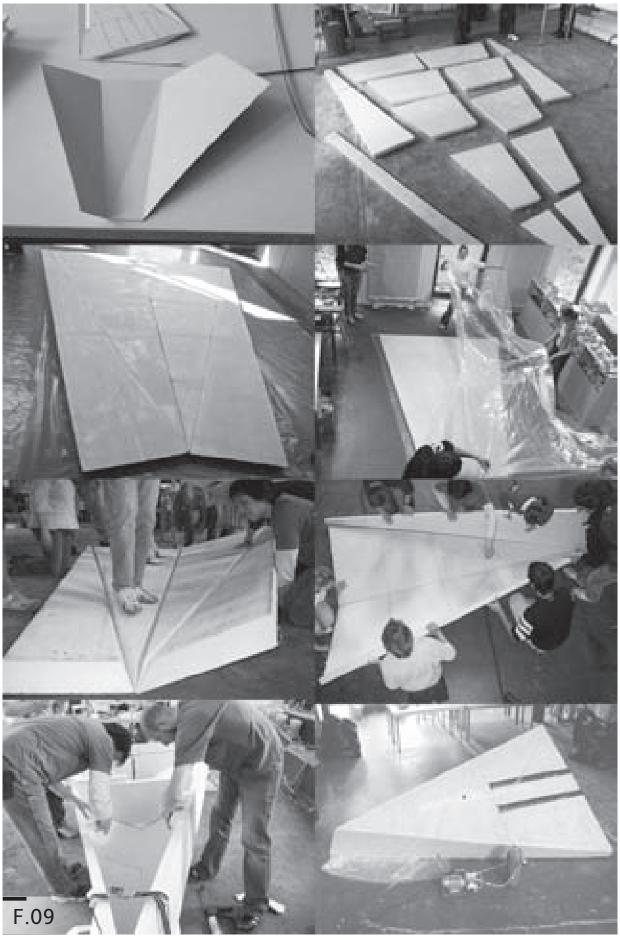
One important factor for this working method is confidence that random prognoses can also enable targeted and strong developments. The heuristic working method with the levels «Concernment – to immerse – to brood – Execution / Explanation and creative synthesis» is the tool of choice. Different target groups participate in the workshops – students, architects, structural engineers, climate designers as well as façade builders, who depending on the situation, conduct short-term impulse sessions

F.09
Future Façade Principle
sandwich free-form /
Marcel Bilow

F.10
Free-form formwork /
Daan Rietbergen

F.11
Future Façade Principle
rapid-prototyping and
rapid-tooling in the building
industry / Holger Strauss

F.12, 13
Examples Future Façade
Principle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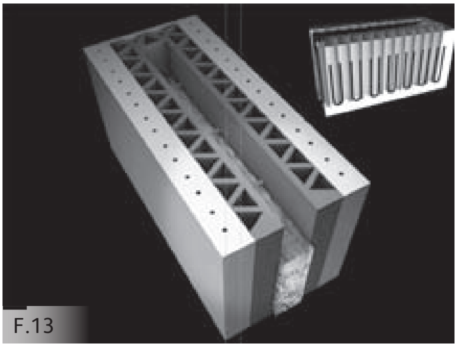
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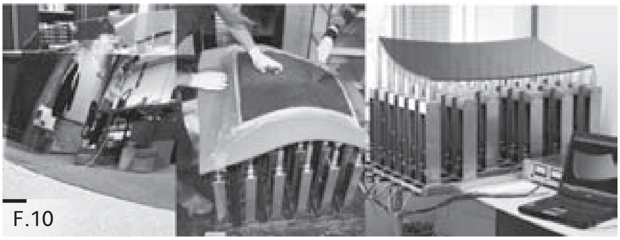
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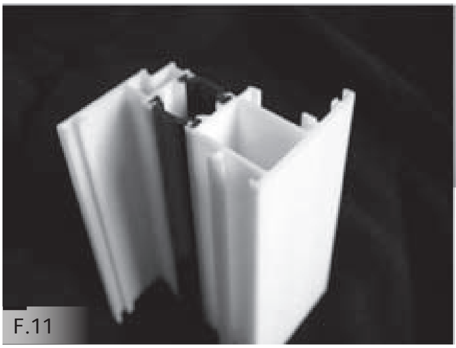
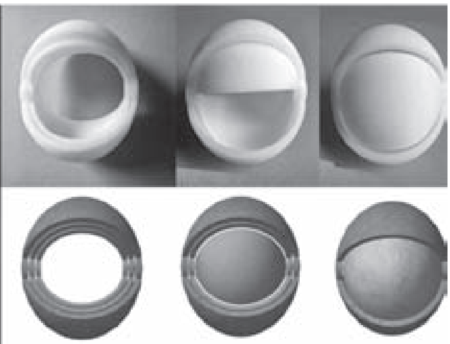

F.11



and/or multi-day workshops to generate developments either deliberately freely or strongly focused. The brainstorming principle has proven very successful, whereby the brainstorming sessions are often followed by evaluating individual solutions and examining technical and aesthetic factors to organise the ideas systematically and to make them easily understandable.[7, 8]

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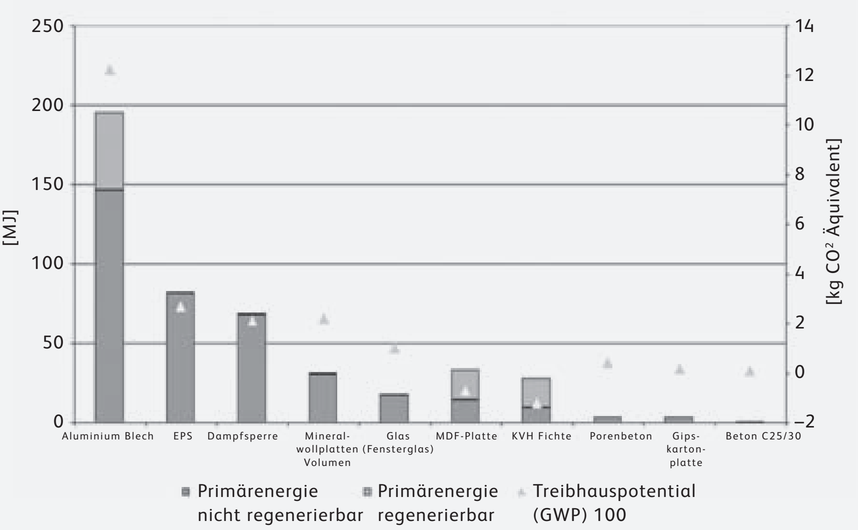
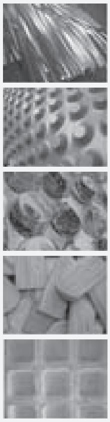
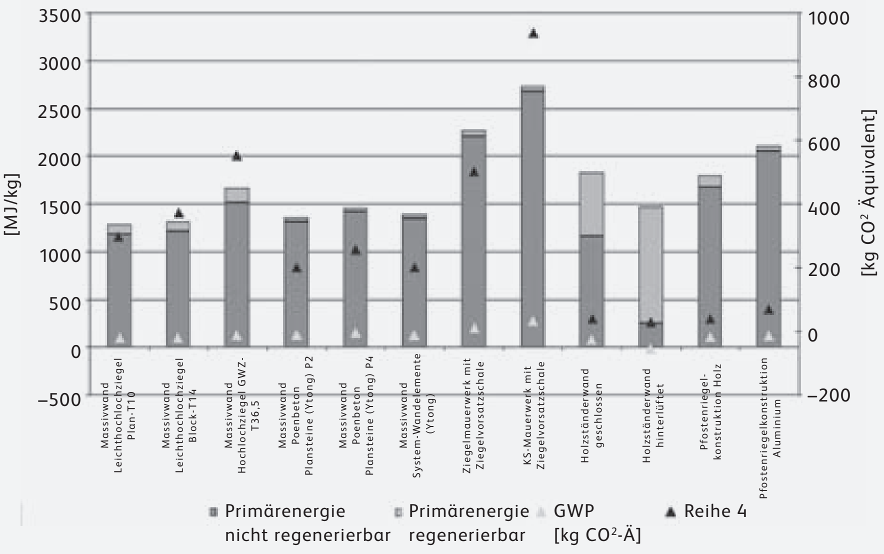




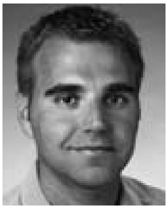


F.14, 15

Grey energy and building envelope / Linda Hildebrand

GLASS TECHNOLOGY

Andreas Luible
LUCERNE UNIVERSITY OF APPLIED SCIENCES AND ARTS, LUCERNE (CH)



This contribution highlights some specific issues with regard to the structural design of glass members in modern highly transparent façades. When glass is used as a structural member the glass edge, with its lower strength than the centre of the glass, is often subjected to high stress due to bending or due to a concentrated load application. Furthermore, in-plane loaded glass panels risk stability failure due to their slenderness. Unfortunately there is a lack of suitable design methods and codes for façade engineers covering these important issues. A project case study demonstrates how glass can be used as a structural element and how stability and load introduction problems were solved.

Introduction

Generally, façade projects consist of different packages covering different areas of a building. While standard curtain wall areas are still the most important part of a façade project with regards to the façade surface, special areas such as entrance lobbies, atrium façades or atrium roofs are often more important with regard to their architectural aspect, costs and the first impression of people entering the building. Clients generally demand these representative areas to be as open as possible to the outside and as a consequence, architects try to design these areas with a maximum of transparency. A relatively new way is the application of transparent materials such as glass for the structural members. Recent technological developments have brought about unprecedented opportunities and major changes in the use of glass in buildings. Glass is a material that is able to resist very high compression stresses; heat treated glasses are able to resist high tensile stresses and new connection methods make it possible to transfer high forces into glass members. Compared with a simple window glass, these glass members are not only subjected to short-term out-of-plane loads due to wind loads but also to long term in-plane loads, creating complex states of stress or resulting in stability failure due to their significant

F.01

F.02

F.01
One Island East Podium glass wall

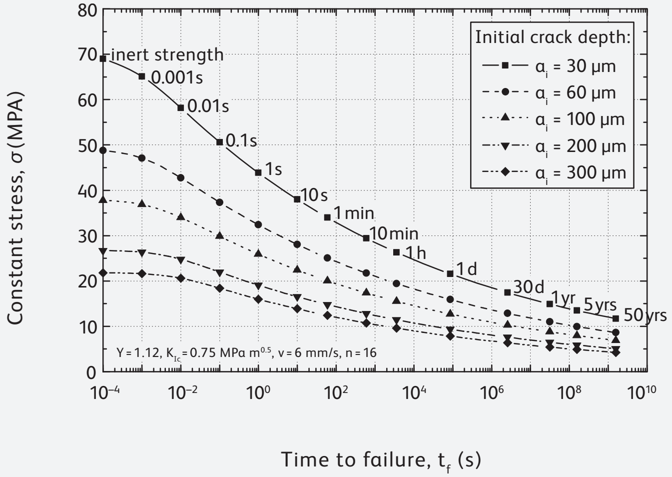
F.02
One Island East Podium glass wall – view from inside.

slenderness. Furthermore, most of the existing design codes cover simple window glass but are not suitable for the design of structural glass elements. Generally, façade engineers and contractors are familiar with glass used in a traditional way, as a four edge supported window glass pane in a curtain wall element, but in recent years they are more and more confronted with the application of glass as a principle structural member. This paper attempts to address this issue by highlighting some important facts when glass is used as a structural member, thereby providing a better basis for the understanding of the structural performance and design of glass in buildings. In the second part, a typical project is presented where glass has been applied as a structural member for an entrance façade of the high rise office building One Island East in Hong Kong.

Structural use of glass

Glass properties and products: Glass shows an almost perfectly elastic, isotropic behaviour and exhibits brittle fracture. It does not yield plastically, which is why local stress concentrations are not reduced through stress redistribution as is the case for other construction materials like steel. The actual tensile strength, the relevant property for engineering, is lower than the theoretical tensile strength based on molecular forces. The reason is that, as with all brittle materials, the tensile strength of glass depends very much on mechanical flaws on the surface. Such flaws are not necessarily visible to the naked eye. While the centre surface of glass panes generally contains fewer deep surface flaws, the glass edge, which is generally subjected to high stress in structural glass members, contains a large number of relatively severe flaws due to mechanical edge working. This explains why the glass strength on the edge is lower than the strength in the centre of a glass pane.[1]

A glass element fails as soon as the stress intensity due to tensile stress at the tip of one flaw reaches its critical value. The tensile strength of glass is not a material constant, but it depends on many aspects, in particular on the condition of the surface (microscopic and macroscopic defects), the size of the glass element, the action history (intensity and duration), the residual stress and the environmental conditions. The higher the load, the longer the load duration and the deeper the initial surface flaw, the lower is the effective tensile strength.[1] This is different to materials such as steel or aluminium and an often forgotten fact when structural glass elements are designed. *Figure 3* gives a rough overview of typical strength values as a function of the loading time and the initial crack depth. Furthermore, not

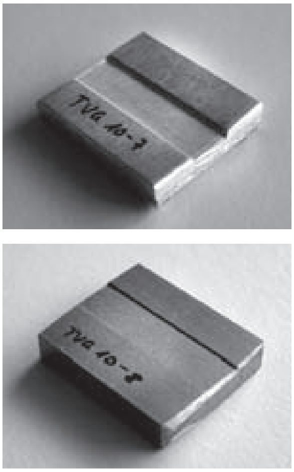


F.03
Strength of a surface crack as a function of the loading time and the initial crack depth

only the surface condition of the glass just after erection has to be considered but also more severe surface defects that might occur during lifetime, caused, for example, by vandalism or mechanical tools during cleaning.

The compressive strength of glass is significantly greater than the tensile strength because surface flaws do not grow or fail when in compression. This is important for glass structures as it allows glass to be used in members which transfer loads in compression such as columns, compressed panels or stiffeners in frame structures. Until today, very little research work has been carried out to study the compressive strength of glass. *Figure 4* shows the enormous compressive strength of glass with a small aluminium plate and a steel plate that were used in a load introduction test.[2] Both materials show plastic deformation caused by the pressure of the glass edge. The contact pressure on the steel plate at the time of glass failure was ~600 MPa.

Tempering is the most important processing method when glass is used as a structural element. The idea is to create a favourable residual stress field featuring tensile stresses in the core of the glass and compressive stresses on and near the surfaces. The unavoidable flaws on the glass sur-



F.04
Indentation of aluminium (above) and steel (below) by a glass edge after a load introduction test[1]

face can only grow if they are exposed to an effective tensile stress. As long as the tensile surface stress due to actions is smaller than the residual compressive stress, there is no such effective tensile stress and consequently no crack growth.[1]

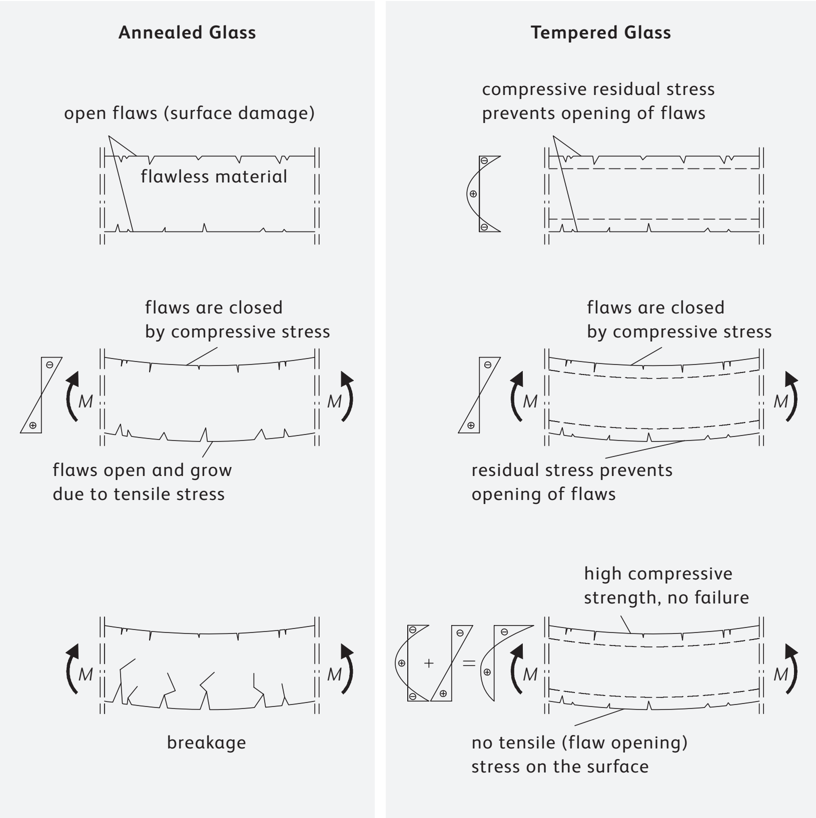
Fully tempered glass has the highest residual stress level and usually breaks into small pieces. Nevertheless, when falling from a height of several meters, even small glass pieces can cause serious injury. Fully tempered glass has the highest structural capacity of all glass types but its post-failure performance is poor due to the tiny fragments. Heat strengthened glass provides smaller residual stress and is a compromise between fairly good structural performance and a sufficiently large fragmentation pattern for good post-failure performance. Annealed glass is standard float glass without any tempering. Heat strengthened and annealed glass normally break into large fragments but if they are exposed to high inplane loads, the elastic energy stored in the material due to elastic deformation can lead to a fracture pattern similar to fully tempered glass.[2] While the residual stress distribution in the centre area of the glass can be directly determined with optical methods, the residual stress at the edge is difficult to measure. For the design of structural glass elements, it has to be kept in mind that the residual stress on the edge is not constant, depends on the glass thickness and might be less than in the centre of the glass pane[1, 4] *(Figure 6).*

One option to overcome the problem of post-breakage behaviour and robustness of glass structures is the use of laminated glass *Figure 7.* Laminated glass consists of glass layers bonded together by a transparent plastic interlayer. Currently there are different products on the market, whereby polyvinyl butyral (PVB) is the most common. Other materials such as SentryGlass® Plus from DuPont (SGP) or ethylene vinyl acetate (EVA) interlayer provide a higher stiffness, temperature resistance as PVB and therefore have a better post-breakage behaviour.

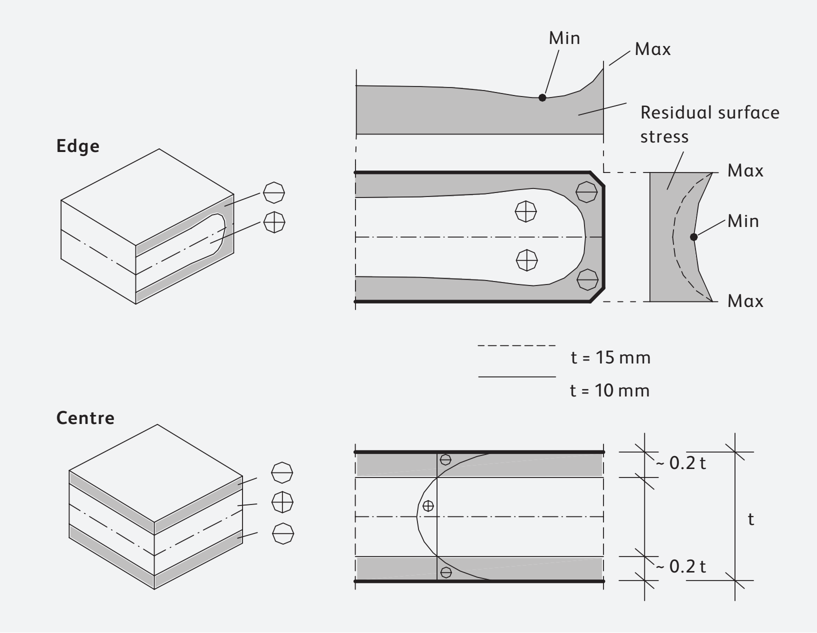
Stability

Glass is a material that is able to resist very high compression stresses. The basic glass products applied in glass structures are panels and, due to their extreme slenderness, these elements must be checked against stability failure *(Figure 8).* Several established design methods exist for common

F.05
The principle of glass tempering[1]



F.06
Typical residual stress distribution at the centre and on the edge of a 10 mm and 15 mm heat treated glass.



structural materials (i.e. steel, timber), but these methods cannot be applied directly to glass, because the influence of production tolerances (thickness, variation in panel size) of the initial imperfections, of the brittle behaviour, and of the viscoelastic behaviour of laminated glass interlayer have to be specifically considered for glass. A lot of experimental and theoretical investigations of the fundamental stability problems (column buckling, lateral torsional buckling, plate buckling) of single layer and laminated glass elements have been conducted at many research institutes in Europe in the past few years. Some of the most important results are summarized in «Structural use of glass»[1]. Nevertheless, results are not yet implemented in existing design standards.

Typical structural elements where column buckling might be critical are glass columns, glass walls where the glass panes have the function to carry a roof structure, or glass fins carrying the dead load of the glazing. Lateral torsional buckling is mainly critical for glass beams and for glass stiffeners such as vertical glass fins, which are often used to replace steel mullions. Plate buckling is critical when glass panes are subjected to in-plane loads while all four edges are supported or when a glass pane has the function of a shear panel in girder structure or a façade element. Currently there are only a few applications where glass is used in such a way, but with the ongoing development of high performance load introduction details and bonding technology this might change in future. First tests at the EPFL in Lausanne[2] and at the RWTH in Aachen[6] demonstrated the enormous load bearing capacity of in-plane loaded glass panes due to the post-buckling capacity.

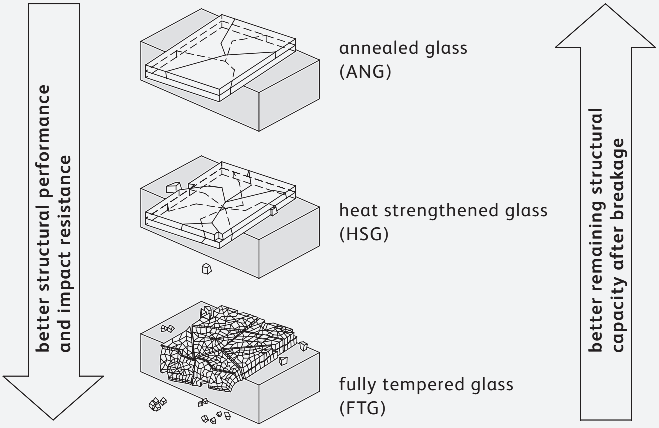
The following design approaches may be applied for a stability analysis: Design based on buckling curves for glass: this is the most convenient approach as it is similar to the design of steel structures and most of the design engineers are already familiar with it. It has been demonstrated that the design concept principally may be adapted but buckling curves need to be developed for glass.[1] Currently, a research group at the RWTH Aachen is working on column buckling curves for glass.[5]

Design based on second order theory or non linear FEM analysis: the calculation must be carried out with a suitable model that is able to take into account all influencing parameters (such initial imperfections and realistic boundary conditions). Existing analytical models can be applied for column buckling but a FEM analysis is recommended for a lateral torsional or plate buckling check. The FEM analysis has to be carried out in several steps as explained, for example, in «Structural use of glass»[1].

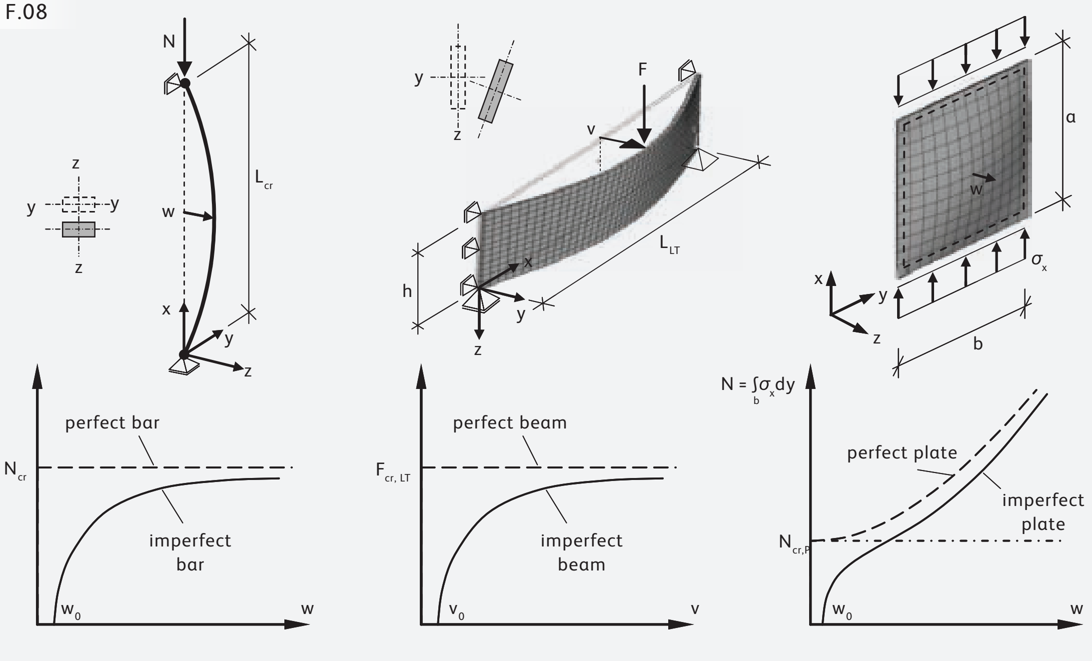
F.07
The post-breakage behaviour of laminated glass made of different glass types.[1]

F.08
Fundamental stability problems and typical load carrying behaviour: (a) column buckling, (b) lateral torsional buckling, (c) plate buckling.[1]

F.07



F.08



(a) column buckling **(b) lateral torsional buckling** **(c) plate buckling**

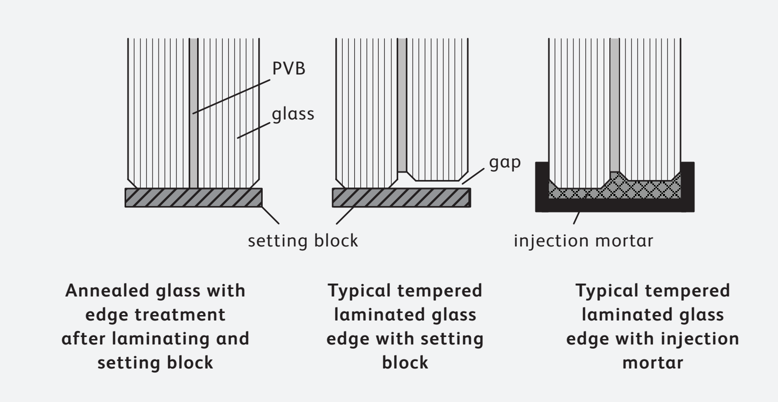
Load introduction and glass connections

The design of the load introduction and connection details is sometimes even more important than the design of the glass panels themselves. A lot of failures in glass structures are due to bad design of these details because high stress peaks were underestimated in the structural analysis or the model was not able to represent them sufficiently accurately. In this chapter a small selection of typical details which are used in glass structures are presented and discussed.

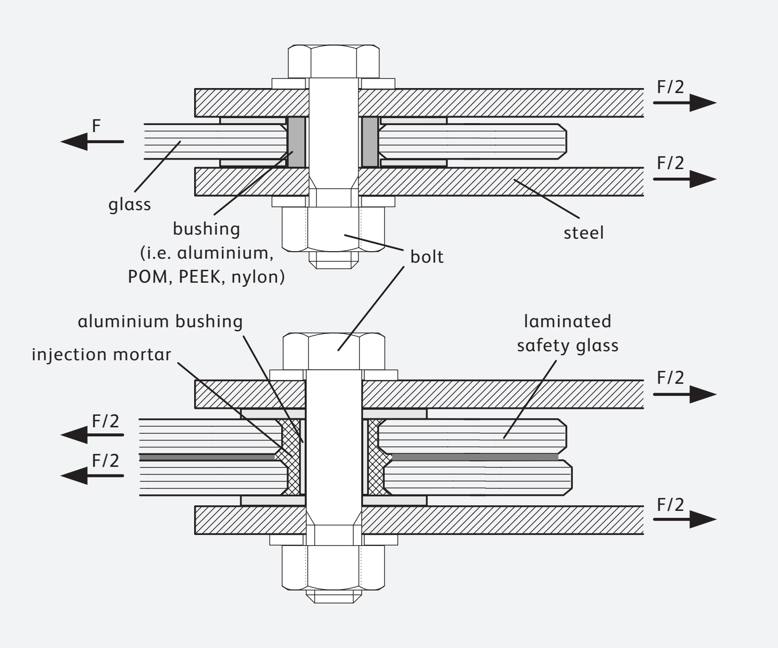
The simplest edge support consists of a setting block. This detail is not critical under small forces and as long as the glass edge is flush. The edge of laminated safety glass made of heat strengthened or tempered glass is normally not perfectly flush. The glass layers have to be tempered before laminating and mechanical edge treatment of tempered glasses is not possible afterwards. This leads to an asymmetric load introduction into the glass edge and a high stress concentration. In case of setting blocks, only one single glass layer would be supported while the other is not in contact with the setting block. A better solution is to employ special setting blocks or steel shoes, where the space between the steel shoe and the glass edge is filled with an injection mortar or glue.

The earliest bolted connection is the through bolt connection *(Figure 10)* where the connection is subjected to in-plane tension or compression which is translated as shear in the bolts. This type of connection may therefore be used in splices (e.g. spliced beams, spliced fins) to construct large structural assemblies. One of the key challenges of structural detailing in glass is to devise a connection in which the high stress concentrations and direct steel-to-glass contact are avoided. This is in part achieved by intermediate materials in the form of bushings that have a lower modulus of elasticity than glass. The materials used for these bushings should therefore be sufficiently strong and stiff to transfer loads to and from the glass without breaking or oozing out of the joint, but at the same time they should be soft enough to redistribute stress concentrations. An adequate resistance to creep and cyclic loading as well as a good UV-resistance is also important. Materials commonly used for bushings are aluminium, plastics such as EPDM (ethylene propylene diene monomer), PEEK (polyether ether ketone), POM (polyoximethylen) or polyamide or injected resin or mortar (e. g. HILTI HIT).

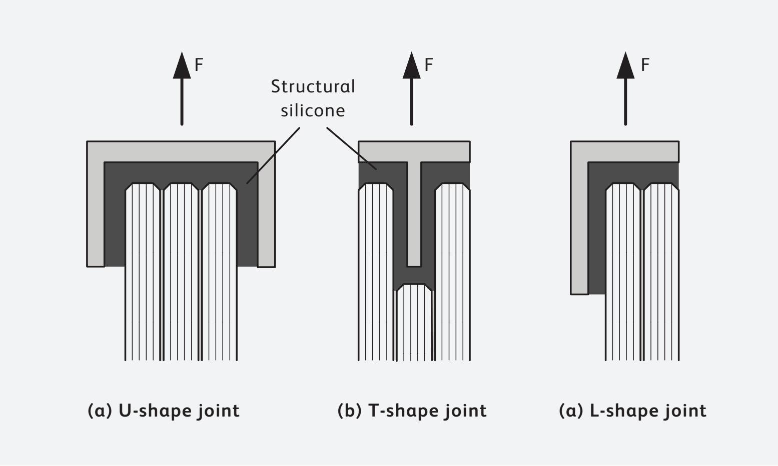
More efficient connections and joints with regard to stress concentration are glued connections. Glued connections provide the opportunity to distribute the loads arising from the connections in a more uniform man-



F.09
Load introduction on the edge of a laminated glass.[1]



F.10
Bolted glass connection[1]



F.11
Typical glued connection with structural silicone.[1]

ner when compared to bolted connections. Generally, two types of glued connections are used for glass applications:

- soft elastic adhesive connections (i.e. structural-silicone-sealant connections),
- rigid adhesive connections (i. e. acrylic adhesives, epoxy adhesives and polyester)

Typical soft elastic adhesive connections are shown in *Figure 11*. Currently a lot of research projects are carried out on glued glass connections.[8, 9]

With the development of the SGP interlayer by DuPont, a new type of glass connection may be realized: the lamination of steel plates directly into the interlayer of laminated glass. Numerous projects such as the glass structures for the Apple stores around the world have demonstrated the outstanding potential of this type of connection.[7]

Case study – One Island East Podium Glass Wall, Hong Kong

Project description: In Hong Kong's Querry Bay, the new high rise office tower One Island East has recently been completed. The tower itself has been designed by architects Wong and Ouyang. The bottom part of the building consists of an entrance lobby which is surrounded by a 14 m high suspended glass wall designed by architects Hugh Dutton Associates (HDA) in Paris. Contracts for the curtain wall, podium glass wall and the link bridge have been awarded to the façade contractor Josef Gartner & Co. (HK) Ltd in Hong Kong, a branch office of Josef Gartner GmbH in Germany. The podium glass wall around the building is divided by the columns of the tower structure into eight bays (four straight and four curved) with a total surface of 2150 m^2. Each bay consists of a horizontal truss made of duplex stainless steel casting segments which give a horizontal support at half height for the 88 suspended 11 m long glass fins. The 1000 mm deep glass fins stop above ground level such that the bottom glass is free from any visual obstruction due to frames or supports and the glass fins are half inside and half outside the glass pane. In total 30 t of duplex stainless steel castings have been used for the trusses, spiders and connection parts of the glass wall. The biggest truss elements have a length of up to 1800 mm and a weight of 180 kg. The face glass is made of 12/12 mm curved and straight laminated low iron glasses with SGP interlayer and max. dimension of 1500 x 4600 mm. The 15/15 mm laminated fully tempered low iron glass fins are made of two pieces connected by a splice joint at a point of minimal bending moments.

The biggest challenge of the project lay in the high demands regarding the limited size of the glass joints, the resulting tolerance requirements for the castings of less than ±1 mm, glass tolerances of <2 mm over 4600 mm height, the building movements due to slab deflection and lateral sway movements of ±15 mm, the movement due to thermal dilatation and wind loads of 3 kPa.

Structural concept: The main structural elements of the glass wall are the horizontal stainless steel truss, the suspended glass fins with the splice joint at half height and the spider castings where the bottom glass is fixed *(Figure 2).* The glass wall is suspended from the 2nd floor slab brackets by thin stainless steel straps, which are hidden in the joint between glass fin and face glass. The glass fin is attached to this strap at splice joint level. The horizontal truss is fixed to this strap at first floor level. The spider, supporting the bottom face glass, is fixed by an injection bolt connection to the bottom of the glass fin. The 22 m long horizontal stainless truss consists of H-shaped single pieces, which are connected by M39 bolts penetrating the glass fin. In vertical direction there is no connection between truss and glass fin in order to allow an independent vertical movement due to temperature dilatation. Rotation of the glass fins is prevented by the spreader arms of the truss elements. The tension rods at the tips of the spreader arms have an additional stabilizing effect. Each truss is supported at four points by props to the first floor slab to reduce the truss cross section.

The face glasses are dead load supported by the splice joint castings of the glass fin, the truss and the spider castings. The bottom glasses are suspended from the spider casting and the second row glasses stand on small legs that are hidden in the horizontal silicone joint.

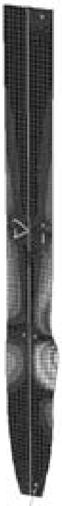
The horizontal wind load is taken by the face glazing and transferred laterally into the glass fin by small aluminium profiles, which are glued onto the glass fins with structural silicone. The bottom glass transfers the wind loads over the two point fixings at the top and the horizontal support at the ground. The glass fin works as a vertical beam supported horizontally at the 2nd floor slab brackets and by the truss. Therefore, the bottom part of the fin works as a cantilever beam.

Vertical building movement and thermal dilatation are compensated by a sliding joint at the bottom of the glass wall. Horizontal movements due to building sway and thermal dilatation are compensated with special sliding joints of the truss, which allow a certain range of free lateral movement and at the same time are able to transfer reaction forces into the RC columns of the building in case of high lateral wind load on the glass fins.

Performance tests were carried out on a test mockup in order to check the air and water tightness, the resistance against wind loads and the deflection under maximum wind loads. Furthermore, fail-safe tests have been carried out in order to check the remaining load carrying capacity after one or both lites of the glass fin are broken.

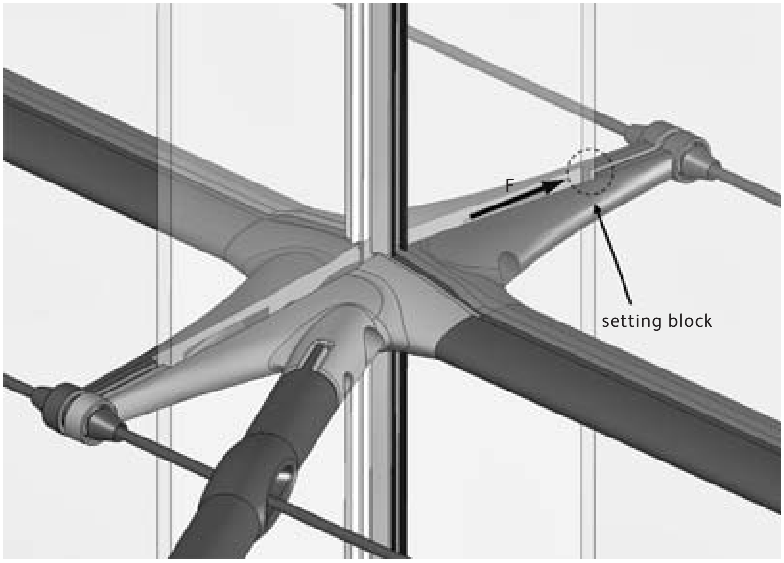
Details: Glass fin splice joint. The glass fin could not be fabricated in one single piece, due to the limited available length of low iron glass at that time. Therefore, it has been decided to place a splice joint connection with an injection bolt connection *(Figure 10)* at a point where the bending moment in the glass fin is small. Nevertheless, the resulting shear force that has to be transferred by the bolts in the joint is up to 42 kN. Position tolerances of the holes in the fully tempered glass fins could be easily compensated with the injection bolt connection. The detail has been studied with a finite element model comprising the glass, the injection mortar (Hilti HIT), the aluminium bushing, the stainless steel bolt and the specific contact conditions between each material. The resulting max. stress around the hole of the glass fin was less than 30 MPa. The glass fins were assembled in a production facility outside Hong Kong and then transported to the building site.

Stability glass fin. The glass fin is subjected to high bending moments and thus had to be checked against lateral torsional buckling. As standards for the design of structural glass elements do not exist in Hong Kong, the Australian Standard AS 1288 has been applied; this is of the few standards containing a calculation method for lateral torsional buckling of glass fins and at the same time accepted by the Hong Kong building authority. Conservatively, the shear stiffness of the SGP interlayer has not been taken into account in the calculation. The critical load factor for buckling of 8.8 was calculated with a finite element model by a linear elastic buckling analysis. *Figure 13* shows the shape of the buckled glass fin with the buckling critical area in the cantilever part of the glass fin just below the truss.

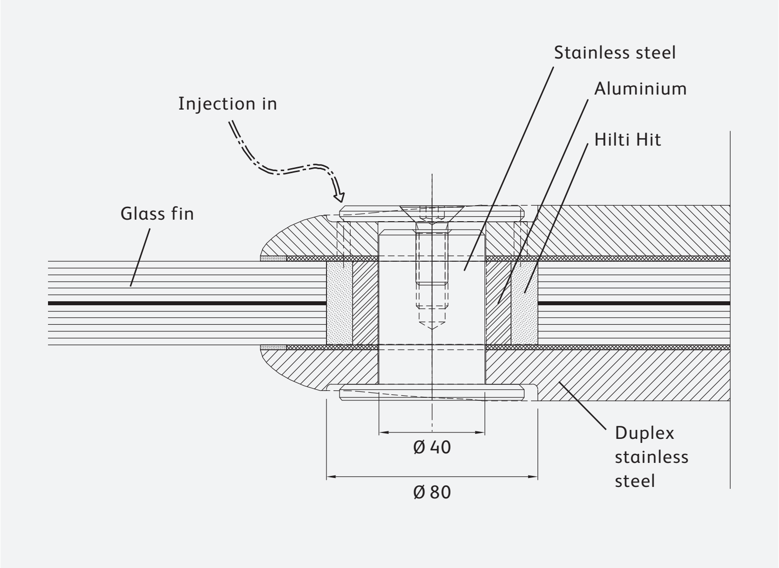


F.12
Lateral torsional buckling model of the glass fin.

Glass fin support at the truss. The biggest part of the horizontal wind load acting on the glass wall is transferred by the glass fin into the horizontal truss. The resulting maximum reaction force is 66 kN which results in compressive stress on the glass edge of 48 MPa due to the small contact area of



F.13
Glass fin support at the truss.



F.14
Splice joint detail.[1]

only 30 x 46 mm. Due to the high compressive strength, this is a minor problem for the glass edge but a considerable problem for the setting block material. Although a solution with an injection mortar *(Figure 9)* would have been ideal with regard to stress concentration, setting blocks made of POM with different thicknesses have been applied in order to allow a free vertical displacement of the glass fin in between the truss spreader arms.

Conclusions

The increasing demand for transparent glass façades and glass structures is a future challenge for façade engineers. While they are familiar with the design of glass in simple window applications, they currently suffer from a lack of standards, safety concepts and suitable methods for the design of structural glass elements. The potential of glass as a structural and, above all, transparent material is high, but further research, e.g. on the strength, on stability problems of glass structures and on new connection techniques, is necessary. An important challenge of glass structures is the strong interaction between architecture, engineering and production techniques and facilities. Therefore, for the success of such projects it is essential that all parties are involved in the design process already at an early stage.

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