Research in Architectural Engineering Series, Volume 10

THE FUTURE ENVELOPE 3

FACADES - THE MAKING OF

edited by Ulrich Knaack and Tillmann Klein

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PREFACE

The association of the book title with the film industry is intentional. A documentary about the creation of a movie can be more exciting than the movie itself. With the background information provided we understand the film and its intention in a different way, and develop a different relationship with it. Once a friend said that that one should never watch the "Making Of" before having seen the movie, but we don't just see ourselves as spectators, but rather as directors in the world of building envelopes. A director needs to master the technique of making films.

An institute for research and education not only has to know the state of the art, it also needs to direct its efforts to explore future developments. At any rate, there seems to be sufficient new material related to facade technology. The requirements keep rising, not only in terms of energy consumption. New materials, foil technology for example, evolve from customized solutions to established systems. New production methods such as rapid manufacturing generate questions about the future of traditional techniques. On one hand, existing methods and technologies are being optimized, and on the other, new ones are finding their way into the market. All of these developments are both a blessing and a curse. Of course they provide unknown possibilities and the term innovation alone makes your heart beat faster, but the developments are also a burden, because they force us to keep pace. We need to comprehend them and react accordingly. The facade is a topic that is and will remain one of the most exciting parts of building technology, and for us the book series "The Future Envelope" is one of the tools to stay on top.

However, it might be interesting for the reader to know that the book is based on an annual conference at our faculty with the same title. It combines research, education and practical application of architecture and facade construction. Professors and students from our partner universities use it as a meeting event. With its accompanying workshops it is a fixed part of the curricula of the Facade Master programs in

Lucerne, Switzerland, Detmold, Germany, and in Delft. Here, the focus lies on practical applicability, which also provides the benefit for the industry. Our goal is not merely to gather and learn what is technologically and scientifically cutting edge, but to create a relationship between those who currently define the business and those who aim to do so in the future.

We thank our partners VMRG and FAECF for their support and the trust they place in our work. We are also grateful to those companies and institutions that have become firm partners in our research activities and are therefore instrumental in the development of the contents of this book.

Ulrich Knaack
Design of Construction
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INTRODUCTION

The goal is to sketch a picture of the future building envelope. Which trends can be seen, what drives these developments and what does that mean in practice? Building envelopes are a broad topic and "The Making Of" refers to all the aspects necessary to produce a facade, from the design to the finished product. This is mirrored by the selection of authors from various disciplines, who contributed to this publication.

The book is divided into four chapters, which will cast a light on areas of future developments from different points of view.

Materials and Technologies

Surely we can expect new developments coming from the area of materials. Acrylics for example are widely used in interior design but not for exterior use. Matthias Michel shows with a number of executed projects what it takes to use this material in facade constructions. The structural designer James O´Calaghan is pushing the limits of the application of structural glass in the Apple Store New York by transferring production technologies from the aerospace industry. Only in the last few years have textile facades developed from experimental projects to an accepted technology. Jan Cremers from SolarNext reports about the latest developments in this field.

New Structural Facade Concepts

The implementation of radical new facade concepts is a big challenge. A chain of inherited dependencies and responsibilities has to be circumnavigated that define the way we are building today. The development of a new suspended facade with load-bearing composite cables is in the focus of Mick Eeckhout's paper. He explains in detail the potential of this approach and the risk bottlenecks that had to be tackled.

The second contribution of Tillmann Klein shows a method to analyse and develop facade structures. A number of student designs are presented that radically depart from the way facades are built today and offer new possibilities.

Industry and Standardization

Today, industrial standards are actually defining the way most facades are built. Jeroen Scheepmakers from Alcoa Architectural Products explains how system suppliers are trying to raise the benchmark for standardized systems. Bert Lieverse is head of the European branch organization for aluminium facade producers. He writes about the experience with a new market concept for the facade industry. How testing becomes an integral part of the implementation of new structures is the third contribution to this chapter by Daniel Meyer from the University of Applied Sciences, Lucerne.

Architecture, Design and Engineering

The constantly rising requirements for energy saving and user comfort, lead to the use of new design tools for simulation and calculation and inevitably to a stronger integrated design approach. In order to illustrate an exemplary design approach, the architect Oliver Kühn uses the new headquarter building for the Süddeutsche Zeitung as a case study. Jan Knippers shows the role of the structural engineer while designing glazed grid shells. In the final contribution "Form follows Energy", Brian Cody explains how he sees new design parameters emerging.

Structural engineer **Dipl.-Ing. Matthias Michel** is specialist in steel constructions, digital workflow and 3 dimensional geometric structures. He is co-founder of the office imagine-structure. During his career he was responsible for the structural design from large scale buildings down to the level of sculptures. Especially the examples about acrylics he is showing in his paper where first used by him for the design of trade fair stands and later with this experience transferred into architectural applications.

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ACRYLIC FACADES - THREE CASE STUDIES

Matthias Michel

Imagine Structure / Structural Design

Introduction

Poly(methyl 2-methylpropenoate) is known as PMMA, Plexiglas, Perspex or just acrylic. Acrylic glass is a wide spread substitute to glass, having excellent optical behavior, low tendency to splitter, light weight, good chemical resistance and so on.

In many kinds of products acrylic has taken the place of glass long ago. How about facades? The choice of transparent materials in buildings is focused on glass. A low price, durable surface and inflammability are key advantages of glass. The pros of acrylic like noise protection, robustness and low weight do not trump the benefits of glass – today.

For advanced building application acrylic offers features that glass cannot provide. Good deformability without loss of optical qualities is only one oft the advantages of acrylic. Easy machining like CNC cutting or CNC engraving of light directing textures, uncomplicated use as structurally activated building members and the possibility to integrate active electronic devices are features of acrylic that are rarely exploit – today.

In the following paper, I present three projects focused on the work with the material acrylic from the technical and structural point of view. It reflects a personal learning process, beginning with acrylic as a nonstructural cladding and closing with the self-supporting transparent shell structure made of acrylic.

Case I – BMW Clean energy Bubble

The Clean Energy Bubble designed by Bernhard Franken for the International Automobile Ausstellung in Frankfurt 1999 resulted from a two-year-old design, a won competition for the same event 1997. However, it was not realized until BMW's automotive design was found to be conservative and out fashioned, so a progressive architectural language should help to polish the companies image and to introduce their hydrogen technology. The Bubble contained an exhibition of the upcoming technology without showing any car in the vicinity.

The project was realized under very limited time conditions and the planning team suffered through an abrupt change of the structural concept and a complete recommencement of production a few weeks before the exhibition's opening. For the first concept a totally self-supporting acrylic shell without supporting primary structure was planned. The second concept featured a primary aluminum structure of flat aluminum ribs with 8 mm acrylic panels as cladding.

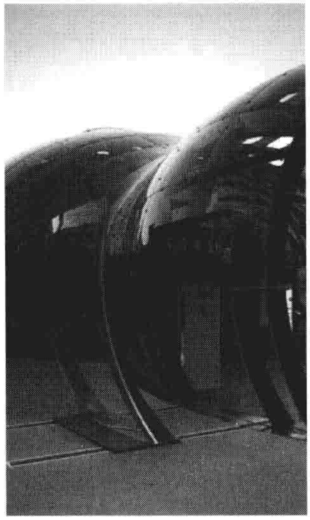

Fig. 1
One of the hardest to solve design questions was how to enter the Bubble
Image: Bollinger + Grohmann, Matthias Michel

The first concept

The architectural form of two water droplets merging into each other showed qualities to be realized as a self supporting shell. The structural analysis resulted in a stress level low enough to try a realization by using acrylic panels that are glued together from individual pieces.

The acrylic panels of 25 mm thickness were heat formed over cnc-milled foam blocks and cooled outside the fabrication site. After cooling, the foam block was milled down to the next geometry and reused.

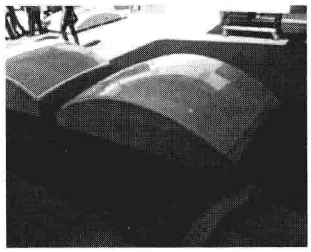

Fig. 2
The panels were deformed on milled foam blocks
Image: Bollinger + Grohmann, Matthias Michel

The panels were trimmed by a 5-axis router and prepared for bonding. However, it was found that the manufacturer was not able to comply with the demands for optical and structural quality at all.

The issues that finally lead to a full stop of the manufacturing were lack of continuity of the surface and bondage strength. The curvature of the individual panels changed after production because of internal stresses, which resulted from a rapid cooling after deformation and the difference between the inner and outer surface temperature during the cooling.

The bonding was made by a polymerization process in order to join two pieces in a similar way like welding. The same material is used as glue and the same process is applied to cure the seam as it is used to produce the adjacent parts themselves. However the process does not require heat. The strong shrinkage of the glued seam results in high internal stress around the seam. Tempering the seam will relieve these stresses. As a controlled polymerization and especially the tempering is difficult to be accomplished in situ, the test results of the bonds were below expectations.

Second Concept

Due to the poor results in manufacturing and with no time to start all over with a different manufacturer, the second concept was created.

The outer shells surface was sliced along a one meter rectangular grid. The ribs result from this projection process. They consisted of three layers of 8 mm aluminum sheets, with two of them being structurally required and one to allow gaps. Each layer of the ribs was individually intersected with the master surface resulting in a stepped outer edge, that adapts better to the facades curvature, also in cases of glancing intersections between rib and skin.

Fig. 3
The cladding finally was 8mm thick warm formed acrylic
Image: Bollinger + Grohmann, Matthias Michel

The cladding was now manufactured from 8 mm acrylic sheets that were held on the ribs by individual small bars, bolted into the narrow side of the aluminum. For the doors 25 mm panels were used, mounted on rails to slide out.

The BMW Bubble is an archetype of the digital architecture because of it's form. It's materials and because it's simplicity of construction, finally resulting from a lack of time to become more complex.

The crucial experience made in this project:

- Heat forming acrylic requires a good amount of production time and experience. Cooling must be slow.
- Compensation of the mould's geometry is required to obtain a good surface continuity in the case of thick panels.
- The use of glue to bond complex curved panels along their edges may be considered as extremely difficult especially if structural qualities are wanted.

Case II – Kunsthaus Graz Skin

The early design concept of Peter Coock and Colinf Fournier for the Kunsthaus Graz featured a multifunctional facade with a many features like transparency or media effects. In accordance to the many functions the facade was named "skin" by the architects.

During planning of the skin some features were omitted while others survived. Finally the technical demands for the outer skin cladding material crystallized:

- The skin should be translucent and of high quality surface finish
- The outer skin was designed to be elevated over the water proving inner skin
- It should be realized by point supported panels of individual form and size
- The facade had to withstand high snow- and wind loads
- Temperatures were expected to be very high on the top of the building
- The shell material was supposed to be flame retardant or fire resistant
- The lifetime of the shell was required to be at least 20 years

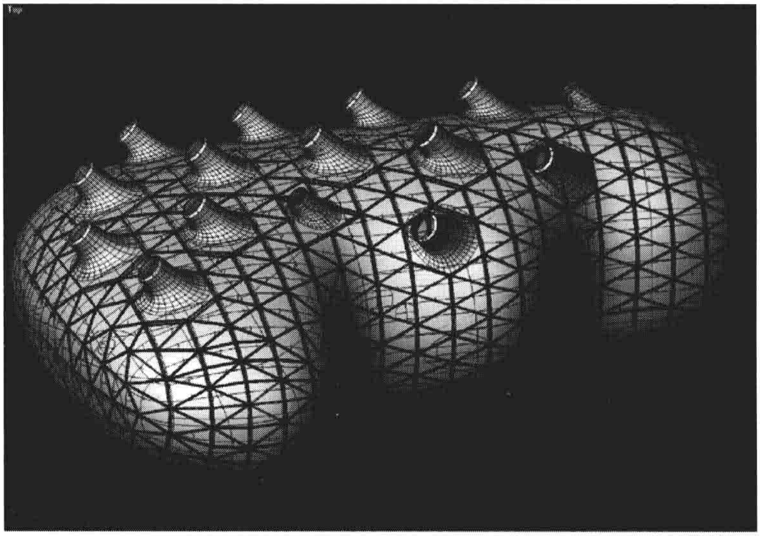

Fig. 4
The structure's geometry was derived from the panel size of the acrylic
Image: Bollinger + Grohmann, Matthias Michel

Soon in was evident that the demands would bring any material at it's technical limits. And it became obvious that there would be no material on the market to meet all requirements.

Although acrylic was the favoured material, research was done towards thermoplalstics as well as duroplastics. The latter, like composite of polyester resin and glass fiber, are better suitable to the demands than thermoplastics like acrylic. A semi transparent composite panel was developed by a company in Germany for the project, that was temperature resistant enough, hat good mechanical qualities and a B1 fire retardant certificate. Unfortunately the material did not meet the budget, so the realization process finally focused on the acrylic.

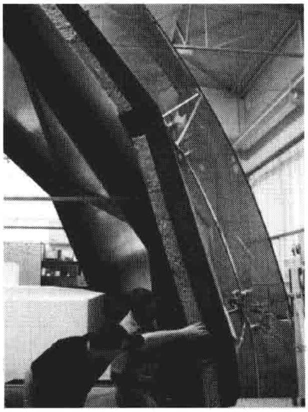

Fig. 5
The acrylic skin covers a triangular steel structure
Image: Bollinger + Grohmann, Matthias Michel

Engineering the acrylic

All geometric dimensions of the skin and it's structure were limited by the maximum available panel size of acrylic, resulting in standard panel sizes of about 1,40 by 2,80 meters. Every panel is point supported at six spots in a two by three layout. Because of this statically indeterminate support, the panel is under strain if it's inside and outside temperature differ, causing it to flex like a bimetal.

As the skin is elevated over the roof seal by ca. 40 cm, temperatures as high as 80°C in the space between were predicted at the flat roof top, resulting in a temperature range of 100°C that hat to be taken into account for planning. Temperature differences between inside and outside layer were expected to be about 40°C, leading to a significant deformation of the panels and evoking the strain mentioned above. Acrylic tends – as every thermoplastic material – to relaxation, meaning that persisting loads result in a persisting deformation. The tendency to relaxation is more critical under high temperatures.

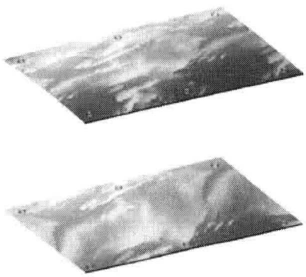

Fig. 6
The effect of long-term relaxation was visualized by raytracing a cloud map on a surface, that is deformed according to the finite elemente analsysis' results
Image: Bollinger + Grohmann, Matthias Michel

The admissible stress in the material depends on the time of exposure to a load and it depends on the temperature range. The admissible stress for persistent loads was found to be about 10% of the breaking strength without risking relaxation. For initial dimensioning values about 5 KN/cm2 for permanent loads and 1,3 kN/cm2 for short term loads can be used as admissible design stress for cast acrylic sheets. Cast acrylic material should be preferred because extruded material is not as durable but more sensitive to chemical exposure.

No fire retardant certificate (i.e. "B1" according to German standard) can be obtained for acrylic sheet products. The material is flammable particularly on the edges. For some flame retarding effect, chlorines are added to the acrylic mixture that was developed for the skin. This is also practiced for the material of noise protection walls. As a side effect, chlorine reduces the temperature resistance and the mechanical strength of acrylic. It is also said to reduce the lifespan of the material.

Finding the right properties

Testing was made to adjust the parameters of the customized acrylic for the skin to get the maximum of flame retardant substances without taking risk concerning the thermal and mechanical stability.

Once a specimen was produced and a data sheet was issued, a test of inflammability was made.

Finally, to ensure the mechanical properties, the flame retardant substances were reduced to a minimum, resulting in a material that did not fully satisfy the fire police. In the fire department's test, the acrylic would continue to burn on the back, inside the facade's interspace, after extinguishing with water from outside. A fully automatic sprinkler system was installed with outlets on both sides of the acrylic. Although costs of a sprinkler system have a substantial effect on every project's budget, in this case the additional costs of the facade were less than 5%.

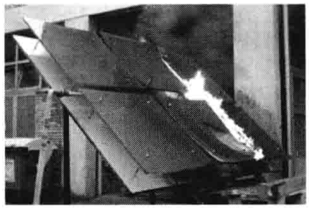

Fig. 7
After extinguishing this mockup from the outside, the inner side would continue to burn
Image: Bollinger + Grohmann, Matthias Michel

Once the material configuration was set up it took long term testing to judge the effects of extreme heat and shock cooling on the quantity of relaxation, that may result from the strained support arrangement of a heated panel.

In 100 cycles a hot summer day with 80°C material temperature was simulated. At the end of each heating cycle the specimen, that was clamped in the test arrangement in a strained way and set under load, was shock cooled on one surface like a sudden thunderstorm rain or hail would cool the outside surface of a panel while the inner side remains hot.

The first test cycles produced most of the lasting deformation, that was abating with every cycle. Based on the test's data the persistent deformation could be estimated and visualized by the use of a lower Young's modulus in the analysis model. The resulting deformation under permanent loads was transferred to a ray tracing software. The rendering of the distortions of a cloud reflection was used as a decision-making aid for the clients whether the amount of relaxation is acceptable.

Point supports

The design of the point supports – brought in by the contractor – features a rather basic technology that finally did it's job. However, the participants probably would decide to keep more influence on the contractors planning in a future project.

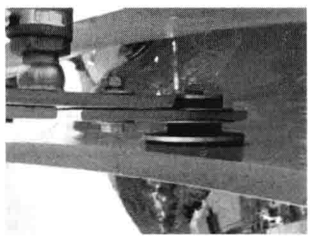

Fig. 8
The point holder assembly as it was realized by the contractor
Image: ARGE Kunsthaus, Schiffer

The dimensioning of the point supports was based in the knowledge and the analysis results of the material study and lead to rather large diameters of the point holder base and the countersunk head plate. The edges of the countersink have a parabolic rim section to minimize the stress and the risk of cracks.

To avoid strain around the point supports, dual layer EPDM elastic point supports were chosen. Thermal expansion was calculated to be about +- 6 mm. As the support's diameter was large enough, slotted holes were cut directly into the support's arm. The degrees of freedom were arranged similar to point supported glass facades.

The facade was finished in 2003 and is in good shape until today, after more than fife years, with no panel having been replaced yet, although all kinds of extreme weather condition showed up in the recent years.

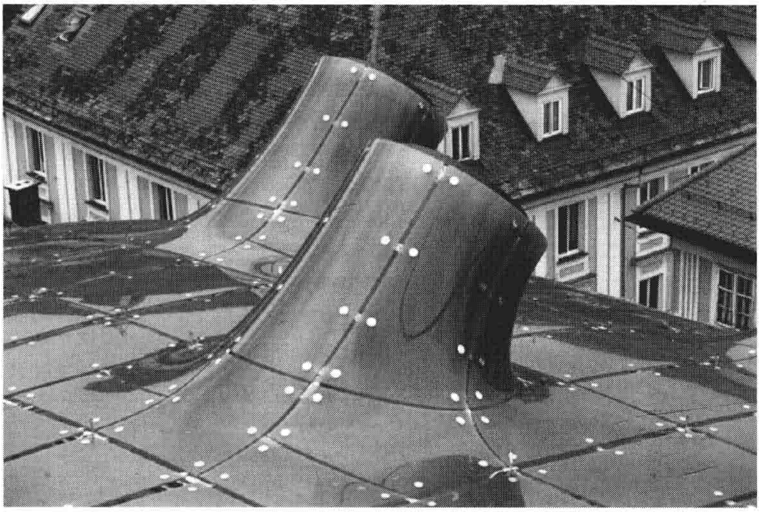

Fig. 9
Forming the nozzles from 25 mm strong acrylic was demanding for the manufacturer

The crucial experience made in this project

- Flame retardant modification and structural qualities difficult to combine – especially under hot conditions
- Strained support arrangement of facade panels should be avoided
- Special care must be taken in the design of point supports
- Thermal expansion of acrylic is often underestimated
- Expect the presence of a sprinkler system if large amounts of acrylic are used in a building project (also the Bubble had a sprinkler system)

Case III – BMW Hourglass for 7 Series Presentation

The knowledge gained by the two preceding cases resulted in the solution found for the BMW 7 series hour glass.

The hour glass debuted summer 2008 at the Red Square in Moscow. A 7-series car was suspended in the upper half, covered with "sand" that ran out continuously, giving view to the new car.