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Stretch controlled shading capabilities of special elastomeric silicone films

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ABSTRACT

A hitherto unexploited effect: the reversible stretch-induced change of translucency and transparency of certain silicone materials is experimentally investigated with regard to an application in a new type of shading system for biaxial bent, free-form building envelopes. In a first step the silicone raw materials showing the effect are processed into membrane shape and the stretch-dependent optical characteristics of the silicone film samples are examined. Shading effects are measured during cyclic and longterm uniaxial tension tests. For multiaxial loading conditions, as appearing in planar biaxial tension tests with cross shaped specimens and bulge tests with inflated circular specimens, optical inhomogeneity effects due to locally varying elongations are documented. Further results concerning a variable transparency depending on the distance of the observer and an object behind the membrane are discussed. A conceptual application of the materials into translucent facades for shading purposes is presented. The closed cavity concept of planar stretched films located between window screens and the implementation of silicone films as inflatable shading structures are discussed. Furthermore the advantages of silicone films in these kinds of cladding types are pointed out, as typical problems i.e. fogging and high-temperature stability pose no major issue.

Keywords: silicone, film, shading, stretch, facade, window.

1 INTRODUCTION

In facades of residential and office buildings sun shading systems are installed to prevent excessive insolation associated with heating and dazzling effects. By regulating the transmittance of sun light the ambient lighting can be controlled. The technical boundary conditions of present shading systems limit the design of free-form building envelopes, because the drapability of slatted blinds and roller blinds is thus far unidimensional [1, 2, 3, 4, 5].

Starting point for extending the design space of shading systems into biaxial bent surfaces was the discovery of a reversible effect: certain transparent silicones change their colour into pure white when stretched. Thereof the idea was developed to install thin silicone shading membranes in closed window cavities and to change their optical properties in a controlled manner due to mechanically or pneumatically caused stretching. In the following material, its performance and possible application scenarios are exemplarily presented.

2 MATERIALS

The effect of strain induced transparency change was first discovered on a commercial silicone product of unknown source. Through producer and material screening two silicone producers were found who knew about the effect and three materials could be identified for further examination. A proven theory explaining the effect is hitherto unknown to the authors. The silicone materials have in common, that they are filled and peroxide crosslinked. Since the phenomenon only could be observed on filled materials the assumption exists that the filling is responsible for the effect. At first the producers delivered the materials in highly viscous blocks of silicone, blended with a crosslinking agent. Later crosslinking agents were exchanged and adapted to an individual industrial production method based on solving the silicone block with petroleum. The following findings refer to the material Wacker, CENUSIL R360.

3 DEVELOPMENT OF FILMS

The production of test specimen was carried out in a vacuum press. A lump of silicone was placed between two massive steel plates and flattened to a circular cake with a diameter of 70 cm. 250 μm thick Teflon membranes were used as abherent. The silicone film thickness was 1 mm in the centre of the cake and decreased continually to 0,2 mm at the edges. The parameters of the production process were:

Compressive force:	4500 kN
Steel plate area:	max. 1 m^2
Abs. pressure evacuated:	200 mbar
Heating-up time:	30 min
Temperature holding:	160 °C, 15 min
Cooling time:	15 min.

The produced silicone film was transparent. Under tensile stress, which led to high strain, the transparency decreased as expected and the silicone turned white while remaining translucent. After unloading and elastic recovery the film again turned transparent.

By admixing petrol to the silicone, the viscosity was reduced to the extent, that sheets with a thickness of 50 to 200 μm could be produced, through transfer coating the dissolved silicone onto a Teflon membrane with a doctor blade. Due to deficient film quality, leading to early film rupture at high strain, a survey of the properties thus far has only been conducted for samples produced in the press.

4 MECHANICAL PROPERTIES

The mechanical properties were determined by uniaxial tensile testing on a universal testing machine Zwick Z 020. New samples reached tensile strains at break > 600%, which dropped to a value of 300% after 1000 load cycles ranging between 0 and 200% strain. The visual impression of maximum whiteness occurred at a strain of approximately 130%. On a new material the necessary tensile stress to reach a strain of 100% is 1,4 N/mm^2. Cyclic loading of the specimens led to a load drop of 30% in the first cycle and progressively another 20% during the following 999 load cycles. In clamped condition, strained to 100% for one hour, the stress relaxed to 78%.

As the exploitation of the optical effect requires considerable strains, lateral contraction gains importance for determining the strain dependent area of the silicone shading membrane. The lateral contraction of a slender, 200 mm long and 50 mm wide specimen decreased linearly from 0,42 at a strain of 20% towards 0,31 at a strain of 100%. On membrane panels with lower slenderness ratios, the obstruction of the lateral contraction exerted by the rigid clamping increases, leading the free edges to be bent.

The strip tensile test revealed residual strain in the specimen. Cyclic loading with growing strain showed proportionality between residual and applied strain. A yield point could not be identified. The residual strain was 4% for samples strained to 100%.

5 OPTICAL PROPERTIES

5.1 VISUAL EFFECTS

The visibility of a high-contrast image, placed 23 mm behind the silicone film constantly decreased with the films strain. An abrupt change of transparency due to stretching was not observed.

Figure 1: Image located 23 mm behind the silicone film strained to 6,67%, 53,33% and 100,00%.

Source: DITF Denkendorf

The transparency as depicted in figure 1 is only achieved for objects located close behind the film, since the visual effect depends on the distances as well between the object and the film, as between the observer and the film. In an unstrained condition the silicone film appears transparent for an image-film distance of 0 to 100 mm. At a distance of 400 mm the background image appears completely blurred and opaque for recognizing details.

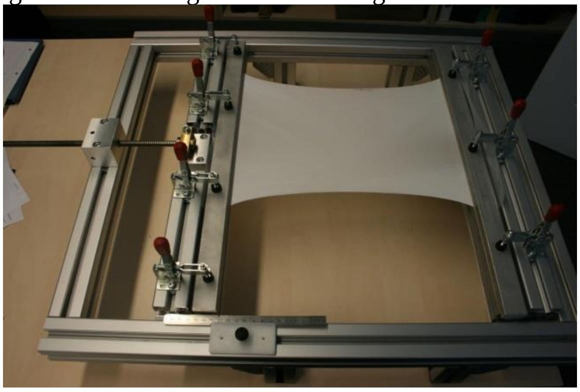
In reverse a 106% strained film appears opaque and pure white to the observer except for one occasion. When the image touches the film and the distance becomes 0 mm, despite stretching, full transparency is given.

It can therefore be concluded, that light scattering plays a decisive role in the visible whitening effect. Consequently the measurement of the stretch induced translucency was of interest for inquiring, whether the light scattering goes along with a shading effect.

5.2 SHADING PERFORMANCE

To prove the shading effect, a silicone film with a thickness of 700 µm and the dimensions 180 mm x 280 mm was strained in a uniaxial stretching frame and the transmitted sunlight was measured with a global radiation measuring head including three integrating sensors. The spectral sensitivities were: UV-A (310 – 400 nm), VIS (360 – 760 nm) and NIR (700 – 1100 nm).

Figure 2: Stretching frame measuring 500 mm x 450 mm



Source: DITF Denkendorf

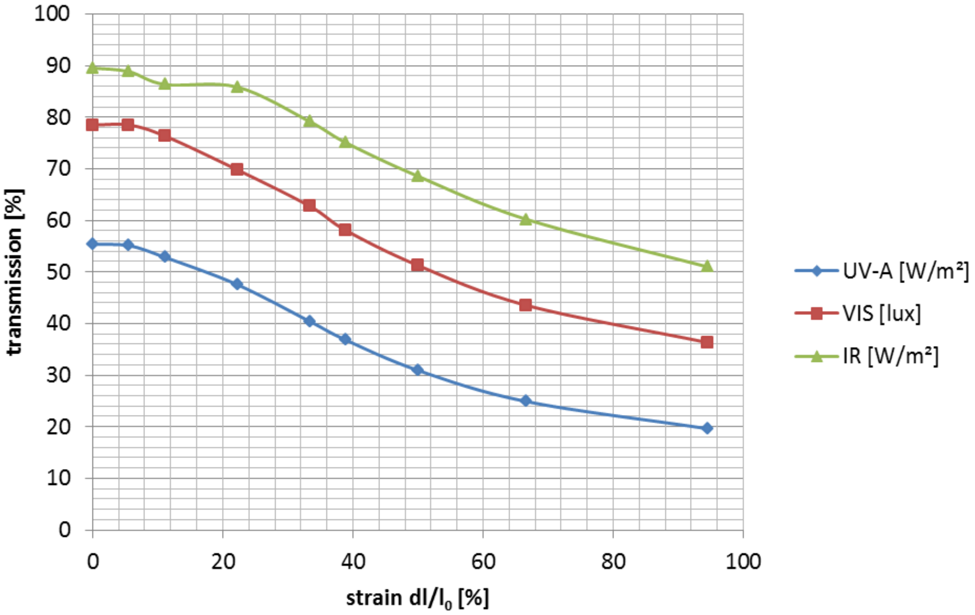
Compared to the unshaded measuring head a clear, negative correlation appeared between strain and transmission in all radiation ranges: UV-A, visible light (VIS) and near infrared light (NIR). An abrupt change of translucency has not been observed. For the strain of 0% and 100% the reflexion and transmission were measured with an IR-spectrometer (Bruker, Vertex 80).

The optical properties of the unstretched film are as shown in figure 4. The VIS region is highly translucent (80%). In the NIR region the translucency drops from 85 to 5%, whereas the absorption increases from 10 to 95%.

The optical properties of the 100% stretched film are as shown in figure 5. The reflection increases to 60% due to the stretch-dependent white colouring, whilst the transmission decreases.

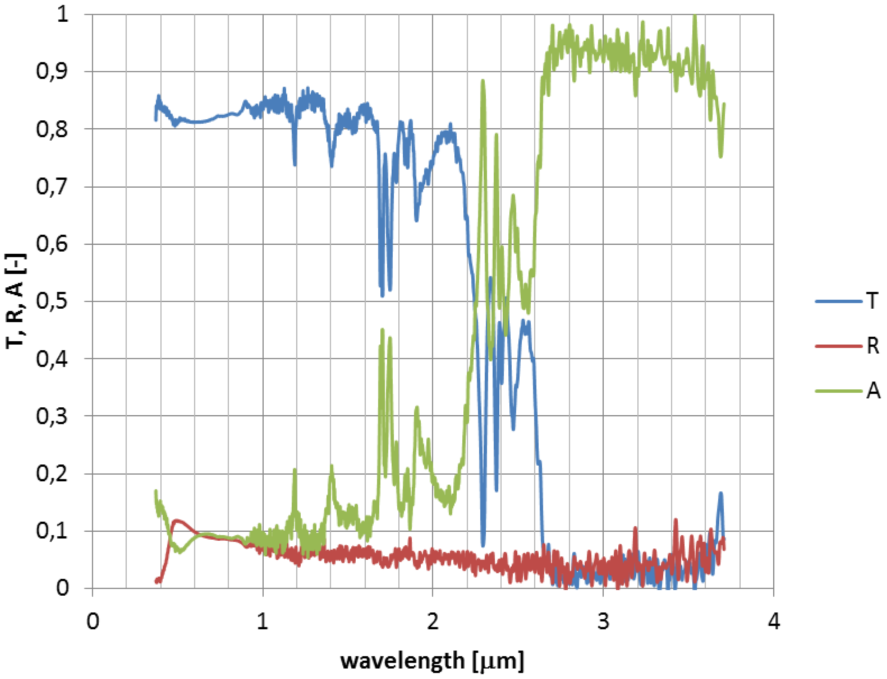
The ratio of the stretched to the unstretched optical properties in dependence of the wavelength is depicted in figure 6. The transmission is reduced to 50% by stretching, whilst the NIR absorption doubles and the reflection increases by a factor of 3 to 6.

Figure 3: Transmission of sunlight through 700 μm thick silicone film versus strain



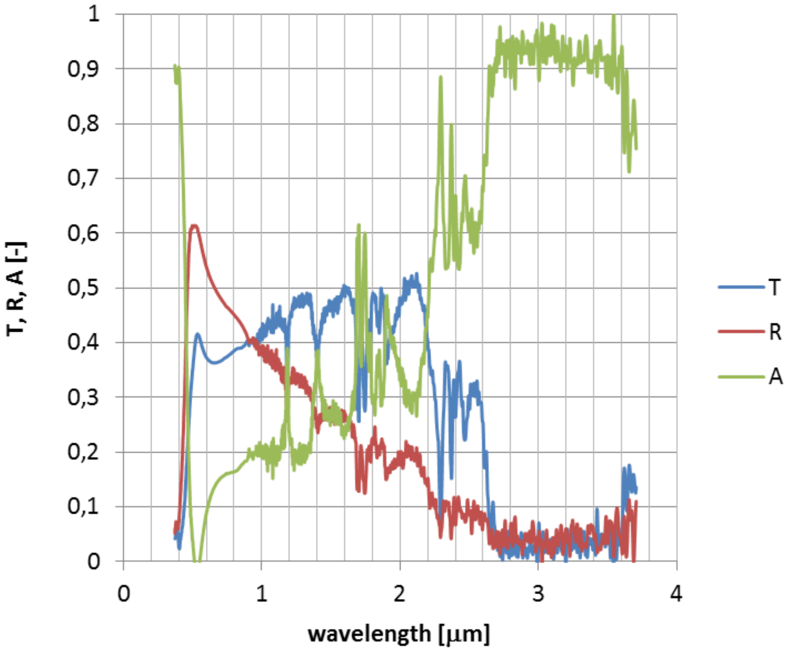
Source: DITF Denkendorf

Figure 4: Optical properties of the unstretched film: transmission T, reflection R and absorption A in dependence of the wavelength



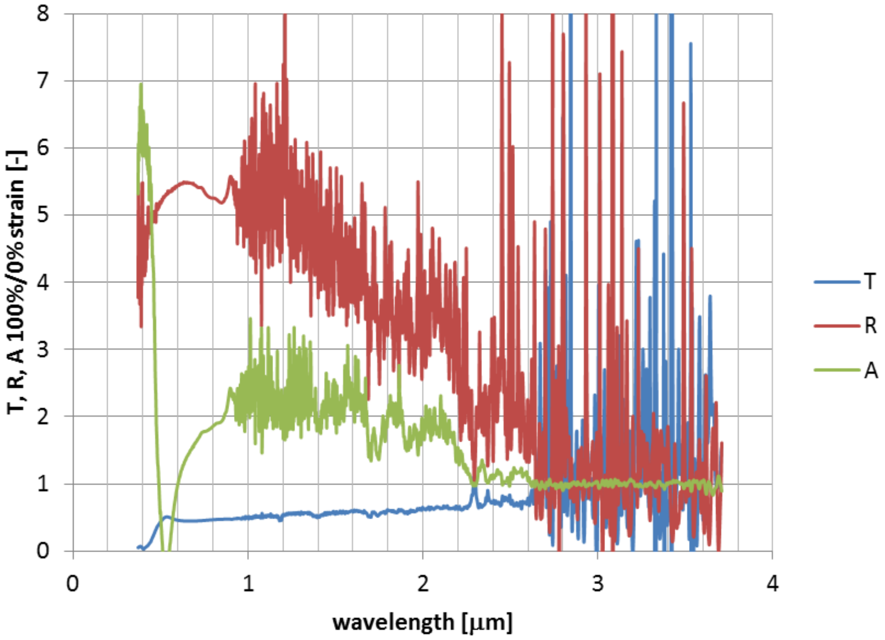
Source: DITF Denkendorf

Figure 5: Optical properties of the 100% stretched film: transmission T, reflection R and absorption A in dependence of the wavelength



Source: DITF Denkendorf

Figure 6: Ratio of the optical properties 100% stretched to unstretched film: transmission T, reflection R and absorption A in dependence of the wavelength

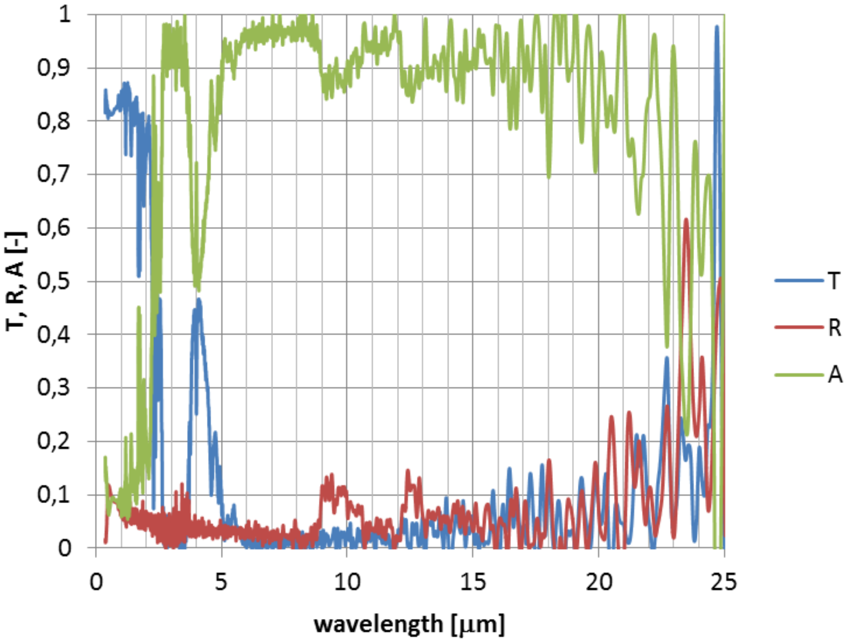


Source: DITF Denkendorf

The stretching of the film does not affect the optical properties in the middle infrared region (MIR) as shown in figure 9. The radiation is largely absorbed as depicted in figures 7 and 8. The IR emission coefficient ε_{IR} = 0,88.

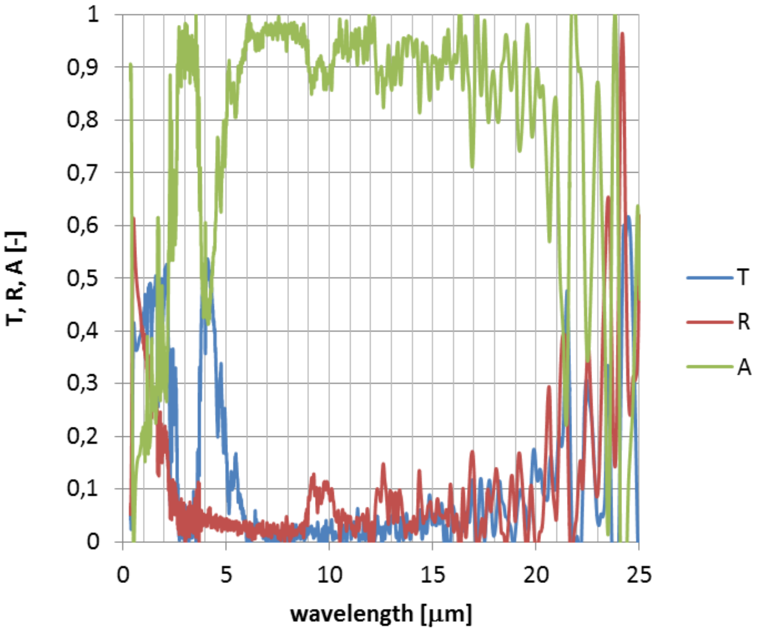
Figure 2 was taken after 5 weeks, clamped at 100% strain. A decrease in whiteness was not detected. The transmission measurement of figure 3 was conducted after the 5 weeks in strained condition. After elastic recovery the film was transparent. Visual time-dependent effects have not been observed. The white effect is long-lasting and reversible.

Figure 7: Optical properties of the unstretched film: transmission T, reflection R and absorption A in dependence of the wavelength



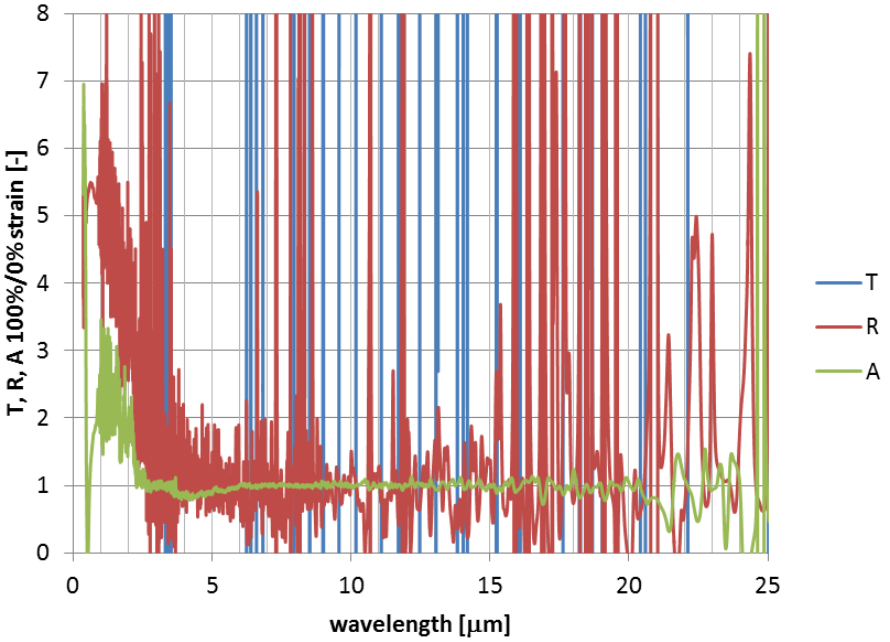
Source: DITF Denkendorf

Figure 8: Optical properties of the 100% stretched film: transmission T, reflection R and absorption A in dependence of the wavelength



Source: DITF Denkendorf

Figure 9: Ratio of the optical properties 100% stretched to unstretched film: transmission T, reflection R and absorption A in dependence of the wavelength



Source: DITF Denkendorf

6 BIAXIAL STRETCHING

Two basic well-known procedures for stretching the film biaxially were tested for changing the optical properties: pneumatic pre-tensioning within a rigid boundary and mechanical pre-tensioning with moving edge supports.

The pneumatic pre-tensioning was effected in a bulge test with a clamp-opening diameter of 150 mm. The rigid edge prevents transverse contraction. The first whitening appears hence at the apex as shown in figure 10. By further inflation, the whitening extends over a larger dome area, but variable shades of white remain, as shown in figure 11. An application of the film in a pneumatic pillow will thus lead to uneven shading. If the whitening of the apex is valued as uncomplete, then inflation requires higher strains than uniaxial tensioning for the same shading effect.

Figure 10: Sample of Wacker R360 inflated to an apex stretching of 86%

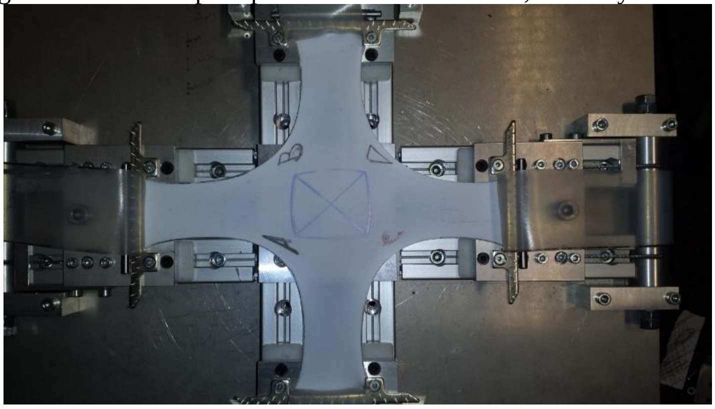
Source: DITF Denkendorf

Figure 11: Sample of Wacker R360 inflated to an apex stretching of 135%

Source: DITF Denkendorf

The mechanical biaxial pretensioning was exerted on a cross shaped specimen with film arm widths of 50 mm. Because of the limited moving range of the test facilitiy, the film was clamped in pre-tensioned condition. The first marked whitening effect occured at the curved junction of the arms of the cross, then was extended to a circle surrounding the center, which became white at last. As can be seen by the distortion of the markings, the strain is unevenly distributed. The whitening strain of the diagonals of the square marking was 43%. The strain in vertical direction was 52 to 68% . The strain in horizontal direction was 32 to 52%. An even whitening effect could not be achieved at mean strains in the cross-shaped. specimens, but the necessary strain for coloring the specimen pure white could be halved.

Figure 12: Cross shaped specimen of Wacker R360, biaxially tensioned



Source: DITF Denkendorf

7 CLOSED CAVITY CONCEPT

LEICHT's research focused on integrating enclosed membrane elements into tessellated facade designs. The installation of the silicone shading mechanism inside of a closed cavity leads to a better control of the films surface environment. Translucent materials, which are more robust to environmental impacts act as exterior protection layers and provide the covering of the enclosure. Window glass for example possesses a smaller reactivity to mechanical weather influences, has better puncture resistance and shows less dirt adherence.

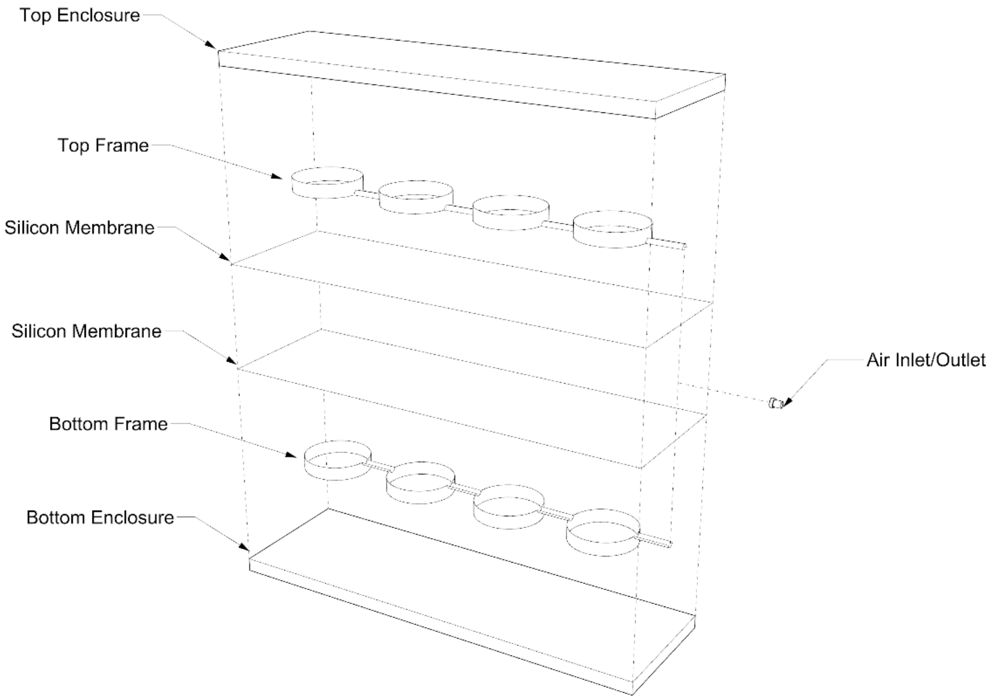
The results of the design studies are, that pneumatic inflation is the simplest and most reliable way of imposing and maintaining the necessary deformation of the silicone film, since only hose lines and air pumps are necessary for its actuation and; that an alternative possibility, the mechanical stretching through moving edge supports, requires relatively complex and delicate mechanisms in order to fully exploit the effect.

A simplified pneumatic design can be seen in the exploded view of figure 13. The two silicon membranes that form the basis of the shading system are installed between two stiff frames, that permanently seal off the pressurized inflatable. The films immediate environment is again separated from the outer environment by two transparent panels. The lateral enclosing system, which is necessary to fix all of the planar elements, is not depicted.

Particularly closed cavities with small spans allow an integration of the inflatable silicone films into transparent architectural design elements and can provide an aesthetic gain for a structural solution. The inflatable surfaces do not have to be planar. An adaption of the concept to curved enclosures with a multitude of membrane setups is conceivable. The vast array of possible designs based on the proposed concept still needs full exploitation.

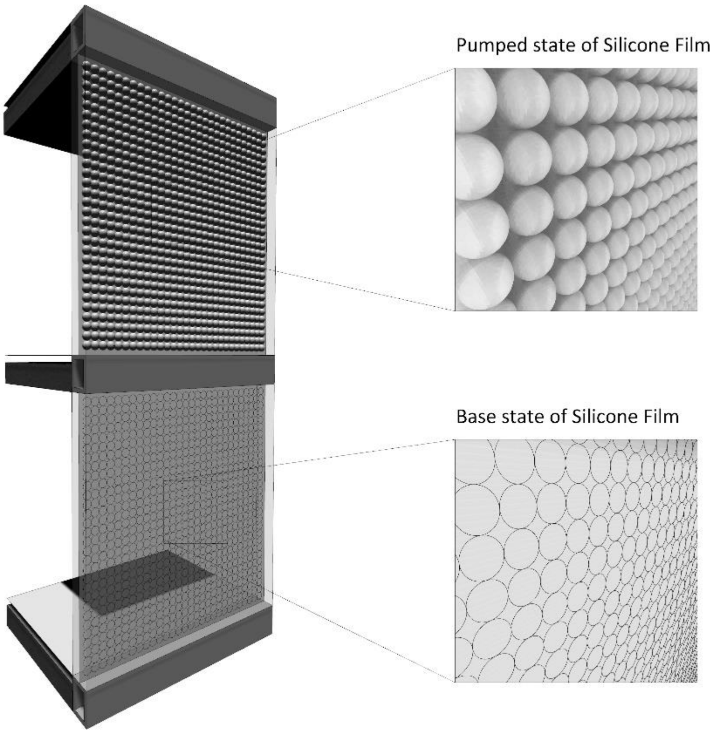
For a practical, more in-depth approach, larger film samples are needed. The lack of large-scale production methods able to produce larger silicone film samples with reproducible optical and qualitatively valuable mechanical properties at date still poses a significant obstacle to the advancement of the concept.

Figure 13: Exploded view of base closed cavity configuration.



Source: Leicht structural engineering and specialist

Figure 14: Rendered view of the possible façade application with closed cavities.



Source: Leicht structural engineering and specialist

8 CONCLUSION

Up to now, unexploited shading effects were presented, by using a specific raw silicone product (Wacker R360), producing small film samples and quantifying their mechanical and optical properties in several test setups. Further, a possible application was explained.

On the basis of the published performance values, alternative application concepts can be developed. The presented prototypical production of silicone films only allows for building small-scale demonstrators. For an implementation into building facades, the industrial production of silicone films has to be advanced. In order to modify the films properties purposely and develop a broad range of similar materials, future research directed towards the understanding of the physical mechanism is needed.

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