Introduction

Openwork blinds, wooden lattices, louvres, sunshields of all sorts are traditional construction elements of the building envelope, anywhere on Earth.

These elements often combine various functions beyond solar protection itself. In hot countries particularly, they form a breathing fence for the accommodation. Most of them are still made of wood.

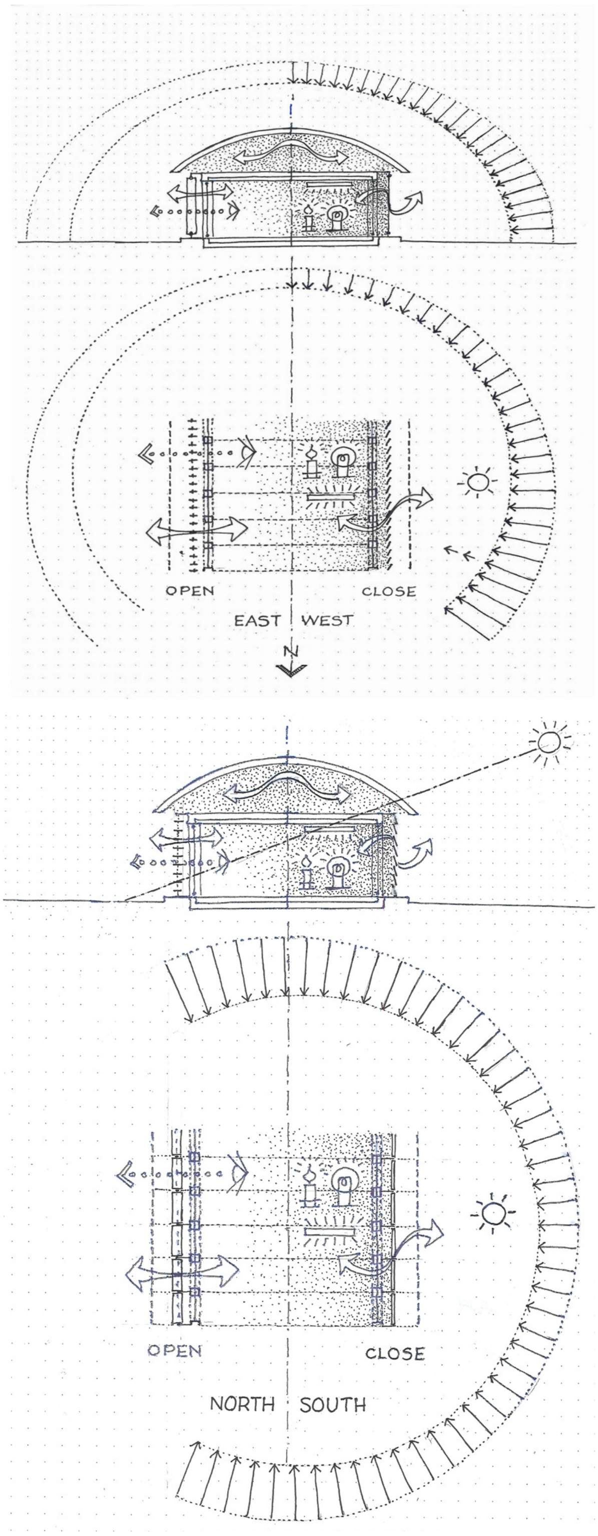


Figure 1

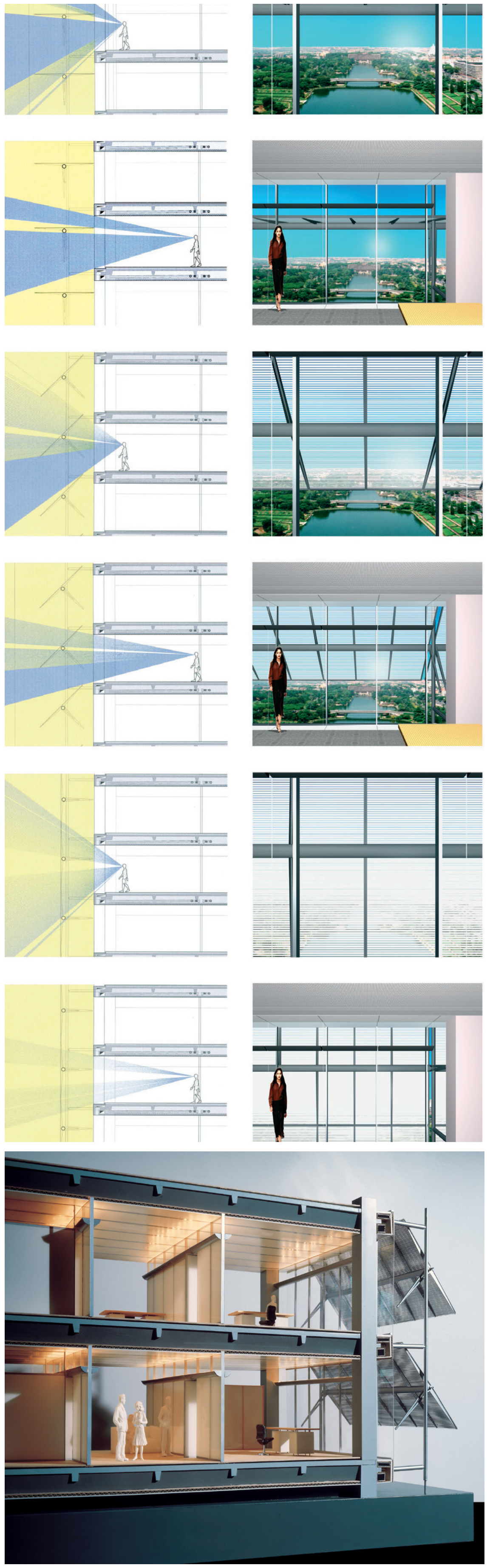
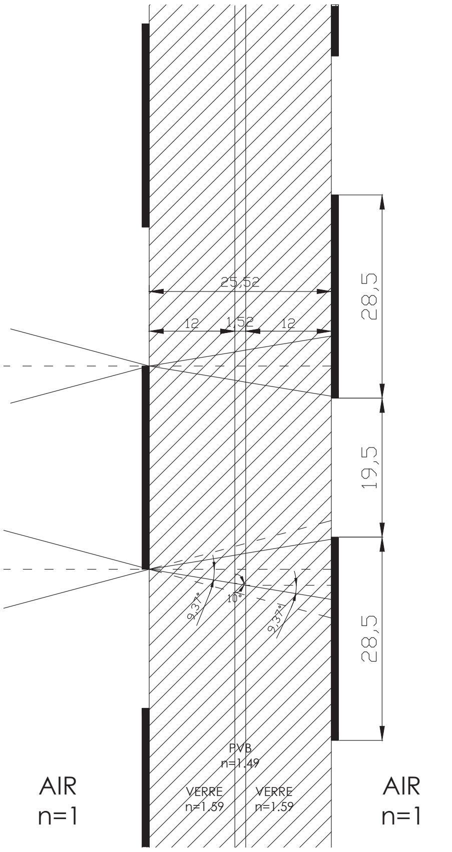
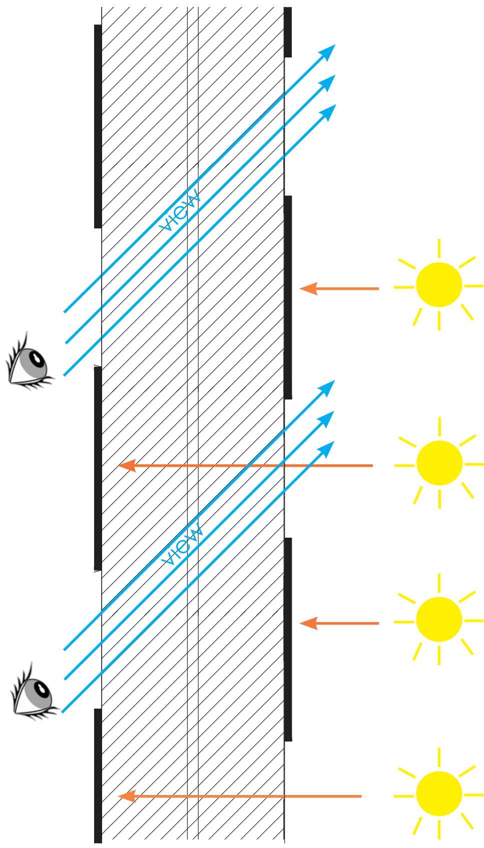


Figure 2



2013-01-07 - Definitive drawing for AGC:
dimensions of the silkscreened vertical louvres.



Maximum visual transparency through the louvre:
(19.5/48) x (0.907 TL) = 33.35%

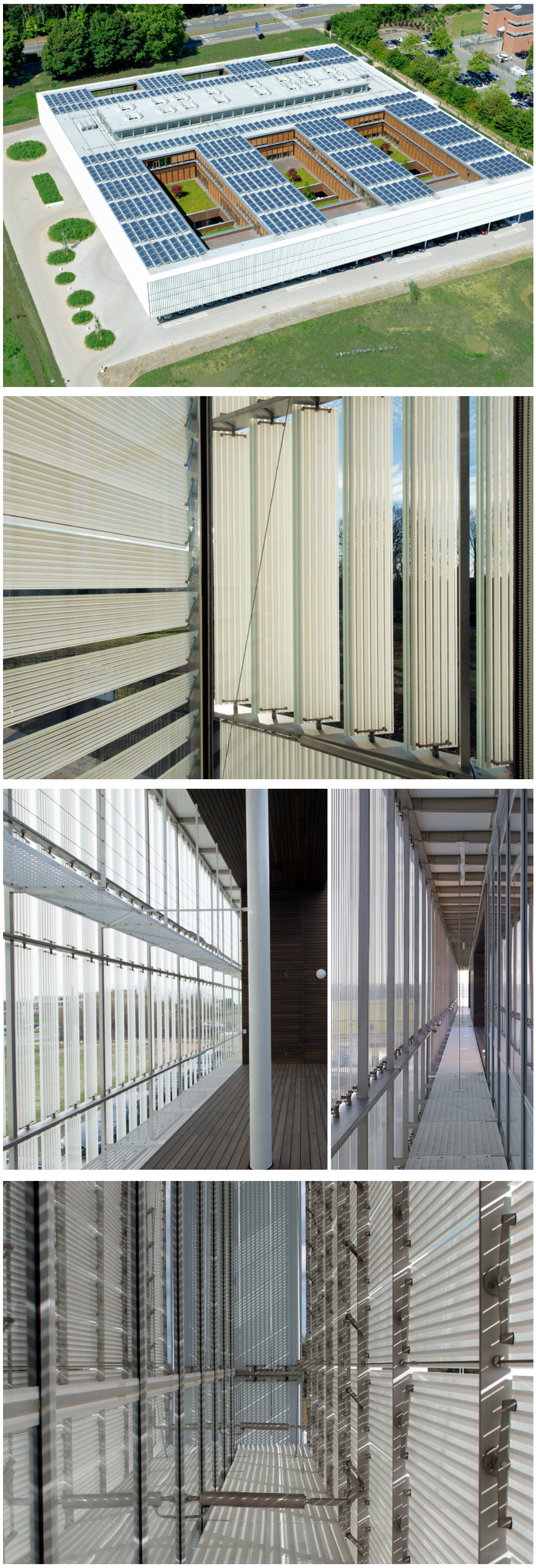
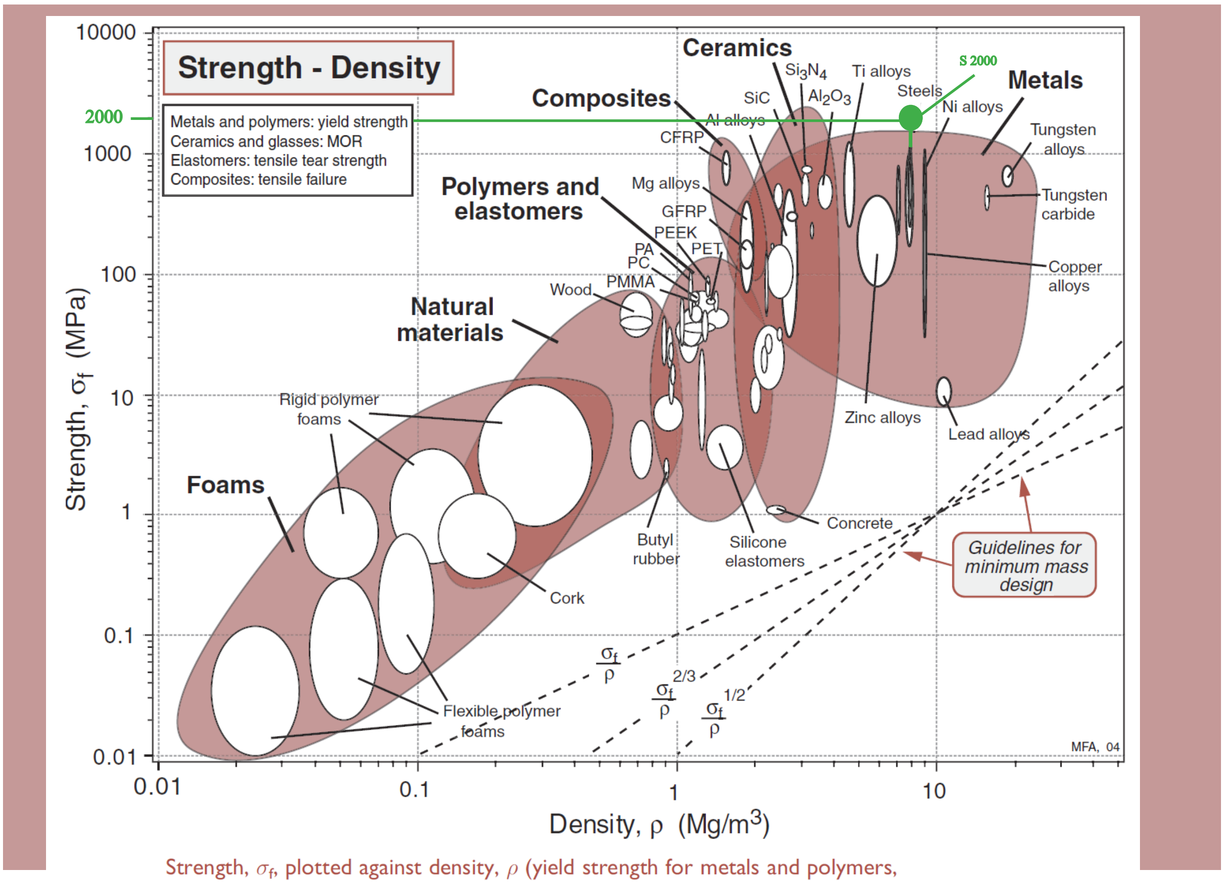


Figure 3



Strength, σ_f, plotted against density, ρ (yield strength for metals and polymers, compressive strength for ceramics, tear strength for elastomers and tensile strength for composites). The guidelines of constant σ_f/ρ, $\sigma_f^{2/3}/\rho$ and $\sigma_f^{1/2}/\rho$ are used in minimum weight, yield-limited, design.

Figure 4

Opaque louvres efficiently counter solar radiation, but inevitably limit daylight penetration. In order to maximise both the efficiency of sun protection and transparency, it is only logical that the louvres should spin according to the sun's path, thereby always remaining perpendicular to it.
If the louvres are placed horizontally on the building's North and South facades, and vertically on the East and West ones, they are less frequently completely shut, and the facade's global transparency rises (figure 1).

However, since it is impossible to fully prevent them from closing when the sun approaches the horizon, it should be possible to significantly increase the amount of natural light entering the building by making the louvres themselves slightly transparent, yet keeping an unaltered level of sun protection.

With this in mind, I imagined as soon as 1998, for the refurbishment of the ENI Headquarters in Rome (the "Palazzo Mattei", 01-375 [1], figure 2), large louvres in clear glass, showing on both sides white stripes, alternating and separated from each other by their width. I could carry out this concept to fruition for the headquarters of AGC Glass Europe [2] in Louvain-la-Neuve, in 2011 (01/577, figure 3), granting a nearly zero energy building with maximum quality of light and transparency [3].

High Resistance Steel

I kept thinking of a cheaper solution than these silk-screened glass louvres to achieve the same result. As we carried out another research aimed at reducing both the weight and the quantity of material for various building components, I was led to study the use of very thin sheets and wires in ultra-high resistance steel, be it stainless or not.
Those materials exist and are available on the market. For instance, wires with a 0.1 mm section, with a 4000 MPa yield strength ("Saw Wire"), are being used to slice silica blocks for photovoltaic cells. So is thin sheet metal, with a thickness down to 0.1 mm thick and a yield strength of 2000 MPa, used in the engineering industry.
One should refer on this matter to the graph in figure 4, courtesy of Michael Ashby [4], in which the density and elastic limit of materials are compared, and where I added a green dot that corresponds to the "S2000" steel. It can be seen from the graph that other materials also present the same "Resistance / Density" specifications ratio.
Steel, however, offers two critical advantages compared to its "rivals." To begin with, 70% of its production nowadays originates from recycling [5] – and it will only go up in the years to come. Barely above 0% only 50 years ago, this figure will rise close to 100% within a few decades. Then, it is one of the few materials that can be crafted with minimal energy.

The Louvre in Thin Steel Sheet

Stainless steel sheet of 2000 MPa, 0.5 mm thick for example, can be fabricated into reels of different widths, and easily corrugated by handcrafted means, anywhere on the globe. It can also be perforated, either industrially in Europe [6] before shipment, or by hand on the place of destination.

The steel louvre consists of a piece of sheet metal profiled into "castellated" waves (squared, rectangular or trapezoidal), in which the "webs" (parts perpendicular to the plane of the louvre, as opposed to the "flanges", parallel) are largely hollowed. Crosswise strips stiffen them. The louvre displayed in the example below presents a maximum "proper transparency" (view at 45°) that reaches 83% of the one of a 25.52 mm-wide glass louvre, silkscreened according to the same pattern.

This louvre is constructed as follows (figure 5):
Parallel lines are drawn on the sheet metal, on the length of the louvre to be built, and describe the castellated wave's width of the flanges and height of the webs (which can differ from one another).
Large, rectangular perforations are pierced at regular intervals on the length of the webs. Enough matter is left on the folds, so as to stiffen the flanges after folding.
The sides of the sheet metal are extended with crosswise straps placed in line with the matter left in between the perforations of the webs.
After profiling, the straps are folded up towards the centre of the louvre to constitute the shape of the long edge. The flanges are tied together thanks to sheet metal strips, which precisely cover the straps and fall into line with the edges of the webs' openings.
Finally, two U-shaped pieces of sheet metal crown both ends in order to give the object its stiffness against shear and torsion.

Any size can be freely chosen: length, width or thickness of the louvre, width of the flanges and of their stiffeners on the webs, length of the rectangular perforations in the webs, width of the straps, of the strips and of the U-shaped sheet metal. This way, each and every situation is granted to find its most appropriate shape.

Advantages and Drawbacks

The steel louvre offers various advantages compared to glass:

- it is cheaper and can be hand-crafted in small quantities,
- it does not need regular cleaning,
- it can deform elastically without breaking,
- it weights 78 g/dm², that is 7.7 times less than a 25.52 mm-thick glass louvre [7],
- it does not filter colours, which means it reaches a colour rendering index of 100%,
- its intrinsic geometric resistance is so high it can be made up of paper in a scale 1:2 (figure 6),
- it is 4.5 times more resistant when bent than its glass counterpart with the same dimensions [8],
- it is air-permeable,
- not only can it be placed as usual in front of the window frame, but it can also be integrated in between single-glass sheets, such as in the very efficient facade system developed by the Permasteelisa Company [9], consisting of three single-glass sheets at a distance of 20 cm and two sets of louvres put between the windows.

However, due to the presence of strips and flange siffeners on the webs, it is less transparent than glass louvres.

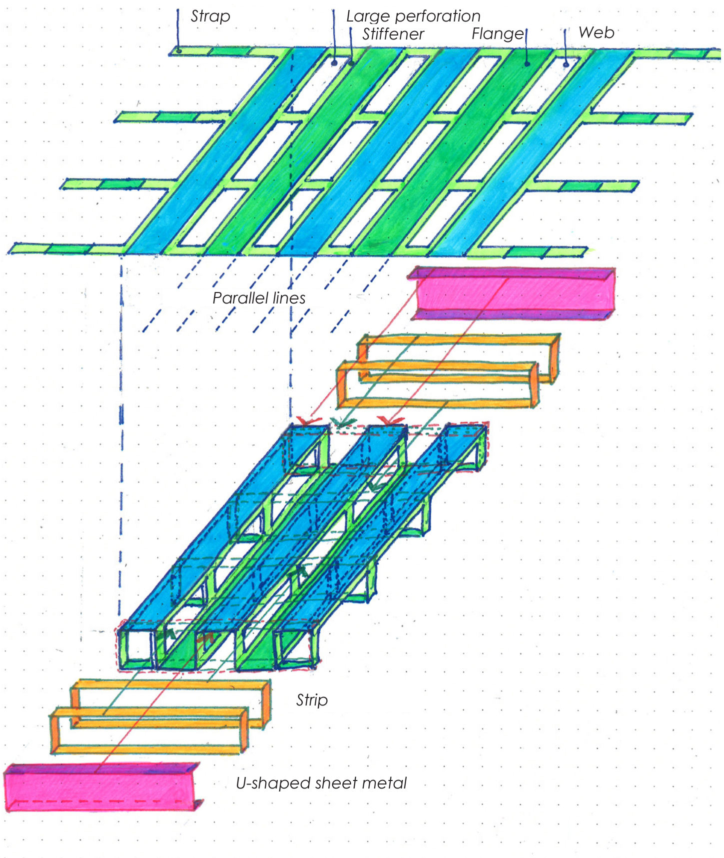
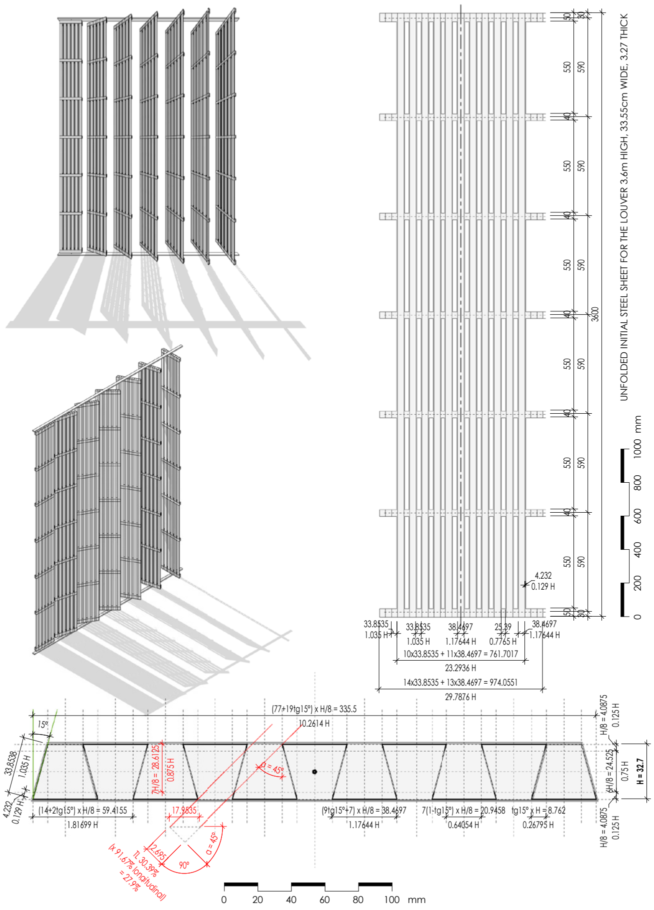


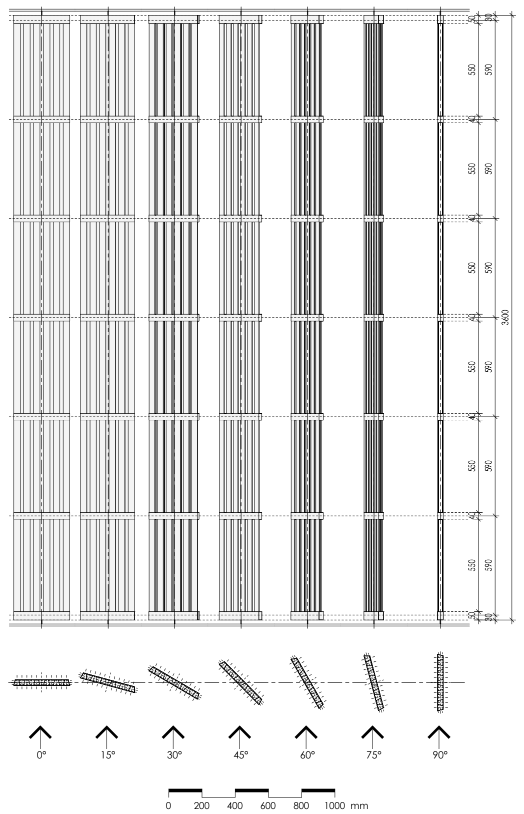
Figure 5

Figure 6



EXAMPLE OF A LOUVER 3,6m HIGH, 33,55cm WIDE (1,35m/4) AND 3,27cm THICK

Figure 7



EXAMPLE OF A LOUVER 3,6m HIGH, 33,55cm WIDE (1,35m/4) AND 3,27cm THICK TAKING THE CIRCUMSOLAR EFFECT INTO ACCOUNT

PERCENTAGE OF VOIDS ON THE LENGHT OF 360cm = 6x55/360 = 91.67%. THE OVERALL MAXIMUM TRANSPARENCY IS THUS OF 30.39% x 91.67% = 27.86% (TO COMPARE WITH A 25.52mm THICK EXTRA CLEAR GLASS LOUVER, PRESENTING A MAXIMUM TRANSPARENCY OF 33.53%. THE STEEL LOUVER PRESENTS THUS A MAXIMUM TRANSPARENCY OF 83% OF THE GLASS LOUVER.

Figure 8

Straight and Slanting Transparency, Circumsolar Effect

The lines of white paint on the glass are not totally opaque. They allow a total of 11.2% light and 12.5% solar energy through.
As far as steel louvres are concerned, the straight-line vision transparency can easily be adapted by microperforating the flanges. This way, equal, higher or lower transmitting values than with a glass louvre can be obtained.

Furthermore, with a light transmission index (LTI) of 90.7% [10], the 25.52 mm-thick "crystal-clear" glass is not fully transparent when viewed from an angle.
The aforementioned louvre achieves 83% of such transparency, a value that should be improved by optimising the sheet metal perforation as well as the width of the strips.

Eventually, the effect of circumsolar radiation should be taken into account when sizing the folding, considering that the opaque stripes must be slightly larger than the stripes letting light through.

Example

Figures 7 and 8 illustrate a 3.6 m-high, 33.75 cm-wide (that is, 1.35 m / 4) and 3.27 cm-thick vertical louvre.
The width of the flange stiffeners here is arbitrarily set at 1/8 of the thickness of the louvre, that is, 4.1 mm.
In the sectional view, its geometry takes the circumsolar effect into account and offers a 30.39% transparency.

Due to the five intermediary 4 cm-wide straps and the two U-shaped pieces of sheet metal at both ends, the maximum transparency rate of the entire louvre is 27.86%, that is, 83% of AGC Glass Europe louvre's (i.e. 33.53%).

Mechanism

These louvres must follow the sun's path so as to always remain perpendicular to the solar radiation.
To achieve that goal, various mechanisms have been tested out in recent years, by the Colt Company among others. They came to the conclusion that only a system of rods and pistons could insure the reliability and mechanical precision required for device-directed louvres.
This is the system we developed with that company for AGC headquarters, and which will continue to be used for complex applications in our wealthy countries.
These steel louvres could nonetheless also be manufactured and used in poor countries, for economical or even rudimentary buildings.
For such a use, a simple mechanism should be developed, for instance based on the principle of old counterweight and pendulum clocks, as illustrated in figures 9 and 10.
The south louvres in figure 9 spin around their horizontal axis. In the morning at 6 a.m., they are on a plane parallel to the facade (closed position), then gradually open until noon (never reaching, in our latitudes, perfect perpendicularity with the facade). It finally goes back to a closed position at 6 p.m.
The east louvres in figure 10 spin around their vertical axis. In the morning at 6 a.m., they are on a plane parallel

to the facade (closed position), then gradually reach a perpendicular position at noon (open position). As for the west louvres, they are perpendicular to the facade at noon, then gradually spin to be on a plane parallel to the facade at 6 p.m.

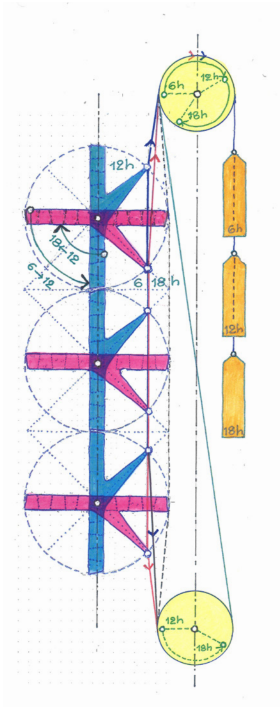


Figure 9

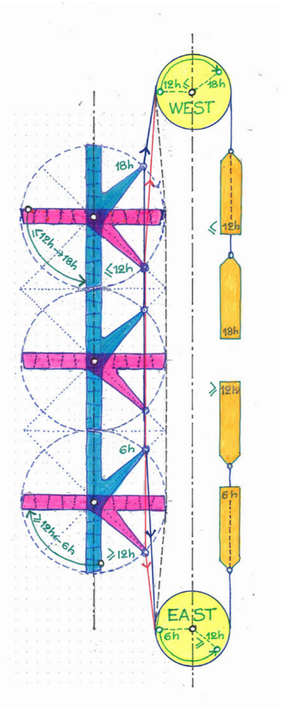


Figure 10

1. Numbers 01-xyz refer to the file number to insert in the "research" field on www.samynandpartners.com for more details on the project.
2. Philippe Samyn architect and engineer – Jan de Coninck: "AGC Glass Building". Lannoo Editions, Brussels, May 2014, 256 p. (in English: ISBN 978-2-87386-884-0).
3. Many other types of glass louvres have been used for decades in Europe without reaching the same performances.
4. Michael Ashby: "Materials Selection in Mechanical Design", picture extracted from the PDF file available on the internet, 3rd edition, 2005, p.54. See also Philippe Samyn: "Etude de la morphologie des structures à l'aide des indicateurs de volume et de déplacement", Académie Royale de Belgique – Classe des Sciences, collection in 4°, 3ème série, Tome V, 2004, 482 p., ISBN 2.8031.0201.3, available in French in e-book on www.samynandpartners.be): see p.23 for {Ma} function of ρ, σ and E (the influence of a material when designing a constructive element).
5. Sustainable Steel Buildings. Edited by Milan Veljkovic, Bernhard Hauke, Markus Kuhnhenne & Mark Lawson. John Wiley & Sons, Chichester, UK, 2016.
6. For instance by RMIG, a European company, the largest metal perforation company in the world.
7. 0.01 dm x 1 dm^2 x 7,800 g/dm^3 = 78 g for steel, and 0.24 dm x 1 dm^2 x 2,500 g/dm^3 = 600 g for glass (PVB excluded).
8. Two pieces of S2000 steel sheet metal (working at 120 kN/cm^2), on average 0.25 mm-thick and 10 cm-wide, separated by 2.4 cm, result in a bending moment of 0.025 cm x 10 cm x 2.4 cm x 120 kN/cm^2 = 72 kN.cm. A glass sheet (working at 1.65 kN/cm^2) of 24 mm-thick and 10 cm-wide results in a bending moment of (2.4^2 x 10/6) cm^3 x 1.65 kN/cm^2 = 16 kN.cm.
9. These developments are run by its subsidiary "Scheldebouw" in the Netherlands.
10. Twice 4% are reflected in the interfaces between glass and air, twice 0.6% are absorbed by the two 12 mm-thick glass sheets, and 0.1% by the divider made of 1.52 mm-thick PVB. It should be noted that anti-reflective glass increases light transmission up to 97%.

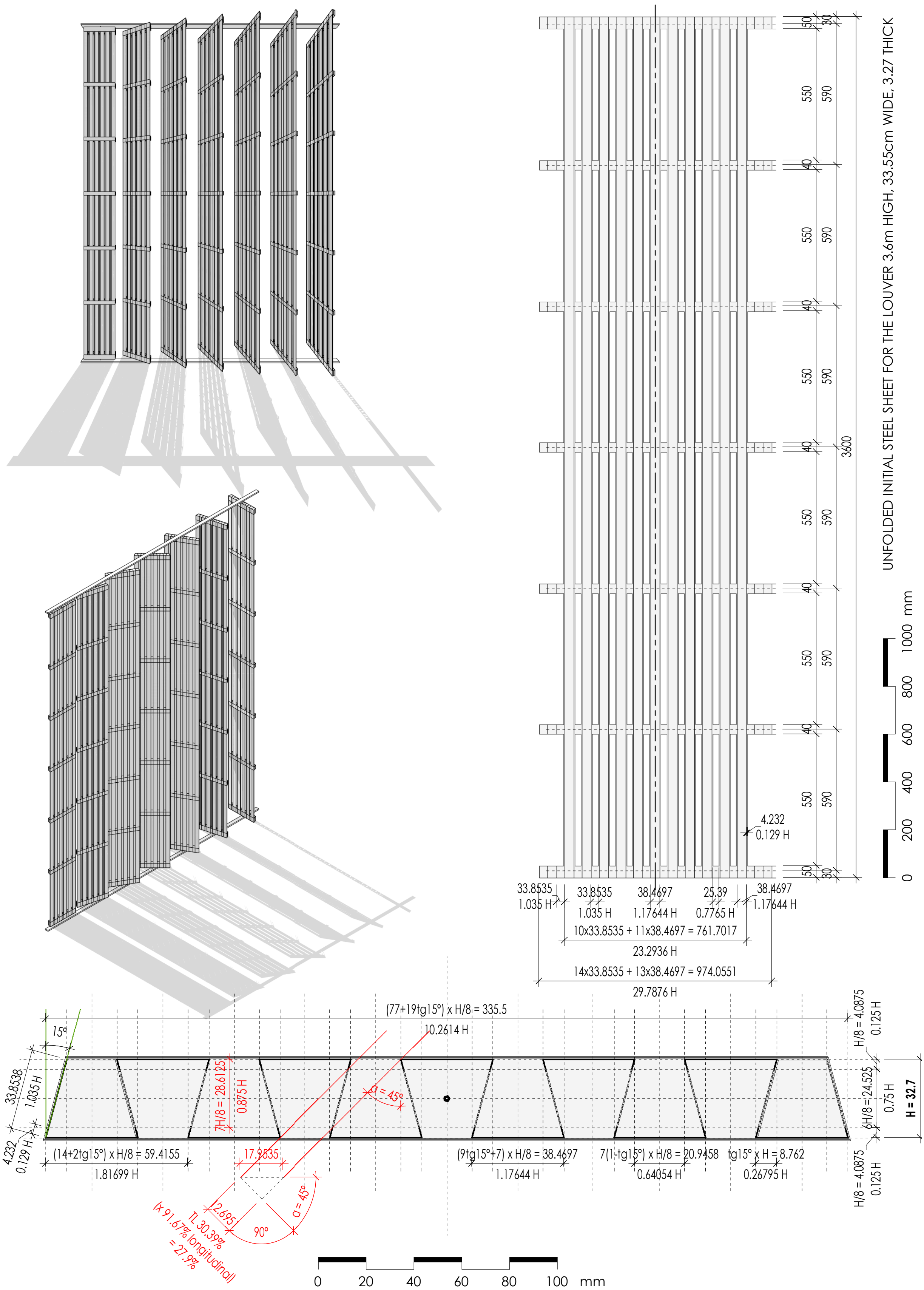


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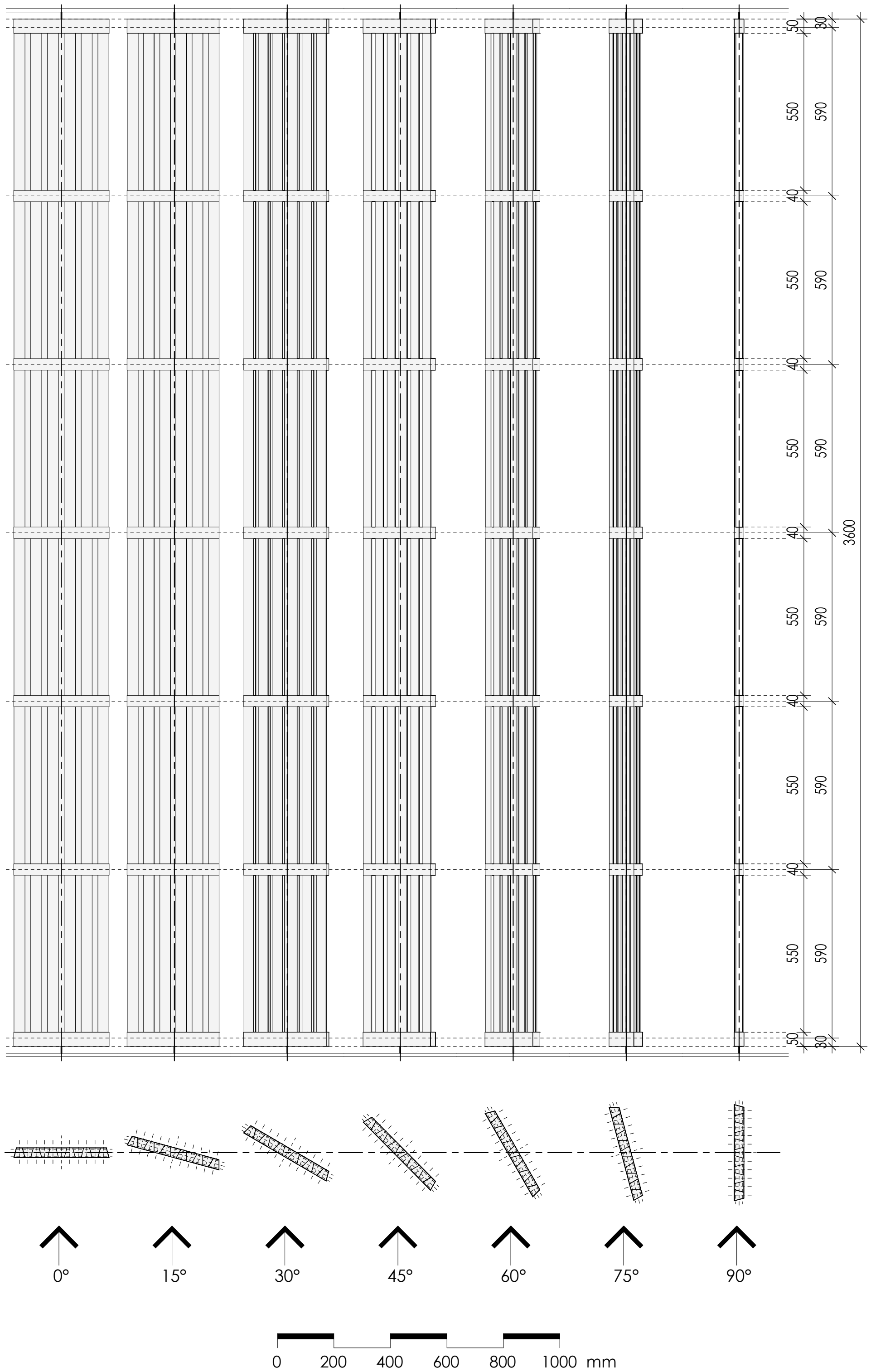
Figure 7



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TAKING THE CIRCUMSOLAR EFFECT INTO ACCOUNT

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Figure 8