All Glass Stair at the Onassis Cultural Center

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Abstract

The new stair at the Onassis Cultural Center in New York City is an all glass construction featuring a novel hardware free tread attachment method. Rather than the typical pairs of drilled fittings at each end of the tread, a four ply glass stringer was used and two of the plies were cut with a saw tooth pattern to create a glass gravity shelf for the treads.

The stair is a switchback configuration with a double cantilever supporting the landing. Force amplification related to the double cantilever resulted in unusually high forces in the connections. Since the glass balustrades were also structural stringers spanning from point to point, the lateral stiffness performance was important so that the treads would not fall off their relatively narrow gravity shelves.

The structural and aesthetic concept was closely linked with the fabricator's ability to execute, especially as regards to creation of the saw tooth gravity shelves in the stringers. The manufacturer developed special technique to create the required structural bond during lamination for these thick and irregular panels, but also to avoid visually distracting SentryGlas interlayer leakage around the saw tooth cut.

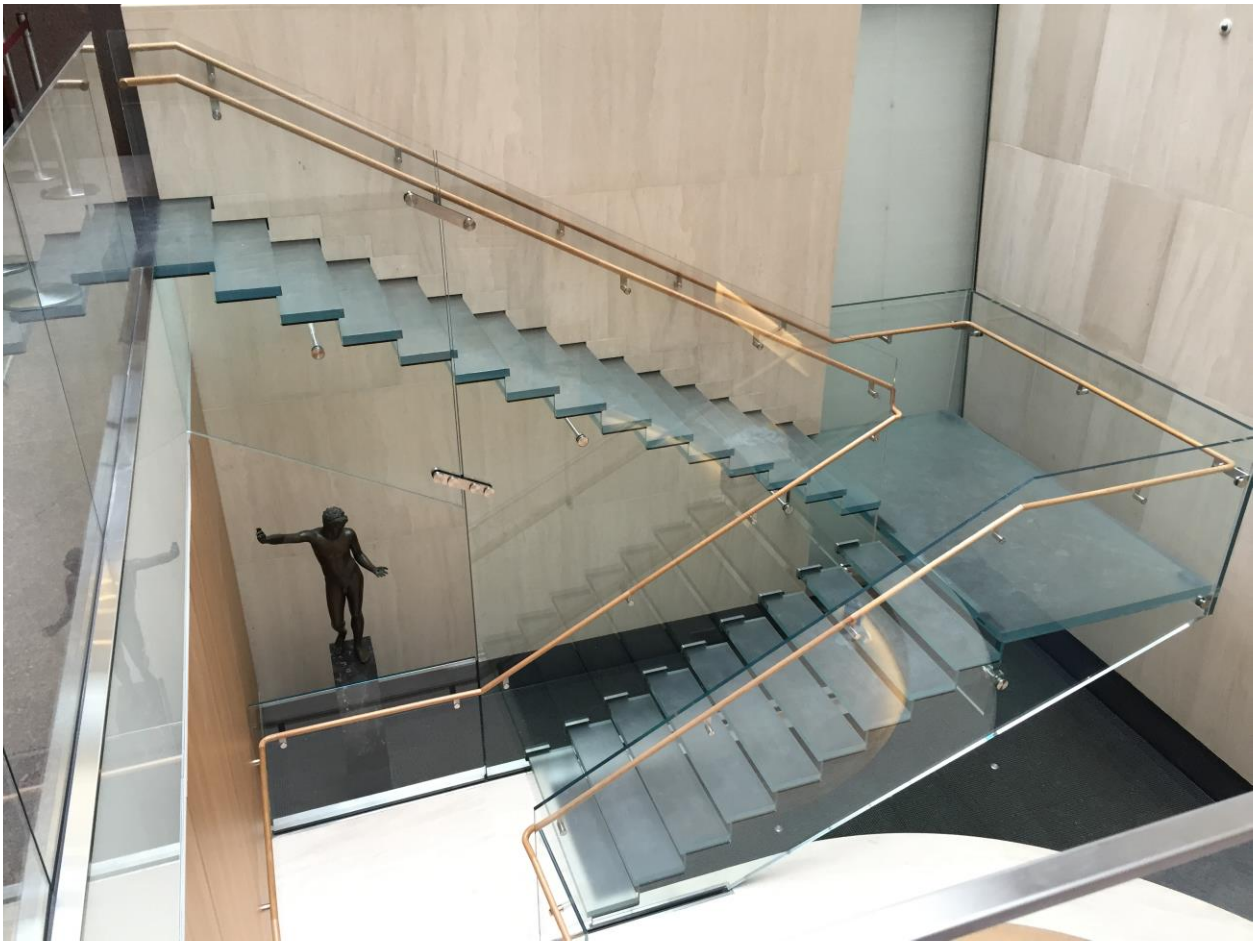


Figure 1. The stair, axo view

Structural Design

The structure is all glass with the exception of bolts and silicone. Treads are annealed and Sentry Glas laminated and span from the center wall to the stringer on the outside. The stringer is supported on a glass landing beam. The landing beam is then supported on the central wall.

Fittings are typically 316 or 17-4 PH stainless steel with Hilti HY70 grouted connections.

The primary feature of the stair is the gravity shelf. Two plies of glass where cut back from the four ply laminate in the central wall and the stringer which form a connection point for the treads to rest. The treads are then structurally silicone in position in the field.

Lateral stiffness of the system is a key concern because the gravity shelf is relatively narrow. Lateral struts are used, as is a moment connection between the central wall and the base building.

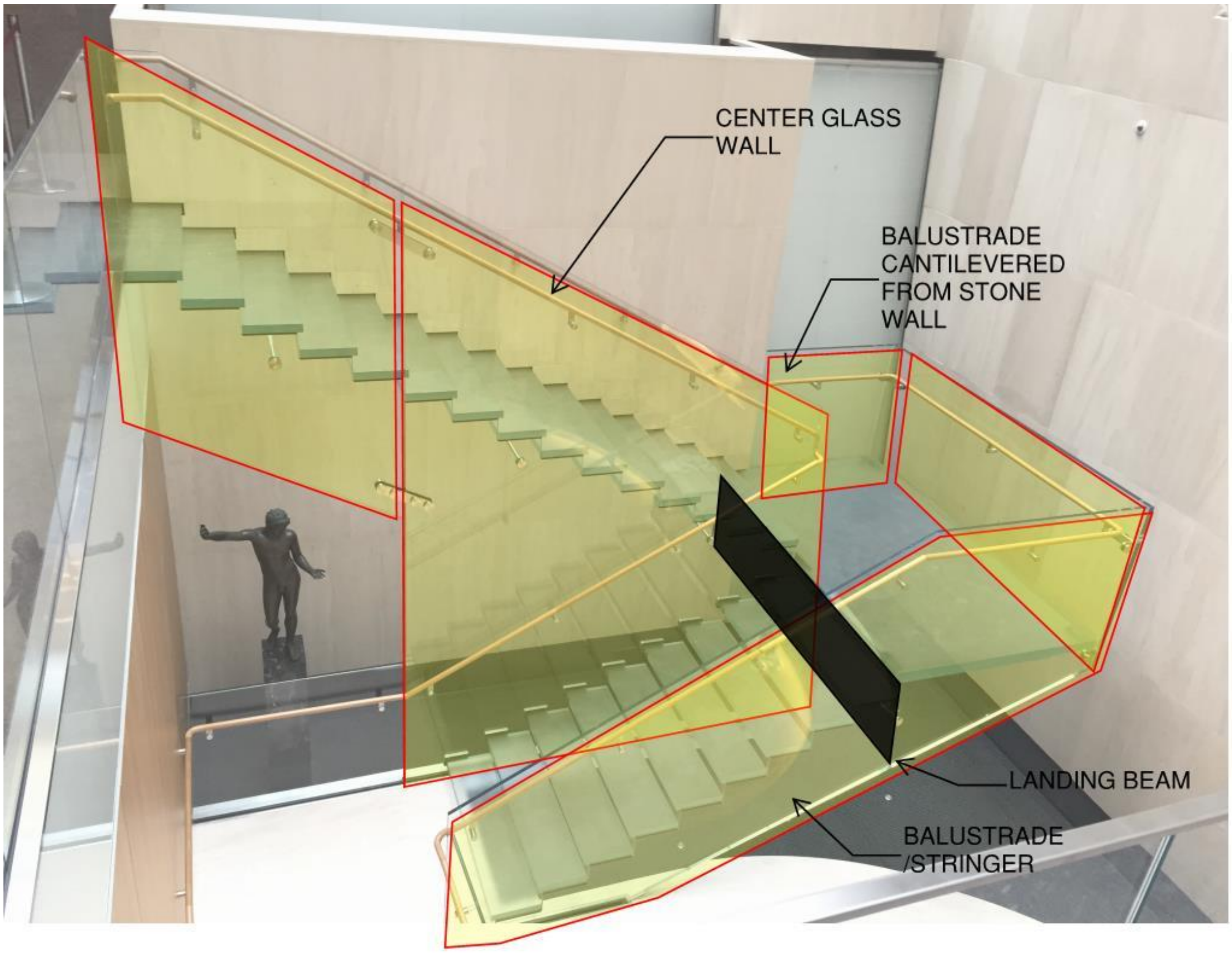


Figure 2: Structural Components

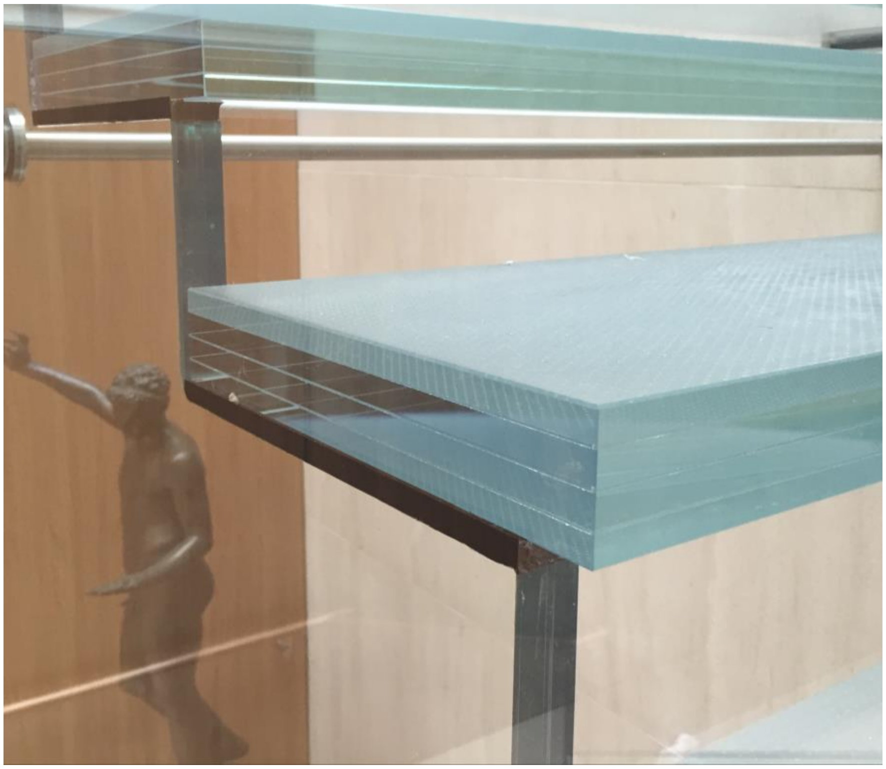
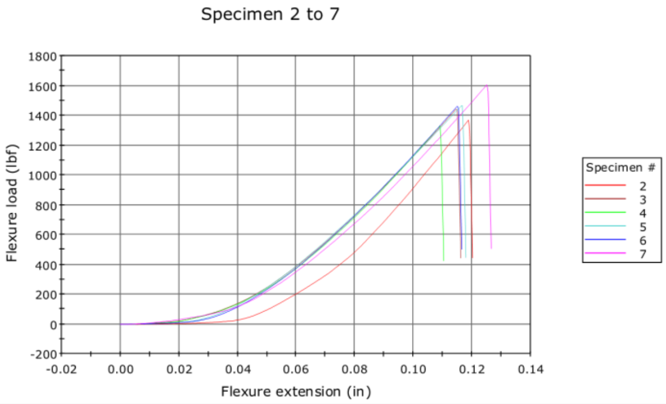


Figure 3: Gravity shelf detail

Figure 4: Embeded hardware is laminated into the glass for the handrail fittings

Mockup and Testing

The treads are constructed from annealed glass and have notches at the ends. The treads were tested to develop relatively high stresses in the notch to prove tha the edgework on the annealed glass would be structurally sound.



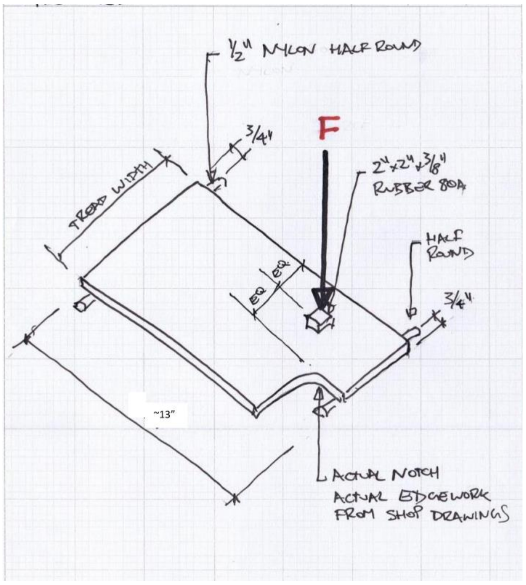


Figure 5: Testing

A mockup was completed with the gravity shelf detail to prove the gravity concept was strong and stiff enough for service.

Fabrication

Collaboration between the design team and fabricator began in 2013 to realize that striking staircase. The pure lines, absence of fittings, simplicity captivated fabrication team to push our fabrication limits. We influenced a few design points: central wall construction, use of annealed components, anti-slip glass surface and encapsulation of metal fittings in the laminate.

The central wall was initially 6-layer with uneven surfaces on exterior plies. The only way we could envision to fabricate it was to attach a 2-layer and a 4-layer laminate with liquid-pour resin. We had limited experience in resin and were not happy by that empirical approach to lamination. We suggested using a combination of mailboxes and zigzag stringer, which was accepted by the architect and customer. This eliminated two layers and allowed us to use a conventional and mastered assembly in clean room. It also contributed to a reduction of haze associated with thick SentryGlas laminate.

To enhance the look and remove a couple of fittings, we jokingly suggested to fuse two panes of the central wall. That did not fall on deaf ears and we ended up with a massive and challenging 115” X 175” piece. The challenges this new size created will be discussed later.

Material choice is paramount and conditions a lot of small details. Because of the absence of holes and lower stress level, it was possible to envision annealed horizontal pieces. This resulted in an easier assembly for us. Use of a thinner 0.035” ionoplast interlayer also contributes to the purity of the tread look. Using annealed glass not only makes this very secure in case of complete breakage, it also allows post-lamination edge polishing. After successfully testing a traction glass on Times Square, we also proposed to use an acid-etched top lite. The etched surface gives a wear-resistant, highly textured surface that delivers pretty good anti-slip properties, enhancing user safety.

Final touch in elegance, embedded treaded inserts offer unobtrusive, cost effective, no maintenance posts for the handrails.

Fabrication challenges

Post-Lami polishing produces our most striking edge finish. For all our edgework, we rely on Italian machines, our single edger being a Latuada. This machine uses 15 grinding and polishing wheels to produce a surface that is as good as, or even better than the face of the glass. Polishing 52 mm thick treads requires a perfect set of tools, fresh machine alignment and a patient operator.

Heat treated components use another method for polishing. To achieve a pristine look, we need to keep a ±0.4 mm – 1/64” tolerance on components, which can be achieved only using accurate CNC machining. On CNC, the most common tools used are peripheral diamond-impregnated wheels. These provide the desired precision and a shiny edge, but leave fine lines, parallel to the glass surface.

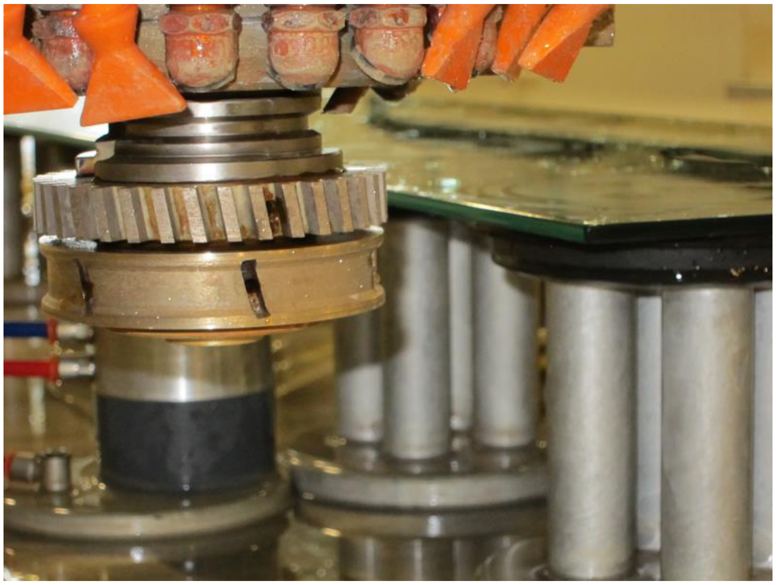


Figure 6: Edge polishing

To match the single edger polish, we use a completely different set of tools. The polishing action comes from the edge of a cup instead of the wheel circumference.

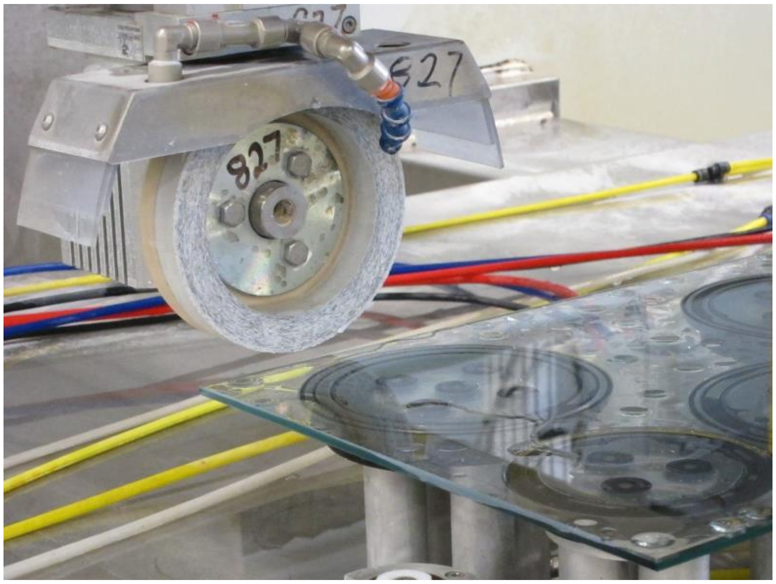


Figure 7: CNC tool

On our CNC, we normally tilt the 5-axis head to use those cup tools. However, the size of the head would not allow us to go all the way in the stringer zig zag. Thus our CNC manufacturer had to devise a gear box to translate the cup 90° on a 5-axis head. This ended up being pricey, as each polishing cup requires its own aggregate.

Heat treatment is the next step in our process. Here, the objective is to get the flattest piece of glass and minimize the anisotropy. Again, technology helps us understand and control our process. Here is a graph created by the infra-red scanner at the end of the oven, just before the quench.

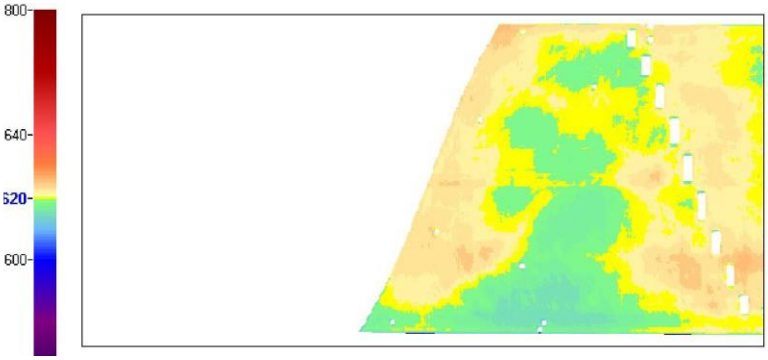
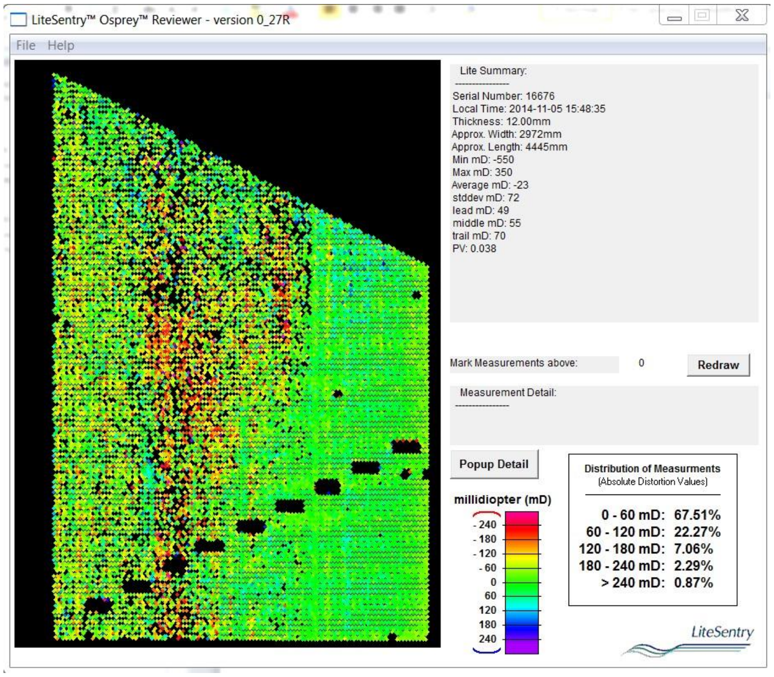


Figure 8: IR Scan

You can see that the heat distribution is decent but, mostly, that the temperature is kept to a minimum, which is the secret for flatter glass. As for anisotropy, special attention in the quench air outlet geometry greatly reduces the quench marks. No more little tubes perpendicular to the glass, now the nozzles blow air tangent to the surface.

At the end of the quench, a second scanner measures the optical power and thickness of the glass. This give us the flatness map of our glass.



Lite Summary:

Serial Number: 16676
Local Time: 2014-11-05 15:48:35
Thickness: 12.00mm
Approx. Width: 2972mm
Approx. Length: 4445mm
Min mD: -550
Max mD: 350
Average mD: -23
stddev mD: 72
lead mD: 49
middle mD: 55
trail mD: 70
PV: 0.038

Mark Measurements above: 0

Measurement Detail:

Distribution of Measurments
(Absolute Distortion Values)

0 - 60 mD: 67.51%
60 - 120 mD: 22.27%
120 - 180 mD: 7.06%
180 - 240 mD: 2.29%
> 240 mD: 0.87%

Figure 9: Optical distortion scan

A common rule of thumb tells us that a roller wave equal to 10% of interlayer thickness (10% of 0.060” = 0.006”) will not create a problem. We find that value a maximum and will reject glass that is in that zone. Notice how flat that glass is around the mail slots and in general.

Lamination challenge: This describes well this project. Four thick layers, large size and weight, zigzag stringer, sizable and numerous openings, exceeding SentryGlas manufacturing sizes, embedded fittings were all combined in a single piece: the Wall. We started prototyping in March and quickly discovered that we needed to use vacuum bagging. Due to the glass size (115” X 175”) it was not possible to work horizontally in our autoclave, so we started to devise ways to make it happen vertically on a rack.

Using vacuum bags with 0.060” interlayer created small mountains of cured interlayer that were very hard to trim. Even with electric tooling and ultra-sharp blades, we estimated trimming time to 2 weeks for the Wall. On the prototype submitted to the architect, the interlayer was uneven and we did not achieve the quality level we aspired to. So we worked on not creating those mountains of rock-hard interlayer and by the end of August, we had a solution. That is as far as I will tell you.

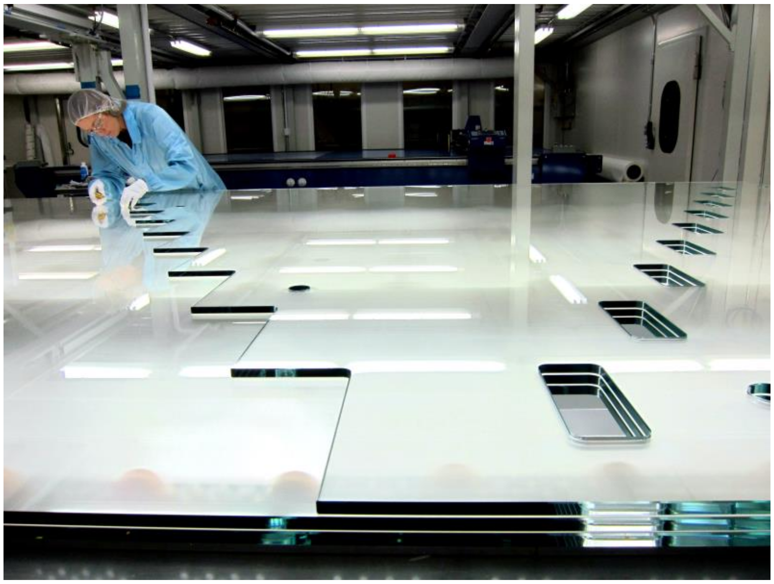


Figure 10: Clean room assembly

SentryGlas can be butted, but it is touchy and can lead to disaster during autoclaving. We chose to work with 0.035” sheets that we overlapped, which created a nice puzzle. We have a vacuum CNC table that allows us to precut the holes and shapes; don’t attempt this without that table. Since Onassis, we have taken step to avoid butting sheets. We now stock 0.030” SentryGlass seamed rolls 130” wide, and are also using Saflex DG, a stiff PVB that has nice structural properties and is available in 126” wide rolls.

Embedded fittings is the last innovation that I will discuss. We like to take advantage of the countersink geometry stability. We use a machined Delrin ring to absorb the thermal expansion differences and, again, very precise machining to keep the surface of the fittings even with the glass surface. Again, a few tricks to keep bubbles away and interlayer out of the treads.

Acknowledgements

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