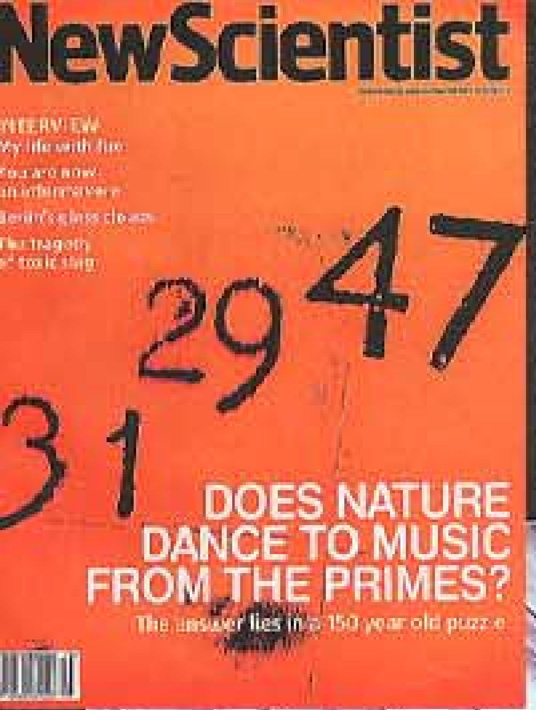

Art of glass

Nikolas Weinstein Studios

Roland Halbe/artur

It looks stunning, weighs more than a large car and could shatter into a million razor-sharp fragments, but **Jonathan Knight** would still be happy to eat lunch beneath this giant chandelier

ON A SUNNY DAY, the atrium of the DG Bank building near the Brandenburg Gate in Berlin is awash with light. It can be so bright that office workers seek shade when they eat lunch here. Fortunately, 30 clouds floating a few metres above the ground offer some protection. They are puffy, curvaceous and a luminous white. And like clouds they appear weightless. Yet at two and a half tonnes, they make up one of the largest all-glass sculptures in the world.

The sculpture is actually a unique chandelier that filters a mix of sunlight and artificial light into the cafe and conference hall below. It was commissioned in 1996 by the bank's architect Frank O. Gehry, and is due to be completed early next year when the final four panels are hung. You might not think that creating big things out of glass would take rocket science, but the chandelier at Pariser Platz 3 is different.

From the outset, the chandelier's designer, San Francisco artist Nikolas Weinstein, was in uncharted territory. "No one had ever tried to put glass together in this kind of way," he says. "Technically, as well as aesthetically, there was really not a lot of precedent for us to look to." The danger that invisible cracks or a dropped wrench could shatter the glass into millions of razor-sharp shards turned the chandelier from an ordinary sculpture into a four-year odyssey that has challenged some of the world's foremost experts on glass.

The team Weinstein recruited included a man who designed windows for the space shuttle, a builder of mirrors for the Hubble Space Telescope and a physicist who models random processes. By the end, they had designed a brand new kiln, developed a software package to assemble the "clouds", and broken an awful lot of glass.

Walk into Pariser Platz 3 and you pass through a hallway into a breathtaking atrium six storeys high. During the day it's flooded with sunlight and, just as at Gehry's Guggenheim Museum in Bilbao, unusual shapes abound. At one end of the atrium a billowy white shell that resembles a bed sheet blowing in the wind shrouds an elevated meeting space. At the other end, an open-sided, arched latticework of steel beams and triangular panes of glass defines a conference hall and cafeteria within which the sculpture hangs.

Weinstein wanted his chandelier to complement this open design. He imagined voluminous, curved panels swooshing skywards like cirrus clouds. But melting huge pieces of solid glass to make the flowing shapes was out of the question. The glass would probably cool unevenly in the kiln and crack, and even if it survived that, such large pieces of glass might not support their own weight once hung.

Instead, Weinstein decided to melt together a raft of long, hollow glass tubes into a flat panel and then warp the whole thing over a curved mould. As a test, he baked a few lengths of glass tube into a briefcase-sized sample. Then a few months later, Tim Eliassen of TriPyramid Structures—the firm that engineered the glass pyramids at the Louvre—arranged a meeting with Weinstein and Graham Dodd, a glass safety expert with consulting engineers Ove Arup and Partners in London.

At a hotel bar in downtown San Francisco, Weinstein pulled out the sample. He was a little embarrassed, since by then it had developed some bad cracks, but to Eliassen and Dodd these imperfections were very revealing. The cracks ran halfway through the sample and then stopped. It looked as if Weinstein had unwittingly created something akin to safety glass. But would larger panels behave the same way?

To construct these panels, Weinstein planned to lay the tubes alongside each other and heat them to 675 °C—hot enough to make the glass tacky. When the assembly cooled, the tubes would fuse, forming a panel that could then be heated again and bent to shape over a curved mould.

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But Weinstein quickly realised that this two-stage approach would never work. Each heating cycle introduces more opportunity for cracking, and the mould creates uneven cooling. Every panel he made broke into fragments.

His solution was a unique, 4-metre-long kiln that could fuse and shape the tubes in one go. It was built by Seattle kiln maker Fred Metz and shipped to Weinstein's studio behind a laundromat in San Francisco's Mission district. Inspired by pinscreens, the toys that record impressions of a face or hand in a layer of movable pins, the bed of the kiln is dotted with discs that can be raised or lowered on rods to shape the softened glass.

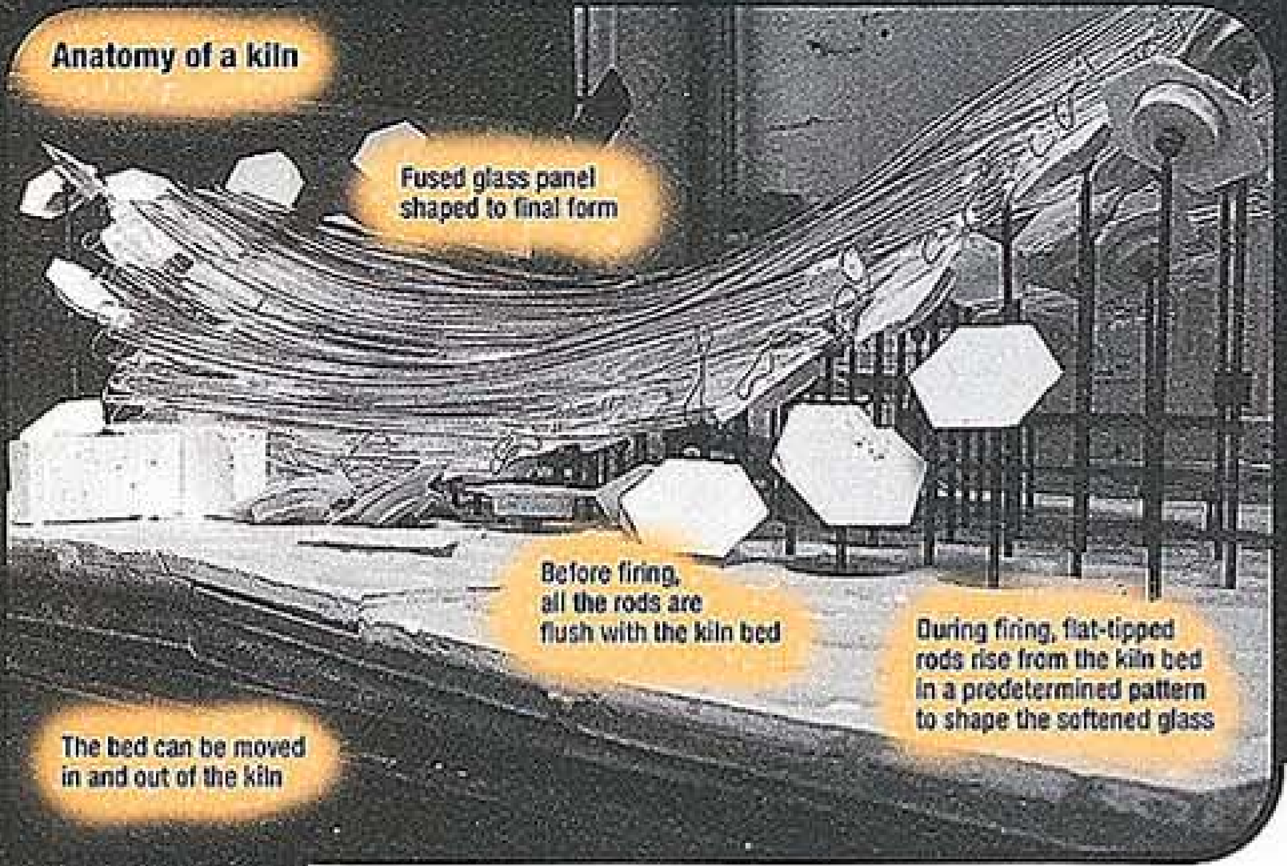
To create a panel, Weinstein makes a scale model of it and pushes it into a pinscreen the size of a briefcase. This creates a scale-model relief map of the panel. He then measures the length of each pin, and uses it as a guide to the height to which each disc in the oven must rise in order to shape the glass correctly. "It's an old-world version of digitisation," he says.

With all the rods lowered, the kiln bed is flat, and Weinstein and his team can lay out the tubes for the panel horizontally on the floor. Once the tubes are in place, he shuts the heavy door and the lorry-sized kiln starts to heat up very slowly to around 700 °C.

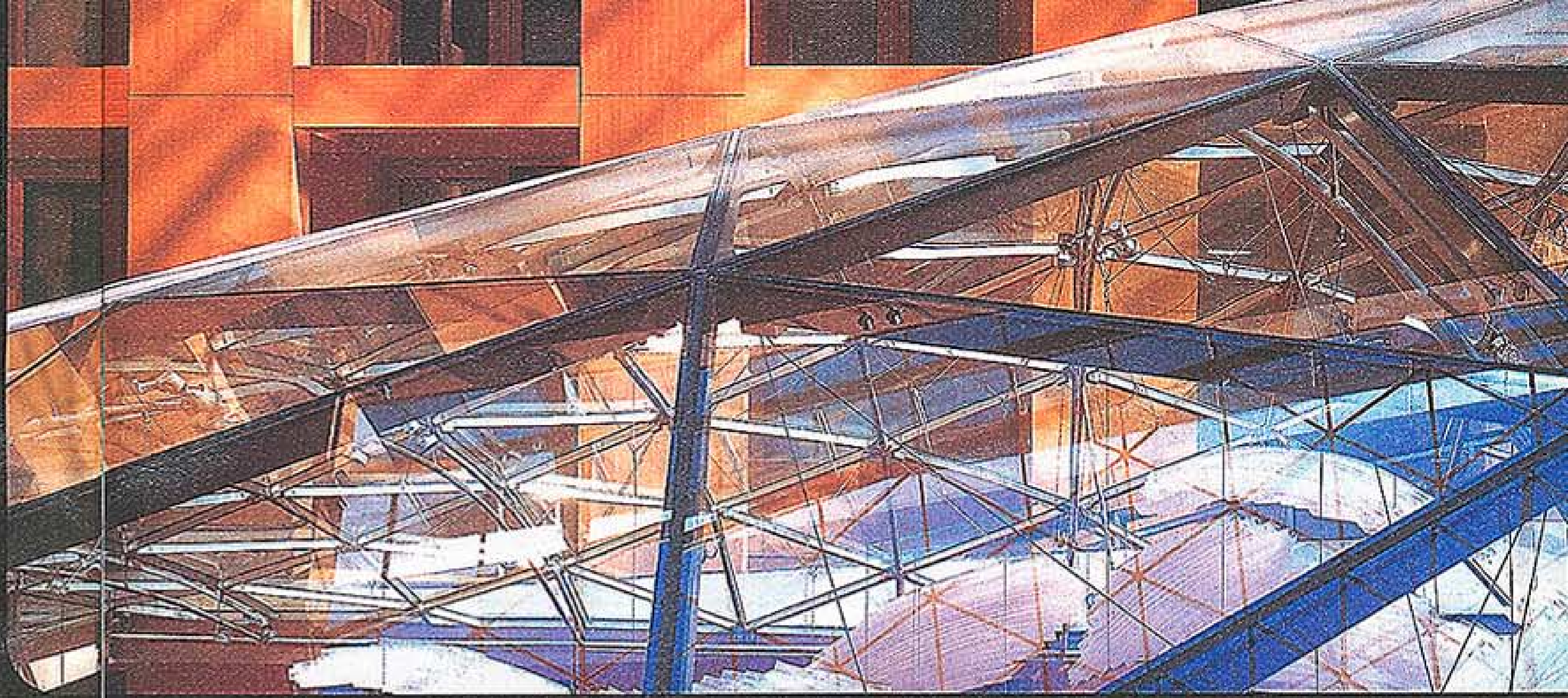
When the glass glows orange, the tubes begin to slump like cooked macaroni. At this point, a metal plate which all the rods run through creeps slowly up below the kiln. Each rod has an adjustable collar that makes contact with the plate. As the plate rises, it pushes the collars and the rods with it. After up to 60 minutes of slow movement the rods have moulded the glass panel to its final shape and the kiln begins to cool very slowly. As far as Weinstein knows, it's the only kiln in the world with a bed that morphs at temperature (see Diagram, p 40).

So would the curved panels be safe to hang above people's heads? To find out, Weinstein called Corning in New York, among the world's leading specialists in heat-resistant glass. Corning suggested he should get in touch with glass expert Herb Miska, who designs high-impact glass for aircraft. He also helped make windows for the space shuttle that would not burst on lift-off or re-entry.

To Miska it was immediately obvious that the panels could not be strengthened with standard techniques such as heat or chemical tempering (*New Scientist*, 11 February 1995, p 23). And unlike aircraft glass, the stresses couldn't be worked out



Meltdown: softening and shaping huge swathes of glass had never been tried on this scale before. So Weinstein devised a giant kiln to do both jobs in one go



Roland Halbe/Artur

Glass sky: Weinstein's clouds will shade diners as they lunch in the atrium of the DG Bank building

Nikolas Weinstein Studios

mathematically. "These panels had a very strange geometry, so it was very difficult to quantify anything," says Miska. There was nothing for it. They would simply have to test the panels to see what kind of stress they could take.

So Miska put one on the floor of his garage and dropped a wrench on it. Incredibly, the panel didn't shatter. The only damage was around the site of impact and never spread beyond it. So he dropped more tools, large bolts, anything that might fall on it during installation or cleaning. Always the damage was local. "The thing had so many walls and surfaces, it was very effective at absorbing energy," he says. "Sometimes things I dropped even got stuck in it." So why didn't it shatter?

Miska believes the glass panels behave like the walls of the old Spanish forts in Florida. Just about the only building material available to the Spanish in the Caribbean was coral. Not only was it light and porous, but they soon realised it was great at absorbing the impact of cannonballs. All the energy of the collision was dissipated in tiny breaks rather than radiating outwards as it might in stone. Weinstein had unwittingly created a sculpture with fortress-like strength. So the panels wouldn't fail catastrophically in a construction accident.

But what about the ravages of time? Over the centuries the Spanish forts have crumbled, so would the chandelier weaken as the years went by? Tiny scratches on the surface of glass create extremely high local stresses. As moisture in the air reacts with the silicon, it weakens the chemical bonds in the glass and the scratches turn into cracks.

To make the panels as strong as possible, Miska encouraged Weinstein to build each one from a variety of tube sizes. By mixing smaller-diameter tubes with larger ones, many of the gaps between the tubes could be filled, and the number of places where tubes touched and bonded would increase. Weinstein liked the idea, too, because a random distribution of tube sizes improved the panels' appearance.

Each panel of the sculpture contains tubes ranging from 3 to 10 centimetres in diameter. But this created a whole new problem. For the best strength, each tube has to touch all of its neighbours. Yet to lay them out like this by trial and error and in a way that looks random would take forever. So late last year, Weinstein commissioned his long-time friend Jamie Bernardin, a physicist and simulation expert, to write a computer program that could do it in minutes.

Bernardin's usual computer simulations use random numbers to model complex phenomena such as financial markets. For Weinstein, he wrote a program that would add tubes at random positions and then jiggle them all a bit until they were as closely packed as possible. The program calculates the "energy state" of each design, a number that gets smaller as more contacts are made within the panel. If an extra tube makes the energy state too high, it is rejected and tried elsewhere. The panel's structure evolves by something like natural selection. The artist can also move tubes if they don't look right, and the program will shift the tube into its best fit at the new position. This way, Weinstein could give each panel a different look, without compromising its strength.

So much for the theory. In practice, things didn't go entirely according to plan. Just one year ago, the project was in deep trouble. Despite all the engineering, and with only two months to go before the panels were due to start arriving in Germany, Weinstein had not made a single one that was crack-free.

The problem was occurring in the kiln during annealing, the final stages of cooling. So on Miska's advice Weinstein called retired Corning guru Hank Hagy at his home in New York. Hagy had been responsible for the annealing of large telescope mirrors, such as those in the Palomar observatory and the Hubble Space Telescope. The first thing he wanted to see were the cracks.

Cracks in glass are packed with information. They reveal where the fracture started and how much stress was involved. Hagy could see that the cracks all originated at the end of a joint between two tubes, where one tube ended and the other continued. Staggering the ends of the tubes gave the clouds a curved profile, but it also meant that if the shorter tube cooled faster than the longer tube, it would pull along the joint. Where that joint ended, the forces were magnified 20 to 30 times.

The solution was to cool each sculpture more evenly. But Weinstein's kiln wasn't really designed for that, Hagy says. A kiln for a telescope mirror would have heating elements all around to control the temperature precisely, but Weinstein's kiln only had elements on the top. "I said,

'The project was in deep trouble. Despite all the work, Weinstein hadn't made a single panel that was crack-free'

'Jesus, you haven't got a kiln, you've got a broiler'," Hagy recalls.

Running short of time, they added insulation and a few thermocouples that allowed them to monitor the temperature of the glass directly, rather than just the temperature of the kiln. Then Hagy slowed down the annealing time from hours to days.

Soon the panels were rolling out of the kiln at a rate of nearly one a week. That left the final challenge: "The thing that made me nervous about it is that the strength of glass is low under long-term load," Dodd says. "If you load the thing up with its own weight, you have to ask yourself how long it's going to hang out before it breaks."

When Dodd and the engineers from TriPyramid delved into all the research they could find on "static fatigue"—the effects of long-term stress on glass—they discovered a magic number: one million. If glass under a constant load can hold up for one million seconds, all the evidence suggests it will hold up forever. So once each panel has been hung at the bank, it is loaded with lead sheets to increase the weight. After a million seconds—about eleven days—the sheets are removed and if the panel is intact it is deemed safe. So far, not a single panel has failed the test.

The chandelier is a feat of engineering, to be sure, but not in the modern sense of number crunching and predictive design. "We did a fairly ancient kind of engineering where you try a few things to get in the right ballpark, and then you go ahead and build it and see if it actually works," Dodd says. "It's reminiscent of the old European cathedrals, with flying buttresses and high, vaulted roofs. All those things were developed by trial and error. Nobody had a technique for calculating stress or load." Old-fashioned it may be, but it works. And with Chartres pushing 800 years, the diners at Pariser Platz 3 have nothing to fear from the glass over their heads. For a few centuries, at least. □

More information at:
www.nikolas.net/html/commission.html