Benthem Crouwel Architects

由Jan Benthem与Mels Crouwel创立于1979年，现在事务所规模已发展到50人，并在荷兰阿姆斯特丹和德国亚琛设有办公室。目前事务所合伙人还有Marcel Blom、Joost Vos、Marten Wassmann和Markus Sporer。Benthem Crouwel Architects在设计中一直关注经济性、社会性、生态性的平衡，尤其重视创新性与可持续性，同时在建筑空间的紧凑与简洁、生态系统的整合、材料的有效利用方面表现得更突出。事务所近来的主要项目：荷兰Schiphol机场、RAI展览会议中心、Ziggo圆顶体育场、阿姆斯特丹Stedelijk市立博物馆、德国Koblenz商业中心、荷兰高铁桥等。

THE NEW STEDELIJK MUSEUM AMSTERDAM

阿姆斯特丹新市立博物馆

阿姆斯特丹著名的现代艺术市立博物馆最初于1895年开放，用来展示前卫的现代艺术，当时在整个欧洲引起轰动。原博物馆是装饰性很强的新文艺复兴风格，在那个时代很受欢迎。一个世纪后，市议会决定对老建筑进行翻新。2004年，5个荷兰建筑师事务所受到阿姆斯特丹市政府的邀请，提交博物馆的翻新及扩建方案。获胜的是来自阿姆斯特丹的Benthem Crouwel事务所，他们鲜明的设计在视觉和技术上脱颖而出。

翻新工程不仅使整个19世纪的建筑重新恢复了昔日的辉煌，而且在它的旁边，一个新的入口和“浴缸”形状的明亮白色的展览空间也建成了。新建筑长约100m，安静地漂浮在广场上。“浴缸”是阿姆斯特丹当地人给这个新建筑起的绰号，这种浮动的形式向外扩张到顶部宽广平滑的屋面上，它实际上构成二层画廊、礼堂及上层办公室的外立面。建筑承担着主入口、大堂、博物馆、商店和餐厅的功能，首层完全被玻璃包裹，显得非常通透。新建筑的屋面和原建筑檐口线高度相一致。屋面的伸出部分为地面上的广场提供了遮蔽，同时可以作为活动的场地，参观者也不受干扰。

流线

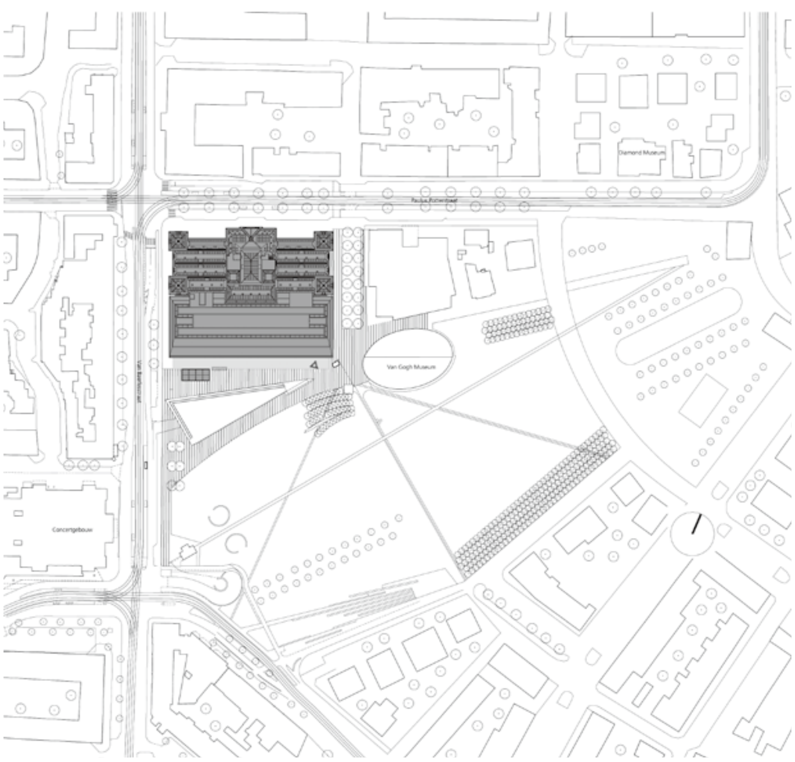
翻新后博物馆的主要入口变换了位置，移到了博物馆广场的公共草坪上，为市立博物馆、梵高博物馆、国家博物馆和国家音乐厅创造了一个积极的共享平台。新加建的博物馆分为地上两层、地下一层。当参观者由新建筑入口进入时，可以自由选择是否直接进入老博物馆，或者通过楼梯和电梯进入新博物馆的展厅。建筑一层是荷兰最大的自由跨度展厅，同时也是一个大黑盒子展厅/表演空间，其他展厅均

Amsterdam’s famous Stedelijk Museum of Modern and Contemporary Art originally opened its doors in 1895 to exhibit the new, “modern” art that was creating a furore throughout Europe. A century later, the City Council decided that the old building itself was in need of modernization. In 2004, five Dutch architectural firms were invited by the City of Amsterdam to submit their proposals for the renovation and extension of the Stedelijk Museum in Amsterdam. The winner Amsterdam-based firm Benthem Crouwel, whose striking design stood out both visually and for its technical ambition. Not only has the 19thcentury building been restored to its former glory, but alongside it, a new entrance and exhibition space has been created in the shape of a bright white “bathtub”, 100 meters long and floating serenely above a paved square. Already known by some in Amsterdam by the nickname “the bathtub”, this floating form, which spreads outward at the top into a broad, flat roof, is actually the envelope for the second-floor galleries, auditorium and offices above. It is entirely encased in glass at the transparent ground-floor level, which houses the main entrance and lobby, museum shop and restaurant. The roof of the new building matches the height of the original building’s cornice line. The roof’s overhang creates a sheltered outdoor plaza at ground level, where programmed activities can be staged and where visitors will be protected from the elements.

Circulation

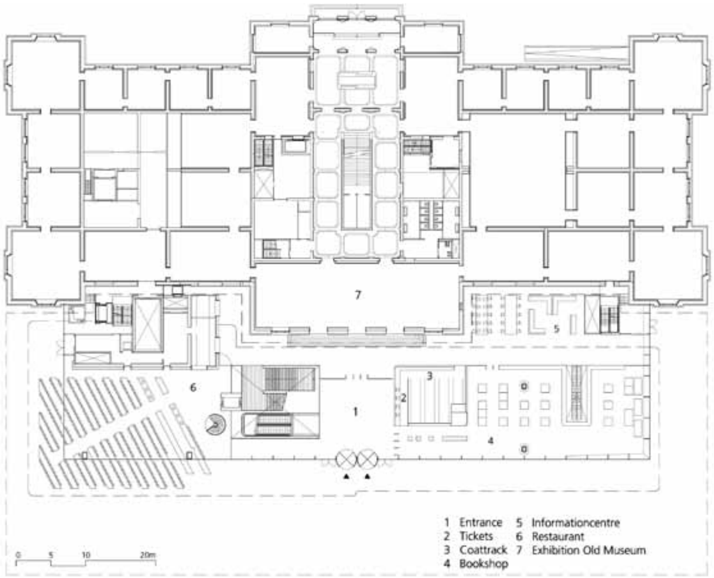
Construction of an adjoining new building (two stories above grade, one below) to house galleries for temporary exhibitions, visitor services, public amenities, library and offices. Relocation of the main entrance onto the great public lawn of Amsterdam’s Museum-plein (Museum Plaza), creating an active, common ground for the first time among the Stedelijk Museum, the Van Gogh Museum, the Rijksmuseum and the Concertgebouw.

Once they have gone past the entrance, visitors may freely choose whether to pass directly into the original building, or else take the stairs or elevator to the new building’s exhibition galleries. The lower level houses the largest

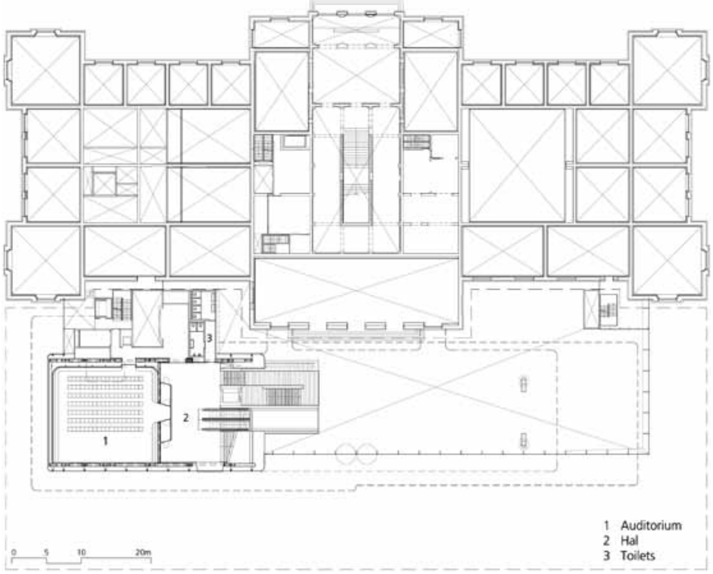


总平面图

客户：阿姆斯特丹市政府
建筑总面积：26 500m^2
老建筑面积：10 023m^2（净面积），4 629m^2（展厅面积）
新建筑面积：9 423m^2（净面积），3 400m^2（展厅和功能空间面积）
设计/建成时间：2004/2012年
主要使用材料：钢、玻璃、Twaron®与碳纤维复合材料、石材、木材
建筑事务所：Benthem Crouwel 事务所
设计团队：Mels Crouwel（设计总监），Joost Vos（项目建筑师），Jan Benthem，Ronno Stegeman，Alexandra Jezierski，Daniel van der Voort，Rogier Putter等
施工管理：DHV Bouw en Industrie
建筑承包商：Volker Wessels
工程咨询：Arup
Twaron®纤维供应商：Teijin Aramid
技术工程：Imtech
技术工程咨询：Huisman en Van Muijen
摄影：Jannes Linders


1 Entrance
2 Tickets
3 Coattrack
4 Bookshop
5 Informationcentre
6 Restaurant
7 Exhibition Old Museum
0 5 10 20m

一层平面图


1 Auditorium
2 Hal
3 Toilets
0 5 10 20m

二层平面图

设在二层。为了让参观者更好地享受展览而不被外部干扰，一层和二层之间安装了一个封闭的直达自动电梯。

外立面材料

建筑师希望“浴缸”结构的表面应该是无缝的，但如此大面积的外立面只能由许多较小的面板拼接而成，而传统的材料在施工时都需要留出一定的膨胀接缝（视材料而定，一般不能超过20mm），这显然会破坏建筑师所要求的无缝外观。为了解决这个问题，需要找到一种具有最小热膨胀系数的材料。最终，经过建筑师、工程师和芳纶及复合纤维的专家的共同努力，找到了一种新型复合材料，即Teijin Aramid公司的Twaron对位芳纶纤维，这也是此材料第一次被大规模运用在建筑外立面上。

建筑外立面光滑的白色表面由271块面板组成，面板使用了以Twaron®纤维作为关键成分的新型复合材料。面板由1 100个铝制支架附着在钢结构上。Twaron纤维作为一种合成纤维，质量极轻，约27kg/m^2（其重量甚至小于正常幕墙重量的一半），而其强度是钢铁的5倍，在不同的天气条件下都能保证自身的形状和强度，并且不会熔化于火。碳纤维和Twaron纤维的复合材料是可塑的，能创造出任何平滑、无缝的表面。Twaron纤维通常用于汽艇、赛艇的船体和帆布以及航空航天、工业部件、运动器材如网球拍、曲棍球棒的制造上。

工程师的观点：把愿景变成现实

建筑师审阅了各个专家的意见，最终，他们采用了一个荷兰工程公司Solico的意见。在建筑和航空航天工业上，Solico有着丰富的轻质高强材料的设计经验。更重要的是，Solico公司了解许多不同材料的性能属性，如铝、玻璃和复合材料等。

Solico一开始就开展可行性研究，以检验是否有材料有可能创造建筑师所需的超平、超光滑的建筑表面。同样为了得到最小的热膨胀性

free-span exhibition gallery in the Netherlands as well as a large black-box gallery/performance space. The other galleries are on the second floor. To allow visitors to enjoy exhibitions without distractions, an enclosed escalator runs directly between the lower level and second floor.

Facade Material

An important part of the architects' vision was that the surface of the bathtub – the façade – should be seamless. Such a large area would need to be made out of a number of smaller panels. And conventional construction materials need a little space-in the form of dilation seams – to expand and contract as the temperature rises or falls. But, of course, those dilation seams (which, depending on the material, might be anything up to 20mm wide) would totally spoil the flawless look the architects were aiming for. To solve this, the architects needed to find a material with absolutely minimal thermal expansion. Before this could happen, however, architects and engineers and experts in aramid and composites all had to push the boundaries of their fields. That's because the bathtub could only be made out of a pioneering new composite material, with Teijin Aramid's Twaron para-aramid fiber as the key ingredient. This is the story of how a multi-disciplinary team went from that fiber, to the new façade.

The smooth white surface of the facade is made up of 271 panels of a pioneering new composite material with Twaron® fiber as its key ingredient. The panels are attached to the steel structure by 1,100 aluminum brackets. Twaron, a synthetic fiber, is extremely lightweight (27 kilograms per square meter, or less than half the weight of a normal curtain wall), is five times as strong as steel, maintains its shape and strength in varying weather conditions and does not melt in fire. Because the composite with carbon fiber and Twaron can be molded, it permits the creation of a smooth, seamless surface of virtually any area. Twaron is ordinarily used for the hulls of motorboats and racing yachts, sailcloth, aerospace and industrial components and sports equipment such as tennis rackets and hockey sticks. At the Stedelijk, it is being used for the first time for a large-scale architectural facade.

An engineer's view: turning vision into reality

Not easily discouraged, the architects looked around for advice from the experts. They were eventually referred to the Dutch engineering firm, Solico, which has extensive experience of designing lightweight and strong products for the construction and aerospace industries. What's more, Solico has the

能，Solico公司还需要测试材料的刚性，如在有风的环境中测试材料弯曲和变形的可能性。在这样一个大且高光泽的表面上，任何扭曲都会显而易见，从而破坏建筑整体的效果。除此之外，建筑外立面还要承受可能的建筑室内外高温差。

Solico的可行性研究表明，唯一能满足建筑师要求的复合材料（至少在理论上符合）是一个由碳纤维和Twaron芳纶纤维组成的特定材料。其基本的原理是，当温度升高时，合成树脂会膨胀，而碳纤维和Twaron芳纶纤维由于纵向热膨胀系数为负，反而会收缩。这就是他们要找的具有最小热膨胀系数的复合材料。Tejin Aramid的纤维研究所测量了在拟定施工中实际样品的热膨胀系数，其实验结果与Solico的计算相符。

复合面板的生产

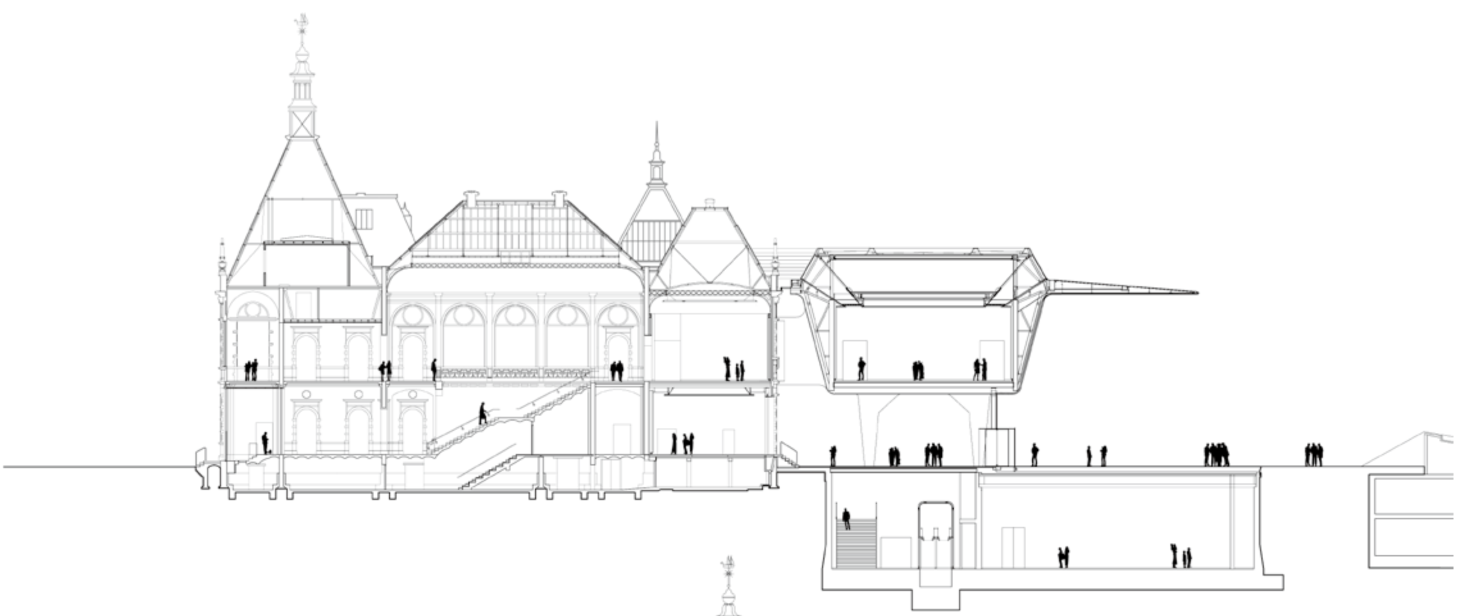
在材料的可行性确定后，接下来的挑战是如何真正地将这185块要用作建筑外墙的巨大复合板生产出来。Solico刚好认识一家能制作这种面板的公司——位于荷兰莱利斯塔德（Lelystad）的Holland Composites公司，它以游艇制造起家，是建筑行业复合材料制造的先驱者。

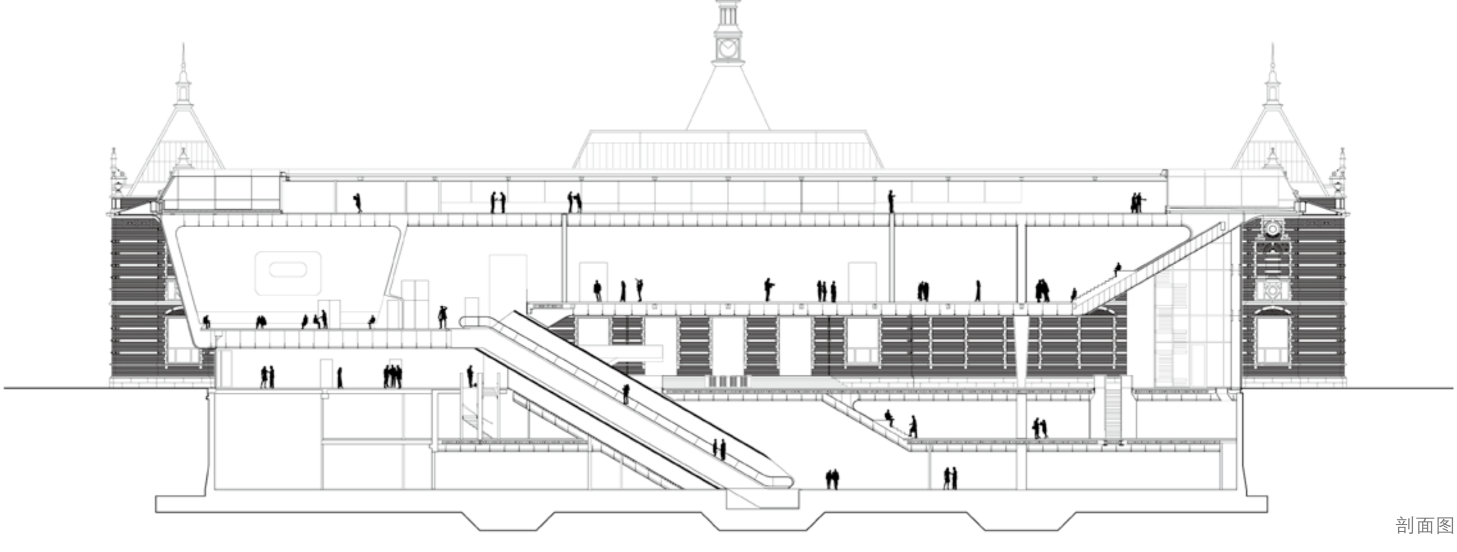
第一步是探索在实际中这个夹层结构的性能是否与Solico公司可行性研究中的表现一样优良。因此，Holland Composites公司制造了6个面板为一组的原型，将它们绑在一起，打磨并涂漆，让它们就像真正

necessary knowledge and insight into the behavioral properties of many different materials, such as aluminum, glass and composites.

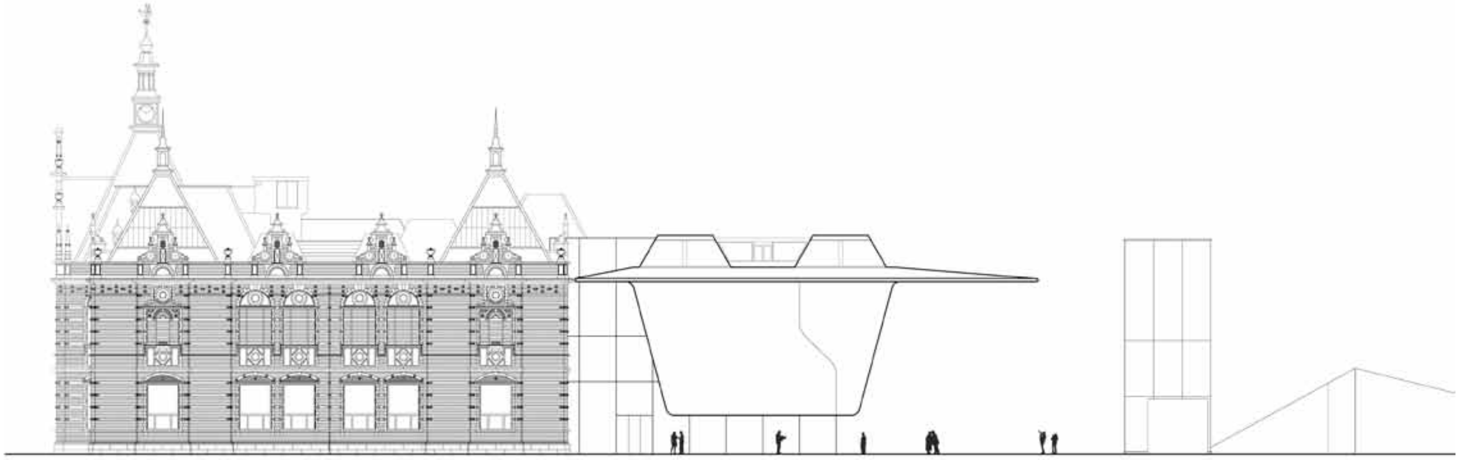
Solico was first asked to carry out a feasibility study to see whether there were any materials that would make it possible to create the super flat, super smooth finish the architects wanted. As well as minimal thermal expansion, Solico also needed to test for rigidity – or, to put it the other way round, the potential for the material to buckle or warp, particularly in windy weather. On such a large, highgloss surface, any distortion would be immediately visible – ruining the overall effect. Plus, the façade needed to withstand the potentially large differences in temperature between the inside and the outside.

The architects had supplied Solico with a 3D digital model of the outermost surface of the façade. Isolating certain sections, Solico added in the dimensions and properties of the different elements and materials, and included static sections to indicate where the façade would be fixed to its supporting steel structure. Using data from the Dutch building codes on wind loading and temperature ranges, Solico could then use this model to simulate how particular composite materials would withstand the various stresses and strains of high winds, high summer temperatures and freezing winter frosts. To really make certain of the wind-loading data, Solico also built a physical model of part of the façade – including static mounting points – for testing in a wind tunnel. For the wind testing, Solico only tolerated a deformation level of up to 3% of a panel's total dimensions. And its tolerance for thermal expansion was even lower. Even on a hot summer's day, the panels could only expand by 0.1% of their total length (the range of temperatures that Solico predicted the facade would be exposed to was from -25ºC to +35ºC). Glass and metal were out, due to their thermal expansion properties. The only option was composites. And fiberglass – a

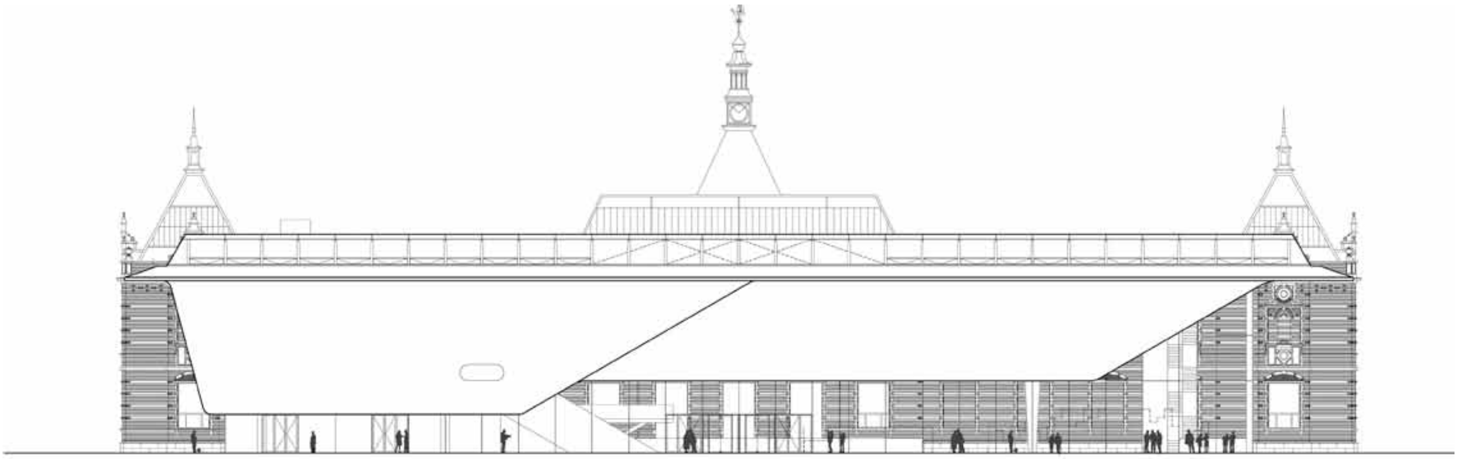




剖面图



西立面图



南立面图

的建筑外立面一样。通过使用这个实验面板，Holland Composites公司和Solico公司确认了Twaron加强型复合材料在100m长的表面上膨胀程度只有几厘米，可以用来施工。

尽管最大的面板尺寸将有15m×3.5m，但这还不足以成为对建筑最大的挑战。真正的挑战在于这些面板必须保证是完全平整的。

复合材料做成曲面是很容易的，但人们不能在一个曲面上发现角度或方向上的微小差异。因此Holland Composite公司不得不设计一个巨大的桌子，要比15m×3.5m还要大，这样他们可以利用它作为对复合板注塑成型的基座。一旦这一巨大的桌子在工厂建造并到位，Holland Composite公司就可以开始进行面板的实际生产。面板的生产采用了“真空注射成型”技术。在生产过程中，第一步是将Twaron对

reinforcing fiber often used in composite materials for the building industry – was not suitable, as its thermal expansion was still too high. Solico's feasibility study showed that the only composite to meet all of the requirements, at least on paper, was a particular combination of carbon fiber and Twaron para-aramid fiber. The basic principle is that whereas the resin expands as the temperature rises, both Twaron and Tenax fibers, due to their negative longitudinal thermal expansion coefficient, contract. The result is a composite with a minimal thermal expansion. Teijin Aramid’s fiber research institute measured the thermal expansion on actual samples of the proposed construction. The laboratory experiments were in line with the calculations made by Solico and confirmed that the Twaron and Tenax reinforced composite identified by Solico could indeed turn the architect's vision into reality.

Production of the composite panels

With feasibility established, the next challenge was to work out how to actually produce the 185 enormous composite panels that would be needed to make the façade itself. Solico knew just the right company to produce these panels: Holland Composites, based in Lelystad (Netherlands), started out as yacht builders, and is now a pioneer of the use of composites in the architectural sector.

The first step was to find out whether the sandwich construction would perform as well in real life as it had in Solico's feasibility study. So Holland Composites constructed a prototype – a set of 6 panels, bound together, sanded and coated just as if they formed an actual part of the façade. Using this test panel, Holland Composites and Solico were able to confirm that the Twaron-reinforced composite would not expand by more than a couple of centimeters over a 100m surface. That was exactly the minimal degree of thermal expansion that would give the composite material the green light: Holland Composites could begin construction.

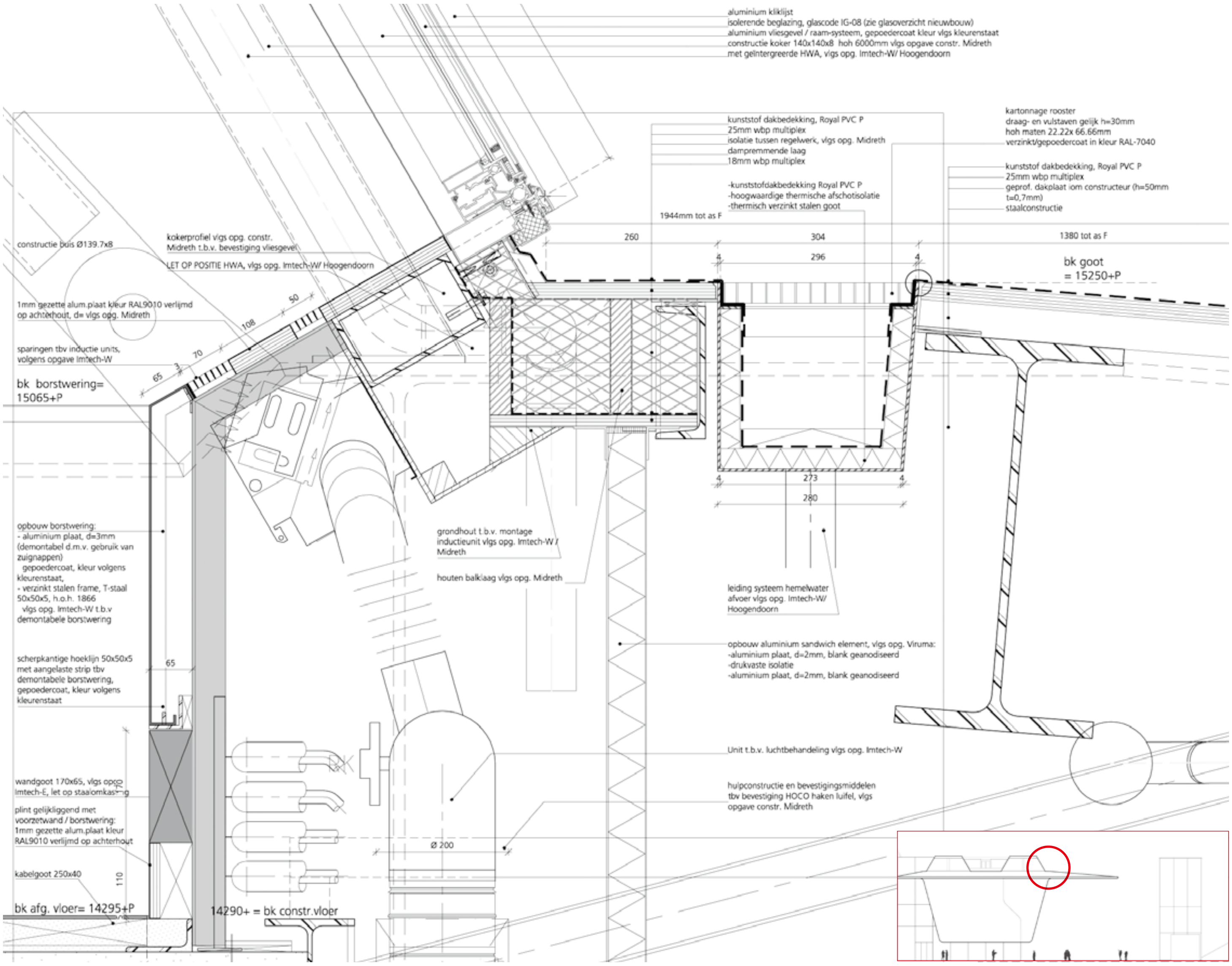
Although the largest panel would be 15 meters high and 3.5 meters wide, it wasn't their size that caused the biggest challenge. It was the fact that they had to be perfectly flat.

Composites can be molded in virtually any shape. And curves are easy, because humans can't spot small differences in angle or direction in a curved surface. However, we are very good at detecting the slightest deviation in a flat surface – especially when the surface is glossy. So Holland Composites had to design a huge table – larger than the largest 15m by 3.5m panel – that they could use it as the base for injection molding the laminates for the composite panels. Once this remarkable table was constructed and in place at their factory in Lelystad, Holland Composites could start the actual panel production. The panels are produced by a well-known composites production technique called “vacuum injection molding”. In this process, the first step is to lay down theunidirectional fabrics of Twaron para-aramid and Tenax carbon fiber on top of a film on the surface of the giant table. Next, the PIR foam is put in place, and the sandwich is completed with set of layers of Twaron and Tenax fabrics. Plastic film is wrapped around the sandwich to make the mold completely air-tight. A vacuum is applied and tubes leading to vats of vinylester resin are attached.

Once the valves in the tubes are opened, the vacuum pulls the resin out of the vat and into each and every nook and cranny inside the mold. After the resin has hardened, the impregnated fabrics and foam are transformed into a tough, durable sandwich construction with one perfectly flat surface.

Building the façade

Early one wintry morning, while the rest of Holland was still sleeping, a convoy of trucks left the workshops of Holland Composites to make the two-hour journey to the Dutch capital. Their load: 185 composite panels made with expertise and precision. The Stedelijk Museum is right in the heart of Amsterdam, so to avoid bringing the city to a halt, Amsterdam traffic regulations only allowed a small window of opportunity for such big deliveries – everything had to be unloaded by 6.30 a.m.! The panels were unloaded into a pretty unique building site. For one thing, it was clean, uncluttered, and sealed off from traffic fumes and whatever the Dutch winter weather could throw at it. The site was even heated, and had air extractors to ensure that it was virtually dust-free. Why? Once the panels were in place, they needed to be sanded, bound together and finally coated with a slick layer of glossy white paint. And that super-smooth surface would be impossible to achieve with dust and rain settling between the panels or on the wet paint. But first, the architect’s ambition of a super-flat façade depended on how the panels were actually mounted. Each one had to be fixed to the steel skeleton with extreme precision. If just one was only a single millimeter too far forward – or too far back – it would distort the shape of the entire 100mlong façade. And with 185 panels to mount,



节点详图

位芳纶纤维和碳纤维的单向织物放置在巨大桌子表面的薄膜上。接下来，PIR泡沫到位，包含多层Twaron纤维和碳纤维的夹心层完成。用塑料薄膜包裹在夹心层的周围，使模具完全气密。然后抽成真空，将通向乙烯基酯树脂桶的管道相连。

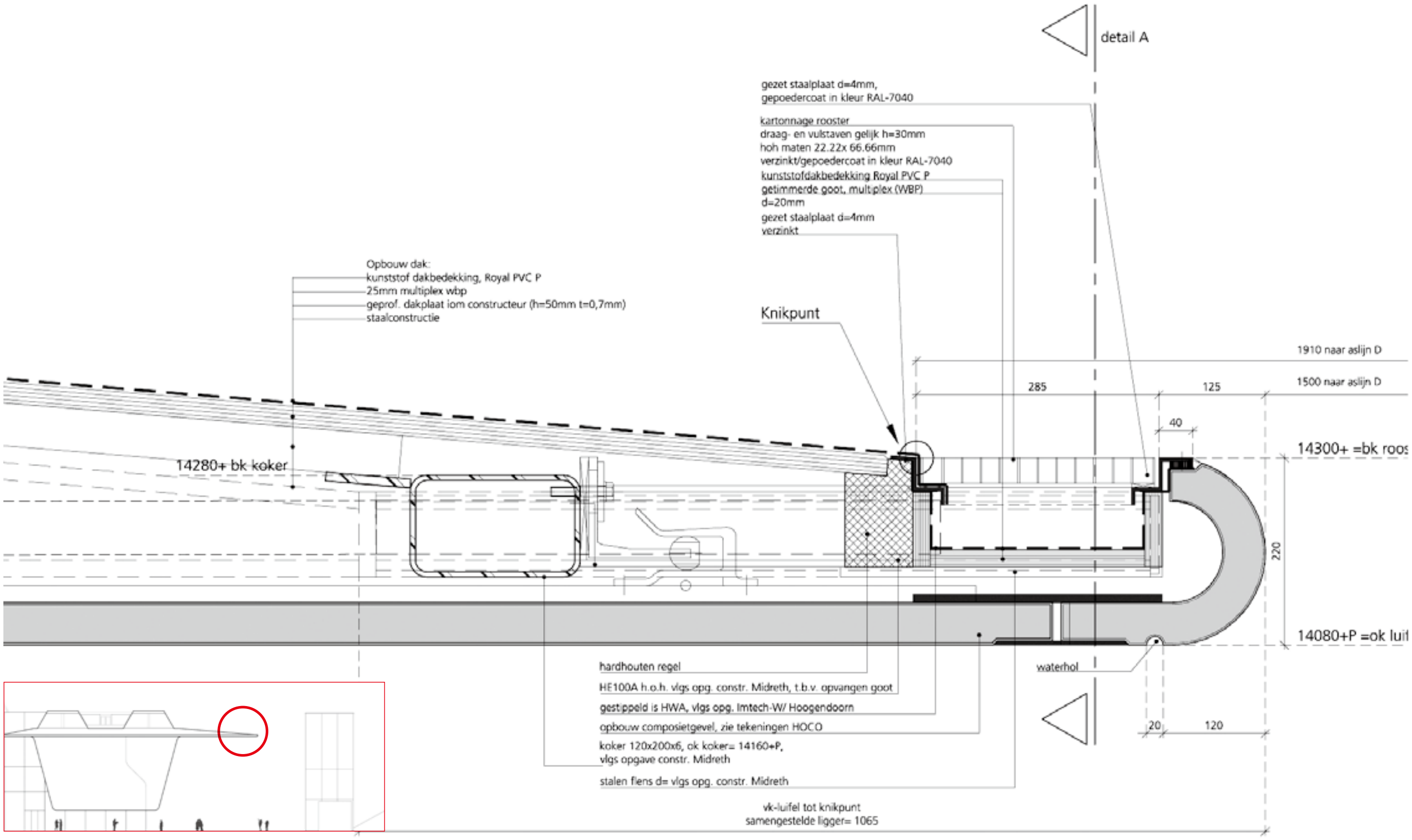
一旦管道上的阀门被打开，真空将合成树脂剥离出桶并填充到模板的每个角落和裂缝中。在合成树脂硬化后，浸渍的织物和泡沫被转化成了一个坚韧、耐久、有着完美平滑表面的夹层结构。

建筑外立面的建造

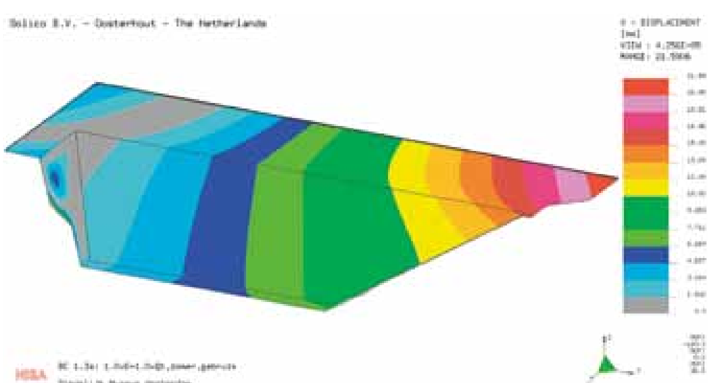
一个寒冷的早晨，当大部分荷兰还在沉睡时，一个装载了185片精密制造的复合面板的卡车队离开了Holland Composites公司的复合材料加工厂，行驶两个小时来到荷兰首都阿姆斯特丹。面板被卸载到一个相当独特的建筑场地。首先，场地很干净、整洁，不管外面是什么样的冬天，场地都被密封起来，远离交通污染。另一方面，场地甚至被加热过，并用吸尘器来保证无粉尘状态。之所以这样做是因为，一旦面板到位，他们需要进行打磨并绑扎在一起，最后涂上有着光泽感的白色油漆光滑层。而且超光滑表面不会接触到面板间或潮湿油漆上的灰尘或者雨水。但首先，建筑师想要的超平建筑外立面取决于面板实际如何安装。每个面板都必须极其精确地固定到钢骨架上。如果有一个面板安装得靠前或靠后1mm，哪怕就一个面板，都会使整个100m长的外立面发生扭曲。185个面板的安装需要定位将近1 800个安装点，且要达到毫米级别的准确度。施工单位最终在这项工作上完成得相当好，保证了3mm内的精确度。到这个阶段，Holland Composites公司就可以真正地开始安装面板了。

面板需要多至15个挂钩来固定在内表面上，而且所有的挂钩都必须同时放置在塑料封盖的安装点上。唯一的解决方法是使用一个遥控器来扭曲和倾斜面板，直到面板到了确切的位置，才轻轻地降低入位。这是建筑行业上第一次使用这种高精密的技术。在面板安装后，它们需要被组合成一个单一的表面。Holland Composites公司设计的面板最外层Twaron纤维加强型树脂复合层压材料只比下层的面层薄几英寸。所以当直接把面板相隔放置时，面板外表皮之间将会有两英尺的间隙。接着Holland Composites公司直接在下面暴露的PIR泡沫上，将芳纶聚酰胺增强层压材料填入到该间隙中，并将两端的层压材料粘结起来。这个“粘结层压材料”在面板之间形成了一个加强的桥架，保证了整个外立面结构的整体性。外立面结构基本已完成，最后涂油漆层。

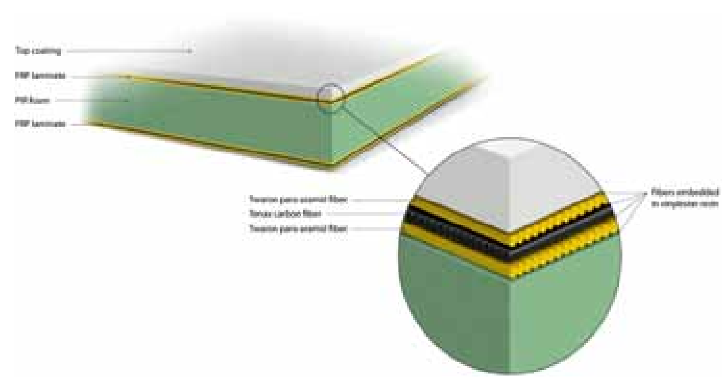
新建筑的外表面光滑、无缝、洁白，而新文艺复兴风格的老建筑则是密集的装饰和红色、金色的砖，两者形成了鲜明的对比。新建筑的外立面是世界上最大的合成结构，而这个结构能成为现实也要感谢Twaron对位芳纶纤维的独特性能。（译/赵欣，校/吴春花）



节点详图



立面热膨胀状况模拟（提供：Solico）



Twaron对位芳纶纤维复合板示意（提供：Teijin Aramid）

立面建造过程

there were nearly 1,800 mounting points that needed to be positioned with sub-millimeter accuracy. The construction company that had built the steel structure had done an excellent job. They had guaranteed accuracy to within 3mm. But that wasn'tgood enough. In order to solve this dilemma, Holland Composites first needed to know exactly which mounting points were out of alignment. A company specializing in precision assessment was brought on board. It used lasers to draw up a map of the exact position of each of the mounting points – which revealed which ones needed to be adjusted, and by how much. The next step was to "move" the mounting points either forward or backward. To do this, Holland Composites had designed six plastic caps that could fit over the mounting points already welded to the steel structure. The six caps were shaped so that they could effectively shift the position of the mounting block underneath by either one, two, or three millimeters, in either direction. Next, a team of construction workers scaled the steel skeleton, each equipped with a bag of plastic caps and a map of the mounting blocks' locations, and started putting the caps in place. Only now could Holland Composites begin actually mounting the panels. But in order to protect their outer surfaces, the panels had to be handled with extreme care. So the team commissioned a unique attachment for a forklift, which could carefully lift each panel using vacuum clamps – just as if it was a pane of glass.

The panels had up to 15 hooks each fixed to its inner surface. And all of those hooks needed to be placed over the plastic-capped mounting points at exactly the same instant. The only solution was to use a remote control to twist and tilt the panel until it was in the exact position, before gently lowering it into place. The use of this high-precision technique was a first for the building industry. After the panels had been mounted, they needed to be bonded into one single surface. Holland Composites had designed the panels so that the outermost layer – a Twaron-reinforced resin composite laminate – was just a few inches narrower than the layers beneath. So when the panels were placed directly next to each other, there was a 2-inch gap between the outer skins of each panel. Holland Composites then glued a strip of the aramid-reinforced laminate into this gap, directly onto the exposed PIR foam beneath, and bonded it to the laminate skins on either side. This "bonding laminate" formed a strengthening bridge between the panels, ensuring the entire façade behaved as a single unit. The façade was almost complete. All it needed was a coat of paint. And the white glossy finish that the architects dreamed up was identical to the gleaming hull of a luxury yacht – so it was time to call in the master yacht painters. After plastering and sanding the façade, they were ready to begin. It's almost impossible to stop and start the painting process without leaving a visible stripe. So the entire 100m-by-15m façade had to be painted in one go. Luckily, the new extension is about the same size as a giant yacht, so the painters knew exactly how to go about it. At one end of the façade, they installed paint sprayers at three levels – one above the other – raising them off the ground on unique high workers. These "platforms on wheels" then drove carefully along, in perfect synch with each other, with their onboard sprayers coating the façade as they went along.

At last, the façade is finished. Its smooth, seamless, shining white surface forms a striking contrast to the existing neo-renaissance building, with its densely decorated red and gold bricks. The new façade is the largest synthetic structure anywhere in the world. AT