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Innovative and Sustainable High-Rise Façade Systems in Asia

亚洲高层建筑创新和可持续的幕墙体系

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Thomas Winterstetter studied structural engineering and economics and completed a doctorate degree in lightweight steel structures design. He has worked on many important projects, including the Mercedes Benz Museum in Stuttgart, the Munich Highlight Business Towers and the award-winning KfW Westarkade high rise in FrankfurtSince 2008 he has been Managing Director of the Stuttgart main office.

Thomas Winterstetter学习了结构工程学与经济学，并获得了轻型钢结构设计博士学位。他曾参与完成了许多重要项目，包括梅赛德斯-奔驰斯图加特博物馆、慕尼黑Highlight商业大厦和屡获殊荣的法兰克福KfW Westarkade大楼。自2008以来，他一直担任位于斯图加特总部的常务董事。

Werner Sobek is architect, consulting engineer, checking engineer for all fields of structural engineering, and holds a Shanghai Engineering License and an Illinois Structural Engineering License. As a successor to architect Frei Otto and engineer Jörg Schlaich, Werner Sobek heads the Institute for Lightweight Structures and Conceptual Design at the University of Stuttgart. He is also Mies van der Rohe Professor at the Illinois Institute of Technology.

Werner Sobek，建筑师、咨询工程师及结构工程所有领域的审核工程师，持有上海工程许可证和伊利诺伊州结构工程许可证。作为建筑师Frei Otto和工程师Jörg Schlaich的继任者，Werner Sobek是斯图加特大学轻型结构和概念设计研究所的负责人。另外，他还是位于芝加哥的伊利诺伊理工学院的密斯-凡-德-罗（Mies van der Rohe）设计课教授。

Benjamin Beer joined the Werner Sobek Group in 2005 After working for two years in the New York office, he became executive vice president of the Dubai office. In 2009, he re-joined the Stuttgart main office and currently works as a team manager on high rise façade designs, mainly in Russia and the Far East.

Benjamin Beer于2005年加入Werner Sobek集团。在纽约办事处工作两年后，他成为了迪拜办事处的执行副总裁。2009年，他重新加入斯图加特总部，目前担任团队经理，该团队主要负责俄罗斯和远东地区高层建筑的幕墙设计工作。

Abstract

This paper presents modern optimized high rise facade systems on outstanding projects in the Far East and Central Asia. The variety of architectural ideas, the need to save energy and the specific demands of high rise construction, different locations, locally available construction techniques and climate conditions requires customized solutions. Current Asian projects in various design stages, under construction, and recently completed will be presented to demonstrate innovative solutions, where the latest European construction and energy-efficiency know-how is adopted to meet the local needs overseas. Iconic projects like the ones presented herein clear the path for innovative solutions and for a wider application of the specific systems invented to make them real.

Keywords: High Rise, Façade, Energy Efficiency, Innovative Solutions, Design and Engineering

摘要

本论文介绍了远东和中亚地区一些杰出项目的优化的现代高层建筑幕墙系统。建筑理念的多样化、能源节省的需要以及针对高层建筑、地域差异、当地现有的施工技术和气候条件的特殊要求均需要定制不同的解决方案。本论文将介绍亚洲地区目前处于各个设计阶段、正在施工中以及最近完成的多个项目以展示创新型的解决方案。这些设计方案采用了欧洲最新施工和节能技术以满足海外地区的各地特定需求。本论文中介绍的标志性项目帮助清除了创新型解决方案及其特定系统实现更广泛应用道路上的障碍，使之能够成为现实。

关键词：高层建筑、幕墙、能源效率、创新型解决方案、设计与工程

Introduction

Innovative and iconic high rise buildings all over the world combine latest integrated design know-how, energy-efficient building envelopes and up-to-date construction technology to create an optimized, multi-functional, recognizable and unique appearance. Recently completed projects will be presented to demonstrate the latest developments in aesthetics and engineering.

Siemens Center Shanghai: Use Of The Benefits Of A Double Skin Façade In East Asia

The Siemens Campus in Shanghai consists of four buildings (Phase 1) with a 13-floor high rise main entrance building being the gateway to the four building compound (see Figure 1).

The buildings' main structure is a wide span slab on RC beams, on generously spaced columns, with shear walls providing the lateral stiffening system. The complicated geometry of the main building, with recessing and protruding lobby areas, was a challenge for the structural design.

The aim of the project was to use modern comfort-and-sustainability knoweldge- for the

引言

世界各地的创新性和标志性高层建筑充分结合了最新的一体化设计技术、节能建筑围护结构和最新的施工技术，以创造更优化、多功能、可识别和独具特色的建筑外观。本论文将介绍最近完成的一些项目，以展示美学和工程领域的最新发展趋势

西门子上海中心—东亚地区双层幕墙优点的运用

西门子上海中心由四座建筑物（1期工程）以及一幢作为通向这四座建筑物的通道主入口的13层高层建筑组成（见图1）。

这些建筑物的主体结构为钢筋混凝土梁和间隔较大的柱上的大跨度板以及提供横向加劲系统的剪力墙。主建筑复杂的几何结构以及凹凸的大堂区域是结构设计面临的一项挑战(见图1）。

该项目的目标是充分利用现代关于舒适性和可持续性的专业知识—首席顾问为GMP建筑师事务所/ Inros Lackner股份有限公司。创新型幕墙是一大特色，其可使建筑物总能耗比其它建筑低1/3以上。

该项目采用双层幕墙，内层是一个隔热层（主立面），带有用于自然通风活动窗户，并带有一个永久性的装有外部遮阳设施的通风口；外层是一个单平面。“额外”的平面形成了第二层幕墙，满足了一

Figure 1. Siemens Center Shanghai under construction
图1. 正在建造中的西门子上海中心

lead consultant gmp Architekten / Inros Lackner. The innovative skin is a major feature to lower the total energy consumption of the building by more than 1/3 compared with others.

With a double-skin type of facades, there is an insulated layer (primary façade) at the inside, with operable windows for natural ventilation, a permanently ventilated cavity where an external sun shading device is located, and an outside mono-plane. The "additional" plane, forming the second skin, meets a set of important requirements:

- Protection of motorized external sunshade blinds from wind,, dirt and debris; putting the sunshade outside the insulated envelope is the key to low cooling energy, and keeping them clean is the key to efficient use of daylight direction devices;
- Reduction of outside noise level to enhance natural ventilation through operable panels without being disturbed by traffic noise;
- Reduction of wind effects, providing protection from wind draft through natural ventilation openings especially in open-plan offices.

The very large, 2.8 x 4.0 meter size façade units were preassembled completely in the factory of Jiang-He, with operable louvers, motorized blinds, and glass and glazing which were lifted up on site without the need for any external scaffolding (see Figure 2). Therefore, installation speed was very high and installation quality was very good.

Another important feature of this project is the generous entrance lobby with its 33m high cable façade, which covers an area of approxamently 2,300 square meters. The main structural element is the vertical cables with 36mm diameter having pre-stressing forces of approximently 365 kN which are transferred through the slab on top by widely spaced columns back to the ground. The result is an amazingly transparent screen around the main access to the compound.

Office High Rise In Hanoi, Vietnam: Modern Curtain Wall Meets Special Structures

This project is a compound of two high rises with a large lowrise podium building totaling 300,000 square meters of office space. It was designed and built in a very short time of only 2.5 years. Here, the architectural idea of an integrated special structure super-transparent cable façade was chosen and further enhanced (see Figure 3).

Figure 2. Siemens Center Shanghai – prefabricated large double skin façade units (Jiang-He CW contractor plant)
图2. 西门子上海中心—大型预制双层幕墙装置（由Jiang-He CW承包厂生产）

系列关键要求：

- 外部电动遮阳百叶窗可防止风、灰尘和碎片的进入；将遮阳设施置于隔热围护结构外面是降低冷却时能源消耗的关键，并且保持其清洁性是高效利用采光定向装置的关键；
- 减少外界噪音水平，通过活动板加强自然通风，而不会受到外面交通噪音的干扰；
- 减少风的影响，通过自然通风口（尤其是在开放式办公室）提供风流保护。

大尺寸（2.8 × 4.0米）的外墙装置在Jiang-He工厂完全预安装好，包括活动遮阳板、电动百叶窗、玻璃和玻璃窗。这些都在现场吊起，无需使用任何外部脚手架（见图2）。因此，安装速度非常快且安装质量非常高。

这个项目的另一个重要特点是建有宽敞的入口大堂及其33米高的索网幕墙，其占地面积约为2300平方米。主要结构元素是直径为36mm的垂直索网，具有约365kN的预应力，其由间隔较大的柱子通过顶板传递回到地上。设计效果是建筑群主要通道周围展现出令人惊叹的透明屏幕。

越南河内高层办公大楼—现代幕墙满足特殊的结构要求

这个项目是一片由两幢高层建筑物和一幢大型低层裙楼组成的建筑群，办公空间合计为30万平方米。设计和建造仅用了短短两年半。该项目选择并进一步强化了使用一体化特殊结构、超透明索

Figure 3. Office High Rise Hanoi compound - view from the lake
图3. 河内高层办公建筑群— 湖边视图

Figure 4. Office High Rise Hanoi – partial view of main building with cable-façade lobby
图4. 河内高层办公建筑— 主建筑及索网幕墙大堂局部视图

Figure 5. . Office High Rise Hanoi, view through special structure cable facades
图5. 河内高层办公建筑—特殊结构的索网幕墙视图

The whole project was clad with a fully unitized façade, in a variety of different faced types according to the architectural demands. These facades included innovative features for Hanoi, such as integrated operable natural ventilation louvers, and operable external sunshades, similar to the preceding project (see Figure 4). The façade construction type and the use of highly relective , neutral solar-control, multifunctional insulating glass units were not common to the country, and special production and processing lines were set up specifically for this project

The main entrance lobby is located underneath the main highrise building, Together with gmp Architekten and the structural engineers from Inros Lackner, two generous, 30m high and 45m wide super-transparent cable façades were developed, which are suspended only from two large steel trusses carrying the solid volume of the high rise above (Figure 4). The result is a breathtaking and de-materialized appearance which makes the building instantly recognizable (see Figure 5).

Maritime Museum Linggang: Symbiotic Structural And Façade Engineering

A further development on the integration of special structures is the Maritime Museum in Ling Gang, China, where the 50m high main building essentially consists of one huge special structure (see Figure 6). The main structural body consists of two curved, white-clad "sails" resembling the sails of an ancient Chinese Junk, which were made of a steel truss system with bolted connections. The sails meet only in one central hinged point high up, in the middle, giving the whole assembly a special structural appearance.

In between there are two super-transparent cable-net insulating glass facades. The double-curved geometry of these double-curvature facades was determined by computerized form-finding routines, and they fit very well in the overall geometric complexity and size of the project (see Figure 7).

The Heydar Aliyev Center: Iconic Freeform Architecture At Its Best

Another very challenging project is the Heydar Aliyev Center which will be the national cultural center of Azerbaijan, a country located

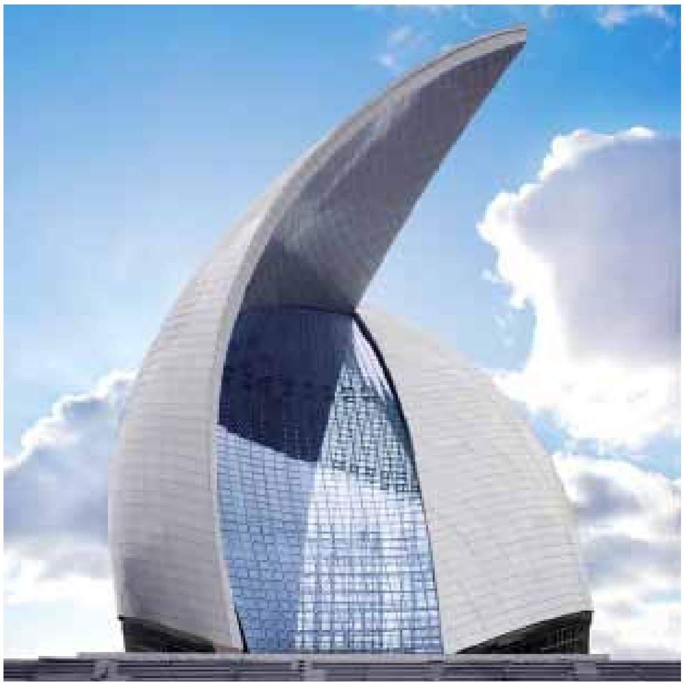

Figure 6. Maritime Mueum Linggang – view showing the two structural "sails" and the cable-net in between
图6. 临港航海博物馆—本视图显示两种结构的"帆"及"帆"之间的索网幕墙

网幕墙的建筑理念(见图3)。

整个项目根据不同的建筑需求采用各种不同面型的整体式幕墙进行覆盖。这些幕墙包含一些在河内具有创新意义的功能，如集成式自然通风活动百叶窗和外部活动遮阳板，与前一个项目类似（见图4）。幕墙建筑类型与高反射、中性采光控制、多功能隔热玻璃装置的使用在越南并不常见。根据这个项目的需求，设立了特殊的生产和加工线。

主入口大堂位于主高层建筑的下方。GMP建筑师事务所和来自Inros Lackner股份有限公司的结构工程师共同设计开发了两种30米高、45米宽的大型超透明索网幕墙，该墙仅悬挂在两个大型钢桁架上，用于支撑高层以上的实体积（见图4）。设计效果是令人惊叹的无物化外观，使该建筑具有了非常高的识别度（见图5）。

Figure 7. Maritime Museum Linggang – Partial view during construction
图7. 临港航海博物馆—施工期间的局部视图

between the Caucasus Mountains and the Caspian Sea, where Europe meets Asia.

Baku is the capital of Azerbaijan, a country at the south side of the Caucasus mountain range, between Russia (north), Georgia (west), Turkey and Iran (south) and the Caspian Sea (east). Azerbaijan is a former soviet republic which has been an independent state since 1991. The country is rich of natural resources, especially oil and natural gas. In history, it was a hub for the Silk Road for centuries and preserves a rich Islamic cultural heritage.

The climate of Baku is comparably harsh, with heavy winds blowing very often, hot and dry summers with very low precipitation, and cold temperatures up to -10°C in the winter coming from Siberia. The atmosphere is typical for the seashore-location of the city.

Baku lies on the Absheron Peninsula, the eastern extension of one of the main Caucasus ridges marking the fault line between the European and Anatolian continental plates. Therefore, Azerbaijan is subject to elevated risk of earthquakes, similar to Anatolia and northern Iran.

The Heydar Aliyev Centre will be the national cultural centre of Azerbaijan, housing a museum, an auditorium / opera house, and related cultural facilities. It is located at a central spot in the city, overlooking a large park, and its unique and iconic design is also intended to be a memorial to the founder of modern Azerbaijan.

The center was designed by Zaha Hadid Architects, London, in their specific organic, parametric-design style (see Figure 8). Both the external envelope and the interiors are 3D freeform shapes, and many engineering innovations were necessary to make them real and make them meet the architect's design intent.

The basic architectural idea is that the main building developed its form from the plaza in front of it. The plaza is divided into wide strips which wrap upwards around the main building volume and create a free-flowing 3D shape. The freeform envelope which is reflected in the interior 3Dceiling, floats above the building's access and circulation areas, merging into the volumes of the functional spaces.

The main building consists of a combined in-situ cast-in-place RC concrete and composite-steel-frame structure. Some parts of the building have wide span composite beams with RC slabs cast on metal deck, whilst in other parts, conventional RC slabs on RC beams were used, depending on the architectural requirements.

The lateral stiffening system addresses the very limited space created by the architectural constraints as well as the high horizontal forces

临港航海博物馆—共生结构和幕墙工程

对特殊结构一体化的进一步发展在中国临港航海博物馆项目得以实现。该项目主建筑高50米，基本上由一个庞大的特殊结构组成（见图6）。主要结构体由两个弧形白“帆”构成，与中国古代平底帆船的帆相似，其由钢桁架系统及螺栓连接件组成。“帆”仅在中间高处的中心铰链点汇合，使整个组装呈现出一种特殊结构的外观。

在这两个“帆”结构之间有两层超透明的索网隔热玻璃幕墙。这些双曲幕墙的双曲几何结构由计算机化的找形分析程序确定，它们与该项目整体几何结构的复杂性和尺寸非常协调（见图7）。

盖达尔-阿利耶夫中心—最佳标志性自由曲面造型建筑

另一个非常具有挑战性的项目是盖达尔-阿利耶夫中心，它是未来的阿塞拜疆国家文化中心。阿塞拜疆位于高加索山脉和里海之间，是欧亚两洲接壤之处。

阿塞拜疆位于高加索山脉南侧，四面分别毗邻俄罗斯（南）、格鲁吉亚（西）、土耳其和伊朗（南）和里海（东），巴库为其首都。阿塞拜疆是前苏联加盟共和国，1991年独立。该国拥有丰富的自然资源，尤其是石油和天然气。历史上，该国在好几百年时间中一直是丝绸之路的枢纽，并且保留了丰富的伊斯兰教文化遗产。

巴库的气候条件相对恶劣，大风频繁，夏季炎热干燥且降水量非常小，冬季常有来自西伯利亚的寒流，最低气温达-10° C。属于典型的海滨城市气候。

巴库位于Absheron半岛，是高加索山脉主脊之一的东部延伸，位于欧洲和安纳托利亚大陆板块之间的断层线上。因此，阿塞拜疆属于地震高风险地区，与安纳托利亚和伊朗北部相似。

盖达尔-阿利耶夫中心将是未来的阿塞拜疆国家文化中心，其由博物馆、音乐厅/歌剧院和相关的文化设施组成。它坐落在城市的中心，俯瞰一座大公园，其独特的标志性设计是为了纪念现代阿塞拜疆的创始人。

该中心由扎哈-哈迪德建筑师事务所设计，具有他们特定的一体化参数设计风格（见图8）。外部围护结构和内部结构为3D自由曲面造型，为了使具有现实可行性且满足建筑师的设计意图，需要进行许多工程创新。

基本的建筑理念是主体建筑从其前面的广场展开造型。该广场分为几个宽带状块，围绕主体建筑容积向上盘绕，形成一个自由流动的三维形体。其内部三维天花板使用了自由曲面围护结构，悬浮在建筑物入口和流通区域上方，与功能区域的空间融合在一起。

Figure 8. Heydar Aliyev Center in Baku, Azerbaijan, during construction
图8. 阿塞拜疆巴库的盖达尔-阿利耶夫中心—施工期间的视图

Figure 9. Heydar Aliyev Center – structural bonding unitized 7.5 x 2.5m façade panels
图9. 盖达尔-阿利耶s夫中心 – 由7.5 × 2.5米大小的整体式幕墙板形成的结构连接

caused by earthquake accelerations. In the front cone area, there is a 3D-freeform shearwall concrete core. In the lower areas which are approximately 20m high, there are various RC shear walls. In the highest part of the building, more than 70m high, the stiffness of a very slender concrete core and a steel section frame system have been combined.

The space frame roof structure was designed in a multi-step process, starting with the definition of a structural zone between the architectural freeform shapes of the 3D external skin and the 3D inner skin, following a design freeze. Afterwards, the space frame was coordinated with the structural design of the main structure. First, top and bottom chord gridlines were defined along the number axes, with the structural gridlines at 9m offsets being multiples of them. Then, a grid of three-dimensional diagonalswas inserted, the geometry was checked for clashes with the architectural shape, then an FE model was generated and computed, the steel sections and quantities have been calculated and optimized by the space frame contractor, MERO using specialist software, and finally the support forces and details were coordinated with the main structure. During the computerized stress analysis, it was particularly important to include a correct model of the combined action of the spaceframe and the main structure beyond, with each having different frequencies and oscillation behavior.

The external envelope consists of white, 3D, solid-cladding parts and vertical, glazed parts. The glazed parts were designed to be a unitized, structural-bonding curtain wall, with very large units having dimensions of up to 7.5m x 2.25m (see Figure 9).

The solid skin was installed in three layers. The first layer is a structural, unitized, three-dimensional steel space frame system (see Figure 10). The second layer is a weatherproofing-and-insulation tray system made of prefabricated, approximately 10sqm large metal deck panels, each having individual dimensions matching the offsets of the space frame nodes. The third layer is a secondary structure above the waterproofing layer, which receives the 12,000 glass-fiber reinforced plastic (GRP) panels, which were also uniquely produced, with each part different and in customized single-use moulds.

The building was completed in May 2012, and it is already known as a bench mark on what modern computer-supported architecture and sophisticated engineering can achieve.

主建筑由现场浇注的钢筋混凝土和钢框架组合结构组成。建筑物的某些部分有大跨度组合梁及在金属板上浇注的钢筋混凝土板。而对于其它部分，则在钢筋混凝土梁上采用传统的钢筋混凝土板，这主要取决于建筑的要求。

横向加劲系统解决了因建筑限制而产生的空间有限问题以及由于地震加速所引起的超高横向力问题。在前方的锥形区域，有一个三维自由曲面形状的剪力墙混凝土芯。在大约只有20米高的较低区域，有各种钢筋混凝土剪力墙。在建筑物70米以上的最高部分，一个非常纤细的混凝土芯和一个型钢框架系统被合并到了一起。

空间框架屋顶结构采用多步骤流程进行设计，从三维外层和三维内层建筑自由曲面造型之间结构区域的确定开始，然后确定设计。随后，对空间框架与主体结构的结构设计进行调整。首先，沿着数轴确定桁架网格线及其9米倍数偏移的结构网络线。然后，插入一个三维对角线网格，并检查几何结构与建筑造型是否有冲突；然后，利用计算机生成并计算有限元（FE）模型，型钢及其数量已由空间框架承包商MERO采用专业软件进行计算和优化，最后，就支撑力和细节与主体结构进行协调。在计算机进行应力分析的过程中，尤为重要的是要包括一个关于空间框架和主体结构之外组合作用的正确模型，它们各自有不同的频率和振荡。

外部围护结构由白色三维坚固包层部分以及垂直釉面部分组成。釉面部分设计为整体式结构性连接幕墙及巨型尺寸的装置（最大尺寸为7.5 × 2.25米）（见图9）。

坚固的包层安装在三个层中。第一层是整体式结构性三维钢空间框架系统（见图10）；第二层是防水隔热塔盘系统，其由约10平方米的大型预制金属板构成，每块板具有与空间框架节点偏移量相匹配的各自尺寸；第三层是防水层上面的二级结构，包含专门生产的12000块玻璃纤维增强塑料（GRP）板，各部分均不相同，均采用单独定制的模具生产。

该建筑完成于2012年5月，已被公认为现代计算机辅助设计建筑和复杂工程所能达到高度的一个里程碑。

巴库火焰大厦—标志性自由曲面造型的高层建筑实现最优化几何结构

与上述各项目一样，许多现代项目采用自由曲面造型的建筑风格，以打造具有高识别度的标志性建筑外观。因此，在很多时候，减少几何结构的复杂性可能是使其具有可行性和经济适用性的关键。一个很好的例子就是巴库火焰大厦项目（见图11）。该建筑群包含三幢160米~180米高的多功能大厦，最下面是一座大型零售商场。

Figure 10. Heydar Aliyev Center – Construction of the 3D envelope in functional layers
图10. 盖达尔-阿利耶夫中心—各功能层中三维围护结构的施工

Figure 11. Baku Flame Towers, Azerbaijan – total view
图11. 阿塞拜疆巴库的火焰大厦 - 全视图

Baku Flame Towers: Optimized Geometry For Iconic Freeform Highrises

As on the projects above, many modern projects use free-form architecture to create an iconic and recognizable architectural appearance. So, very often, reducing the geometric complexity might be the key to making it feasible and economically affordable. A good example is the Baku Flame Towers Project (see Figure 11), with a set of three mixed-use towers ranging between 160 and 180m height, sitting atop a large retail podium .

The project's main structure is a conventional RC concrete system with shear walls and slab on RC beams and columns. Again, the unusual shape with inclined columns and overhanging areas, and the high risk of earthquakes imposed high challenges on the structural design.

The three towers were originally designed by HOK Architects /London, to a freeform non-uniform rational basis spline (NURBS) shape resembling flames (see Figure 12). Consequently, an optically very disturbing triangularization and a very expensive curtain wall would have been used to clad the buildings. The 3D engineers of Werner Sobek Stuttgart optimized the tower massing in order to transform it into a seemingly freeform, but developable, shape with which it became possible to install a modern unitized, four-corner panels, storey-high fully glazed curtain wall (see Figure 13).

Another special feature of this project was the extremely high wind loads. The specific, very windy climate of Baku located at the Caspian Sea on the verge of Europe and Asia, the location of the site atop a steep hill overlooking the sea, the wing-shaped tower massing and ensemble effects from the grouping of the three buildings create very high wind forces with façade loads up to more than 800 kg /sqm, which demanded very special care during designing and testing of the curtain wall units.

Concluding Remarks

The present paper shows modern trends in façade design demonstrated on recent projects in Asia engineered by Werner Sobek Stuttgart, including the following topics:

- Energy efficiency and the related issues of efficient external sun shading, natural ventilation, and a state-of-the-art modern multifunctional envelope will become increasingly important.
- The desire to add something unique and iconic to major projects calls for recognizable architectural features which are very often generous steel-and-glass special structures.
- The modern trend towards 3D computer-generated parametric architecture calls for a very qualified engineering, because new solutions are needed to deal with the complexity of single-parts-production.

该项目的主体结构为传统的钢筋混凝土结构以及剪力墙和钢筋混凝土梁和柱上面的板。同样，不同寻常的造型、斜柱和伸出的区域以及地震的高发性对结构设计提出了很大的挑战。

这三幢大厦最初由伦敦HOK建筑师事务所设计成自由曲面的非均匀的合理B样条（NURBS）造型，类似于火焰（图12）。因此，建筑物外墙将采用非常昂贵且具有光干扰性的三角形幕墙覆盖。来自德国斯图加特的Werner Sobek集团的3D工程师对大厦建筑体型进行了优化，将其改造成一个看似自由曲面但可展开的造型，以便可以安装现代整体式四角板和全层高玻璃幕墙（见图13）。

这个项目的另一个特点是非常高的风荷载。巴库毗邻欧洲与亚洲边缘的里海，具有多风的特殊气候条件，而该大厦群位于陡峭的山坡之上，俯瞰大海，翼状大厦的建筑体型和三幢建筑物群的整体效应形成了非常高的风力，幕墙负荷超过了800公斤/平方米，这要求在设计和测试幕墙装置时采取非常谨慎的态度和原则。

结论

本论文显示了德国斯图加特的Werner Sobek集团最近在亚洲设计的项目中所体现出来的现代幕墙设计趋势：

- 能源效率以及高效的外部遮阳、自然通风和最先进的现代化多功能围护结构的将变得越来越重要。
- 为重大建筑项目添加一些独特的标志性设计的需求要求具有识别度的建筑特色，其通常为大量的钢材-玻璃特殊结构。
- 由计算机生成3D参数建筑结构的现代趋势要求非常高质量的工程设计，因为需要新的解决方案来处理单件生产的复杂性。

Figure 12. Baku Flame Towers – Optimization of tower shape to rationalize façade installation
图12. 巴库火焰大厦- 优化的大厦造型，以使幕墙安装更趋合理

Figure 13. Baku Flame Towers facades during construction
图13. 施工期间的巴库火焰大厦幕墙