BIRKHÄUSER

multi layered

engineered variety

sbp

schlaich
bergermann partner

multi

layered

engineered variety

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Augmented Reality

① Download the sbp-AR-app available for iPhones, iPads, or Android devices at Apple App Store or Android Google Store.

② Point your device at the page with the trigger AR-icon.

③ Watch the image come to life as video content.

multilayered—
engineered variety

The title of our book may seem puzzling at first glance and some readers might wonder why we have chosen to call it *multiple layers—engineered variety*. Two years ago, we began thinking about a follow-up to *The Art of Structural Engineering, Light Structures,* and the volume in the *DETAIL engineering* series. It didn't take long to identify a number of key aspects of our work that seemed important to us and deserved publication.

Before choosing the actual content, we considered the questions of whether the book as such is still a viable medium in our digitized world, and whether it is adequate for presenting our way of working. Nowadays, doesn't a publication have to appear online in order to be continually updated? This led to a passionate debate among us. In the end, we agreed that a book about schlaich bergermann partner would also serve as a personal record of recent years, which would be indispensable because of the topics that it covers, and which would give pleasure not only to others but also to ourselves. So really, a book just for ourselves? No, because that would not do justice to its contents. We are sure that the issues, as we have experienced and addressed them in the book, will also arouse the interest of others—not least because they give insights into the design culture at schlaich bergermann partner.

Once this decision had been made, we were faced with a wide variety of possible content to choose from, ranging from the many projects on which we had worked since our last book in 2012 to innovations in geometry optimization and in form finding, as well as rapid development in the solar energy sector, and unbuilt ideas. We also considered topics such as our sketch-based working method, and the locations and circumstances in which our projects are built all over the world. In short, we wanted to show the full diversity both of our work and of the team at schlaich bergermann partner.

We believe that the complexity of planning tasks that exists today can only be tackled and managed by well-coordinated designers in a partnership of mutual understanding, which is how our own team functions. In this respect, what schlaich bergermann partner has achieved in recent years is the sum of the contributions made by each employee. We, the partners, see ourselves as the initiators of these feats, as sources of ideas and inspiration, but only by working together as a unified team are we able to turn our ideas and visions into reality.

We want this book to reflect the versatility of our team and the many facets of our work, which is why it is built up in layers. These are experienced as separate parts, visually and tangibly, while their contents remain interlinked. Additionally, the analog content is supplemented with digital content (for more details see front cover flap), which can be viewed in parallel or separately You can, of course, read the book in the traditional way, starting at the front and finishing at the back. Alternatively, you can jump from layer to layer, following a thread of thought or an internal connection, and pause to delve more deeply into a particular topic or browse a *set of pictures*. This book is meant not as a textbook but as a window onto the world of our work in all its breadth and creative energy. We hope it will give you an idea of what we are passionate about and will encourage you to contact us in person with your own thoughts, because what makes schlaich bergermann partner special is best experienced when you work directly with us.

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Perhaps this book will be the first step on a shared journey. On behalf of all the partners and staff, you are very welcome to join us.

Sven Plieninger

Layer 01

Working Methods

by Clementine Hegner-van Rooden

I have been allowed the opportunity of shadowing, questioning, and looking over the shoulders of the people who make up the consulting engineers schlaich bergermann partner (sbp). For over a year I have been at their sides in meetings, workshops, and discussions, and chatted with them during lunch and coffee breaks. Gradually, I have been able to peel away the layers one by one and discover what lies behind that well-known name.

The result is a progress report, a snapshot of an engineering consultancy's dynamic history that is far from being over. From its offices in Stuttgart, Berlin, New York, Paris, São Paulo, and Shanghai stems a continuous flow of buildings, bridges, and other impressive structures. Some are dynamic, elegant machines, while others are first and foremost virtuous, slender structures—always precise and cleverly thought out, right down to the details. The projects appear just as dependably in the industry's specialist literature as they do among the prizewinners of major design competitions. Looking at the list of almost 3,000 projects and recognizing many notable building works by their name or their picture, I found myself questioning in more than one case how that happens. While walking through the modern offices and looking over the shoulders of the staff, I wondered how they arrived at such a productive and creative method of working.

After many hours of observation, I had the answer and it was so obvious, even in how their projects themselves come across: sbp strives for balance—not only in the design for each project but also in the design team. Therefore, the structures are based on a balanced interplay of forces and the team on a balanced interaction of members. This aspiration is the most important prerequisite for good structures. Only in this way can projects emerge that accord with the values and guiding principles applied from the time sbp was founded in 1980. Building culture is indivisible. Appropriate design and ecological efficiency are on an equal footing with functionality and architectural quality. Form and load-bearing structure convince the beholder when they merge into a single, self-explanatory whole that can be understood as part of a comprehensive "Baukultur".

The values sbp live by at work are an important part of the corporate culture. That became especially clear to me during an inspiring presentation by Mike Schlaich in front of all his employees: ***"I want everyone who works in our office to understand where we come from and what makes us who we are. I want to communicate the passion and pioneering spirit embodied in so many of our projects—and ideally I would like to infect the younger generation with it."***

A working climate characterized by team spirit and lateral organization prevails in the company with the aim of enabling everyone to identify with the values and projects. The free expression of opinion is paramount here. Andreas Keil believes everyone should be encouraged to play an active part right from the beginning, when they join the company as young engineers. He goes on to stress: ***"Strictly hierarchical practices are simply out of date in the modern world. Participative leadership is a much more common approach today—as it was already under Jörg Schlaich and Rudolf Bergermann, when we, today's partners, were the newcomers to the company."*** Sven Plieninger adds: ***"You have to trust people. Jörg Schlaich and Rudolf Bergermann let me handle my first project directly by myself—naturally accompanying me with constructive criticism."*** This way of influencing the future generations of the company is axiomatic and actively promoted. Without asking questions and trying things out, people cannot learn. Everyone must pull together. Thus, fresh views get to mix with decades of project experience and specialist knowledge; the one gains equally from the other. The individual pieces of knowledge are collated within the company and communicated as a consistent and authoritative body of knowledge to the outside. This gives rise to added value for employers, architects, and clients because the whole is more than the sum of all the individual parts. Underlining this thought, Knut Göppert adds: ***"It's just as in sport: the team that leaves the pitch as the winner is not the team with the best individual players but the team that plays the best together."***

The objective of teamwork is to make the right use of every ounce of talent and bring together individual strengths in the right projects. The stronger the team spirit and the cohesion within the group, the easier it is to achieve the set goals. This is also confirmed by Knut Stockhusen: ***"If we are all helpful and considerate to our colleagues and all our individual capabilities are used to best effect, then success is also easier to achieve."*** That is an important aspect because projects are often only achievable by working together as a group.

So far, so good. But how is this team spirit to be promoted amid all the pressures and urgency of the everyday work? Sven Plieninger answers the question in this way: ***"Working together within a team can only happen not only by knowing the individual team members but also by interacting with them."*** Not quite so simple if the team is spread all over the world and has grown to more than 180 members. By giving employees the space and time to enter, maintain, and strengthen the required communication, the partners build the link between each individual's knowledge and a genuine collaborative work effort. Individuals and teams that are committed to networking on a personal and a business level minimize errors that often arise from poor communication or lack of knowledge. Knut Göppert believes that the projects themselves also benefit: ***"The more we know and the more we are able to interlink this knowledge, the more flexibly and inventively we can react to complex requirements and the more confidently we can explore what is feasible and get to grips with what we do not yet know."***

Everyone is involved in this integrated process. Mike Schlaich puts it metaphorically: ***"We pick up the employees and take them with us on the journey."*** And naturally this includes all new employees—as it has been over generations. Jörg Schlaich and Rudolf Bergermann achieved milestones in engineering and passed their way of building and designing on to their successors. The current partners also allow their employees to play a significant part in the development of the project. Consequently, it is sometimes not at all easy to find potential candidates for the team. ***"We recognize from a very early stage of the application process whether the person sitting in front of us is a match for sbp, someone who has a passion for structures, someone who can think unconventionally and has an affinity for architecture,"*** says Knut Göppert. Every new member of staff adds strength to the team. ***"Because we are all involved in the work process, we create a fruitful basis for discussing solutions in a can-do atmosphere. Together we have the courage to make reality what may have been thought impossible,"*** explains Knut Stockhusen.

The five partners give their employees an early opportunity for continuing professional development. Everyone who is willing may and should develop their professional skills in a personal or project-specific context. Those who are willing and able to take on a leadership role are given the opportunity. And others who wish to remain out of the limelight are allowed to contribute in the background. This is the way skills are built up and passed on to others. It is also the way to remain successful over the long term.

Exchanging views and opinions internally is also interdisciplinary: not only in the field of solar energy must structural engineers work with mechanical engineers, energy specialists with physicists, and aeronautical engineers with electrical engineers. With sbp, you will find no siloing of skills. The employees think across disciplines, thus creating added value for present and future projects. After all, collaboration is the foundation of good structures. Cooperation with different disciplines is enriching and stimulating, and generates new ideas. Buildings that arise from real cooperation between the disciplines are the best examples of how synergies can be used across projects and new insights advanced. So we see an increasing number of moveable structures emerging with the development of solar energy solutions, and *the question of form finding* comes up in projects time and time again. With each new cross-connection, sbp extends its horizons and the body of knowledge. ***"That also means,"*** says Mike Schlaich, ***"that we engage with the industry's current challenges. We concern ourselves with questions of energy efficiency, conservation of natural resources, cost effectiveness, and retention of value."*** As Jörg Schlaich wrote in sbp's book *leicht weit—Light Structures* in 2003: ***"Baukultur is the only adequate means of partly making good our destruction of nature."***

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Communication tools developed in-house for sbp support this dialogue in and between individual offices. Similarly, the design of the offices contributes to spontaneous meetings and informal discussions. All offices have a common coffee break, which is used regularly for short project presentations. In addition, they also hold monthly events where information is transferred between different offices, where project-specific and internal-office innovations are discussed, attention is drawn to conferences or articles, and lessons learned from completed planning or design processes are shared.

After one of these coffee break presentations about a successful competition for a bridge in China, Sven Plieninger said: ***"The exchange of detailed information and knowledge can function effectively or be improved only if we are actively interested, open, and ready to assist in other areas of work, offices, and countries. This creates the fertile ground for our office culture to thrive."***

The same applies in the workshops, where knowledge transfer and collegial relationships are fostered through projects carried out jointly by different offices—capabilities from Berlin are brought to Stuttgart or knowledge is transplanted from Stuttgart to São Paulo. In addition, there are regular Lunch-and-Learn events with external speakers, and the sbp Academy. These professional development sessions are internally organized and specifically focused on the requirements of sbp projects. Internal know-how on topics such as cables or membrane behavior, dynamic aspects of lightweight construction, or structural details in bridge construction is disseminated at these events. This format enables employees to satisfy their curiosity on different subjects. Special events for entry-level engineers ensure that everyone is supported in their early professional life and that nobody has to rely solely on the skills and knowledge they already had before joining sbp.


To hold the lightsteel tubes at here position.
We catwalk to get more stability.

All partners and project managers with whom I have spoken also emphasize that they themselves want to continue to learn and develop professionally. They are always looking for new information and opportunities to learn something new. They work in an environment of continual change, because when the principle of "old solutions for new problems" does not apply, people must *develop their own solutions*. This echoes what Albert Einstein once said of his success: "I have no special talent, I am only passionately curious." The basis of innovative activity at sbp is therefore its openness to new experiences—curiosity is one of its core competences. Andreas Keil puts it this way: ***"The creativity embodied in many projects is ultimately a product of our curiosity. That is the basis of our good reputation. And we cultivate this reputation prudently, because it is not carved in stone."***

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This wish or desire of sbp to try out and learn from new things as a natural mindset is one thing that marks them as different from other offices. Another is the typical sbp philosophy of storytelling. Stories are an instrument, as old as they are effective, to start a thinking process. A lively story gains the attention of other people much more easily than a sober speech. Stories fascinate people, engage and motivate them to form an opinion. The engineers at sbp know a story about a design, about a structure—from the initial idea through the planning to the implementation. Listeners remember these subjectively cast messages for many years, because they are reinforced by the personal connection with the messenger. Authentically delivered, they also increase identification if the storytellers project themselves as other than infallible—and that is a personality trait approved and encouraged at sbp. Together with their message, it generates the fascination, perhaps even the charisma, that the office radiates. They also drew me in and made me feel a connection to the work and the people.

The stories are part of the history and tradition of the office. They help sbp retain and emphasize its heritage, even with the constant growth of the company and in spite of changing organizational structures, technologies, and media landscapes. They add excitement to the projects, an emotional commitment that flows into the designs. They whet the employees' appetite to work on a project, contribute to it, and cooperate with others. ***"Because,"*** says Mike Schlaich, ***"the effect is better when the design is told as a story. Therefore communication is very important to us. My father was a master at this. With his stories of the Olympic Stadium, the Hooghly Bridge in India, and the solar updraft tower, he inspired and carried us all away."*** Knut Stockhusen added from his own recollection: ***"Jörg Schlaich saw this as a way to infuse vitality, emotion, and color into the world of engineering, which was technocratic and perhaps a little aloof. He always accompanied his theoretical rationalizations and highly technical explanations with impressive examples."*** In easy-to-understand, straightforward language accompanied by illustrative sketches, he rendered the sometimes complex or abstract structures accessible to all—including the lay public. Regardless of whether the listener understood every last detail, they would pick up the main points and, in the ideal situation, be inspired. This approach is very beneficial in discussions with clients, architects, or other project stakeholders. When people communicate effectively, they are able to discuss and evaluate different, sometimes contradictory requirements and have the opportunity to react appropriately to them.

sbp works together with many people on a wide range of project types over both longer and shorter periods of time. The engineers see countless designs with an abundance of climatic, technical, contextual, or local boundary conditions. There are competitions, alternative proposals, conceptual designs,

detailed designs … The breadth of ideas—including many that are never built—is large. This multifarious world of thought is a resource for new designs, and each engineer at sbp can contribute to this as an equal partner in the design process. Clients who become involved in this creative discussion and know how to benefit from it can gain great information to advance their projects. Andreas Keil reemphasizes the point in this context: ***"Engineers are frequently seen as number-crunchers for architects, following the architect's proposals without adding ideas of their own. We, on the other hand, always look for other options with the intention of entering into a dialogue with the architect. This is appreciated by many of them, because this interactive and interdisciplinary process leads to fully developed and convincing buildings."*** According to Knut Stockhusen, sbp remains credible ***"because during the design we represent the interests and objectives of our clients and design partners, and with our know-how and all our passion we stand fully behind our projects all the way up to their completion."*** The numerous *long-term partnerships* of the office are the best testament to this strength, which finds its expression in the complex process of structural design. For the engineer, structural design often means performing a balancing act between safety, cost efficiency, rational functionality, and high levels of innovation and aesthetics. The result turns out well if the designers strive to react sensitively to all these requirements. This inner drive becomes obvious in Mike Schlaich's assertion: ***"We don't allow ourselves to rest until the best solution has been found."*** Then again, for Sven Plieninger, ***"the finished building is the motivation to keep on going. Naturally, there are always projects that never make it beyond the competition design stage. But after putting so much thought into often complex ideas, I would rather like to see them constructed eventually."***

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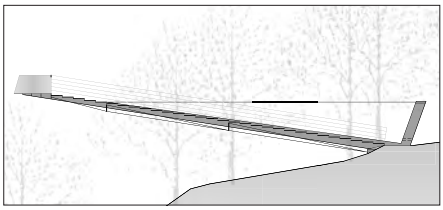
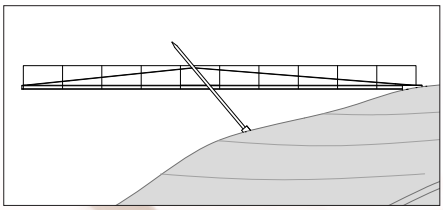
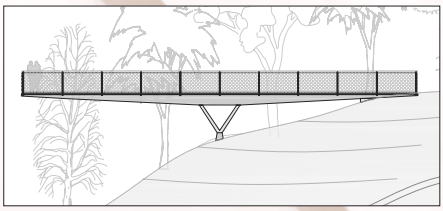
Andreas Keil adds that engineers must develop an acceptance of this design process: ***"It is demanding because it needs effort to design something that appears to be effortless."*** It sometimes seems challenging in that respect to keep the project development perfectly on track, and Knut Stockhusen's observation rings true: ***"We may drift well off course from time to time, making a detour. But this detour has never done us any harm. On the contrary, we find interesting approaches that may fit, if not in this project, then perhaps in another."***

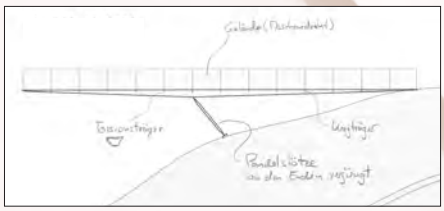
An internal design competition exposed the intrinsic motivation for this design process and put the focus on a deliberate form-finding procedure on display: As part of the Remstal Garden Show 2019, a platform was to be constructed at the **Sieben Linden viewpoint** near the village where Jörg Schlaich was born. There was a lively interest in this competition within the office; 34 employees decided to respond to the challenge. They would do it in their free time and continue with their ongoing projects at work. Following a detailed examination of the proposals, a jury made up of internal and external members chose the winning project. Andreas Keil puts it succinctly: ***"We considered every project individually and arrived at the most technically and aesthetically apt solution for the specified requirements. What was perceived as a fairly restrictive brief concealed an enormous design potential."***

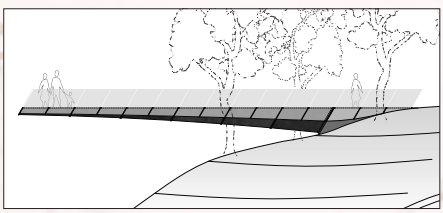
"Creativity in design and contextually appropriate structures contribute to the art of Baukultur" is the guiding principle of the office. Special solutions are designed with this as the theoretical basis. In addition, sbp takes advantage of its many years of experience, the use of innovative technologies, and a coherent choice of materials.

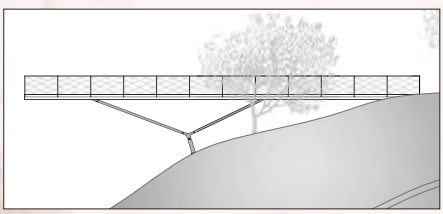


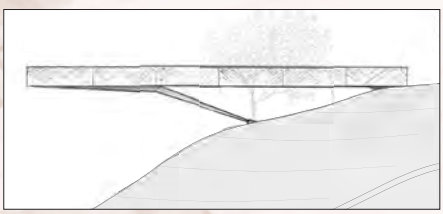


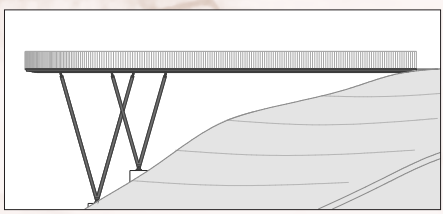












The characteristic traits of the partners vary in as many different forms as there are different sbp projects. However, despite their individual personalities and their different interests and emphases, they show the same passion. They are curious, hungry for knowledge, empathetic, and dynamic. They do not turn their backs on any culture—be that a regional or *international social culture,* or any particular design or architectural culture. This characteristic provides the foundation for sbp's capabilities and performance. Knut Göppert summarizes it like this: ***"The core of our creative work lies in the fact that we have learned to be courageous. And we would like to pass this trait of curious courageousness on to others."*** And Sven Plieninger expands on this: ***"Thanks to our many successful activities abroad, we also contribute to maintaining the good reputation of German engineering."***

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It is the shared pride in the projects that motivates the whole team, drives them forward, and is celebrated throughout sbp. Every employee is thoroughly trusted by the partners, which prompts them to identify much more strongly with their projects. Young engineers receive a unique opportunity to build up experience and—with a guiding hand—to bring their own projects to fruition by their own efforts. This process is also interlaced with pain, which is not surprising for something driven by passion. Passion holds potential. And from the released potential comes enthusiasm for more completed projects. As Newton's third law says: Action and reaction are equal. An action gives rise to a reaction.

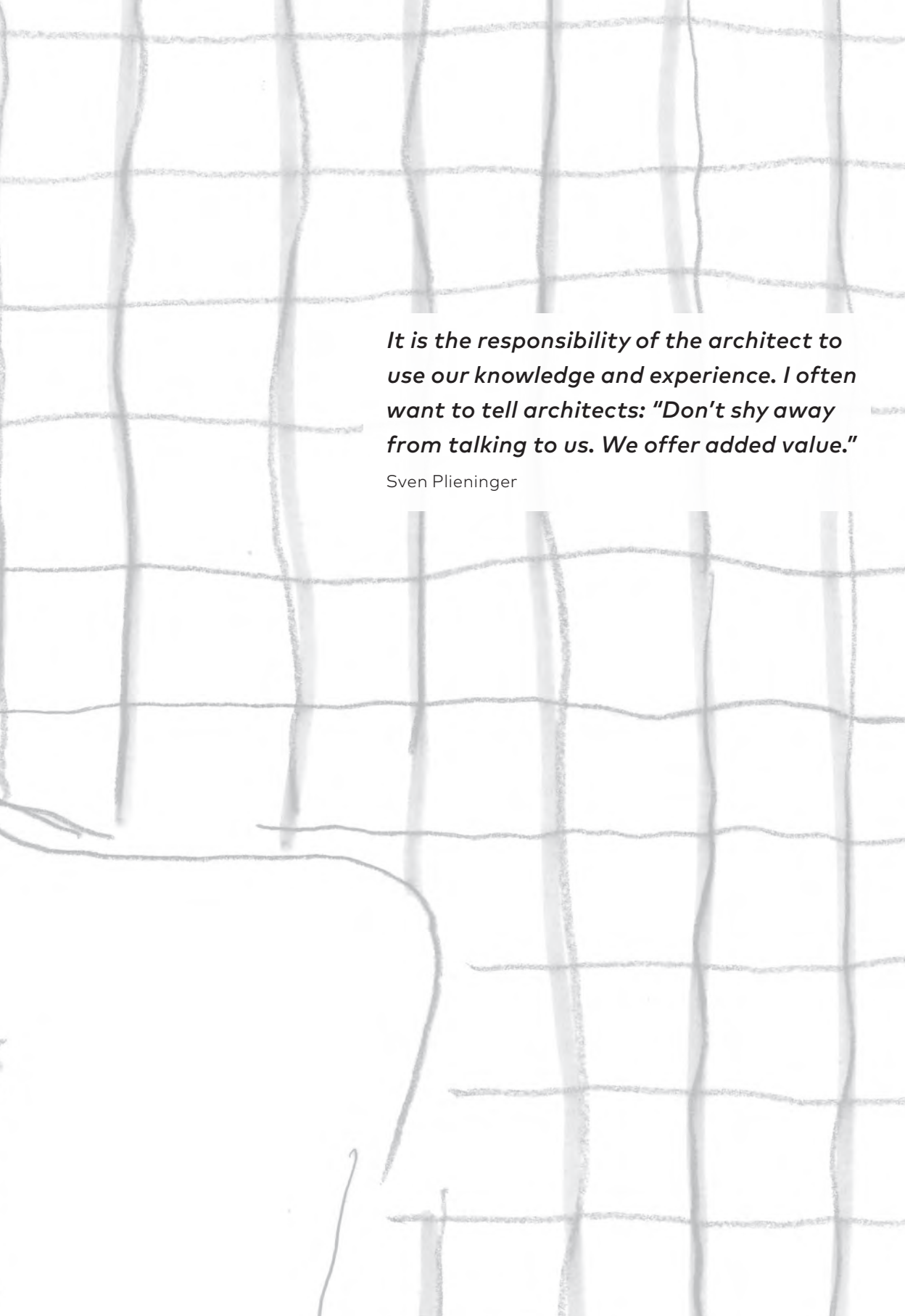
The result is the balance mentioned at the start of this chapter: schlaich bergermann partner believes in achieving a balance of forces. A balance in which creativity and careful design keep the scales level; in which passion and obligation complement one another. The balance of the collegial interplay of forces, consisting of a creative team of people with various capabilities, is reflected in the resulting multifaceted structures. And from this ultimately arises the creative power of sbp, which has existed at home and all over the world for decades.

I am impressed and doff my cap to the self-composure, patience, and calm of the partners. Because without doubt, during my interviews and visits, all of their construction sites throughout the world have been buzzing with activity. This presence makes clear how trust allows them to spread the responsibility among many different shoulders. This eases the burden on each individual and enables them to bring their abilities to bear. It is smart and farsighted. And it deserves every respect.

Building Construction

Cultural Buildings

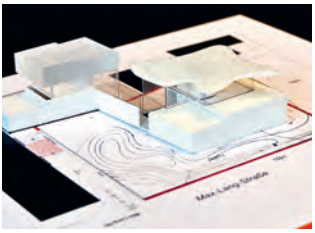
Glass

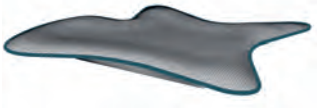


It is the responsibility of the architect to use our knowledge and experience. I often want to tell architects: "Don't shy away from talking to us. We offer added value."

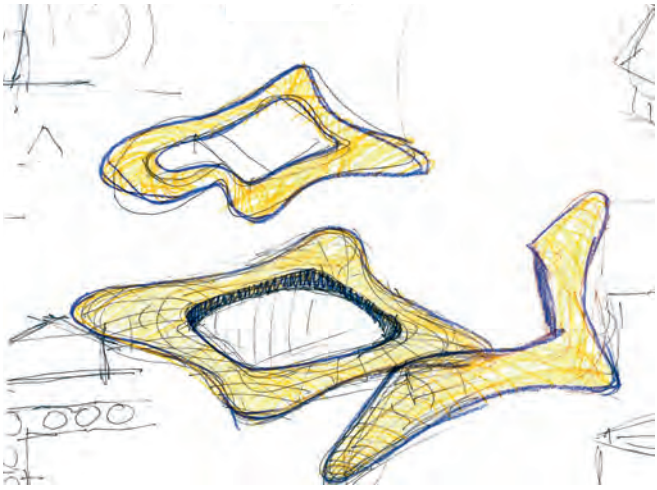
Sven Plieninger

Living the values established by our founders and upholding them in every project often requires an almost unconditional, even idealistic attitude to work. These values, which assume that structural engineers, too, assign importance to architecture as an art, lie at the heart of our practice; they are communicated to—and are instilled in—every new member of staff.



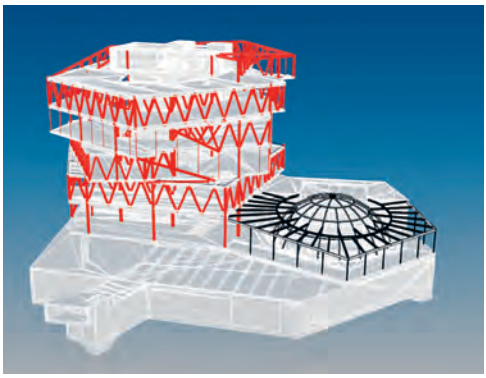


Among other things, we see our engineering work as a contribution to culture. Ideally, the creative and inspiring interplay between architectural and structural design is reflected in an unforced manner in the buildings themselves, as with the **Froehlich Foundation show depot.** The Froehlich commission was preceded by a project for the German National Library in Leipzig, on which we collaborated with the architect Gabriele Glöckler. Collaboration works best on an equal



footing. The independent, professional viewpoint of each individual results in a creative whole that is more than the sum of the contributions made by the two disciplines. Bit by bit, the architectural and engineering aspects become ever more closely interwoven, at both the conceptual and constructive levels.

Taking the initial idea of a cloud floating over the building and working it up to arrive at a supporting structure in monocoque construction is a feat that requires a process of abstraction in which the actual load-bearing behavior is broken down into the elements of a structural concept. A complex entity is reduced to a simple, clear, and ultimately calculable static system, whereby the pattern of forces should remain comprehensible.



This approach is not based on a rigidly inflexible system. The process is rather governed by complex and sometimes contradictory constraints and by experience. The solution is approached iteratively, but may be guided by intuition.

The **Experimenta** stands on the banks of the Alt-Neckar in Heilbronn and was completed in 2019. The Science Center introduces visitors of all ages to the world of science and technology using an innovative, interactive exhibition concept. The new building is the result of collaboration with Sauerbruch Hutton architects and Drees & Sommer (General Construction Management). It forms an ensemble with the existing building, an old warehouse with an extension dating from 2009. The exhibition space of 7,500 m² is thus boosted by an additional 13,500 m².

The new space is spread over five levels with pentagonal floor plans in a sophisticated geometrical arrangement. Each floor is offset at an angle to the next, creating a twisting effect. The exhibition is accordingly divided into sections, the "theme worlds." These are linked by circulation and recreational spaces arranged in sequence as a spiral. The area of the building's footprint that is common to every floor contains the reinforced concrete core, nearly 7 m wide and 22.5 m tall, which braces the steel composite structure

Owing to the design's geometric complexity, 3-D modeling was used to develop the structure from the start, with parametric modeling, calculation, material selection, optimization, and exploration of alternatives. This was later integrated into BIM software and prepared three-dimensionally for the production process.

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of the rest of the building. From the spacious foyer, an atrium rises through all of the floors, and inserted into this volume are heptagonal steel modules housing the "studios." Here visitors can try out the practical applications of what they have learned in the exhibition. These rooms are linked to the exhibition spaces on the respective floor by short steel bridges. The exhibition spaces—organized in four themes from the worlds of natural science and technology—are arranged in a rising helix. They are constructed as Holorib-composite decks supported at the perimeters by floor-to-ceiling steel trussed girders. The glass facade, which is transparent in the circulation spaces, frames views of the neighborhood as a counterpart to the exhibits, some of which are of a microscopic scale. In the exhibition areas, the building envelope is opaque but is articulated in triangular elements that express the underlying structure on the outside. The interdisciplinary work that gave rise to this building can thus be experienced directly in the architectural design, reflecting the dialogue between technology and people that Experimenta represents.

Accordingly, we want our projects—built or not (yet) built—to appear uncontrived and thus, at best, to outlast their time and passing fashions. This is especially the case with cultural buildings, which, owing to the spotlight of public attention, are treated as flagship projects for the construction sector as a whole, in terms of both architecture and structural engineering. Buildings for cultural use ought to create an identity and a sense of place as well as, ideally, serving society as a mirror of its cultural values. This can be achieved not least through high-quality architecture and an efficient, well-designed, robust structure that embodies and complements the architectural concept. This kind of project therefore tends to succeed best when there is genuine dialogue between all of the parties involved.

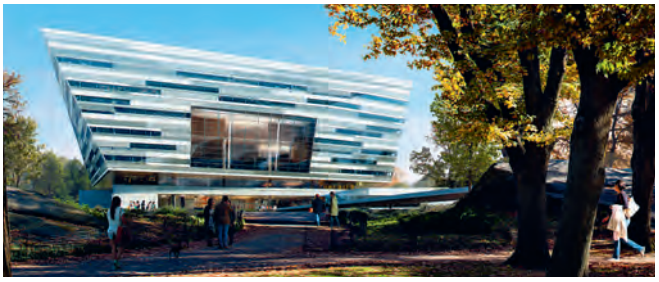
One such productive dialogue was the one that developed with BIG (Bjarke Ingels Group, New York). We worked with them on a competition entry for the headquarters of the **beverage manufacturer San Pellegrino.** This **flagship factory** project involved creating new buildings, refurbishing existing buildings, and constructing a road bridge. The design was inspired by the brand, translating "purity, transparency, and naturalness" into architecture. The jury was impressed by the architecturally simple and clear vocabulary of the load-bearing structure, consisting of uniform arches constructed completely of concrete, which exemplified a successful cooperation between the architect and the structural engineer.

The concept for the **Art Mill** in Doha owes its memorable quality to a bold, creative intervention. We won the four-stage competition as part of a team with ELEMENTAL, Transsolar, and Stantec. The gallery is to be built near the port of Doha, on the site of a former flour mill. Important goals of the art gallery concept were to integrate the existing grain silos into the design and to condition the interiors in the most natural and resource-saving way. The distinctive cylindrical shapes of the silos defined the character of the location and were to be retained as industrial heritage.

The design by ELEMENTAL, the Chilean architectural practice of Pritzker Prize–winner Alejandro Aravena, proposes interrupting the strict geometry of the rows of silos. This is achieved by adding further silo-shaped structures and connecting the existing grain silos by cutting large openings of varying sizes in their walls. This allows air to circulate through the buildings and facilitates their conversion into

art gallery spaces. The resulting interiors combine old and new and, despite their immense size, form a built work of art that fulfills all of the requirements.

On occasion, the visible structure—most impressively in its purest form—truly expresses the complexity of the engineer's contribution. The **Shanghai Library East** is a particularly striking example of this. Situated in an earthquake zone, the distinctive building, designed by Schmidt Hammer Lassen Architects, represents the efficient solution of a classic problem.



Quite different, but characterized by its structure to an equal extent, is the **Black Forest National Park visitor and information center** at Ruhestein. Designed jointly with Sturm + Wartzeck, EWT engineers, and [f]landschafts-architektur, it won an international, interdisciplinary design competition in 2015. The site lies among wooded slopes at more than 900 m above mean sea level (AMSL). The initial inspiration came from seeing fallen tree trunks lying on top of each other, which found architectural expression as a complex of multiple buildings in the form of long, thin bars. Measuring up to 65 m in length, they provide exhibition space totaling 3,000 m². The natural environment of the Black Forest is reflected in the facades as well, which are clad in wooden shingles. The unconventional architectural concept allows the complex to blend harmoniously into its surroundings, despite its considerable size. The highlight of the visitor center is the open-air skywalk at treetop height, 35 m above the ground, which leads to a tower and lookout platform.

The long buildings overlap each other and some are gently inclined at a slope of 3.5 percent. Some of them have point supports, while others are connected off-centre or cantilever out. Their main structural elements are trussed girders made of beechwood, which as a hardwood can withstand

significantly higher forces than softwood. The girders form the longitudinal walls of each building, and the wooden roof and floor elements are hung between them. This construction of trussed walls and decks functions statically as a box with point supports, either horizontal or (in the case of the tower) vertical. In addition, some of the buildings have been constructed as "mega-tubes" of construction-size panels consisting of cross-laminated timber. At the truss nodes, the flanges and the diagonal struts have multi-shear connections with slotted plates and bolts. Concrete has been used only for parts of the building that touch the ground, or are subjected to bending or high stress. In certain places, wood had to be replaced by steel. Thus the supporting structure in some sections of wall is a hybrid wood-steel truss. The timber construction method with flexible shear connectors makes the visitor center better able to withstand earth tremors, while the choice of materials is consistent with the design concept of affinity with nature.

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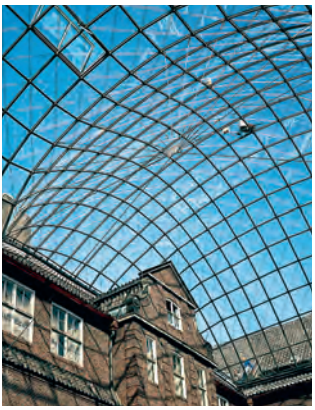
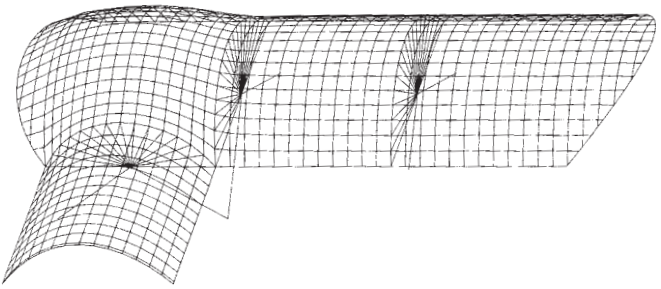
Our "art" lies in contributing to an architectural design in the early stages, which in the best case allows the opportunities for a good structure to arise in harmony with it. Andreas Keil





Adding value

The motivation for building glass structures is clear for all to see. It results in highly transparent, lightweight structures that offer protection from the weather yet allow views in and out as well as merging indoor and outdoor space. The building envelope also allows a *degree of climate control that extends the temperate season of the year*. These intentions are perfectly illustrated with the **glazed roof over the courtyard of the Hamburg Museum,** which we developed in 1989 with gmp · von Gerkan, Marg and Partners Architects. A delicate, lightweight lattice shell spans the L-shaped museum courtyard. Sophisticated and elegant, the roof structure is also a groundbreaking innovation, which attracted international attention at the time and since then has often featured in publications and inspired other designs. It was needed so that the outdoor space could function as a continuation of the interior rooms. However, a conventional glazed structure, with a hierarchical geometry of regularly arranged arches and purlins, proved to be unfeasible. It was inappropriate from an architectural point of view, owing to the irregular rhythm of the existing facade; and impossible in structural terms, because the historic building was inadequate for bearing additional point loads. Rather like a kitchen sieve, the glazed lattice of steel mesh, cross-braced by prestressed cables, distributes loads evenly across the existing structure without overloading any one point.

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The design, calculation, and dimensioning of transparent shells are complex processes. Construction with glass requires comprehensive knowledge of structural behavior, material science, and expertise in the field of geometry, including the software skills needed for calculation. As engineers, we can achieve the greatest possible transparency and slenderness only if we optimize the supporting structure statically and geometrically, and do so in a unified, integrated way.

The roof geometry is generated by translating a transverse arc along a longitudinal rail (scale-trans surface). The gaps between the roof perimeter beams and the eaves of the building's two wings are closed with inclined panes of flat glass. This means of modeling makes it possible to surface the roof with transparent glass: rectangular panes of flat, laminated glass.

We *refine and adapt existing models* to arrive at new glazed roofs, such as the canopy over the public plaza of the **Ernst & Young headquarters** in Luxembourg, by Sauerbruch Hutton architects. Here we see an extremely shallow variant of the cable-braced lattice shell. The volume below it is trapezoidal in plan, 20 m high and 36 m in length, with considerable spans: 17 m back at the building's main entrance and 42 m where the plaza opens onto the street. In addition to the parameters of the ground plan, there were restrictions on height: the roof was not permitted to rise more than 3.8 m above the top of the last story, and the horizontal edge beam on the street facade was to be at the same level as the eaves of the building's wings so that it could appear to continue as a fine, straight line. This left very little leeway for the rise (the structural height) of the canopy shell. In the first phase of design development, we explored the potential of lattice shells, membrane structures, and cable-supported lattices in countless variations of orientation and arrangement.

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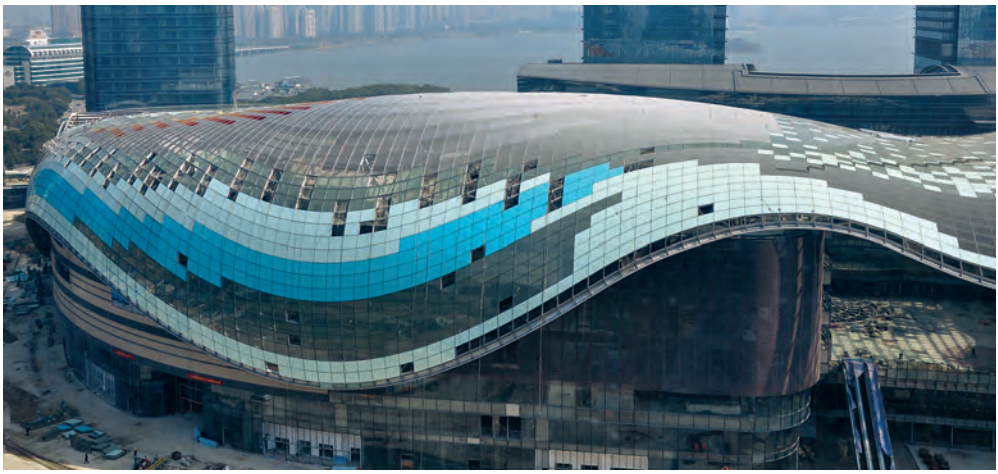
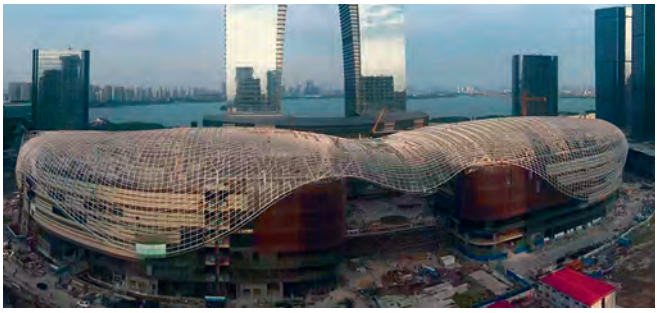
The inverted shallow lattice shell proved to be the most suitable design solution—being transparent, cost-effective, and structurally efficient under the given conditions. The requirement to rise from the same height on all four sides of the trapezoidal plaza led to a biaxial arched grid with a variable panel size of 1.7 m × 0.8 to 1.7 m. The lattice consists of standard hollow steel rods with uniform dimensions of 140 × 80 mm and wall thicknesses varying from 8 to 14.2 mm, depending on the stresses. Since the ratio between arch rise and span is only 1:15—the usual target is a ratio of 1:5, or at a minimum 1:10—additional supporting elements have been inserted to prevent problems with the structure's stability, such as warping or buckling. Every second transverse axis of the roof is therefore trussed with cables. These spiral strand cables are prestressed so that dead loads do not cause horizontal deformation at the bearings. Vertical hinged struts are installed between the roof envelope and the cables. When asymmetric loads occur, these pendulum rods activate the truss cables and stabilize them, thus making it possible for the dome-like canopy to have an unusually low rise. Thanks to their small diameter, the struts and cables are barely perceptible. Efficient load-bearing behavior thus combines with sophisticated geometry to create an aesthetically pleasing, delicate roof structure.

The projects demonstrate again and again the potential of glass-and-steel structures, and the variety of forms and applications possible when you build with glass. Sven Plieninger

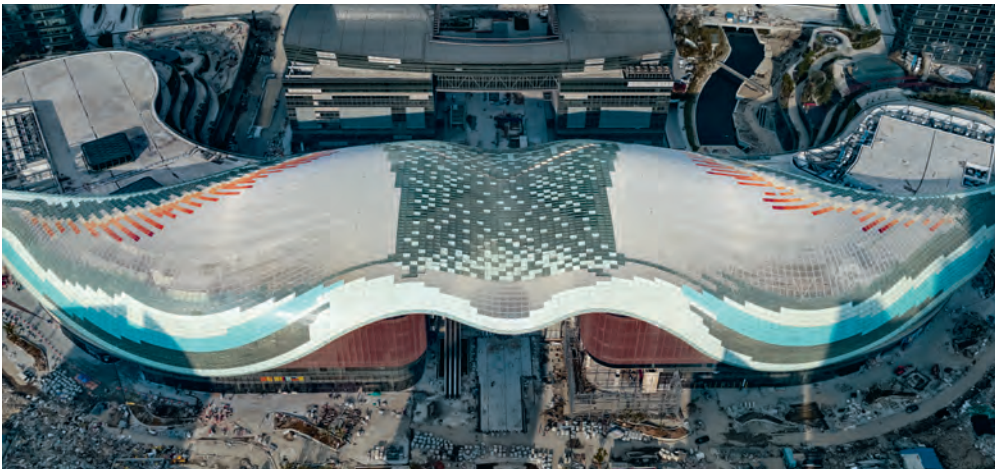
The aforementioned models find their next stage of evolution in the free-form, sculptural glass roof of **Jinji Lake Mall** in Suzhou, China, completed in 2017. This project, which we planned together with Benoy Architects, combines various static systems as a unified whole, so in a way it symbolizes the wealth of experience accumulated in our office, which we continue to enlarge with each project.

The huge glazed roof covers a shopping and leisure center in the new district of Jinji Lake. As well as sheltering the courtyard from the weather, it links the four seven-story buildings of the complex to form an instantly recognizable landmark. Its shape is supposed to recall the wings of a phoenix. The roof is illuminated at night, making the mall and the skyscraper behind it (named "The Gate of the Orient") into an attraction for many tourists and visitors. The complex is located in an area where strong earthquakes can occur, so this too had to be accounted for in the calculations.





The four buildings of the shopping and leisure center are statically decoupled from each other. Since it connects them, the glass roof had to rest on them in such a way that any forces would be distributed among the individual buildings without the latter transferring stresses to the roof in the event of seismic activity, when each building would act completely independently of the others. Seismic movement joints in the roof were undesirable, as these would interrupt the continuity of the phoenix's wings. We therefore chose a lightweight structure based on the principle of the cable net. Above the large courtyard, the cable net becomes a suspended roof. This is a more efficient way of coping with the long spans of up to 60 m needed there; it reduces bending moments and allows the rods to have narrow cross sections throughout the roof. Formed without movement joints over its entire length of 600 m, the roof can withstand high stresses and large relative displacements of the buildings if they move independently in an earthquake. Instead of the nets of triangular mesh or braced square mesh that are commonly used, we created a flexible square net without diagonal bracing, because it allows change in the internal angles of the mesh and can thus absorb deformation and



The treelike supports, spaced 15 to 25 m apart, reduce the spans within the canopy, which covers 35,000 m²—one of the world's largest free-form glazed roofs. Branching them allows the supports to be slenderer at the roof and shortens the spans in an efficient way.

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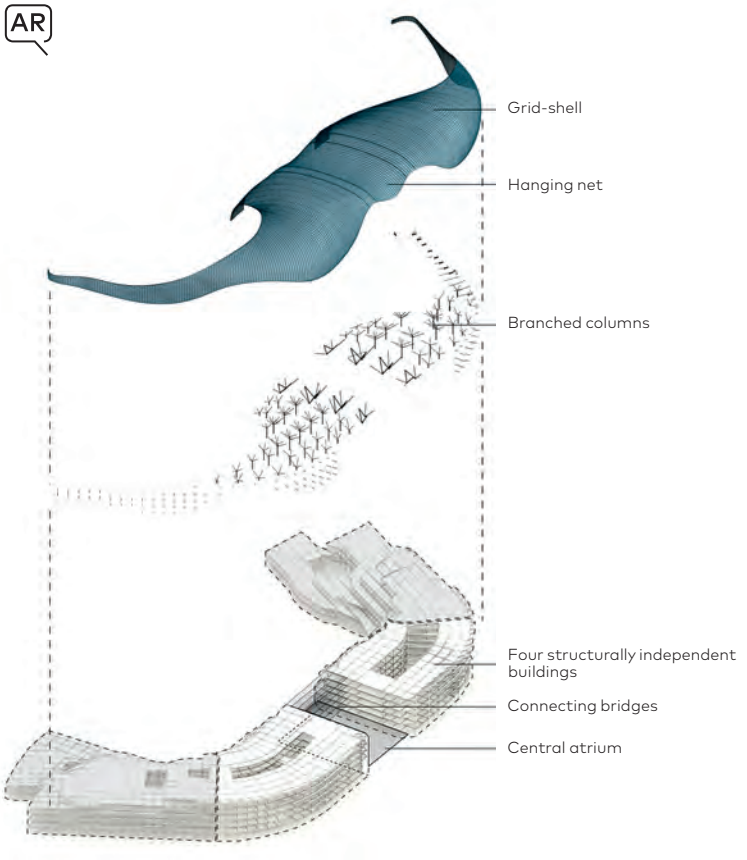

distortion. Furthermore, eliminating diagonal members makes the net more transparent, reduces the number of rods and panels, and significantly simplifies the nodes.

It is usually difficult to subdivide the area of free-form structures into identical smaller areas. Identical components simplify both the production and construction processes on-site, which is economically advantageous. Nevertheless, to standardize the mesh openings as much as possible and thus reduce the number of glass pane types, the surface geometry of this design had to be rationalized within strict boundary conditions with regard to rod length, spatial distortion of the glass panels, and consistency of the internal angles. This was done using subdivision surface modeling, a complex but unified digital workflow and automated process with which the huge geometric shape was developed and prepared for static analysis and optimization. This enabled us to process the numerous static and geometric parameters and their variation in different sections of the roof in a common digital and iterative workflow.

The rational digital process was particularly important for the joints to be formed between the glass panels. Since the internal angles of the mesh change under load, the joints must be capable of absorbing these deformations and must be dimensioned accordingly in order to prevent any contact between adjacent panels of glass. The width of the joint—acting as a buffer for panels of various dimensions—was therefore the critical boundary condition for defining glass panel categories. By making use of these joint tolerances, it was possible to lower the number of unique panels significantly. Finally, static optimization reduced the distributed steel mass of the roof structure to 60 kg/m².