BIRKHÄUSER

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GRAPHIC DESIGN, LAYOUT AND TYPOGRAPHY
Rein Steger, Pau Segarra
Proxi, Barcelona

EDITOR FOR THE PUBLISHER
Andreas Müller, Berlin

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A COLLABORATIVE PROCESS

The 2004 completion of the Swiss Re Tower (30 St. Mary Axe) in London, England, designed by Foster + Partners with Arup, marked the beginning of the evolution and application of the modern diagrid building using a perimeter support system.

WHAT IS A DIAGRID?

Over the last 10 years, diagrid structures have proven to be highly adaptable in structuring a wide range of building types, spans and forms. In most applications, diagrids provide structural support to buildings that are non-rectilinear, adapting well to highly angular buildings and curved forms. The diagrid in its purest form is capable of resisting all of the gravity loads and lateral loads on the structure without assistance of a traditional structural core. This permits unique deviations from structural types that are dependent on a core for stability.

The term "diagrid" is a blending of the words "diagonal" and "grid" and refers to a structural system that is single-thickness in nature and gains its structural integrity through the use of triangulation. Diagrid systems can be planar, crystalline or take on multiple curvatures; they often use crystalline forms or curvature to increase their stiffness. Being single-thickness differentiates a diagrid from any three-dimensional triangulated systems such as spaceframes, space trusses or geodesic structures, although it will be shown that some of the developments of diagrid structures have been derived from the details of these three-dimensional systems. The diagrid structural systems that will be explored in this book are used in the support of buildings, predominantly as perimeter systems that are associated with mid to high-rise buildings. Perimeter diagrids normally carry the lateral and gravity loads of the building and are used to support the floor edges.

Diagrid systems are also used as roofs to create large column-free spans. Diagrid systems for this function have been derived from lamella structures, which may be made from a variety of materials but predominantly use wood. The majority of lamella structures, however, are not diagrid structures, as they use a diamond grid and tend not to triangulate. The structural ideas behind the wood lamella contributed to the evolution of the steel lattice grid. The detailing of the steel lattice grid system is significantly different from that of the perimeter structural diagrid for larger buildings. This type of structure was addressed in my previous book *Understanding Steel Design: An Architectural Design Manual* in *Chapter 12: Steel and Glazing Systems*. The design and technical exploration of diagrid structures addressed in this book will build on the introductory material addressed in *Chapter 9: Advanced Framing Systems: Diagrids* of the same book.

FROM SHUKHOV TO FOSTER

The origins of the diagrid structural typology lie at the crossroads of engineering and architecture. Initial explorations by the Russian engineer Vladimir Shukhov were intended to provide a structural system to serve a civic works function that was not necessarily "architecture" in the purest sense of the word. The initial details and member choices were fairly utilitarian and simple. It is significant that Norman Foster has referenced the work of Shukhov as an inspiration for his diagrid explorations. This affirms the role of Shukhov's towers as a precedent for buildings such as the Swiss Re Tower and the Hearst Magazine Tower. It also allows us to examine the changes that were made to the method of detailing and construction as the hyperbolic paraboloid form transitioned from a "hollow" tower to one that needed to support floor loads and was clad. This was a tremendous change in the role of the structure, with significant implications on the design, detailing and construction processes undertaken by Foster and Arup in Swiss Re. The decisions taken in the design of Swiss Re and the Hearst Magazine Tower continue to inform all variations of the diagrid to the present day.

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The preference for the use of large steel tubes with concrete fill is regional. This type of construction is very common in China but is seldom seen in Europe or North America. The Western markets tend to make use of hot-rolled sections or built-up plate when larger sections are required. While this construction method would have been expected on the Guangzhou IFC and Canton Tower, it is interesting to see that the structural diagrid system used for the Doha Tower in Qatar, designed by Ateliers Jean Nouvel, uses a similar concrete-filled tube system. The detailing of the diagrid of the Doha Tower is very similar to the one used on the Guangzhou IFC. Given that the engineers and contracting company used for the Doha Tower were Chinese, a globalization of construction methods may show itself here.

Differences in labor rates and construction safety concerns also tend to drive the choice of structural type. Great concerns over worker safety in North America, Australasia and Europe tend to aim to diminish the amount of welding done on site. There is a very high amount of welding required on the connections for concrete-filled tubular steel systems, which involves a high amount of work being done at height.

Intumescent Coatings

Intumescent coatings provide both fire resistance and a painted appearance for exposed steel. They contain a resin system that is pigmented with various intumescent ingredients which, under the influence of heat, react together to produce an insulating foam or "char". This char layer has low thermal conductivity and extends to a volume many times that of the original coating. The char layer reduces the rate of heating experienced by the steel, thereby extending its structural capacity. As this material can extend the fire resistance rating of exposed steel to a maximum of two hours, it has become quite popular for AESS applications in diagrid structures. The fire resistance rating is in part dependent on the type and thickness of the coating as well as the type of fire that might be anticipated in the building use. Increasing the fire resistance rating is usually achieved by applying multiple coatings of the product. The coating will have a slightly thickened appearance with a finish akin to an orange peel. This needs to be taken into account when deciding on the details for the connections and members.

Intumescent fire protection is used on the architecturally exposed steel structure of Capital Gate. The expression of the members and their connections is a very important aspect of the design and so an intumescent coating was the applicable choice.

The exposed structure of The Leadenhall Building made use of intumescent fire protection to permit its structure to be expressed as part of its double façade system.

The all-welded HSS diagrid columns that create the structural and focal point for the new entry pavilion at the World Financial Center in New York City, designed by Pelli Clarke Pelli, use intumescent fire proofing to allow for this exposure of the structure. The finish works well with the uplighting system. The form is very reminiscent of the original hyperbolic paraboloid diagrid towers designed by Vladimir Shukhov. Steel fabrication was done by Walters Inc. and erection by Metropolitan Walters.

THE LEADENHALL BUILDING, LONDON, ENGLAND

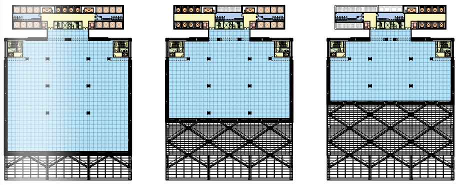
The Leadenhall Building design combines ideas about the relationship of contextual requirements to a structural solution with Architecturally Exposed Structural Steel detailing of the highest quality. The distinctive triangular form that goes under the nickname of "The Cheesegrater" was developed in response to view corridor requirements for St. Paul's Cathedral nearby. The 50-storey building is planned to be 225m/735ft tall. The application of the diagrid structural system is unique and coherent to the extreme that there is no central core. Instead the core has been placed behind the building. The support structure for the tower, predominantly located on the exterior, uses a combination of a diagrid system on its sloped street face with a modified diagonally braced structure on the sides of the building. Arup refers to the total system as a "megaframe", a type that is characterized by the use of large, widely spaced perimeter columns; this type is combined with the diagrid to take advantage of the best qualities of each system. 85% of the building's construction value consists of prefabricated and off-site construction elements, which benefits overall constructability as well as acknowledges issues relating to difficult site access and practical limits on staging area in this dense urban location.

ARCHITECT
ROGERS STIRK HARBOUR + PARTNERS
STRUCTURAL ENGINEER
ARUP
WIND ENGINEERING
RWDI
CONTRACTOR
LAING O'ROURKE
STEEL CONTRACTOR
WATSON STEEL STRUCTURES
PROJECT COMPLETION
TOPPED OUT 2013

The Leadenhall Building makes a striking addition to the historic fabric of the City of London.

The office floors, rectangular in plan, measure 48m/157.5ft in width and up to 43m/141.1ft in depth at the lowest full office floor (level 5). This large floor plate has required the use of interior columns to support the spans. At the same time, the grid is quite large, measuring 16m/52.5ft x 10.5m/34.5ft in order to minimize the number of columns, thereby achieving the degree of openness desired for maximum flexibility in space planning.

The triangular profile of the east and west sides of the tower is subdivided into seven-storey modules. While normally a diagrid module is defined by the measurement from tip to tip of the major diamond shape, which measures 14 storeys on the south façade, the seven-storey designation has more significance to the design of the overall structure because the southern diagrid face is integrated into a megaframe system. Seven 4m/13.1ft-high floors fit within the 28m/91.9ft height that describes the seven-storey module, with each floor 750mm/2.5ft narrower than the previous. The typical floor structure consists of a 150mm/6in deep precast concrete slab over 700mm/2.3ft-deep steel beams. A raised floor system is used to handle services. Arup introduced a passive constrained-layer damping system to reduce the bounciness of the floors.



The plan views of levels 5, 22 and 31 show the placement of the core and services outside of the tower and the open floor arrangement for the offices. This has required the use of columns within the floor plate, which is not usual for more standard arrangements that would see the core and services housed within the floor area.

The building consists of seven full seven-storey modules. They sit on a five-storey base that uses a modified structural arrangement to respond to the significantly different program requirements of the galleria space. Here the third and fourth floors are suspended from the fifth floor level and hang within this space. As the perimeter diagonals and columns that comprise the base cannot be braced by the floors, they have been artfully reinforced. The ground level will be accessible to the public.

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