Leadenhall Building, London

Flair Meets Function in London's skyline

Leadenhall is an iconic structure that has set new standards in both exposed steel architecture and creative design thinking. Known locally as the 'Cheesegrater' for its distinctive shape, Leadenhall features a uniquely slanted megaframe to meet an ambitious design vision while protecting cherished views of St Pauls Cathedral.

Architecturally exposed steelwork is rarely featured in office buildings. A key aspiration for design and construction of the 224m tall Leadenhall building was to present systems honestly and legibly – creating a unique and dramatic new public space at ground level. Voted in as City of London's building of the year in 2015, Leadenhall now attracts some of the highest rent in the city while forming a sensitive and elegant addition to London's treasured skyline.

Designed by Arup in collaboration with architect Rogers Stirk Harbour + Partners (RSHP), the project applies the principles of clarity, openness, flexibility and legibility, which are distinctive elements of Rogers' earlier masterpieces. It showcases several multidisciplinary engineering systems and modern collaborative digital methods, all of which prove that these ideals can be applied successfully to a 21st century skyscraper.

In 2001, Arup and Rogers won an invited competition for design rights on the site. The proposal was for a wedge-shaped tower with a profile that made best use of the developed area without impacting too greatly on the view of the famed St Paul's Cathedral from the Fleet Street end. The planning application was submitted in 2004 and work commenced in 2007. It was put on hold during the economic downturn in 2008 but returned to production the following year.

Laing O'Rourke was duly appointed for construction, with Watson Steel Structures (later Severfield) given the nod to supply the steel frames featured in the design. Known locally as the 'Cheesegrater', the completed project was unveiled in the summer of 2014, before going on to achieve record-breaking rents for the City of London. The building comprises 45 floors and 610,000 square feet of office space and plays home to 2,000 staff of Aon, the world's largest insurance company, among other commercial residents.

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The design team had to work with a collaborative spirit and open-minded approach to overcome technical challenges and meet a demanding aesthetic. Several innovations were implemented, such as a solid precast floor system and a core built from volumetric prefabricated steel modules. Temperature loading had to be considered carefully, as did the significant permanent horizontal movements that presented themselves during the build.

The Duke of Cambridge and Prince Harry admired views from the 42nd floor on the opening day of the building. They were presented with a bespoke Lego model of the building in honour of the engineering and design feats, particularly with regards to the application of steel as a key feature of the project's design, construction and striking aesthetic.

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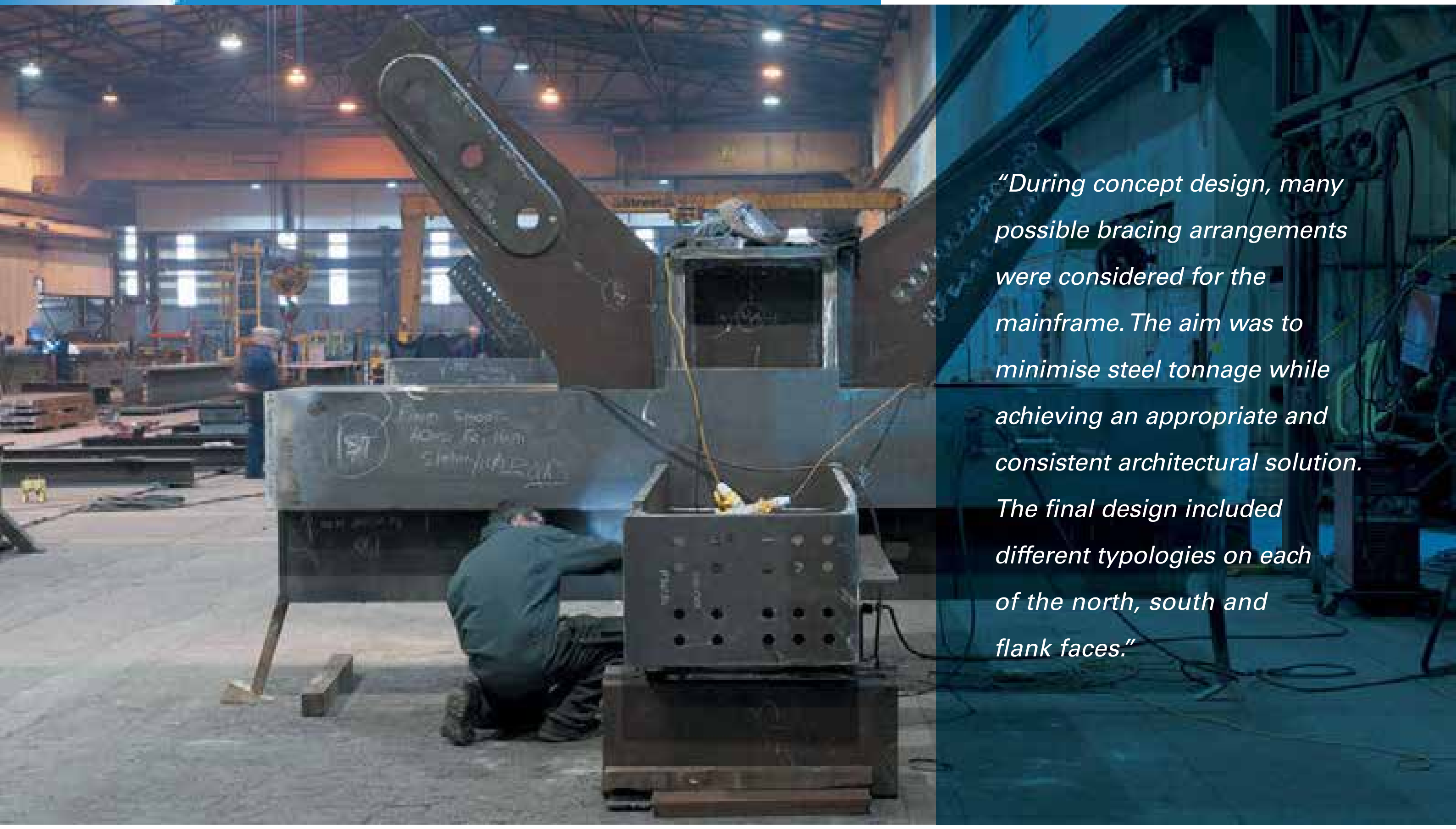

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Building the Megaframe

The Leadenhall building does not use a conventional central core for stability, instead relying on the structural integrity of an external mega-frame. This approach has been applied to similar structures, however, the main core positioning outside of the frame is unique. The layout allows services to take centre stage on the exterior with structure and cladding while also creating a clear space in the building's footprint for multi-aspect floor plates.

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South carries a small vertical load and utilises a pure diagrid. On the north side, where forces are highest, vertical columns have been combined with symmetrical bracing. The flanks on either side take the form of an asymmetrical diagrid, with columns at 10.5m centres linked by beams and inclined bracing. Megaframe members are all seven storeys high and restrained against buckling by the floor beams behind. These are, in turn, stabilised by vertical trusses in the firefighting core, acting as a secondary bracing mechanism.

Five engineering studies were carried out by Exova Warringtonfire to reduce the fire rating from 120 minutes to 90 minutes. The external steelwork is fire protected with Firetex M90 and M95, an epoxy intumescent coating. The remainder has a thin film intumescent coating.

The megaframe itself was built using a system of separate 'node' and 'member' pieces. This ensured that the most complex geometrical issues were resolved through welded joints within the nodes, while the site splices occur within the straight members and therefore can be standardised. The significant challenge of developing node designs that were visually appealing and suitable for the building's architecture was addressed with digital design models, in collaboration with engineers, fabricators and architects.

During construction, movement of the structure due to wind and temperature had to be addressed as well as a significant permanent lean. This was the result of foundation settlements and the elastic shortening of columns. Settlements were larger in the north side of the building, causing the megaframe to rotate, while vertical columns shortened under loads while diagonal members did not.

The strategy employed to counter the sideways lean under gravity loading was called 'active alignment'. The building was originally erected as a square shape, with vertical members pre-set against axial shortening. Flank diagonal braces were built with additional packing to pull the building back towards the south. The nature of the bolt box details suited this procedure. Connections could then be loosened using the original hydraulic jacks. The joints could then be opened as soon as the nuts were loosened. Adjustments were made progressively at each megaframe level.

By starting with an orthogonal structure, the active alignment approach avoided complex geometric alternations to the nodes in fabrication. The site adjustments could be calculated just before they were made, significantly improving the accuracy of the alignment through the knowledge gained from monitoring. When the process was completed, the transferred grid lines were within 20mm of the correct location through the full height of the structure.

Managing Steel Temperatures

The effects of temperature had to be considered in the design of the megaframe, north core and Galleria floor. The megaframe's location within a glazed cavity along with sheer size, exposed it most to temperature fluctuations. To tackle the problem, three critical thermal load cases were identified, representing maximum temperatures on the south face and west face for sun, along with special consideration for the cold during winter.

Arup carried out preliminary building physics research to establish the temperatures of steelwork to be considered. This looked at ambient air temperature, thermal gain within the cavities, and direct incidental solar radiation on the steel. Testing was also carried out to determine solar absorptance of alternative paint colours.

Maximum design temperatures were -9°C for steel in the cavity and 42°C for fully external steelwork. Minimum was -9°C for the former and -11°C for the latter. The critical steel temperatures in the cavity depended significantly on parameters controlled by the cladding design. This was therefore set as performance requirements for the supplier, Yuanda, who ultimately submitted their own thermal calculations to meet requirements.

Temperature differences between the megaframe and internal columns caused the floors to tilt, creating fluctuations of up to 70mm at the highest office floor levels. To limit the impact of this, a set of bracing structures just above level 45 was implemented to connect the internal columns with the megaframe. This succeeded in keeping the structures moving harmoniously together.

In some connections between beams and megaframe, it was found that daily tilting movement could generate local stress concentrations. A 'safe life' design approach was taken to identify an allowable limit of peak temperature-induced stress. This was collated using Miner's linear cumulative damage rule. Flexible plate specifications were developed and used to provide lateral restraint to the megaframe and ensure the temperature stress stayed within the allotted limits.

Galleria Steelwork

Located on the ground floor of the Leadenhall is the stunning 'Galleria' which celebrates the exposed steel design of the 45-floor structure. The lack of heavy elements in the centre of the building opened the door for a unique and dramatic public space which could provide both a sheltered urban area outside the building entrance and an effective passageway connecting all directions of entry. The architecture has also allowed this space to join with the existing St Helen's Square to the East.

The floor beams above the galleria are most prominent, with several secondary beams aligned in the north-south direction. At level five, these continue beyond the megaframe to form the wind canopy over Leadenhall Street. Edges of the floors at levels three and four are suspended via circular rods from level five, 64mm to 100mm in diameter and fire protected with thin film intumescent. A seamless transition to the supporting beams is provided via bespoke connections.

The megaframe is unrestrained below level five to a height of 28m. To account for this, the sections were subtly modified at this level to increase bendability in the construction. All of the members have twin webs, which are inset at the connections and move out towards the edge of the sections at mid-height.

There are two passenger lifts in the Galleria area which serve between ground level and level three. There is minimal lateral support with three vertical ladder frames and two layers of horizontal tension members. A CHS member visually completes the structure, defining the corner of the building. It is tensioned to 260kN and concrete filled to mitigate against potential wind problems.

Leadenhall is truly an example of what can be achieved when steel is applied as part of ambitious design thinking from the outset, as well as a central element of 21st century construction.