

Title:	Case Study: The Leadenhall Building, London
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Subjects:	Architectural/Design Building Case Study Structural Engineering
Keywords:	BIM Mega Frame Prefabrication
Publication Date:	2013
Original Publication:	CTBUH Journal, 2013 Issue II
Paper Type:	1. Book chapter/Part chapter 2. Journal paper 3. Conference proceeding 4. Unpublished conference paper 5. Magazine article 6. Unpublished

CTBUH Journal

International Journal on Tall Buildings and Urban Habitat

Tall buildings: design, construction, and operation | 2013 Issue II

Europe Special Issue: 2013 London Conference

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Case Study: The Leadenhall Building, London

Tall, Light, and Handsome

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Andy Young joined Rogers Stirk Harbour + Partners (then Richard Rogers Partnership) in 1996 and was made an Associate Partner in 2011. He has led the Leadenhall team as Project Architect since 2005 and previously worked on a number of high profile projects, including 88 Wood Street and the Lloyd's Register of Shipping, both Stirling Prize-nominated. Andy has also been involved in expanding the practice's work into the Middle East, working on projects in Beirut, Lebanon.

Nigel Annereau has worked for Arup for 26 years and is a director within one of the London building teams. He has been working on Leadenhall since 2005, initially looking at the demolition of the original structure, then leading the basement design phase, and subsequently providing day-to-day leadership of the structural project team.

Andy Butler has worked for more than 30 years in the UK construction and property industry, and has a diverse, proven capability that ranges from managing commercial development at every stage, including delivering large-scale prestigious developments from funding through occupation. In addition to his commercial development roles, Andy plays a key role in the technical development of innovation within our organization and in the wider construction industry environment. He is a leading mentor for graduate, postgraduate, and executive development programs within the Laing O'Rourke Group.

Brian Smith is a director within the London Commercial team at Davis Langdon, an AECOM company, and has led the cost consultant team on Leadenhall since 2006. In more than 17 years of leading and delivering a variety of projects within central London and abroad, including work on tall buildings around the world, Brian understands the key drivers for delivering large-scale developments. He is also member of the company's tall buildings group, leading collaboration with other regions around the world.

The Leadenhall Building leans back to make way for views to St. Paul's Cathedral and other historic sites in a crowded section of the City of London, but it also springs forward with an innovative structure and a dynamic street presence. Stopped once during the economic downturn, the tower is rising again under a new joint venture. Scheduled for completion in 2014, the 224-meter-high building was more than 50% leased before topping out. Members of the design, engineering, and construction team here detail the thinking process that led to the building's unique tapering shape – the components of which were largely built off-site – that is making the “Cheese-grater” stand out from the crowd as both an icon and a lucrative investment property.

Introduction

At 47 stories and 225 meters high, The Leadenhall Building will contain the highest office floors in the City of London on completion. In addition to its distinctive tapering shape, it is remarkable in many ways. It is built to the edges of its 48 x 62 meter plot and incorporates significant new public space at the ground level Galleria.

From a structural perspective, the building is unusual for a building of its height. There is no central core; instead, the building makes use of a “tube” structural perimeter envelope, with an external support core, that allows for open floor plates (see Figure 1). In addition, 85% of the building's construction value will consist of prefabricated and off-site construction elements.

On the site of the City's ancient Roman center, this distinctive building sits across the road from the Lloyd's Building. This earlier building, completed in 1986, at 25 years old became the youngest UK structure to be awarded a Grade 1 listing, the highest level of protection for historic buildings. Other high-profile neighbors include the Sir Norman Foster-designed 30 St. Mary Axe tower, and several protected historic buildings, including a former bank designed by Lutyens, and two Grade 1 protected churches, from the 12th and 16th centuries, respectively (see Figure 2).

The project was started by BritishLand in 2001. Design development followed, and planning permission was granted in 2005. Two years later, demolition of the existing 14-story, 1960s P & O (Peninsular & Oriental) headquarters building was underway simultaneously





Figure 1. The Leadenhall Building, London with St. Andrew Undershaft at front. © British Land/Oxford Properties

with construction of the new building (see Figure 3). By spring 2009 the global economic downturn had bitten deep, and with construction still at basement level, the project was put on hold. Work re-commenced in 2011 as a joint venture between British Land and Oxford Properties. Following a competitive tender, Laing O'Rourke was appointed under a design and build contract, which is due for completion in mid-2014.



Figure 3. P & O headquarters being demolished from ground up. © BritishLand/Oxford Properties

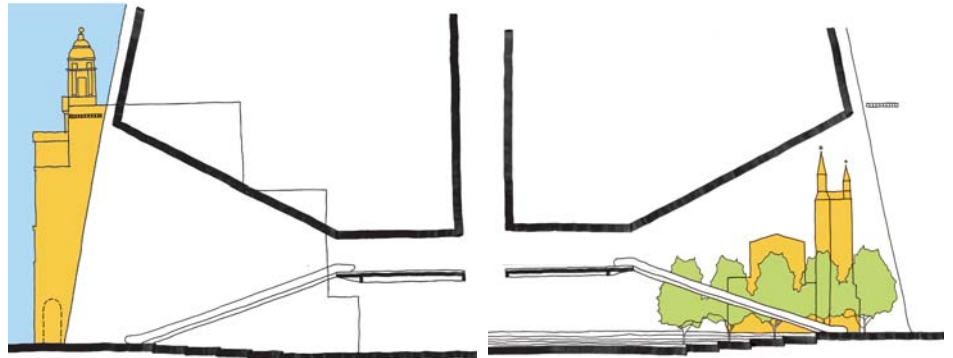


Figure 2. The Leadenhall's design concept responded to the existing historic structures. © RSH+P

Design Evolution

Built as a speculative office building particularly suitable for insurance or banking occupiers, the brief included creating a distinctive building, with a major new public space for the City, while also achieving the maximum floor space for the plot.

The Leadenhall Building is firmly rooted in the practice's family of structures that goes back to the nearby Lloyd's Building and includes Lloyd's Register of Shipping and 88 Wood Street. And, like these buildings, it combines a distinctive approach to its context, with provisions for highly flexible and open office space.

The Leadenhall Building comprises a tapering, perimeter-braced diagrid structure containing the office floors and adjoins a northern support core, which houses all passenger and goods lifts, service risers, on-floor plant, and lavatories. Office floors are connected to the structural tube, termed the "mega-frame," at every floor, without the need for further perimeter columns.

In the lower portion of the tower, the office floors are rectangular in plan, 48 meters wide and up to 43 meters deep, and virtually column-free. At 16 x 10.5 meters, the large column grid means that only six internal columns are required on the largest floors (see Figure 4). Floors range from 1,950 square meters to 557 square meters, enabling a wide range of occupiers' requirements to be met.

Unusually, the perimeter columns are outside the cladding line, and almost all of the

services and lifts are located in the north core, with two secondary fire-fighting and escape cores located at the northeast and northwest corners of the main office floors – all features that make the floors extremely flexible for internal space planning. The contrasting colors of the expressed steelwork show the division between office and service space. The expressed triangulated mega-frame is divided into eight "mega levels" of 28 meters high, each containing seven floors, apart from the first, which is five floors (see Figure 5).

The distinctive wedge shape of the building evolved as a design response to two main issues. The first was the desire to ensure that the form of a tall building on the site would not significantly affect the silhouette of the dome of St. Paul's Cathedral from a viewpoint

“Leaning away from St. Paul’s, the building’s tapering silhouette means less of the mass emerges above surrounding buildings, the key view of St. Paul’s remains unaffected...”

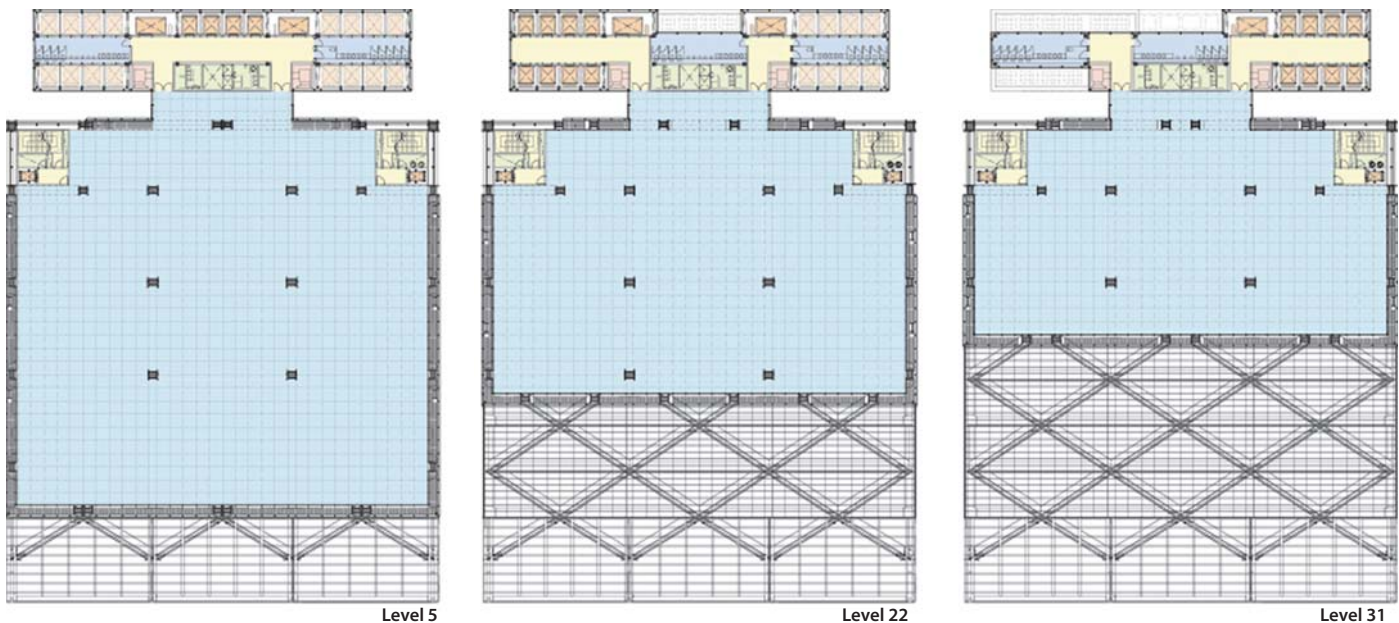


Figure 4. The Leadenhall Building – floor plans. © RSH+P

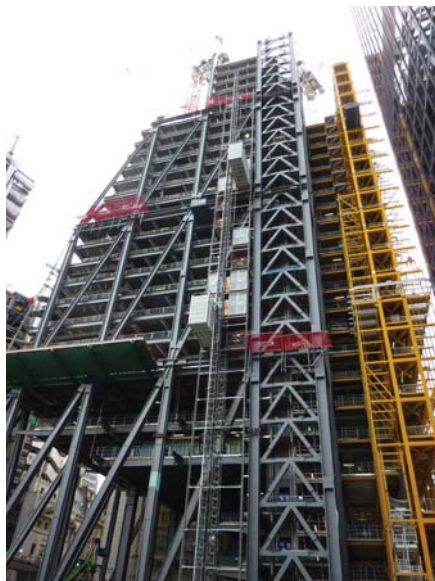


Figure 5. Mega-frame. © Phil Oldfield

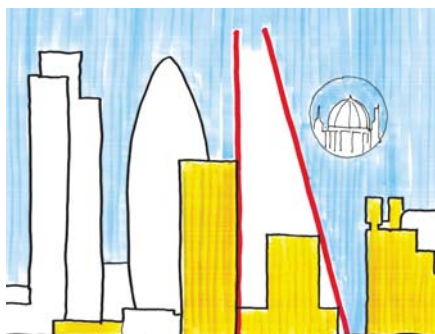


Figure 6. Leadenhall tapering silhouette responding to the viewpoint to the St. Paul's Cathedral. © RSH+P

on Fleet Street (see Figure 6). Leaning away from St. Paul's, the building's tapering silhouette means less of the mass emerges above surrounding buildings, the key view of St. Paul's remains unaffected, and the tower can be much taller than would otherwise have been possible in such a sensitive location. This profile was also closely integrated with a structural solution that features architectural steelwork detailing of the highest quality.

The second issue concerned the architectural approach, which from the outset intended to express the structure and functional elements of the building. By choosing a form that is consistent with a structural solution, the expression of that structure can be inherent to the architectural language of the building.

The shape allows a mix of floors throughout the building; large and efficient floors at the base, ranging to smaller floors at the top (see Figure 7). Overall, the net-to-gross efficiency above ground is equal to, or better than, any comparable high-rise office scheme in the City of London. With a building of this height maximizing its entire site, the plot ratio at 29:1 is exceptional for central London, where most office buildings are lower-rise and have a ratio of 20:1 or lower.

Unique Qualities

Architecture

■ *No central core*

Instead of using a central core, The Leadenhall Building's stability structure is integrated into the external mega-frame. This in itself is not unique, but the positioning of the main service core outside of the structural frame is very much a departure from the standard arrangement.

This layout not only allows for the services to be expressed on the exterior through structure and a lightweight cladding framework (see Figure 8), but also provides a clear, unobstructed space within the building footprint, creating large, multi-aspect flexible floor plates (see Figure 4).

■ *The galleria and public space*

The lack of obstruction and heavy structural elements in the center of the building has permitted the creation of another unique element – the galleria.

At ground level, almost the entire footprint of the building will be a 28-meter-high open public space. This will provide pedestrian routes across the site and a sheltered urban environment, within which two sets of escalators connect to the building's two

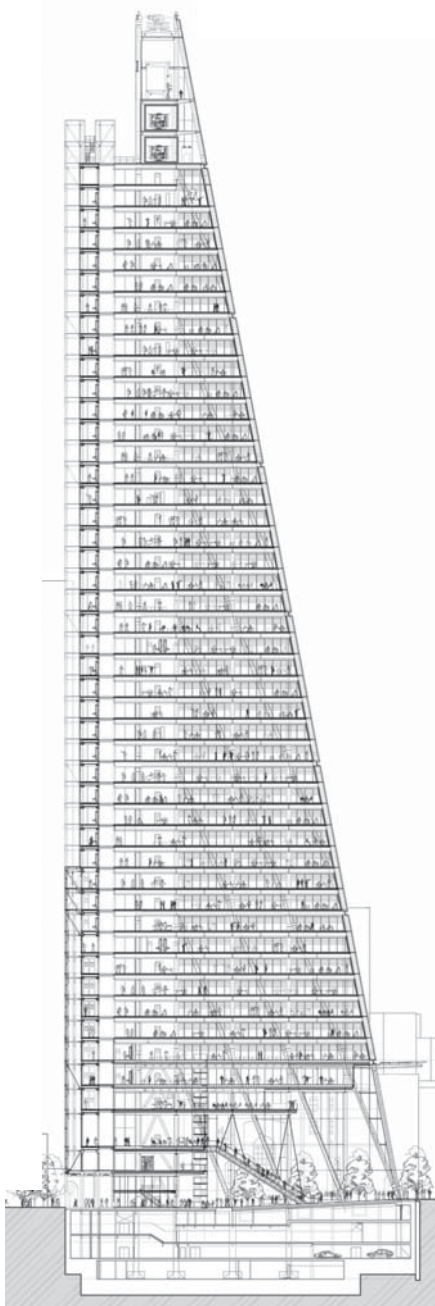


Figure 7. The Leadenhall – typical section. © RSH+P

reception spaces. The lack of central core means that the landscaped public galleria will connect with the existing St. Helen's Square to the east of the site. It will create a large new public space for the City of London and re-establish better connectivity between neighboring routes and buildings (see Figure 9).

The inclined structural columns at the site perimeter and large, oversailing canopy not



Figure 8. The Leadenhall – the north core at night. © BritishLand/Oxford Properties

only define and enclose the galleria space. They also help to tie the building into its context by aligning with the parapet height of adjacent buildings (see Figure 10), allowing the tower to completely fill its site in close proximity to other structures.

Structure

■ The mega-frame

The perimeter-braced mega-frame structure is a braced diagrid, surrounding all four sides of the office zone and typically located within the externally ventilated façade. It is arranged on a large scale, dividing the building elevations into eight, seven-story modules. Each mega-frame story is therefore 28 meters above the previous one. To brace the floors and internal columns across the large distances between the node levels (mega levels), a secondary stability system was also required. This takes the form of chevron or "K-braced" panels (see Figure 11), and is located in the northernmost bays of the east and west faces and in the end

“The Leadenhall project is piloting the application of radio frequency identification software to track components through manufacture, supply and installation. This will enable preventative action in the event of any delays downstream.”

bays of the north face around the east and west firefighting cores.

The building's triangular geometry in profile, and the layout of the mega-frame enable seven floors to fit within a 28-meter-high section (see Figure 5), with each floor 750 millimeters narrower in plan than the one below. The typical floor build-up within each 4-meter story consists of a 150-millimeter-deep concrete slab over 700-millimeter-deep fabricated steel beams. A zone of 150 millimeters is provided for raised



Figure 9. The Leadenhall – the galleria. © BritishLand/Oxford Properties



Figure 10. The Leadenhall – entrance canopy. © BritishLand/Oxford Properties

floors, and the services pass through holes in the steel beams. This ensures that a 2.75-meter floor-to-ceiling height is maintained throughout.

The internal floor spans direct much of the office floor load to the perimeter. As a result, the mega-frame columns are designed to carry a substantial portion of the building's weight and can therefore naturally resist wind loading with minimal additional material. Uplift forces to the foundations are also minimized. The office floor beams are connected to the mega-frame via sliding bearings. These allow small horizontal movements to occur freely, so that the mega-frame can expand and contract without transferring forces into the floor structures behind.

■ *Basement*

The 14-story 1960s P & O building that previously occupied the site had a three-story basement, but the new building required more volume below ground, so a fourth level was introduced. To avoid undermining adjacent perimeter structures, the extra basement level was confined to the site's central area (see Figure 12) while the third basement level foundation slab was designed so that, together with some minor temporary works, it could be built first and give



Figure 11. K-Braced panels. © Terri Meyer Boake

support to adjacent structures. This minimized the temporary works needed to construct the lowest basement story.

The superstructure arrangement led to very high loads under the mega-frame at the edge of the site, as well as under the six internal columns. This contrasts with most buildings with a central concrete core, where the largest foundation loads tend to occur under the core. Here, the loads are supported by large diameter bored piles founded in the London clay. Since the mega-frame lands at the very edge of the site, these large-perimeter piles must be eccentric to the mega-frame. They are therefore linked to the internal column piles via a 2.7-meter-thick raft slab covering most of the site. This thickness reduces to the south where, by virtue of the building shape, the column loads are considerably less.

The perimeter mega-frame columns to the east, west and south

sides are supported on new retaining walls cast on the insides of existing perimeter structures. Large base plates and columns are cast into these walls at first or second basement level, so as not to impact architectural requirements at ground level.

Construction

■ *Active alignment*

During construction of the building, the diagonals are assembled with shims located at the nodes. At predetermined stages of the construction, the diagonal mega-frame members on the east and west faces are held by jacks, shims are removed, and the diagonals are subsequently shortened by jacking to align the building if required. When the alignment is corrected, smaller shims are inserted, the bolts are re-stressed, and the jacks removed. Since the amount of shortening is decided after much of the structure has been erected, this means that the construction pre-set can be adjusted as necessary to reflect the actual movements on site.

■ *Off-site manufacture*

Laing O'Rourke's strategy of *Design for Manufacture and Assembly* was taken to unprecedented levels on The Leadenhall Building. This approach was supported by the client, along with the architect and engineer.



Figure 12. Three-story basement. © Arup

The off-site manufacture includes all mechanical, electrical, and plumbing (MEP) risers, together with on-floor, basement, and attic physical plant rooms.

In addition, the north core was reconfigured structurally into three table elements per floor level. The fabricated steel table was fitted with mechanical and electrical plant; then, precast slabs were placed on top. This resulted in 141 tables, delivering the entire north core from ground to Level 47 (see Figure 13).

The use of precast and off-site manufacture has been embraced by contractor, architect, and client for a number of reasons, including the constrained logistics of the site, and the aim of reducing noise, disruption, and deliveries in consideration for neighbors, increasing on-site safety, and speeding construction.

At tender, the building was designed to have a conventional floor system of lightweight poured concrete on profiled metal decking acting compositely with the floor beams. However, on appointment Laing O'Rourke and Arup elected to use precast planks above Level 5 (see Figure 14). This method removes the requirement for an in situ topping, reduces the work force required on site (by around 40% compared with traditional builds), reduces noise, can be trafficked almost immediately, and offers good tolerances. Critically, it is also far quicker and safer.

■ Digital engineering

Using multidimensional Building Information Modeling (BIM) technology, the team devised an innovative delivery strategy that harnesses the benefits of off-site manufacturing. This "virtual construction" approach enables Laing O'Rourke to visualize the solution in intricate detail. Critically, by integrating data from the architects and structural engineers, the team was able to achieve the early design coordination needed to meet such a challenging program. The model also combines information from key trades to ensure the compatibility of different packages.



Figure 13. The Leadenhall – precast steel table fitted with mechanical & electrical plant. © BritishLand/Oxford Properties

■ Logistics and design for manufacture and assembly

The intense public interest in the development leaves no room for logistical error. Its high-profile location – characterized by narrow and densely populated streets – along with the site's remarkably tight footprint, represent considerable obstacles. To work around these constraints, much of the structure – including the cores, basement, and building services – is being constructed off site. However, with components up to 26 meters in length, this creates its own challenges. Once again, the team used BIM to perfect its strategy for just-in-time assembly.

Now in delivery phase, the project is piloting the application of radio frequency identification (RFID) software – which uses data tags attached to building components to allow them to be tracked through manufacture, supply, and installation. This will enable preventative action in the event of any delays downstream.

When integrated with BIM, RFID can be used to render a data-rich replica of the project in real time. Going forward, this technology will be used to enhance project controls and – against these – develop robust key performance indicators.



Figure 14. The Leadenhall – precast floor plank. © BritishLand/Oxford Properties

Conclusion

The teamwork on this project has been exemplary. Incorporating considerable ingenuity in design, engineering, and construction, the team firmly believes that in comparison with other buildings labeled "iconic" or "landmark," this one truly is worthy of the title. One test of its quality is the market response. In spring 2013, it is already more than 50% pre-let. One couldn't ask for a more eloquent endorsement. ■

Project Data

Height to Architectural Top: 225 meters

Stories: 47

Total Area: 56,000 sq m

Building Function: Office

Owner: British Land and Oxford Properties

Design Architect: Rogers Stirk Harbour + Partners

MEP/Structural Engineer: Arup

Construction Contractor: Laing O'Rourke

Steelwork Contractor: Watson Steel Structures

Cladding Contractor: Yuanda

Vertical Transportation: KONE

Cost Consultant: Davis Langdon, an AECOM company