The creative input of the Structural Engineer

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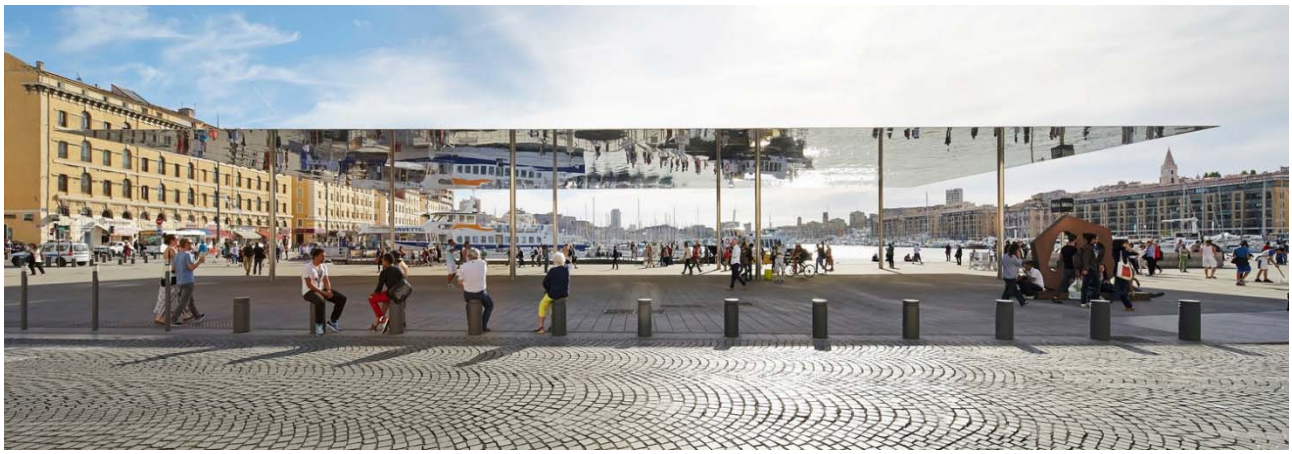

Figure 1. Marseille Vieux Port Canopy

Abstract

Does structural engineering influence the design process or ratify it? In the current design zeitgeist, designers enthuse on the close working relationship between the disciplines; much is made of the early influence of engineering during conception. When the resulting concept is built, it is often difficult to see where engineering has usefully contributed. Are engineers simply post rationalising a convenient story for a foregone decision, or do they genuinely influence the outcome? Are they roommates with the other design disciplines, sharing the responsibility, intensity and pressure of creation, or room meat, filling a design meeting so that structural engineering can be ticked off as present during the process?

Our approach at Foster + Partners has always been to involve engineers from the outset of any project. The structural engineering team at the practice was set up in 2011, and now has projects completed and under construction worldwide. Structural engineers, along with environmental designers and other specialists, contribute to the design from the earliest stages. The aim of this paper is:

- to describe the design goals of the structural team at Foster + Partners
- to list five themes which have emerged as being essential to our design process
- to illustrate these themes with examples of projects of the practice

Keywords: Conceptual Design and Realization, Innovative Structural Systems.

1 Our design goal

As structural engineers we have an extraordinary opportunity to participate in the design of the built environment, to reduce construction cost and energy consumption in buildings, and to contribute to the creation of beautiful efficient designs.

At Foster + Partners, we aim for a design that is inevitable and that has integrity. We are looking for the most efficient elegant resolution of a brief, a design that looks as though nothing else can be removed.

Figure 2. Kensington Park

This is a photograph of Kensington Park in London. Despite the fact that the path on the left is muddy and uneven, and that there is a fence at the end to discourage its use, it has still become a route, simply because it joins the two nodes of travel across the park by the shortest distance. It is the inevitable route.

Figure 3. Millennium Bridge

The original concept of the Millennium Bridge was to create a walking surface that hovered above the water, with a supporting structure so shallow that it would never rise above the eyeline of the pedestrian bridge users. The bridge needed to fit under the protected view towards St Paul's Cathedral, but also rise above the river navigation channel. The bridge is aligned with the axis of St Peter's Hill in order to create connectivity deep into the City of London.

2 Structural Engineering at Foster + Partners

Many of the processes that defined an engineer's day-to-day activity twenty years ago have been automated. The possibilities presented by the increasing computer power for both analysis and information modelling mean that our most valuable input is our judgement, our knowledge and the innovation that we bring, rather than our ability to carry out repetitive tasks.

Around 85% of Foster + Partners projects are outside the UK. Accordingly, it is necessary for the team to have skills and knowledge to match the diversity of technical challenges presented by the projects. 60% of our team are from mainland Europe, with others from all over the world. The team leadership include engineers from China, Italy, America, Singapore and Britain, and the knowledge and experience they bring reflects the different training and specialisations of those countries.

Every project undertaken at the practice starts from scratch. The different disciplines and specialisms within the wider team study the brief and the site, and conceive the project together from its earliest inception.

There are five themes which have emerged as being essential to the design process in the group. There are described in the following section.

2.1 Commitment

Figure 4. Chateau Margaux Winery

The more attention spent on a design, the more potential there is for improvement. Commitment is not necessarily the same as time – it is not enough simply to work long hours and expect a good solution to emerge. Hard work will still be involved; but the distinction is in the intensity of the process, the genuine appraisal of different options, regardless of where they came from or how long they took to develop. The step beyond simply spending time on a design is the focus that is needed to advance it.

The development of the supporting tree structures of Chateau Margaux evolved through a discussion of their structural function – to provide both horizontal and vertical support for the roof - and the need to resolve a roof that is inclined, down to the ground plane that is horizontal. The node evolved through a number of iterations, that resulted from discussions between the architects, the engineers and specialist modellers who generated the three-dimensional form which was then directly exported to structural software for analysis. The result was subsequently sent to the steelwork contractor, to be built initially as a mock-up, and then ultimately as the final roof structure.

Figure 5. Château Margaux Design Review

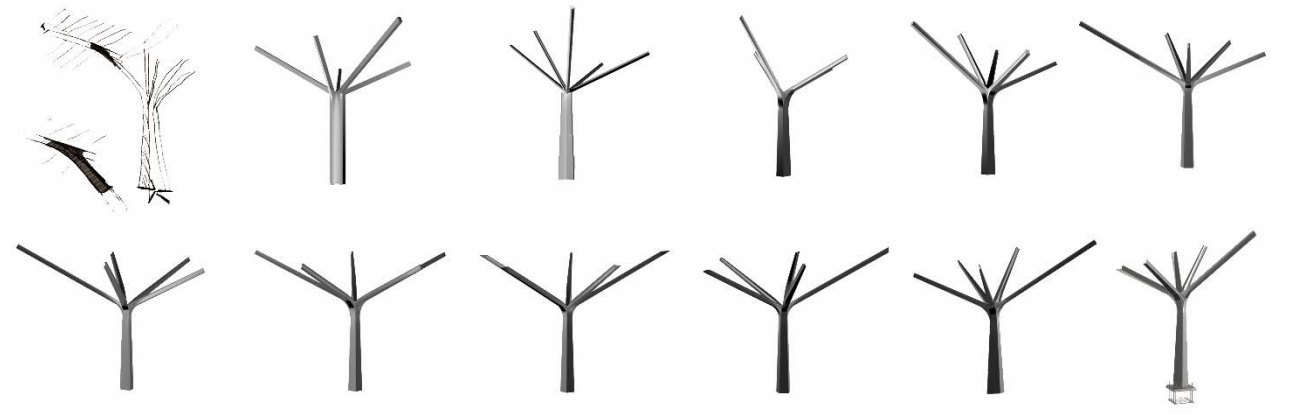

Figure 6. Château Margaux Tree design evolution

2.2 Technical knowledge

Figure 7. Tocumen Airport Competition Scheme

There is no substitute in engineering for technical expertise, based on an understanding of structures from first principles. The ideas put forward by engineers resonate if they have the understanding of how they would be able to deliver them. This is not the same as being immediately aware of the final design from the first moment of conception – innovation requires research and development time. Engineering is a team activity, and different skills and backgrounds complement one another. The structural team at Foster + Partners has particular knowledge in seismic and dynamic design, as well as the design of tall buildings. This knowledge is complemented by partnerships with other firms around the world who bring other technical strengths and experience.

The design intent at Panama's Tocumen Airport was to create a series of long-span secondary beams that defined the gently curving line of the roof along the length of the building. Light will filter through this 'comb' of parallel lines to create a naturally lit interior space with minimal visual clutter in the ceiling. In order to achieve this, the secondary steels are supported by round hollow section primaries through their centreline, and do not node on the columns below. This unusual geometry and the use of large round hollow sections in a seismic area, meant that the structure could not be designed according to prescriptive design code methods, nor could the nodes be defined with pre-qualified connections. The structural team devised a ductile 'fuse' at the top of the reinforced concrete column. By coupling reinforcement bars of a reduced diameter in the hinge zone, ductility was achieved at this location. This prevented the full seismic load being delivered to the steel roof, which as a consequence remains essentially elastic during the maximum considered seismic event.

Figure 8. Tocumen Airport recent site progress

Figure 9. Tocumen Airport recent site progress aerial view

425 Park Avenue Tower was a competition that Foster + Partners won in 2012. The tower concept arose initially through the detailed analysis of the prescriptive volumetric requirements of the New York planning laws. The structural philosophy is a direct manifestation of the forces that need to be resisted. A single line of vertical structure on the front of the tower, coupled with the cores at the rear, provides both vertical and horizontal support. The bifurcation of these columns at the two intermediate levels transfers shear between the front and the rear, there are no hidden belt trusses or additional stiffening elements.

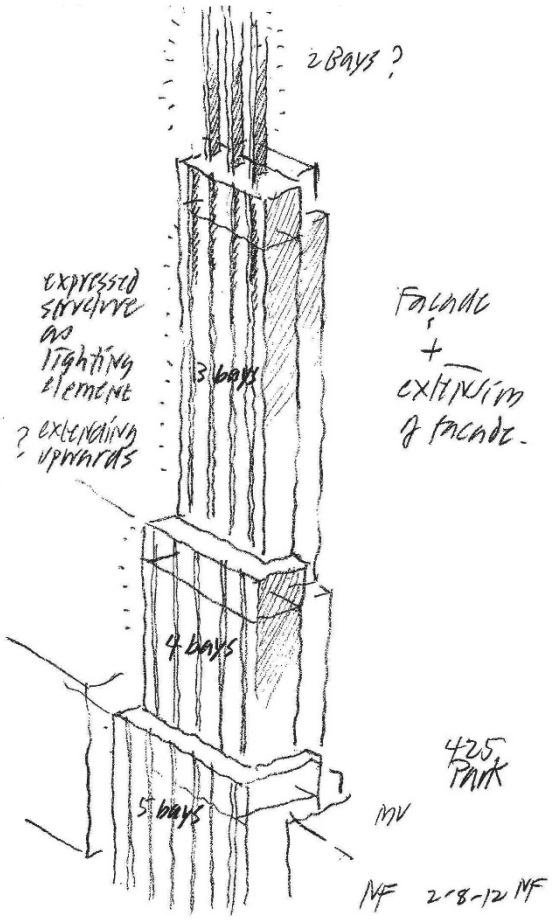

Figure 10. 425 Park Avenue Norman Foster's sketch

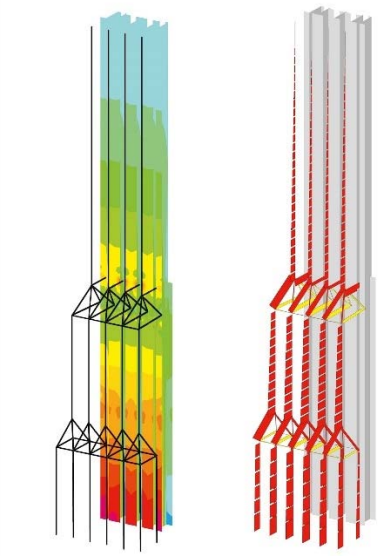

Figure 11. 425 Park Avenue structural analysis: bending moment in cores, axial loads in columns and braces

Figure 12. 425 Park Avenue visualisation

2.3 Culture of collaboration

Building design at Foster + Partners is the work of many different disciplines and specialisms. The differentiator in the practice is the nature of the collaboration. There is a huge benefit in the aims and priorities of the core disciplines – architecture, structural and environmental engineering - being aligned during the development of a project. The team live through all aspects of the design evolution together, be it the need to evolve a new solution, or make a change, or share in the intensity of a deadline.

The new Maggie's cancer centre in Manchester evolved through consideration of the spaces that would create an inviting open atmosphere for the visitors to the building. Timber was chosen as the primary building material for its aesthetic and structural properties, as well as for cost and carbon efficiency. The intention was to minimise the use of material so that it is only present where needed, and to avoid the heavy steel detailing that is sometimes required to connect timber frames. The laminated veneer lumber trusses provide both lateral stability across the building, and vertical support to the roof. The form and density of the trusses is optimised to the forces that they resist, any part of the structure that is superfluous has been removed. A key point of the structure is the triangular node, where vertical loads from the roof are transferred to the columns below. This node also acts as a portal frame haunch to provide the rigidity required for the horizontal stability of the building across its width. The project won the 2016 Timber Awards *Arnold Laver Gold Award* and the *Structural Award* and in their commendation the judges stated:

'It is a project that all engineers would love to work on. It demonstrates that a simple, coherent structural diagram, when beautifully and carefully developed and detailed, can result in a solution of considerable merit'.

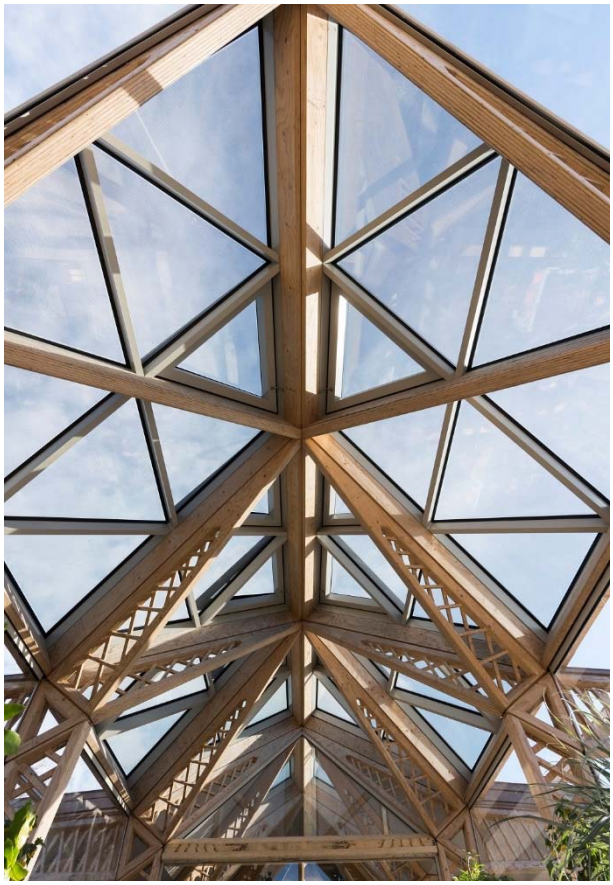

Figure 13. Maggie's Centre Roof

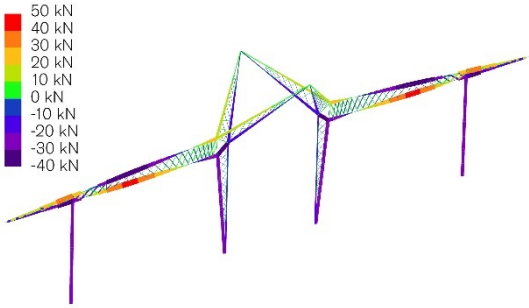

Figure 14. Maggie's Centre axial load in members

Figure 15. Maggie's Centre node

Figure 16. India Tower

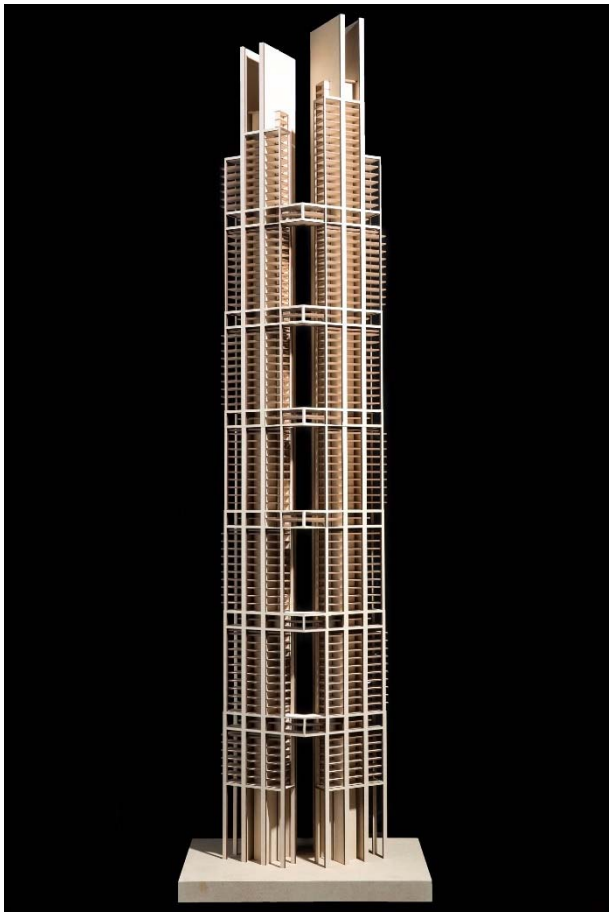

Figure 17. India Tower Model

The structural concept for the proposed new India tower in Mumbai arose through the client's strong preference for the living rooms of all apartments to have the same view - to face towards the sea. This gave a single orientation to the 425m tall tower, with the aim being to keep all service rooms and circulation to the rear. It became clear that two separate cores would better serve this arrangement, allowing for up to four apartments to be arranged along the front. These cores are deep enough to provide the lateral stability in their strong axis. A truss between the two cores links them to provide lateral stiffness in the orthogonal axis. Only vertical shear is transferred at the central node and therefore no further bracing is required. The resulting structure is as minimal as possible, and located on the rear side only of the tower.

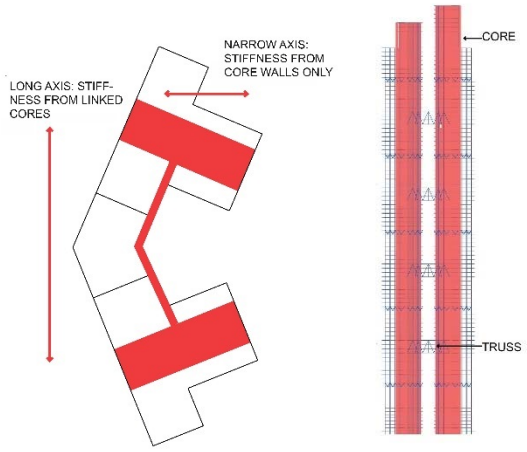

Figure 18. India Tower structural behaviour diagram

The recently completed Apple Union Square is supported by a giant steel truss structure that spans over the ballroom located in the basement underneath the store. The internal space contains a 10m cantilevered mezzanine floor, which tapers to less than 30cm, through which the lighting, air and sprinkler requirements of the space below are integrated, along with tuned mass dampers to control the response of the floor. This tightly integrated design was achieved through close teamwork between the different disciplines and coordination with the other partners involved in the delivery process.

Figure 19. Apple Union Square Interior

Figure 20. Apple Union Square interior

2.4 Curiosity

Design is a non-linear and iterative process. The debate and discussion in the practice across a range of different subjects contributes to the evolution of a concept. Awareness across a series of different fields is communicated both formally, through meetings and reviews, and informally, through shared meals, or simply a chance encounter around the office.

Curiosity allows for a wider view of design, and enables the practice to address challenges which fall outside more traditional briefs.

Figure 21. Droneport project

The Droneport project arose when Jonathan Ledgard of the Redline Group approached Foster + Partners with the idea of using drones to deliver essential medical supplies in remote rural areas with developing infrastructures. To achieve this, he was looking for a design for 'Droneports' that could be built easily and cost effectively. The engineering concept developed was to create a form that required modern analysis techniques and knowledge, but that could be built with indigenous materials, by local workers. The proposed masonry vaults are modular and repetitive; they can be built without formwork with tiles produced either on site or procured from nearby foundries.

2.5 Purposeful Innovation

Innovation in design can manifest itself in all aspects of the process, from the analysis, to materials, through to new products. We seek and develop technical innovation where it benefits the project.

The Engineering team at Foster + Partners is working on two areas with particular potential:

2.5.1 Energy efficient design

Despite the increasing frequency with which sustainability is mentioned, the debate continues to be in its infancy. Increasing energy costs would cause the discussion to move faster.

2.5.2 High volume building materials

There are significant opportunities to advance the structural design of the 'mass-produced' aspects of construction. As labour costs continue to rise in comparison with material costs, it will become increasingly cost-effective to minimise on-site labour.

As structural engineers, we have the knowledge, and are involved in the design process at the right time, to significantly improve the efficiency of the buildings that we design. Innovation, curiosity, a culture of collaboration, technical knowledge, and, perhaps above all, commitment are the means to deliver creative engineering.

Credits

Marseille Vieux Port Canopy

Structural Engineer: Foster + Partners
Steel Contractor: Eiffage

London Millennium Bridge

Engineer: Arup
Artist: Sir Anthony Caro

Chateau Margaux Winery

Structural Engineer: Foster + Partners
Steel Contractor: Seele

Tocumen International Airport

Structural Engineer: Foster + Partners
Collaborating Engineer: Simpson Gumpertz & Heger
Engineer of Record: Oscar Ramirez

425 Park Avenue

Structural Engineer Competition/Concept: Foster + Partners
Structural Engineer of Record: WSP Cantor Seinuk

Maggie's Cancer Centre

Structural Engineer: Foster + Partners
Timber specialist contractor: Blumer Lehman
Timber Engineer RIBA stage 4: SJB Engineers
Maggie's quotation: Wood Awards Supplement, The RIBA Journal December 2016

India Tower

Structural Engineer: Foster + Partners
Structural Engineer of Record: Mahimtura Engineers, Mumbai

Apple Union Square

Integrated Design: Foster + Partners
Engineer of Record**:** Simpson Gumpertz & Heger

Droneport

Structural Engineer: Foster + Partners.
Engineer for Droneport Prototype at Venice Biennale: Ochsendorf Dejong Block