



APEX OF DESIGN

With a new wave of high-rise buildings on the horizon, what can architects and engineers learn from London's icon, **The Shard?**



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*“I SEE IT AS LIKE A GIANT SAIL
EMERGING FROM THE RIVER, AND
SO THE SHAPE OF THE SHARD
WAS CONCEIVED”*

RENZO PIANO

Partner and Founder,
Renzo Piano Building Workshop



INTRODUCTION

REACHING FOR THE SKY

The Shard is a glistening pyramid that towers 310m above London, an emblem of one of the world's greatest cities and a monument to the architectural and engineering prowess it embodies.

Completed in 2012, The Shard's 95 storeys are a testament to what can be achieved when vision meets innovation. It triumphed over a challenging location and a tight schedule to fast become London's stand-out high-rise icon, yet its true significance lies beyond the scale of its physical achievement.

As the skyscraper enjoys a major renaissance – driven in part by rising populations and the scarcity of development land in major cities – The Shard's mixed-use 'vertical city' ethos and pioneering construction techniques have helped to pave the way for a slew of ambitious high-rise projects.

What follows is an exploration of The Shard's scale of ambition, from concept to creation and taking in the extraordinary engineering feats and technical design solutions that helped turn Renzo Piano's architectural vision into a reality.

For engineers and architects in particular, the lessons from the Shard's success continue to echo throughout new skyscraper developments around the world.



DESIGNING THE SHARD

FROM LUNCHTIME SKETCH TO GLOBAL ICON

The Shard's evolution from initial idea to finished project got off to an inauspicious start. Irvine Sellar, the developer and joint owner of the development site, had invited architect Renzo Piano to lunch at a Berlin restaurant to describe his vision for a mixed-use skyscraper. But Piano was initially reluctant.

"You know, I hate tall buildings," he remarked.¹ "They are arrogant, aggressive, like fortresses."

Over the course of the meal, however, Piano began to come round to the idea. "The most important thing that attracted me was this idea of mixing use, and the fact that it was sitting in a vital place of interchange," he says.² "It provided an excellent occasion to show that you could provide life in a city without increasing the traffic – by using public transportation."

Piano was soon excited about creating a ground-breaking addition to London's skyline, in a highly sustainable location, with a design inspired by its historic London setting next to the River Thames. He remembers thinking: "I see it as like a giant sail emerging from the river, and so the shape of The Shard was conceived."³

Piano turned over a menu and started sketching an outline of a building. Sellar was captivated. "As he sketched, I said, you've got it," he recalled. "You've now got my vision."⁴

Height:

309.6m

Floors:

95

Flights of stairs:

306

Number of lifts:

44

Length of pipework:

61km

Length of wiring:

322km

Number of workers:

1,450

Total number of glass panels:

11,000

Total floor space:

27 acres

Concrete used:

54,000sq m



COMMERCIAL AND AESTHETIC DESIGN

FUNCTIONALITY INSPIRED DESIGN

Piano saw that Sellar's vision of a tower atop a one-acre site, incorporating a broad mix of uses, would lend itself to a super high-rise design which elegantly tapered towards the top.

"Progressively changing from functions requiring large floor plates at the lower levels towards functions requiring small floor plates towards the top, would allow the tower to have a light presence in the London sky," said Joost Moolhuijzen, partner in charge at Renzo Piano Building Workshop.

At the peak of Piano's "spire" – a nod to the London steeples and masts depicted by Venetian painter Canaletto⁵ – would be eight sloping glass facades that would be the "shards" that define the design and reach to the sky. It was a design that made sense both aesthetically and commercially.

"For me, it represents a financially secure investment, not depending on any single sector or tenant," Sellar told a conference in New York in 2015.⁶



ANALYSIS AND MODELLING

BEATING THE ODDS

Perhaps the most eye-opening achievement of The Shard is that it was actually built at all. Even ignoring the context of the 2007/08 financial crisis and the planning hurdles, the odds were stacked against it from the outset.

“I remember people saying to me, ‘It’ll never be built. No one’s ever going to build it’”⁷ recalls Ron Slade, design director at WSP, the firm that was selected to engineer The Shard.

The site that Sellar had acquired to build The Shard was directly above London Bridge station, one of the UK capital’s busiest commuter hubs. The fact that the foundations had to contend with the force of the neighbouring River Thames and avoid interfering with underground train lines running beneath only added to engineers’ headaches.

Furthermore, The Shard’s irregular pyramid meant complex geometry, a challenge made even more tricky due to the irregular shape of the development site. Every floor plate would be different, requiring extensive analysis and use of 3D modelling.

To put the scale of the project into context, it meant erecting a 300m+ building with a 500-tonne steel spire, more than 40 lifts and 11,000 glass panels, in a busy central London location and with a build programme of less than four years.



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RON SLADE
Design Director,
WSP



TOP-DOWN CONSTRUCTION

PUSHING NEW LIMITS OF DESIGN

Pulling this off meant pushing new limits of design and engineering in tall buildings. One of the solutions was to pioneer a topdown approach to constructing The Shard's huge core. This involved casting the ground floor slab and excavating the ground below at the same time as continuing work on the superstructure above.

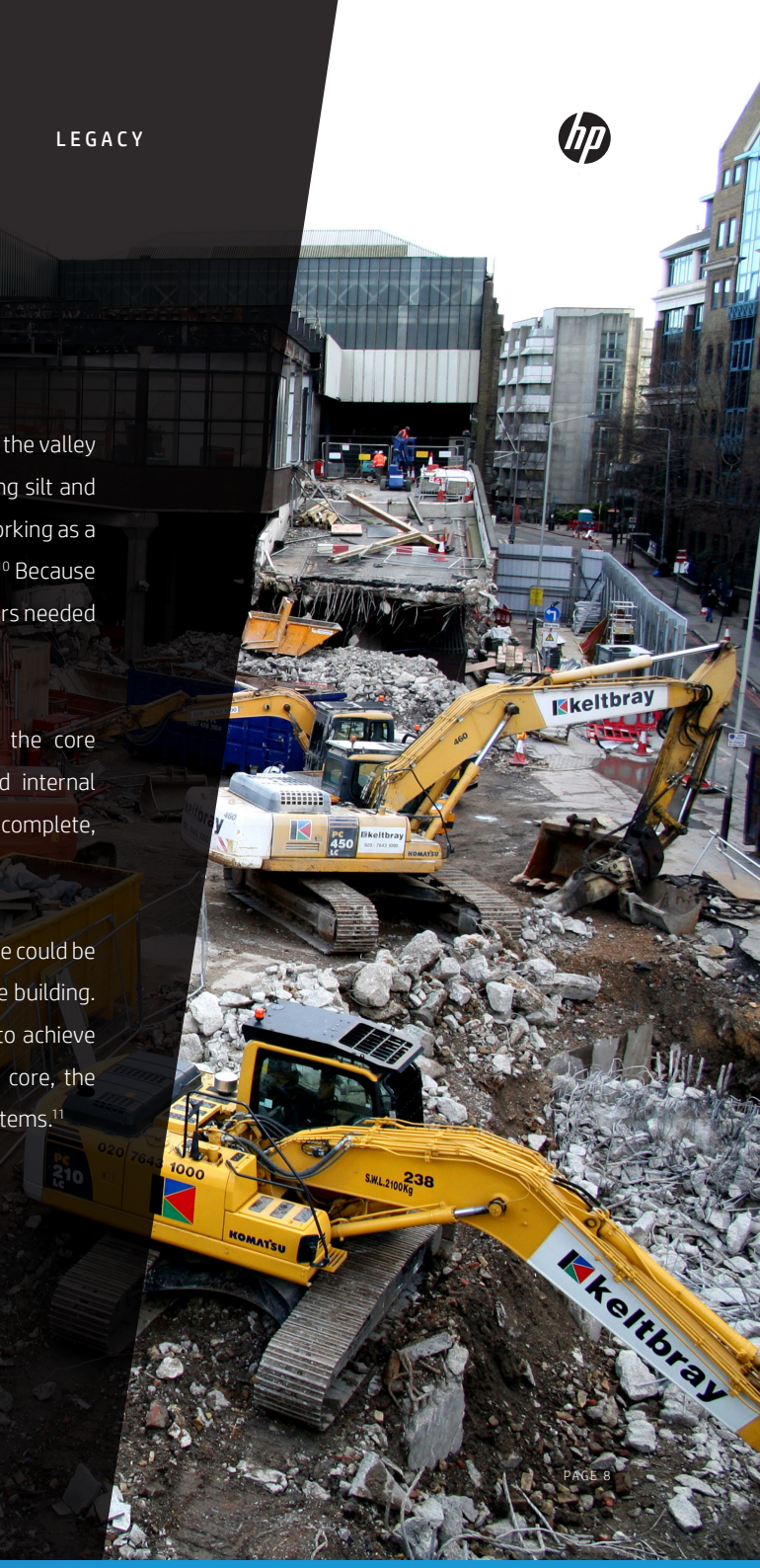
This approach – a world first in such a tall building – saved more than three months of build time and kept the build cost below £450m.⁸ “It was a difficult thing to do, it had never been done before [with a structure as tall as the Shard],” says John Parker, Shard Technical Director at structural engineering firm WSP. “But now everybody seems to be doing it.”⁹

Construction of The Shard began in November 2009. A piled basement wall and other piles were installed first while steel ‘plunge’ columns were cast in the top 5m in strategic locations. The ground floor slab could then be cast across the piled wall and columns, leaving a gap from where excavation could proceed underneath.

“A big challenge that London poses is the ground. We're in the valley of a river, which over millions of years has been depositing silt and creating clay,” says Roma Agrawal, who spent six years working as a structural engineer on The Shard while employed at WSP.¹⁰ Because clay expands when wet and shrinks when dry, the engineers needed to go deep when laying the foundations.

The plunge columns provided temporary support for the core and basement floors while underground expanses and internal structures were created. By the time the substructure was complete, the superstructure had already reached 23 storeys.

This was built using the slipform method, whereby concrete could be poured almost continuously, while formwork slides up the building. This approach operated at a pace of 3m a day. In order to achieve accuracy of plus or minus 25mm in the position of the core, the construction contractors used GPS and laser guidance systems.¹¹



HYBRID STRUCTURE

THE MATERIAL DIFFERENCE

To achieve Sellar's goal of having 900,000sq ft (83,613sq m) of lettable floor space, there was a need to consider nonconventional material choices.

At the outset Piano had intended the building to be entirely constructed using steel. However, WSP proposed a hybrid structure better suited the building's mixed-use purpose. As a result, the tower alternates between steel to level 40, concrete to level 69, and is topped off by a 23-storey steel spire.

"We thought to ourselves, why don't we just use the right material for the right usage?," said Agrawal. "Even though this sounds like a very simple concept, we only really know of one or two other buildings in the entire world that have done this."¹²

The decision to use concrete for the hotel floors and apartments meant that, by reducing the storey height from 3.75m to 3.1m, it was possible to squeeze in an extra two floors as fewer ceiling mounts were needed.¹³ The material had other structural benefits too. "The concrete also gave us damping in the building – it absorbed energy as it moves in the wind,"¹⁴ says Parker.

SPIRE AND
VIEWING GALLERY
STEEL



APARTMENTS
CONCRETE



HOTELS
CONCRETE



RESTAURANTS
CONCRETE



OFFICES
STEEL



BASEMENT
CONCRETE



DYNAMIC MODELLING AND OFF-SITE CONSTRUCTION

MANAGING HIGH-RISE FORCES

At 310m high, The Shard would have to contend with high-speed winds of up to 100mph. While the concrete helped to counteract the sway – around 300-400mm at the top – more had to be done to increase the stiffness of the building. The obvious solution was to use a tuned mass damper. However, this approach would be costly, use valuable lettable space and add 600 tonnes of weight.¹⁵

After conducting dynamic analysis of the entire building, WSP decided to dampen the oscillations and increase stiffness with a hat truss at level 66, with outrigger struts that rise diagonally from the perimeter columns to the central core.

The impractical logistics of the central London site posed additional challenges for erecting the spire safely. The stakes were so high

that steelwork contractor, Severfield-Reeve, did a dummy run of the operation at its Dalton Airfield site in North Yorkshire.¹⁶

The spire had to be split into two-storey sections to make installation easier, with fewer bolted connections on site and more welding off site.¹⁷ Each floor was subdivided into cassettes that could be bolted together easily on-site, while individual modules included, for example, the main structure, floor, catwalk gantries and cladding rails.

“The spire just doesn’t compare with anything you’d ever build anywhere – but the trial assembly resolved all the connection issues,” says Doug Willis, contracts manager at Severfield-Reeve.¹⁸





COLLABORATIVE DESIGN

CROSS-SECTOR COLLABORATION

The project required an extraordinary amount of cross-disciplinary collaboration. Claudio Boccasile, a director at Rebus Engineering Services, which was involved in the redevelopment of London Bridge Station, says: “They did everything in perfect coordination. All the disciplines involved, step by step, day by day, all together.”

Renzo Piano Building Workshop worked particularly closely with engineer WSP to ensure completion of the project before the 2012 Olympics, while staying true to the design.

“The stereotype is very much that the engineer is worried about numbers, and the architect is worried about colour, and all the builder cares about is getting it done quickly,” says

John Parker, senior technical director at WSP.¹⁹ “On The Shard it wasn’t like that. The architect did listen to our concerns about structure, and we listened to him about his concerns about aesthetics.”



ENERGY-EFFICIENT DESIGN

SUSTAINABLE SOLUTIONS

The Shard's 56,000sqm of glazed surfaces posed energy efficiency challenges for Piano, who needed to ensure the building would not need heightened air conditioning requirements due to the potential 'greenhouse' effect of the glass.

His solution was to opt for a 'double-skin' facade, with Venetian blinds installed between layers of glazing, responding automatically to changes in light levels. The building's fractured design, with individual facades not quite meeting at the edges or at the summit, provides natural ventilation to internal winter gardens on the office levels. The building's mix of uses also worked to its advantage.

"We have extra production of heat from the offices that we can reuse in the residential part," Piano explained.²⁰ "This is un-poetic but it is very intelligent."

An innovative form of low-iron white glass was chosen for the facade, avoiding the green tint characteristic of many glazed buildings, causing the surface of The Shard to blend into its surroundings by reflecting and subtly responding to changes in the sky.

"In many ways the simplicity of the external façade belies the complexity behind," says James O'Callaghan, a director at Eckersley O'Callaghan Engineers. "That tension between energy performance and transparency has become even more of a design driver [in recent times]." The Shard is "one of the first [high-rise buildings] that addresses that in an intelligent way."




PUBLIC PERCEPTIONS

DIVIDING OPINION

A month before The Shard opened to the public in 2013, the world was watching. The New York Times summed up the public mood: “Londoners have a love-hate relationship with The Shard, Western Europe’s tallest building, which opens to the public next month. Some of us love it, and lots of us hate it.”²¹

True enough, the project had its detractors but others, such as Piano’s former collaborator Richard Rogers, saw an architectural marvel. “The Shard is the most beautiful addition to the London skyline,” he said. “Even when the sky is dark it captures the light around it and stands like a blade cutting through the clouds.”²²

Many more saw elements of both sides. The critic Edwin Heathcote, writing in the Architects’ Journal, described the building as a “paradox”, noting some failings in the way the building related to the surrounding city but nonetheless describing it as an “extraordinary presence on the skyline” and “a monument that has changed the shape of London and will continue to exert an influence.”²³



“A MONUMENT THAT HAS
CHANGED THE SHAPE OF
LONDON AND WILL CONTINUE
TO EXERT AN INFLUENCE”

EDWIN HEATHCOTE
Architectural critic





RENZO PIANO

THE MAN BEHIND THE VISION

Renzo Piano first made a name for himself in the 1970s. Teaming up with renowned British architect Richard Rogers, he designed the Centre Georges Pompidou in Paris – a building that became famous for boldly inverting its inside onto the exterior.

During a career spanning decades, Piano stamped his vision on a host of other notable projects worldwide including the International Airport in Osaka and Berlin's Potsdamer Platz.²⁴ His work in the US ranges from the New York Times Building to the California Academy of Sciences. Piano's creative passion for architecture is evident throughout all these schemes.

Renzo Piano Building Workshop (RPBW), the practice he founded in 1981, is described as having preoccupation with transparency, beauty and lightness that extends to a striving for 'weightlessness'.²⁵

Piano was born in 1937 into a family of Genoa-based builders, and went on to win accolades including the Pritzker Architecture Prize and the American Institute of Architects Gold Medal. His impact was summed up perfectly in a Financial Times review of a 2018 exhibition dedicated to his life's work at London's Royal Academy:²⁶

"Piano has consistently created urban landmarks, buildings that define skylines and, no matter how controversial or huge, eventually melt into civic-psychic images."





ROMA AGRAWAL

CHARTERED STRUCTURAL ENGINEER

Roma Agrawal is considered one of engineering's rising stars. She has won the Royal Academy of Engineering's prestigious Rooke Award, has been appointed a Fellow of the Institution of Civil Engineers, and is a Member of the Order of the British Empire (MBE) – not to mention the author of a critically acclaimed book, 'Built: The Hidden Stories Behind our Structures'.

When she joined WSP, the engineering firm behind The Shard, in 2005, Agrawal was still a relatively untold engineering story. She spent six years dedicated to The Shard doing some of the enabling works, designing the foundations of the building and also the iconic spire.

"The science of building tall is evolving very rapidly," says Agrawal.²⁷ "We are getting more and more complicated geometry – The Shard has fairly complicated geometry, every single floor is different – and we as structural engineers are pushed to challenge the analysis we do and the construction techniques we use to build things."

Today, Agrawal is an associate director of buildings and places at Aecom in London, where she is focused on championing change in the profession she loves.

"People have preconceptions about what engineering is," she says. "We as a profession need to increase awareness of the problems we solve and the contribution we make to society, from our homes to our mobile phones."²⁸





LEGACY

THE INFLUENCE OF THE SHARD

It's now a decade since construction work first began on The Shard, and in that time it has more than secured its place among the most recognisable structures in the world.

Piano's hope was that it could challenge the narrative that high rise towers were representative of negatives such as money and power. And while the design still has its detractors, its impact is starting to become clear.

Tall buildings around the globe have followed its lead in many of the elements that make it so special. Top-down construction, for which The Shard was an early pioneer, has since become widely used to speed up construction times. Australian tower Crown Sydney, due for completion in 2021, is just one of the latest examples to use it.

Other skyscrapers, such as Landmark 81 in Ho Chi Minh City and Tower One at the Changsha complex in Hong Kong, push the boundaries of what is deemed possible while seeking commercial viability through architectural innovation, a diverse mix of uses, and promises to serve the public good.

This points to The Shard's true legacy – paving the way for a new wave of ambitious high-rise projects that are set to redefine the way we build cities in the future.



What are the trends driving the new wave of high-rise development?

[FIND OUT MORE](#)



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