# INVESTIGATION OF THE SHARD TOWER WITHIN THE SCOPE OF ADVANCED CONSTRUCTION TECHNIQUES

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## ABSTRACT
Today, when technology is in its golden age, the application intensity of buildings with different construction techniques and complex functions is increasing, and in this direction, it is important that the current architectural production systems keep up with the times. For this evaluation, the first building type that comes to mind in the last century is high-rise buildings. The desire for architectural differentiation should not be ignored in these buildings, whose number is increasing day by day and their height level is increasing. How to transfer high-rise buildings, which are symbols of prestige, power and development, to the construction process, especially during the construction phase, is an issue that needs the most appropriate solution proposals against all positive and negative effects that need to be considered. When delving deeper into the subject, a versatile way of thinking and an effective interpretation ability based on knowledge are required. At this point, the aim of the study is; To examine advanced technological developments in high-rise production and to increase the awareness level of architects for high-rise design. For this purpose, the Shard tower, which is an important symbol of vertical architecture in London and was built using advanced construction techniques from the foundation to the superstructure, is discussed. The Shard tower, which started with the decision to demolish the Southwark Towers, which were present in a very dense area in terms of population and traffic in the history of architectural practice, and was completed with a new and challenging design process, the effects of the ground on the architectural design in the structure-ground relationship and the problems in the construction process, architectural design and load-bearing system examined under the headings of system design. The effects of advanced construction techniques that will directly guide design in architectural ethics on architectural design have been discussed in this study. As a result, differentiated and progressive time, with the original architecture with an understanding of high-tech architecture with the foundations of one of the pioneers of the Shard architect Renzo Piano architecture of a new era in the design of the tower, found solutions to problems in the application field with the historical texture to be made in the future will be an important precedent for high-rise buildings.
**Keywords:** High-rise building, advanced construction technologies, Shard tower, top-down method

## INTRODUCTION
The search for height, which spread to Europe after it emerged in Chicago and where the Far East region is at the forefront of today's construction industry, has shown a multidimensional movement in the historical process of the past.

Especially in modern times, if the titles of application reasons and application techniques are taken into account, urbanization has increased day by day with the technological developments and the testing of new advanced construction methods. At this point, the problem of finding land in the existing urban texture and expensive square meter prices have made these building types, which respond to the need for vertical growth, as a result of bringing together commercial and residential areas and using limited space on the ground, to an indispensable position.

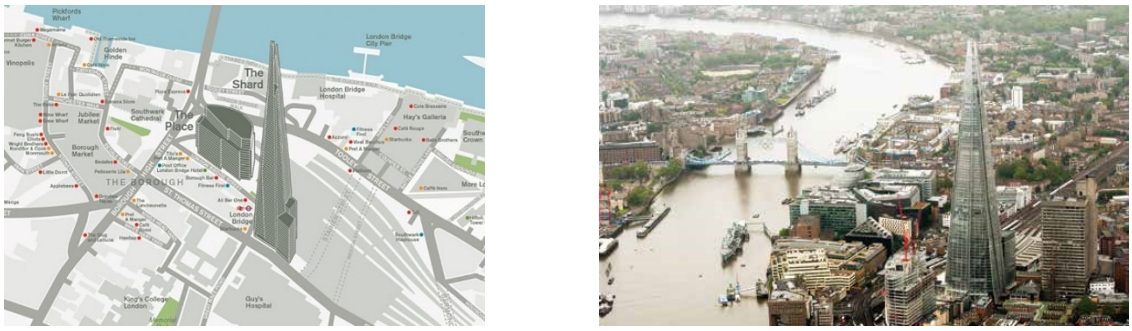
In general terms, a high-rise building is defined as a building with a number of floors above a certain height capacity supported by vertical circulation systems such as elevators, where people are located on each floor and have various functions, technological systems are used, the exterior is closed, and vertical circulation systems such as elevators (Sev, 2001). Looking at the naming in the Great Larousse, one of the main dictionaries, high-rise buildings; The floor area is small and limited, the height is higher than the base dimensions, generally in the form of a tower, it constitutes the delicate building class. High-rise buildings, depending on the campus and location, have also been one of the important building blocks of urbanization. Besides the natural parameters, the texture of the settlement is formed in the totality of vital activities and requirements, compliance with the building tradition and economic opportunities (Ahunbay, 2004). High-rise buildings are also effective in determining the settlement texture in the city and regional planning.

In modern societies, it has become important to keep up with the pace of change and to ensure the continuity of social life by fulfilling the requirements of the age, as well as preserving the past, to preserve the integrity and continuity of historical environments (Tan and Arabacıoğlu, 2020). Contemporary settlements have also been planned in an effort to increase the status of cities and to show power, together with the emergence of new needs with the developing technological systems and advanced construction techniques that allow new trials. High-rise buildings have also made remarkable progress in the design of contemporary settlements.

Beginning in the mid-20th century, high-rise apartment buildings and office blocks were built in most cities in England, with a significant increase in the number of these structures. Accordingly, 46 buildings with a minimum height of 100 meters (330 feet) have been implemented, 41 buildings in London, 4 buildings in Manchester and 1 building in Birmingham (URL-1). The Shard Tower (London Bridge Tower) is one of the highest structures built in London, the capital of the United Kingdom. Its construction was completed between 2000-2012. Built in Neo Futurism architectural style. The structural engineering was undertaken by the WSP Global company and cost 435 Million Euros. The building is built on an area of 110,000 square meters, has 95 floors and has 44 elevators. The Shard tower was built at a height of 309.6 meters (URL-2). The 235-meter-high Canary Wharf Tower, which has been the highest building in England and where London's business centers are located for 18 years, has fallen to second place with the construction of the Shard Tower (URL-3). It has taken over this title from the Commerzbank Tower in Frankfurt, Germany, which has held the title of the highest building in the European Union since 1997 (URL-4). Since the day it was completed, the building is the highest building in the European Union and the country, fourth in Europe and 87th in the world (URL-5).

The site on which the Shard tower is applied is on the south side of the River Thames, in an area occupied by small-scale buildings and narrow roads from Roman times to the 19th century (Figure 1). In 1836, Greenwich station, the capital's first railway line, was built. With the rapid expansion of the station, it covered an area 300 meters long and 130 meters wide by 1893. During the Second World War the area was bombed and destroyed an irregularly shaped corner of the station was. Southwark Towers began to be built in this area in the 1970s. The building consists of a reinforced concrete frame (URL-6).

The Shard Tower was built on the site of the Southwark towers in London, England. Southwark towers, completed in 1975, are 100 meters high and have 25 floors with three structures. In 2008, it was decided to demolish the Shard Tower instead of this building. This process, on the other hand, was the first stage to be solved in the implementation process of the Shard Tower, which is the focus of the study. Located in a historical texture, close to hospital buildings and transportation arteries, Southwark tower is located in St. At the Thomas Street junction and adjacent to the Joiner Street-London Bridge station. It is therefore close to major railway infrastructure, including station platforms to the east and north (Moazami and Seinuk, 2008). During the demolition phase, although the typical way to demolish a building in both the world and the UK is an explosion, due to the proximity of Guy's Hospital and other important structures mentioned, Southwark towers were destroyed by breaking into pieces unlike the explosion method. The structure began demolition in mid-2007, making it the highest building to be demolished in the UK when demolition was completed in the first half of 2009 (URL-7).




(a) (b)

**Figure 1.** (a) Shard Tower location (URL-8), (b) landmarks nearby (Sellar, 2015)

After this stage, the application of the Shard Tower to be built has gained importance in terms of ensuring the integrity of the urban settlement and protecting the historical environment. While contemporary architectural design interventions are carried out in historical environments, preserving the value of cultural identity and urban integrity and transferring it to future generations is the main purpose, architectural design practices that determine its physical change are also directly affected by historical urban space data.

In this study, the Shard tower, which has an important place in the UK building stock and was built in a structurally different way during the design process, is discussed under various headings. The top-down method, architectural design and planning process, and high-tech construction stages, which are the most striking features of the high-rise building, give the building characteristic features. As a result of its unique structural privileges, the stages from the design to the construction process of the Shard tower, which is a precedent for future high-rise buildings, are explained, and it is aimed to create a model for high-tech high-rise buildings in the future.

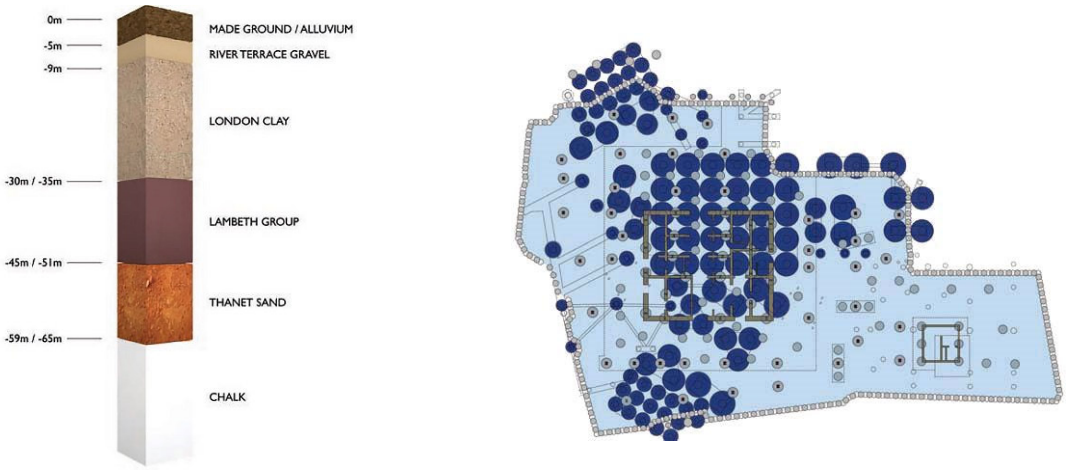
## THE EFFECTS OF THE GROUND ON THE ARCHITECTURAL DESIGN IN THE BUILDING-GROUND RELATIONSHIP AND THE PROBLEMS ARISING IN THE CONSTRUCTION PROCESS

The area where the Shard Tower is built is next to London Bridge tube station, one of the most crowded and nodal points of London's rail transport network. While the metro station is a limiting factor for the construction of the tower, Guy's Hospital, located opposite the building area, is another important limiting factor. Keltbray, an expert in the demolition of Southwark towers, located in a densely building environment, has surrounded the construction site with an acoustic barrier to prevent noise and dust from spreading around.

It was ensured that large parts of the building were removed from the area with a maximum of 30 trucks per day. To speed up the work, a supported intermediate platform was installed on the 19th floor of the building. A work plan has been devised for the demolition and removal of one floor each week (URL-9).

Near the completion of demolition, excavation for the ground concrete of the Shard tower began. Some problems arose with this process (URL-9). It is clear that the columns of the existing structure will not be used and a new project has been developed so that the new piles will not coincide with the current columns. Soil layers of the building land are also important for the project. Considering the soil analysis of the area where the Shard tower was built in London, it is seen that the city has a typical geological formation (Figure 2). As you go deeper from the alluvial ground level, layers such as London clay, fine sands and limestone are reached. The fact that the application area is an archeologically rich region with Roman ruins requires careful and proper settlement of the building. The mentioned data forced engineers to take extra measures at the basement and construction stages (Sellar, 2015).

In the basement design, some sections were reviewed and an application plan was considered in a way that would cause the least damage to the immediate environment (URL-6). The eastern piles were made several meters deeper by the effect of the tectonic plate under the underground layers. The basement design took into account motion tracking, vibration, groundwater and reuse of old piles (Figure 2, 3). Submerged columns are used to support the core and top-down floors. The core plate is four times reinforced in all directions to ensure rigidity and is 3 meters thick (URL-12).




(a) (b)

**Figure 2.** (a) London soil levels (URL-12), (b) Shard Tower existing piles - appearance of new piles (Agrawal, Parker and Slade, 2014)

Due to the strategic location of the building and the sensitivity of the adjacent infrastructure, the main focus of the design is to minimize ground movement during construction. Existing Southwark piles and lateral loads present a major design challenge (Powell, 2013). Top-down strategy (top-down construction) with BIM (Building Information Management) software was deemed appropriate for the solution of the problems. With this method, it is foreseen that both transportation will not be interrupted and the construction process will be shortened.

Steel columns of 50-50 centimeters were inserted through the empty pile holes and placed from ground level to the basement level by immersion method and completed by pouring concrete (Sellar, 2015). 120 piles, each descending to a depth of 53 meters, were used in the basement of the structure (Figure 3). It is calculated that each of them will carry a load of 2800 tons.

One of the difficulties of the excavation is that the structure is very close to the River Thames. The building area is surrounded by a giant retaining wall to ensure a dry and safe floor (Powell, 2013).



(a) (b) (c)

**Figure 3.** (a-b) Southwark Tower basement views, (c) concrete pouring process (URL-9)

After the production of the piles was completed, the preparations for the raft foundation concrete were started. A 4-meter thick raft foundation was the thickest raft foundation manufactured in England at that time. Concrete was poured with 700 mixers in 36 hours. By applying the top-down, top-down strategy in the construction of the basement floors, the superstructure was raised simultaneously with the basement floors (Figure 4). The building has 3 basement floors. The reinforced concrete core was completed by pouring concrete over the reinforced concrete core. A crane was installed on the core and with this crane the core was made ready for raising (Powell, 2013).

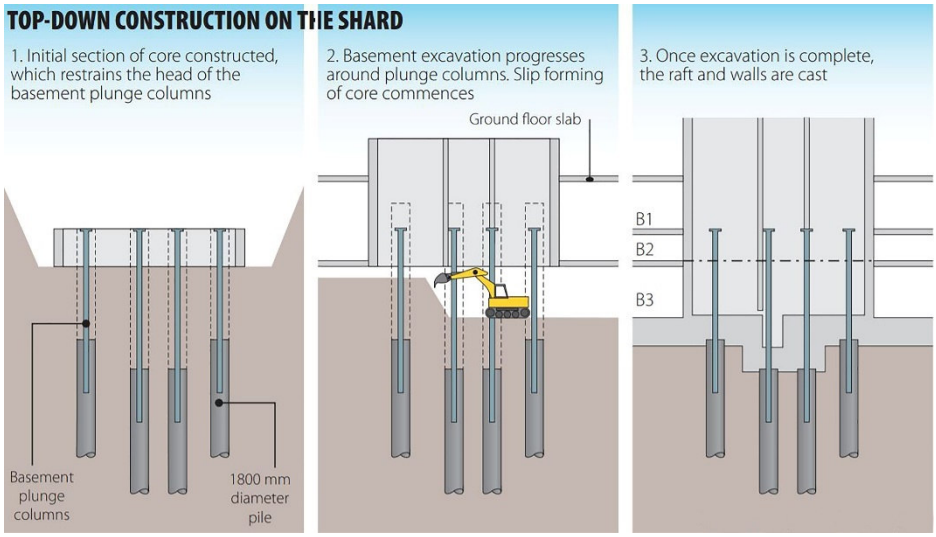



**Figure 4.** Demonstration of the top-down method between basement and ground floors and the operation of the process (Parker, 2012)

With the continuation of the top-down method, the secondary pile wall construction process began simultaneously in the first stage, so that the perimeter walls could be placed. In phase 2 plunging columns and piles are installed as structural support for the ground floor slab. After the ground floor was paved in the 3rd stage, the second level of the basement floor was excavated. Construction of the concrete core continued with the excavations of the basement floors below (Figure 5). With the second floor of the basement fully excavated in stage 4, the floor slab has been applied and the concrete core has begun to rise. In the final step, the construction of the raft foundation in the basement and the installation of the concrete walls to support the core were completed (URL-10).

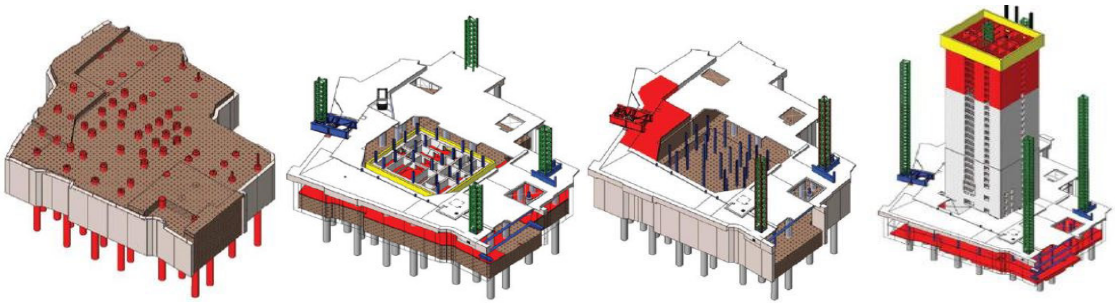


**Figure 5.** The process of building the main load-bearing system and top-down strategy (URL-11)

In general, when the basement construction is listed in stages;
Taking into account that the columns of the collapsed building cannot be used, the ground was evaluated and the basement system was decided. Top-down construction is provided with steel dipped columns (Figure 6). After the composite system of reinforced concrete and steel cured, the core mass and slab concrete were temporarily supported by planar plate structural members as the excavation progressed downwards. The carefully designed piled raft foundation is 3 meters deep around the core mass and 1.5 meters in other sections (URL-6).

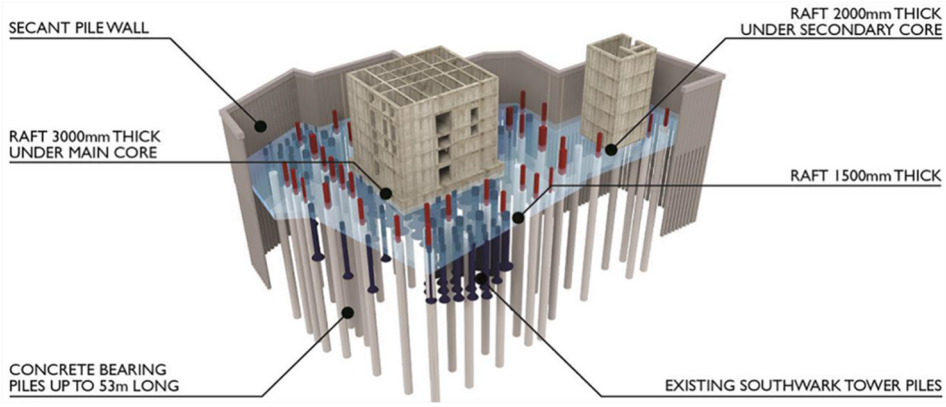



**Figure 6.** Shard Tower ground-basement levels reinforced concrete fabrication (URL-6)

After the application of the intersecting pile walls and immersion columns, the ground floor slab was poured over a slippery membrane for adherence, and then the excavation of two floors of the basement continued up to level B2 (Figure 7). Sliding formwork for core mass is installed on immersion columns at the B2 level. The core mass was raised only on immersion columns until the 21st floor level with the sliding form. Afterwards, the foundation excavation proceeded to the solid ground under the B2 slab. 5,500 cubic meters of basement concrete were poured at a time after the excavation, which was completed to the level of the raft foundation, as a result of a work that lasted 32 hours. By this time, all the load has been carried to the perimeter wall consisting of intersecting piles and immersion columns. The walls of the core mass in the basement were then completed using self-compacting flowable concrete that was pumped from under the concrete molds. The immersion columns, whose tasks were completed, were left in place. This method shortened the construction time by about 3 months (URL-6).

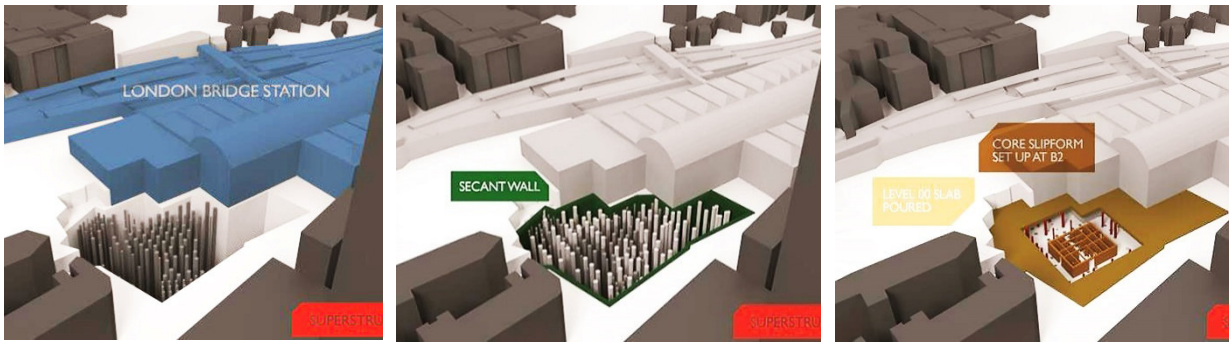



**Figure 7.** Piles, basement and core formation (URL-6)

Some advantages have been provided with the top-down strategy;
- Compared to the traditional system, it strongly supports the head of the wall formed by the intersecting piles, significantly reducing ground movements.
- Provided a large logistics platform at street level.
- It is possible to start the assembly of the superstructure steel elements early.
- Raised bases are supported appropriately for the mounting of tower cranes (Cable, 2012).

This method is suitable for deep basements with site constraints and when soil and water movements must be minimized (Chew, 2017). The top-down method is applied in many parts of the world today. It can be used even in the weakest ground conditions. The areas of application of this method are high-rise buildings (skyscrapers) with deep basement excavations, metro stations, underground parking lots and locations with intensive construction. It is also a strategy that can be applied during excavations in areas where important structures are located (Arıkoler, 2011).

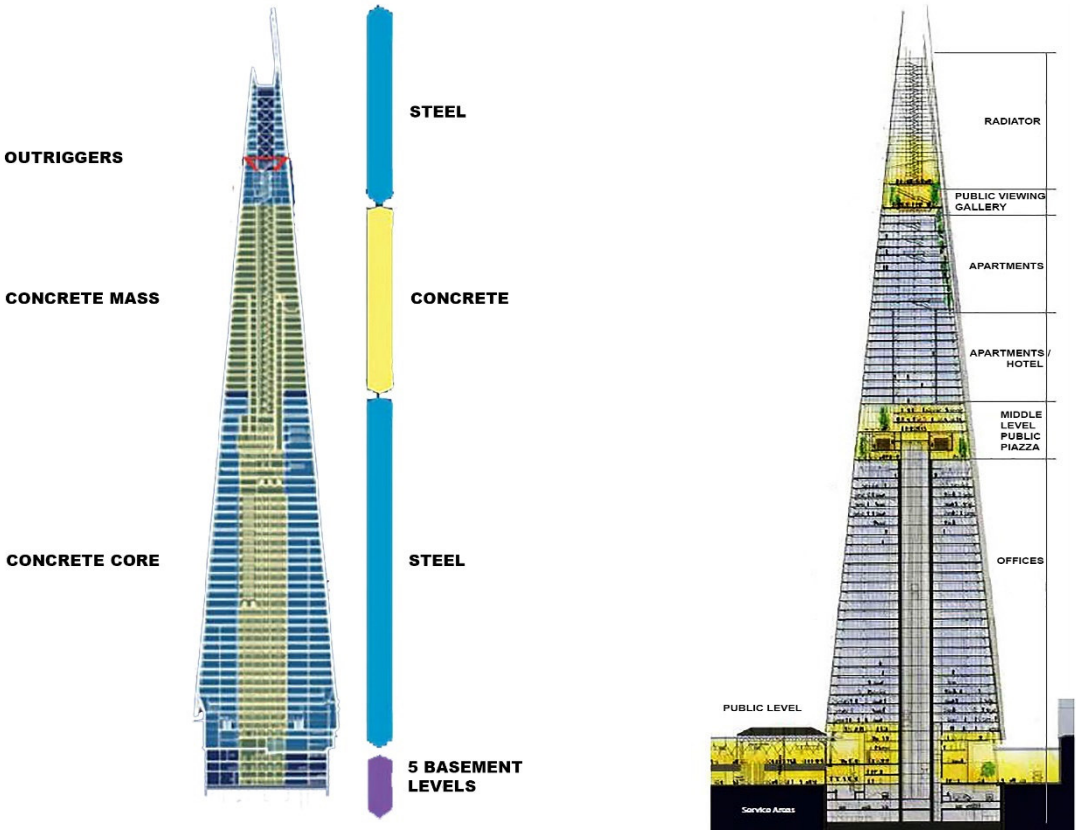
## LIMITED ARCHITECTURAL DESIGN AND ITS EFFECT ON STRUCTURAL SYSTEM DESIGN

The design of the Shard tower was brought up by tower owner Irvine Sellar of Sellar Property Group. Sellar's goal is to build a structure by combining different functions. Sellar met with architect Renzo Piano in Berlin in 2000 to review the building's ideas. Renzo Piano was initially opposed to the idea of a building of this size in London. However, he gave his approval considering that different functions will be combined and advanced construction techniques will be used. Many of the local authorities objected to the first projects he designed, which forced him to revise his project. With the re-planned project, the current innovative pyramid design of the Shard tower has emerged (URL-13).

Sellar has struggled for 20 years to achieve her dreams. First decided to buy the Southwark towers in London Bridge in 1998, right in the center of the business district. Over the next two decades it faced many challenges, from financial support to architectural challenges. However, in 2008, the State of Qatar, which decided to invest in and become a partner in the Shard tower, implemented the project. Thus, in 2012 the building was completed and officially opened by the Prime Minister of Qatar (URL-14). The word “shard” is English and means broken. The reason why the name of the building comes from here is that the floor plans are in broken form, asymmetrical due to the irregular nature of the land, and the windows are arranged in broken form during the design phase (URL-15).

Architect Renzo Piano drew his inspiration from the towers of different London churches and the ship masts that Canaletto depicted in his 18th century paintings. The basic concept of the tower's vision is that the building represents lightness and transparency (URL-14). The conical shape of the building is to minimize the effect of wind load. The conical form has also lowered the center of gravity (Agrawal, Parker and Slade, 2014). Looking at the features of the Shard Tower, it has a capacity of 2 thousand people.

Steel load-bearing structure weight is 11,000 tons (URL-2). Its exterior is covered with 11,000 glass panels, the equivalent of eight football fields. The cables in the building have a total length of 320 kilometers and are large enough to run from London to Paris. Elevators move at speeds up to 6 meters per second (URL-16). 25-floor office floors, three-floor restaurants, an 18-floor hotel and 13-floor apartments form the functions in the building (URL-6). The Shard building is a mix of concrete and steel. Layered reinforced concrete basement floors are laid with steel from the ground to the 40th floor, concrete from the 41st to 69th floors, and steel again up to the top of the tower at the 95th floor level (Figure 8). A huge reinforced concrete core is placed in the middle of the structure, thus making the structure stable and rigid (Parker, 2012).




(a) (b)

**Figure 8.** (a) Shard building structural diagram (Parker, 2012), (b) function diagram (Sellar, 2015)

4 cranes are placed around the reinforced concrete core for the application of steel structural elements. As the building rose, the conditions became more difficult, some days the construction of the upper floors was suspended due to the wind speed. The structural system of the building mainly consists of steel construction elements built around the reinforced concrete core. However, after the 41st floor, it consists of post-tensioned concrete elements. A steel platform is created in front of each concrete slab. Concrete was pumped from the ground floor when the cranes were not working due to the wind. The construction site was continued with a floor laying rate once a week (Powell, 2013).

Different load-bearing systems are integrated into each other to obtain the tapering form of the building. Towards the ground, the exterior column spacing is 6 meters, reduced to 3 meters along the hotel and residence and 1.5 meters along the tower. Wider column spacings and floor openings are within the office space up to the 40th floor (Figure 9). Steel is used in these areas to provide wider column spacing (Cable, 2012).

Within the core mass, there are 21 elevator and stair shafts at ground level, as required by different functions. In accordance with the design, the number of shafts has been gradually reduced to take advantage of the space on the upper floors. Meanwhile, some measures were applied to increase the inertia of the core (URL-6).

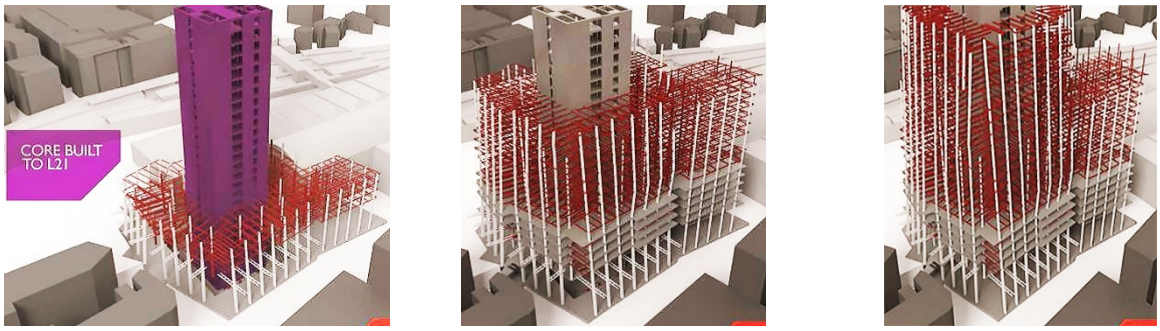



**Figure 9.** Core mass and continued construction of the structure (URL-6)

66-68. The upper truss, consisting of wide-section steel elements at floor levels, connects the core mass and the exterior steel columns to provide load transfer (URL-17). On these floors, the large steel structural elements transfer the forces between the beams and the core and the core to the columns on the exterior (Agrawal, Parker and Slade, 2014). In the steel and reinforced concrete junction, the reinforced concrete frame in the middle ensures that the structure stands in balance with the ground and plays an important role in exhibiting statically rigid behaviors. It is seen that the steel structural elements give external support to the reinforced concrete core part (Figure 10).



(a) (b)

**Figure 10.** (a) Upper trusses in structure (URL-17), (b) 66-68. interfloor truss model (Fu, 2018)

With the thicker, normal weight concrete slabs added to the composite steel floors in the office section on the upper floors, the building has become heavier in mass, but acoustic integrity has been achieved between the offices and the apartment and hotel sections (Sellar, 2015). In the steel structures close to the ground floors, the exterior columns are rectangular. Steel columns wrapped in fire resistant epoxy. High strength (C65 / 80) reinforced concrete columns are used on floors 40 to 50 (Moazami and Seinuk, 2008). Internal columns protected using fire protection panel (Agrawal, Parker and Slade, 2014). While the core structure is terminated at the 72nd floor, the steel structure section called the tower forms the highest part of the structure. The tower structure consists of facilities, maintenance units and viewing terraces of the building and is 60 meters high. In this structure, which was created above the 72nd floor, the steel columns are assembled with fasteners at every three floor level and the floors are arranged in open grids. The planar areas of the façade are finished at different floor levels, and the form that gives the building its name is derived from these fractured finishes (Figure 11).

The façade elements rise 18 meters above the 87th floor and complete the building. One of the biggest challenges in the construction of the tower is to ensure that it is built quickly and safely (URL-17).



(a) (b)

**Figure 11.** (a) Tower structure of high-rise building (Sellar, 2015), (b) view of the glass panels of the building (URL-18)

Two important constraints determine the design of the tower part, which is manufactured as a precast. The first is that the cranes have a load carrying capacity of eight tons, and the second is that they are not sized to be transported without being escorted by the police from Yorkshire. Each prefabricated module is designed to be stable so it can be lifted without temporary support members. Building the tower in modules not only reduced the number of cranes normally required but also minimized the number of on-site connections at great heights (Figure 12). This work, in which various companies undertake different tasks, was completed in its third year and took its place in the London skyline (URL-17). The tower structure is placed in place by the synchronized movement of the cranes. At this point, an innovative approach, rescue cranes, has been put into operation. The crane used in the core construction took on the task of helping the cranes used in the tower construction.

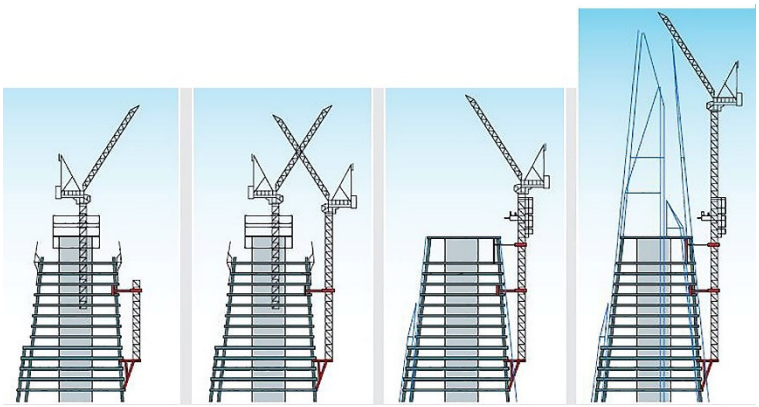
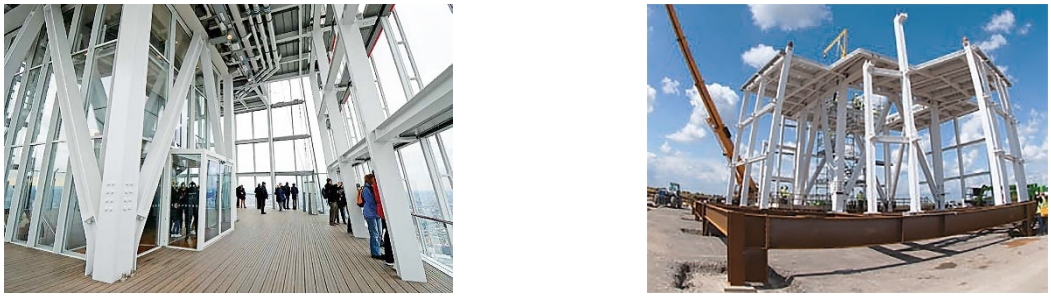


**Figure 12.** Tower structure manufacturing stages (Parker, 2012)

Most of the vertical transport of the shard tower is provided by double-deck elevators in the main core. Elevators have special evacuation modes and different elevators are connected to the same shafts. There are plant areas on the 29-30 and 66-67 floors. Combined heating, cooling and power plant systems are used to achieve maximum efficiency. A mechanical trolley stacker also provides accommodation for 48 cars in the basement. The building has received BREEAM certificate as it is equipped with advanced technological arguments (Agrawal, Parker and Slade, 2014). The architect worked with the steel contractor to cover the joint cover plates where bolted connections could not be made in the structure.

For example, curved plates are produced in the joints between vertical, horizontal and diagonal bracing. The filler and other connections in the wing walls are anchored by welded or concealed top cladding elements (Figure 13). John Parker, technical manager of WSP engineering, said there was a lot of trouble minimizing the size of the connections and properly welding (URL-12).



(a) (b)

**Figure 13.** (a) Shard Tower public viewing terrace (Sellar, 2015), (b) steel structure view (URL-17)

The exterior of the building is covered with more than 11,000 glass panels (Figure 14). The parts were created in a factory in the Netherlands. These elements were lifted into place by crane and mounted from floor to floor. The assembly of each piece took an average of 15 minutes (Powell, 2013). Air heated by the sun rises and exits through the vent above the glass panels. These panels draw cold air from below. Thus, the ambient temperature is balanced. In addition, there is a management system operated by the building. The window does not open when the temperature is too low or the wind speed is too high. Double glazed units can be opened to clean and maintain the outer space. The windows can only be opened for a short time at an angle of about 6 degrees from the vertical due to the slope of the facade and have special maintenance systems (Agrawal, Parker and Slade, 2014).




**Figure 14.** Glass module views of the facade (URL-17), (Cable, 2012)

## CONCLUSION

The Shard tower is one of London's distinctive high-rise buildings. Ten years of planning, design and implementation overcame many challenges and overcame engineering challenges. A number of innovations have been introduced to the construction methodology to overcome space constraints and address the complexities of pavement construction. "The Shard" has redefined London's skyline. Careful planning and site management ensured implementation after four months as well as reducing potential risks of delays with excavation. Innovation in the tower's architecture and structural engineering is matched by innovation in construction methodology.

Some of these innovations were implemented for the first time in London. Top-down method and rescue crane strategy are a few of them. The top-down construction method won the Institute of Civil Engineers (ICE) London awards in 2010. After the Shard tower was finished, several more projects using this method started in London. This method is especially preferred in places where construction is intense in the city, close to historical buildings, important buildings and where the construction needs to be completed quickly. It provides significant cost savings and helps reduce dust level in construction. It also reduces the damage to the environment, as it reduces the volume of concrete used and saves on carbon production. It has little effect on the surrounding traffic density, top-down strategy operations are carried out within the construction site. It offers wide applicability to buildings for multi-storey basement buildings and high-rise buildings. The application areas of the top-down system have been increasing in recent years and it is becoming a popular technique. The rescue crane strategy, on the other hand, can provide a cost-effective and safe way to get cranes to the upper floors in high-rise structures. As more complex sites are developed and increasingly complex building profiles are constructed, rescue cranes have become a necessity rather than an option in the UK. The Shard tower, where innovative innovations are used together, has an important position in this respect.

In the study, the data about the Shard tower, which was built with the top-down method, and the architectural design process were discussed. How the Shard tower was built, and how the existing Southwark towers were replaced with the application stages, were shown and supported with visuals. The reason for considering the Shard Tower is to explain that it is one of the highest buildings in London and that it integrates the existing basement system with the new construction system. At the same time, this high-rise building was preferred because it is an interesting and rare example to be built on the basement structure of an existing building. The research is to understand what the top down method is in this context, and to highlight the method by referring to the application processes based on building construction. It is predicted that the tower, which is a precedent for the construction of future high-rise mechanisms or complex construction systems, will be a model in the context of production and application of advanced technology construction methodologies.

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