Burj Khalifa, The Shard, and Rivals

by Eva Bogomil

Introduction

From the early days, we have invariably been interested in the world we live in, exploring, analysing, and altering it at our will. Humanity has gone a long way from caves to modern skyscrapers, aiming for ever greater heights. The power of human ingenuity has conquered the elements to reach the sky and beyond. Nowadays technologies allow us to build skyscrapers that totally change our idea of a modern world.

Throughout the centuries brilliant engineers have been inventing more advanced and complex technologies, expanding our abilities. The Acropolis, St Paul's Cathedral, the Eiffel Tower and the Sydney Opera House are all marvellous buildings that have remained objects of admiration for historians, architects, and artists, as well as a source of inspiration for many generations. Even to the general public the structures appear breathtaking. The 21st century saw the dawn of super-skyscraper construction. The Shard, Taipei 101, the Princess Tower, the Abraj Al-Bait Towers, and the Shanghai Tower are just some of the outstanding examples the modern world can be proud of. Burj Khalifa, currently the tallest building in the world, crowns this list of our achievements (Figure 1.0) which keep attracting people, making them wonder how such structures could have been built.

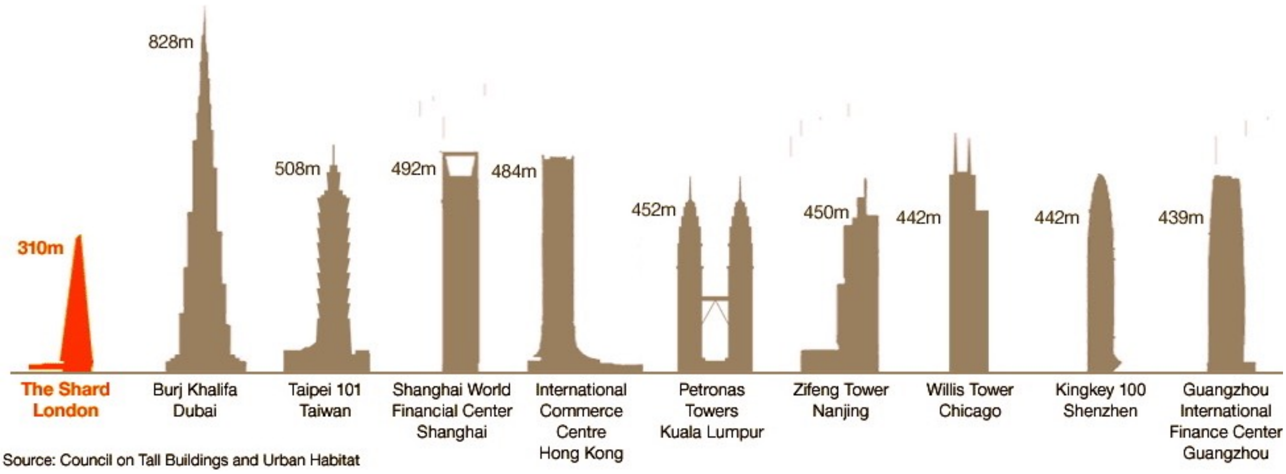

Figure 1.0: Height comparison of some of the tallest buildings in the world

This essay will focus mainly on London's Shard and Dubai's Burj Khalifa. Both of these skyscrapers are unique in their own way, yet similar. The Shard — currently the tallest building in the United Kingdom — dominates London skyline. One cannot ignore this magnificent building, yet Burj Khalifa, currently the tallest building in the world, interests me the most since its construction was a definitive breakthrough in the history of skyscrapers. The skills and technology had to be taken to a completely new level. The very construction of both skyscrapers challenged the forces of nature.

Overview

The Shard*.* The magnificent shiny 95-storey-high skyscraper became the tallest building in Europe upon its completion on 30 March 2012 at a height of 309.6 metres (1,016 feet). The project was first envisaged in 2000, but it was not until 19 March 2009 that the works had started. The delay was caused by the Chartered Association of Building Engineers (CABE) and English Heritage who believed that the construction of such a skyscraper would ruin the view onto such historic London places as St Paul's Cathedral and Westminster (Figure 2.1). 'Tear through historic London like a shard of glass', said English

Heritage, unintentionally giving the skyscraper its current name [12]. That happened despite the Shard's designer, Renzo Piano, claiming to have been inspired by the spires of London churches and masts of tall ships [4].

Burj Khalifa. The tallest skyscraper in the world with 160 floors and 828 meters high, located in Dubai, UAE was launched on 4 January 2010 (Figure 2.2). The tower is classified as 'supertall' (with a height in excess of 1,000 feet) [3]. After 6 years of combined effort of more than 12,000 workers, the tower has become the icon of the city. The design of Burj Khalifa was inspired by local nature — the spider lily. The building also set a number of World Records, including the highest occupied floor, the tallest operational elevator, and the tallest aluminium and glass façade, among others [3].

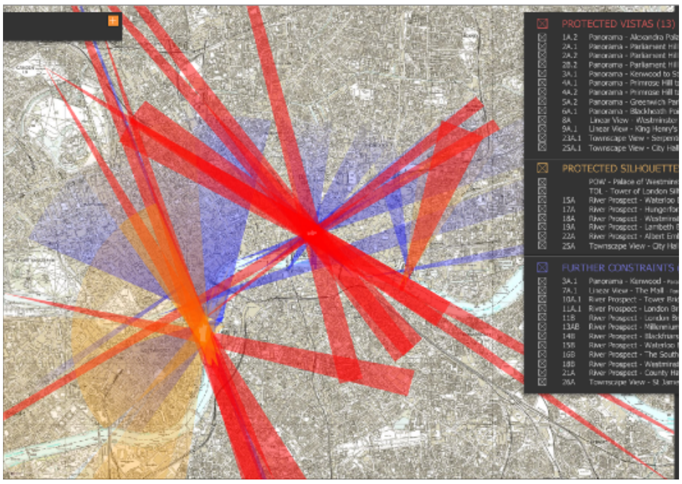

Figure 2.1: The 'view' planning of the Shard
Image: http://www.shardldn.com/construction-history-html/

Foundations

The Shard towers above Southwark just a couple of streets away from the river Thames. The hole for its foundation was dug down to the clay layer. To construct a firm foundation for the skyscraper and prevent the structure from sinking into the clay, the latter was removed before filling the concrete [2].

The Shard was planned on the site of the former Southwark Towers, and its piles remained in the ground. Since it was impossible to remove them and because the area was surrounded by the London Bridge Station and other facilities, the engineers had to come up with an alternative way to construct the basement [13].

In order to reduce the cost and the timescale, the top-down construction method was used. It enabled the first three storeys and the underground structure to be built simultaneously: the secant pile wall was built together with the steel columns of the bearing piles. The giant hole in the ground level slab gave access to the piles, while the wall kept them from being flooded. A rig attached to the steel plunge columns was then used for supporting the concrete core, while the excavation of the basement floors was taking place underneath. By the time the thin basement slab had been completed, the Shard already had 20 storeys [1][13][14]. This was, indeed, a truly innovative method (Figure 3.1).

Figure 2.2: Burj Khalifa
Image: https://www.archdaily.com/882100/burj-khalifa-som

Miles away from the Shard, Burj Khalifa is situated in the desert of Dubai. Yet it faced similar problems. Weak and fractured rock, saturated with ground waters was a challenge for the engineers. It could not carry much weight, and to prevent the building from sinking into the sand, 125 piles were made out of steel-reinforced concrete [8].

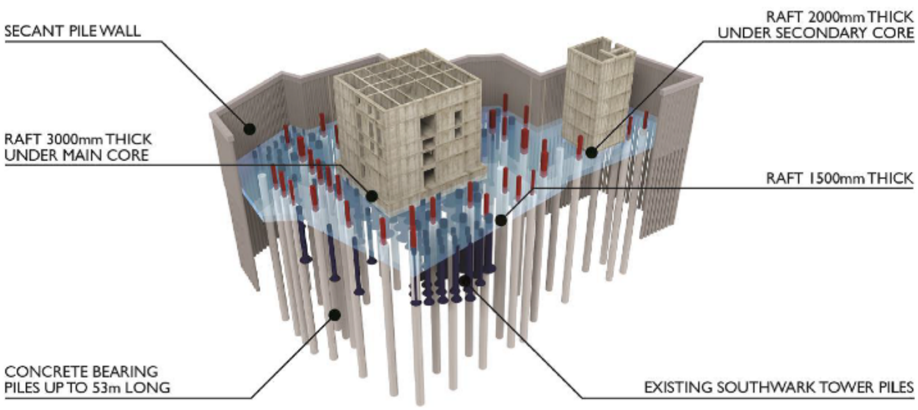

Figure 3.1: The foundation of the Shard
Image: http://www.engineersjournal.ie/2016/01/26/engineering-the-shard/

In order to build a foundation that could support the structure, 50-meter-deep bore holes were dug in the soil and filled with viscous polymer slurry to stop them from caving in. Concrete was then poured in, displacing the lower density slurry and forming foundation piles. High sulphate-rich ground waters posed the danger of corrosion. To minimise potential damage special corrosion inhibitors were added to the concrete [8].

Structure

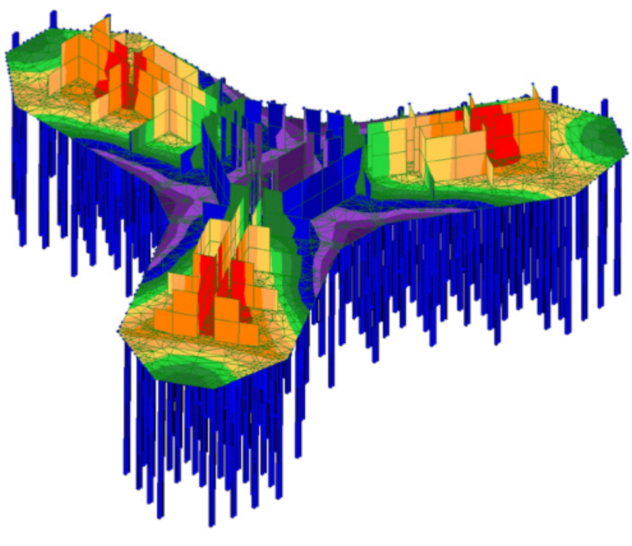

Figure 3.2: Foundation diagram of Burj Khalifa showing the areas of different load (red for highest, blue for lowest)
Image: https://commons.wikimedia.org/wiki/File:Burj_Khalifa_foundation_structure.gif

The amazing thing about the construction of the 95 storeys of the Shard and the 160 storeys of Burj Khalifa is that the work was completed in 4 and 6 years, respectively. In construction business, time is money, making the timescale one of the main priorities. A major development in the skyscraper technology took place during the construction of the World Trade Centre in New York City in 1975, when the so-called «kangaroo» cranes were used to deliver pre-fabricated skeleton blocks to the upper floors. Every time each subsequent storey was built, the cranes lifted themselves up the building [8].

The same type of cranes was used in the construction of Burj Khalifa. Steel skeleton parts were made on the ground and lifted up. The resultant shape was then filled with concrete. After it solidified, the shape could «jump up» to the next floor [3][8]. This enabled the workers to complete a storey almost every tree days. Once the building reached its 99th and 159th floors, special 'recovery' cranes were used to disassemble the operating cranes. The cranes at the very top, however, did that themselves when moving down level by level [3].

With the Shard, an even more exciting method was developed. A whole floor shape was moved up the building and filled with concrete, so that the core grew up at a rate of 3 meters a day (Figure 4.1) [2].

At greater heights, it becomes progressively harder to bring the concrete up. This was a serious issue when constructing Burj Khalifa. The process was done only at nighttime. Concrete was cooled down and water was replaced with ice. It was a real challenge for the chemists to get the right consistency of the concrete: not thin, yet not too thick, otherwise there was a risk of it hardening inside the tubes. Four different types of concrete mixes were used at different heights [8]. It took longer than 40 minutes to pump up the concrete to the top floors at a pressure of over 80 MPa [3]. Along its length, the pipe had several 180 degree bends to imitate the loss of pressure [15]. Consequently, Burj Khalifa broke the world record for vertical concrete pumping [3].

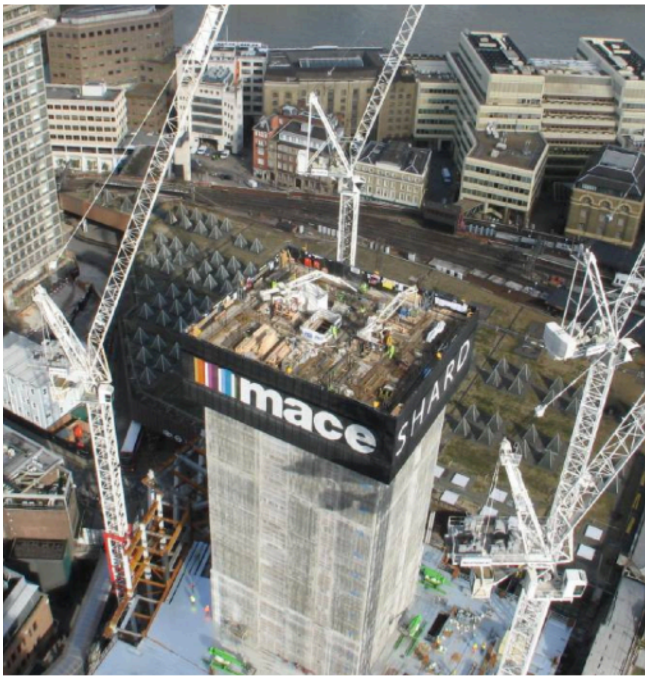

Figure 4.1: The view on the core construction of the Shard. The concrete mould is moved up for each level.
Image: http://sbi.se/uploads/source/files/SBD/presentationer-12/1530.pdf

The mixed-use purpose of the Shard led to the unusual application of the materials (Figure 5.1). As the offices needed large open space, those floors were constructed from steel which behaves equally well in both tension and compression. All of the equipment, such as air conditioning and power cables, was hidden between the ceiling and the slab, using I-beams. At the same time, hotel and residential floors had to be subdivided into smaller rooms, and it was decided to use concrete, because concrete columns could be hidden in the walls, and concrete slabs are thinner so more floors could be built. Moreover, concrete is very sound absorbing, which was a great advantage for the residential space [1].

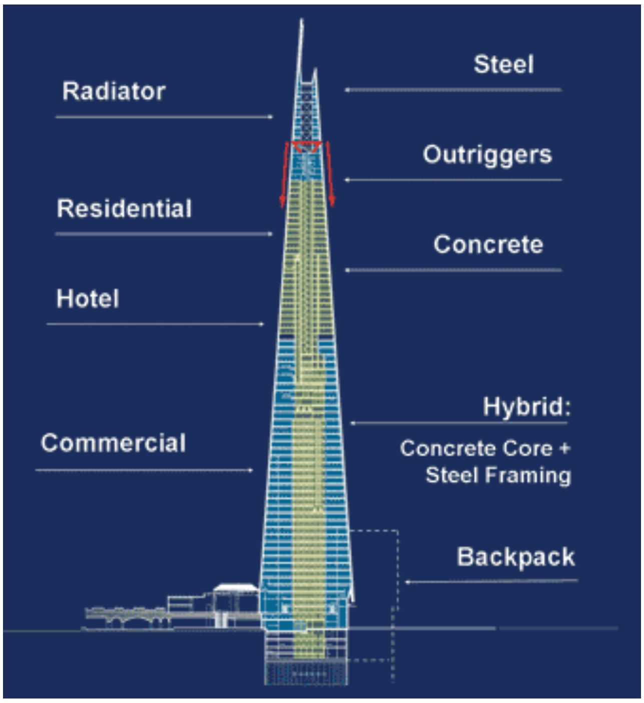

Figure 5.1: Side view of the Shard showing different materials used in construction
Image: http://www.goodshomedesign.com/shard-europes-tallest-building-unveiled-london/the-shard-europes-tallest-7/

A buttressed-core system was used in the construction of Burj Khalifa (Figure 5.2) [15]. Its core has a hexagon shape with three wings anchored to it. It makes each wing to be supported by the other two. This system allows us to construct much higher buildings than ever before, and was first tried out on the Tower Palace, Seoul [7][8].

Due to the sheer weight of Burj Khalifa the perimeter columns are always exposed to compression. Its influence was reduced by matching the self-weight gravity stress of the columns and the concrete walls (Figure 5.3). Outriggers on the service floors allow the gravity and lateral loads to be equally distributed along the walls and the perimeter columns. Similar volume-to-surface ratios allow the structure to shorten at the same rate [5][6].

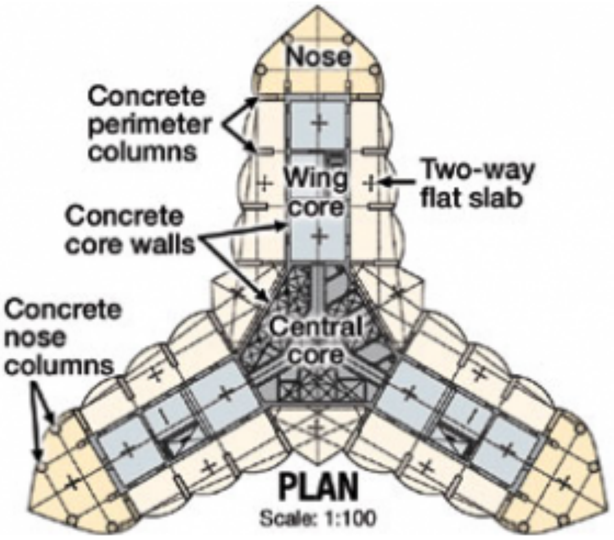

Figure 5.2: Buttressed-core system of Burj Khalifa
Image: http://www.estate123.com/insight/2017/06/reach-for-the-sky-the-tech-of-taller-buildings/

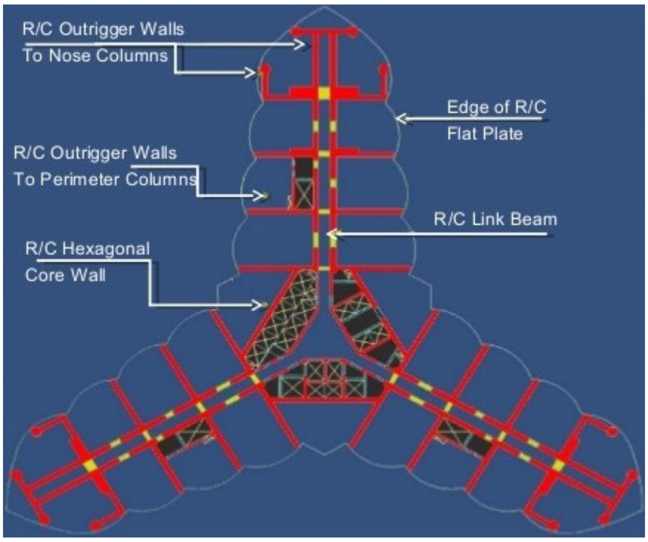

Figure 5.3: The location of the outrigger walls in Burj Khalifa
Image: https://www.slideshare.net/safaamohammed5496/burj-khalifa-48217403

In Dubai temperatures can easily rise up to 40ºC with an average humidity of just below 60%, which creates truly extreme weather conditions for a glass skyscraper [16]. The desert landscape presents another challenge due to infrared radiation. An air conditioner would not be able to cope with that amount of heat absorbed. The solution to the problem was special hand-cut glass panels with two faces. The metal coating on the outside reflects ultraviolet rays, while the silver coating on the inside reflects infrared rays, preventing Burj Khalifa from overheating [8].

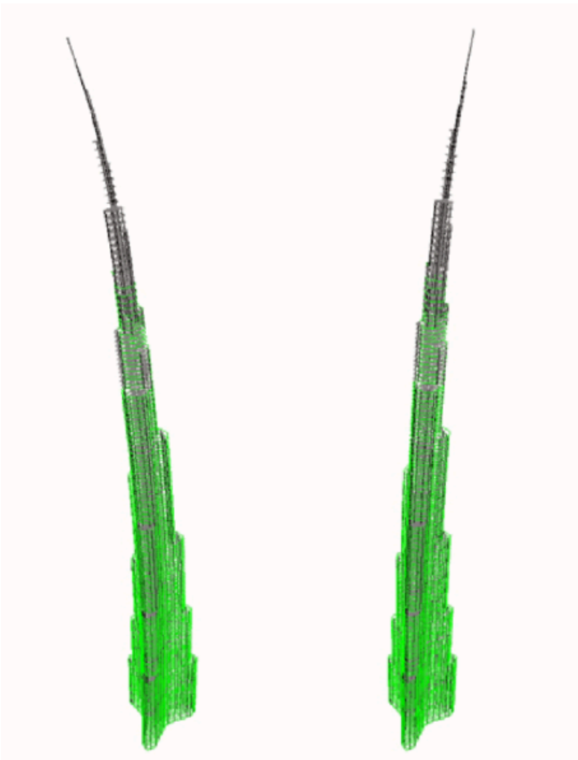

Figure 6.1: 3D model of Burj Khalifa swaying
Image: http://www.civil.ist.utl.pt/~cristina/EBAP/FolhasEdifAltos/burj-dubai/160.pdf

Heights and Winds

Skyscrapers are exposed to winds and it is essential that the structure is strong enough to withstand this relentless force. Wind can affect the building in multiple ways: it can overturn the construction, move it sideways in the soil, or swing it.

Swaying of skyscrapers is not as big a problem as it may seem. Most of the time, people do not feel it. However, if the swing is too fast, people at the top of the building may suffer from sea-sickness. Normal swaying limits can be calculated using a simple formula [1]:

swaying limit = height of skyscraper / 500

Thus, for instance, the Shard with a height of 306 m will have a sway of about 0.6 meters. Yet the taller the building, the more it sways. Therefore, Burj Khalifa with a height of 828 m will sway more significantly, at about 1.7 m (Figure 6.1).

Thanks to their cores and exoskeletons, skyscrapers remain stable during storms and tornadoes. However, at the heights of Burj Khalifa winds can create powerful mini-tornadoes — vortices around the building (Figure 6.2). Low pressure makes the building move sideways, which can become very dangerous. Rather than to fight the wind, the engineers of Burj Khalifa decided to design the tower to deflect the wind flow at different angles. That way the vortices are never fully organised, since at each level the wind has to flow around a different shape [8][9].

More than 40 wind tunnel tests were conducted, challenging a Burj Khalifa model with a variety of winds and façade pressures [15].

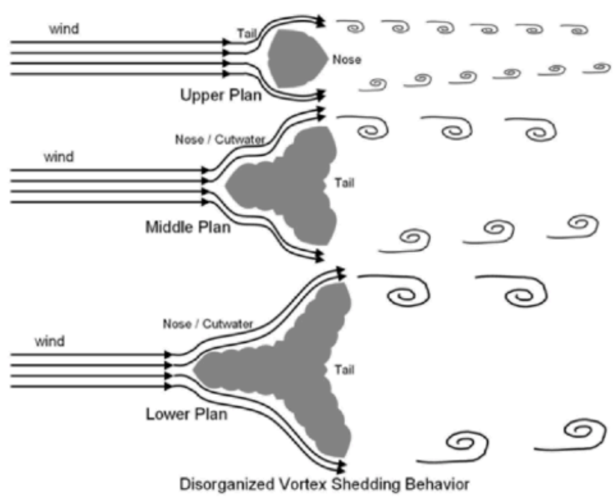

Figure 6.2: Vortex formation around Burj Khalifa
Image: http://www.civil.ist.utl.pt/~cristina/EBAP/FolhasEdifAltos/burj-dubai/160.pdf

Natural Disasters

Earthquakes are yet another potential danger to skyscrapers. It is of major importance that the natural frequency of the building is not similar to the frequency of the earthquake, otherwise the building will resonate and could be severely damaged or even collapse. The natural frequency of the building can be adjusted by adding more weight to the core or the frame, making them stiffer. Alternatively, vibration absorbing rubber bearings and shock absorbers can be installed into beam connections [1]. Burj Khalifa can withstand earthquakes of magnitudes up to 6 on the Richter scale, thanks to its reinforced skeleton [8].

Remarkable ways of fighting earthquakes were adopted by the Comcast Centre in Philadelphia and Taipei 101 in Taiwan. The former features a huge U-shaped tank filled with 30,000 gallons of water on one of its floors, which oscillates at the natural frequency of the structure [10]. The latter boasts a tuned mass damper just under its roof — the 728 ton pendulum protects the skyscraper from swaying, making Taipei 101, as claimed by its designers, one of the safest places during earthquakes [1].

Human Disasters: Terrorist Attacks and Fires

11 September 2001 had a ripple effect on the skyscraper construction. Two planes collided with the World Trade Centre towers in New York. The towers were engineered with the possibility of an aircraft impact in mind (more specifically Boeing 707 which was the largest aircraft at the time of the WTC construction). Despite that, the towers collapsed. One of the causes of such a devastation was the fire that spread after the collision. The beams of the exoskeleton had to carry more load than usual. Burning fuel made the steel hot and hence weak. When the temperatures reached 1000ºC, the columns bowed starting a domino effect with lower floors [1]. This was a painful lesson to be learnt, and nowadays skyscrapers are designed to avoid a repeat of the Twin Towers' tragedy.

Concrete of modern skyscrapers is naturally fire resistant and all skyscraper designs are checked with fire departments first. The Shard is the first building in the UK capable of using elevators in case of emergency. This decision was made due to the number of floors in the Shard. The structure would not be approved if all the floors were to be evacuated using stairs [17]. In case of fire in Burj Khalifa there are special refugee rooms every 30 floors, with a supply of oxygen and special walls that can withstand fire for 2 hours. A network of powerful fans forces clean air through fire resistant ducts to push the smoke away from the stairs, cleaning access way to the refugee rooms [8].

Vertical Cities

It is hard to imagine a single building holding the same number of people as a whole city. While historically towns have usually grown only sideways, occupying nearby lands, modern technologies allow us to build our cities upwards. Originally, the main use of skyscrapers was for offices. However, multi-purpose skyscrapers are becoming more and more widespread. Thus, for example, in addition to 37 office floors Burj Khalifa has 175 hotel rooms, over 1,000 residences and, surprisingly, a library [3].

High-rise cities of the future are also likely to be more environmentally friendly, as they will tend to grow upwards without affecting the natural landscape around them. Such cities could also have higher capacity compared to present-day cities as there will be more people living on the same area of land. Moreover, the very concept of a skyscraper aims to be much greener than any other form of building. Skyscrapers need less energy due to extensive use of natural light and ventilation [10]. Sustainability is another important topic: for example, 95% of the Shard's construction materials were recycled, according to the Guardian [11].

Unfortunately, there are multiple economic and commercial issues preventing us from constructing very high buildings. There was an idea of mile-high tower, suggested by Frank Lloyd Wright back in 1956. Such a tower was technically impossible to construct at that time. An ambitious project linked to Frank Lloyd's ideas was proposed once to Dubai. The Nakheel Tower had a design height of 1,400 m, 610 m higher than Burj Khalifa. The project was eventually put on hold due to financial problems and was never built. Another extreme skyscraper, Burj Mubarak al-Kabir, a megatall skyscraper, inspired by the 'Arabian Nights' folk stories, will reach a height of 1,001 m, if accepted for construction [10].

Probably the most anticipated skyscraper today is the Jeddah Tower which is planned to be finished by 2020. Upon completion it will become the tallest building in the world, having its peak at breathtaking 1,008 m above the ground.

Conclusion

The Shard, Burj Khalifa and others are, without doubt, some of the brightest examples envisaged by the creative human mind. The innovative methods that were developed to build these skyscrapers will have a strong positive impact on future constructions, as they start being commonly used worldwide. Yet it is not the limit, and even more magnificent projects are being planned already, taking humanity from Earth further up to the sky. Has the race of the skyscrapers just begun?

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