Supertall Buildings

Construction risk assessment in the 21st century

How the world’s tallest buildings have grown

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The rise of the world’s tallest buildings

Difference in height between

Philadelphia City Hall – world’s tallest building at the start of the 20th century
and Kingdom Tower (1km) which is six times taller

Record increase in height of world’s tallest building over its predecessor – Dubai’s Burj Khalifa (828m) compared with Taipei 101 (509m)

Increase in height of the world’s tallest building in the past 10 years when Kingdom Tower is completed in 2019.

Buildings to hold the title of world’s tallest building between 1901 and 1998 – all in the US. Height increase of 275m over this period

Buildings to hold the title of world’s tallest building since 1998 (2 in Asia, 1 Middle East). Height increased by 386m during this period

Record increase in height of world’s tallest building over its predecessor – Dubai’s Burj Khalifa (828m) compared with Taipei 101 (509m)

Average height of world’s tallest 100 buildings in 2014. Up 25% since 2000.

Including Kingdom Tower number of world’s tallest buildings since 1998. All insured by Allianz Global Corporate & Specialty (AGCS).

830m
60%
100%
9
3
101
358m
4

Executive Summary

Tall buildings are becoming taller and being built faster than ever before, driven by rapid growth in Asia and the Middle East. The number of supertall buildings (300m+) (101) in the world has almost tripled in the last seven years. Just 15 were built between 1930 and 1995.

More than half of the world’s 100 tallest buildings have been built in the past four years alone (59) - 90% in China, SE Asia or the Middle East. This “construction shift east” will continue, driven by investor appetite, increasing populations and lower labour costs. Half of the 20 tallest buildings in the world in 2020 are expected to be in China alone.

US skyscraper dominance is declining. In 1930 99% of the tallest 100 buildings were located in North America with 51% in New York. Today, this has declined to just 16%. South East Asia (48%) and the Middle East (30%) are home to more than three quarters of the tallest 100 buildings. Europe, South America and Africa account for just 2%. China has the most tall buildings in the top 100 (30) across more than 15 cities, double North America. Dubai is home to 20% of the tallest 50 buildings.

The average height of the world’s tallest 100 buildings today (358m) has increased by 25% since the start of this century and will increase further in future. The average height of the tallest 20 buildings in the world in 2020 is expected to be close to 600m. When the Kingdom Tower development (1km) is completed in 2019 it will mean the height of the world’s tallest building will have doubled in 10 years.

The shift east is allowing for more growth. Between 1901 and 1998 all of the buildings to have held the title of “world’s tallest” (9) were in the US. Their height increased by 275m during this period. Over the past 16 years the world’s tallest buildings (3) have been in Asia/Middle East with a 386m height increase.

* supertall building is 300m or greater in height
** CTBUH Journal 2008 Issue II
*** 286m average height in 2000 - CTBUH Journal 2008 Issue II
How high in the sky can they go? A realistic achievable height with current technology is **one mile** (1.6km), although this is not expected for another 20 to 30 years.

Outside of planning restrictions, limiting factors are efficiency and speed of elevators, new building materials to potentially replace steel and concrete, safety measures and damping systems. Cost is the major obstacle preventing developers going much beyond the one-mile mark - at least not in the next few decades. Buildings like Kingdom Tower will remain the exception rather than the rule.

Increasingly complex high-rise building projects present significant risk challenges meaning insurance claims and risk consulting services are particularly important on a construction site.

Impact of any seismic or natural catastrophe activity – in particular flooding during the construction stage; the threat posed by wind loads and fire; choice of building materials, and the unique complexity of managing projects that can involve as many as 10,000 workers and over 100 subcontractors represent the key risk challenges.

Some significant technical issues including pumping and placing concrete at extreme heights; cranage and lifting items to such heights; and significant variation in wind speeds between ground level and higher levels – this affects design and construction works.

In addition, maintaining verticality as the building height increases; elastic shortening of constructed building elements as the imposed weight from the completed building increases; maintenance and repairs of inside and external elements; and building services provisions – electrical, water and sewer disposal.

The insured values involved with supertall buildings are increasing with insurance playing a vital role in ensuring such projects advance past the design stage. Today’s newest and largest buildings easily exceed **$1bn or more** in value. AGCS is the leading reinsurer for the construction of the next building that will hold the title of “world’s tallest” - the Kingdom Tower (see right) which has a total insured value of **US$1.5bn**.

For insurers each project must be planned and assessed on its own merits and specific risks. Timelines may extend, design plans may alter and engineering challenges may arise. Regular sharing of accurate management information to all stakeholders is crucial. Close evaluation of past claims is essential in preventing future claims.

New risk challenges continue to emerge post-construction as demonstrated by increasing concerns over the potential impact of glass facades on the surrounding locality. Unexpected consequences of building so high with such materials highlights the need for ongoing risk mitigation.

Appropriate insurance coverage is a key part of any holistic risk management strategy. As well as providing all risks building and construction protection, insurers such as AGCS also provide after construction coverage, protecting policyholders against physical structural damages arising from defects in design, materials or workmanship.

**Download graphic here**
Introduction

Charting the technological development of tall buildings

Yesterday: The skyscraper era started in the 19th century. A crucial development of technology, the iron frame supporting structure, led to a rapid growth in tall buildings, ultimately enabling transparent glass facades to become common. The 55m (180ft) Home Insurance Building in Chicago, completed in 1885 was one such building and the first to which the term skyscraper was applied*. The ability to produce steel in high volume at a low cost, supported by a growing economy resulted in a skyscraper race developing in the US. Completed in 1931, New York’s Empire State Building (381m/1250ft) – 102 stories supported by a braced rigid steel frame technology which was adapted over many years – was the tallest building in the world for a record 41 years.

At the start of the high-rise building era vertical load distribution represented the most significant challenge. However, as building height increased managing the potential impact from the force of the wind (wind loads) and any seismic activity became more difficult. Therefore the next step in high-rise building development only became possible due to the introduction of innovative structural initiatives such as core- and so-called outrigger systems, tubes, bundled tubes and mixed steel-concrete design.

For example, the tube design was applied to the original World Trade Center 417m (1368ft) in New York. The vertical steel columns formed the outer façade which was designed as a load-bearing structure to cater for vertical and wind loads.

A further development of the tube into a bundled tube design was the Sears Tower (442m/1450ft) in Chicago, now known as the Willis Tower. Completed in 1974, it is essentially built from nine square-cut steel-framed tubes which were bundled at the base forming a large square, ensuring flexibility in organizing the floor areas.

The architectural and structural flexibility of buildings constructed as tube design is enormous. Individual tubes not limited to square-cut can be assembled in any configuration and terminated at different heights without loss of structural stability. Tubes can be built in concrete or in steel and can be combined in a so-called tube-in-tube system which incorporates an inner core made up of a solid, braced or framed tube and an outer core built as a tube**.

The Empire State Building is one of only three buildings to have held the title of world’s tallest building for more than a decade

* Farcountry Press p.29 ISBN 9781560374022
** Architectural Science Review, Volume 50.3, pp 205-223

Photo: Shutterstock
Current trends:
High quality materials

**Today:** High speed computer modeling, finite element calculation methods and high quality materials have influenced further design developments allowing architects to be flexible and creative in terms of design and height and not limited by structural boundaries.

By the end of the 20th century, buildings such as the Petronas Towers (452m/1482ft) in Kuala Lumpur and the Jin Mao Tower (421m/1381ft) in Shanghai elevated their cities and countries to new heights.

A popular system for high-rise buildings is the so-called outrigger system especially when combined with a core-outrigger system which is connected to exterior mega beams.

Core-outrigger design and other special damping systems were applied to Taipei 101 (509m/1669ft) in Taiwan for example, the world’s tallest building between 2004 and 2010. A 660 ton active pendulum serves as a tuned mass damper in the tower. Sophisticated damping systems have been especially effective in reducing the potentially damaging effect from wind and earthquake loads. More controversially, a tuned mass damper was introduced by the Renault Formula 1 racing team as part of its car’s suspension system in 2005 only to be later banned by authorities.

The record for the tallest building in the world is currently held by the Burj Khalifa in Dubai (828m/2716ft) completed in 2010. The structural system can be described as a “buttressed core”, and consists of high performance concrete wall construction*. This central core provides the torsional resistance of the structure.

Burj Khalifa’s unique design will continue to inspire buildings for decades but its place as record holder will soon be lost. Construction has already started and foundation works completed on the Kingdom Tower in Jeddah (see page 10), the first building ever to pass 1km. A tapered “Y” shaped plan was chosen as a structural design as this was deemed to be the most effective fit given the geological limits of the local area.**

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* www.burjkhalifa.ae/en
** CTBUH Journal 2013: Article Kingdom Tower, Jeddah www.ctbuh.org
Technological limits and the prospects of a new mile-high club...

**Tomorrow:** The world’s tallest buildings look set to continue to dominate the skylines of the *Middle East* and *South East Asia* regions for years to come. There remains a strong local appetite for such construction projects as well as significant levels of investment to fund them. Meanwhile, labor and construction costs are largely lower than in the US or Europe.

European and American countries account for 12 of the *top 20* countries in consultancy firm EC Harris’ latest cost of construction index* compared with just two in the *Middle East*. China is only ranked 30th.

It seems to be human instinct to look higher, particularly given increasing population levels. Mooted fantastical concepts such as the *X-Seed 4000* - designed for Tokyo, Japan by the Taisei Corporation in 1995 as a futuristic living environment and the *Shimizu TRY 2004 Mega-City Pyramid* – to be constructed over Tokyo Bay - raised the prospect of building up to 4km - four times the proposed size of the Kingdom Tower.

Although these concepts have not been built experts theoretically see no limitation in regard to how tall a building can be.

However, there are other limits that must be considered. A realistic achievable height with current technology seems to be *one mile (approx 1.6km)*, although Adrian Smith, the Chicago architect responsible for the Burj Khalifa and the Kingdom Tower has previously said this won’t happen for another *20 to 30 years**. Kingdom Tower was originally conceived as a “Mile-High Tower” but was scaled back due to geological restrictions in the Jeddah area.

The main immediate limiting factor according to high-rise building experts is the efficiency and speed of the elevators, which can only travel up to around 600m high at present in supertall and megatall buildings *(see box, page 8)*.

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*EC Harris Research 2013 International Construction Cost report
**September 2012

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Architect’s vision for the Kingdom Tower, Jeddah, soon to be the world’s tallest building

*Photo: Adrian Smith & Gordon Gill Architecture*
Further limitations including availability of building materials to potentially replace steel and concrete, safety measures and damping systems. In addition as climate change concerns have become more vocal the impact of glass facades is increasingly coming under the spotlight (see page 14) with concerns being raised about the long-term impact of “solar gain” - the extent to which a building absorbs sunlight and heats up - with governments introducing regulations around shape and structure. Perhaps most importantly financing will probably not allow developers to go much beyond the one mile mark, at least not in the next few decades.

Beyond one kilometer skyscrapers would likely need to have two or three buildings interconnected with horizontal elements bracing the “legs” meaning that single tower structures such as the Kingdom Tower may be unfeasible.

Increasing population density in certain areas of the world will support the development of tall buildings. However, buildings like Kingdom Tower will probably remain the exception as they are heavily dependent on financial power.

As many as 90
200m+ buildings are planned in 2014

As many as 15
potential building constructions in excess of 300m in 2015

In 2015 the Shanghai Tower (632m) is the only megatall (600m+) building set to be completed.

Source: Allianz Global Corporate & Specialty

The Kingdom Tower could fit nearly 11 Statues of Liberty.

Source: Allianz Global Corporate & Specialty
The challenge of moving people up and down such tall buildings is one of the reasons why the prospect of a mile-high building becoming a reality remains some way off…for now.

The longest distance it is currently possible to travel in an elevator is 504m, up to 638m in the Burj Khalifa, which is home to 57 elevators and eight escalators.

The Kingdom Tower complex is expected to contain around 65 elevators and escalators with preliminary reports indicating that the elevator shaft will be in excess of 600m.

Speed is obviously important. According to initial plans, Kingdom Tower elevators will travel at a rate of 10m per second, slightly over 35kmh in both directions. It is challenging for elevators to go faster because of the rapid change in air pressure over such a distance. For example, at 914 m, the air pressure is over 10 kPa (1.5 psi) lower than at ground level (about 10% less air pressure).

Elevators at the Burj Khalifa take a minute to travel to the observation deck on the 124th floor, already travelling at a similar speed to that proposed for the Kingdom Tower elevators.

To put this into perspective a similar speed was achieved by Usain Bolt when he set his 100m world record (9.58s), equating to 37.58kmh.
Risk register

Assessing the key risks with the world’s tallest buildings

Claims and risk consulting services are especially important on a construction site, even more so when dealing with increasingly complex high-rise building projects which can present a number of significant challenges.

AGCS has been involved in insuring a number of internationally-renowned high-rise building projects, including Taipei 101 and the Petronas Towers, both formerly the world’s tallest building, as well as the current holder of this accolade, the Burj Khalifa.

It is also the lead reinsurer on the Kingdom Tower development in Jeddah and has also been involved in insuring the tallest building in the US and western hemisphere - One World Trade Center, as well as the tallest building in the UK and Western Europe (The Shard).

For an insurer or reinsurer acting on projects of this nature one of the key issues is to assess what level of risk – and impact – any seismic or natural catastrophe activity might have on the structure in question.

“If an event such as an earthquake or another natural hazzard was to occur, it could obviously have a potential impact,” says Clive Trencher, Senior Risk Consultant at AGCS.

“Therefore the foundations need to be adequately designed and constructed to withstand such an event.”
Kingdom Tower is expected to weigh nearly one million tons when completed

Photo: Adrian Smith & Gordon Gill Architecture

**Tall buildings in focus:**

**Kingdom Tower**

Currently scheduled for completion at the end of 2018, Saudi Arabia’s Kingdom Tower, for which AGCS is acting as lead reinsurer via its subsidiary Allianz Risk Transfer, will form the centrepiece of the Kingdom City development on a 50-hectare plot of waterfront land along the Red Sea on the north side of Jeddah.

When completed, the tower, which is expected to weigh nearly one million tons and comprises a mixture of residential and commercial property will reach unprecedented heights becoming the tallest building in the world and the first habitable structure to reach the 1km high mark.

Construction work on the Jeddah Economic Company-backed tower, which is being built by Saudi construction firm Bin Laden Group, began last year with the piling and foundation work now complete.

Both posed challenges: the foundation and the piling – which involves the use of large diameter bored piles to ensure structural stability within the foundations – has had to be uniquely designed to overcome subsurface issues such as soft bedrock and porous coral rock without the pile loads over-stressing the ground conditions. Added to that, the concrete also has to have low permeability in order to resist the salt-laden ground water which is characteristic of the region.

According to foundation contractors, Saudi Bauer the work involved installing 72 piles of 110 meters in length and 1.5 meters in diameter; a further 154 piles of 1.5 meters in diameter and between 49 and 89 meters in length; and 44 piles with a diameter of 1.8 meters, all down to a depth of 50 meters.

The construction work also needs to ensure that the finished tower experiences only minimal building sway, which is more prevalent in high structures because of stronger winds and the sheer scale of the building.

To achieve this, the Kingdom Tower has been designed to limit the excessive movement that would otherwise make the occupants of upper floors experience motion sickness or discomfort on windy days, including using very high strength concrete that will be up to several feet thick in certain parts of the core. This, along with the highly integrated steel frame and shear walls, is also intended to prevent catastrophic structural failure. Additionally, the tower will incorporate a large core not only to support the structure, but also to contain many of the high-speed elevators and extensive building services needed. The stability design of the building is crucial. At Kingdom Tower’s projected height, it is considered unfeasible to use a traditional square design. Instead, like the Burj Khalifa in Dubai – presently the world’s tallest building – it will have a three-petal triangular footprint for stability and a tapering form with a sloped exterior, which will reduce wind loads.

The smooth, sloped façade of the building will create a phenomenon known as wind vortex shedding. Normally, when wind moves around a building it can create tornado-like vortices which initiate sway in the building due to variations in pressure, direction, and velocity. However, the smooth taper of the Kingdom Tower’s design is more aerodynamic, which reduces the risk of the vortices forming, just one of many innovative features that will ensure the futuristic skyscraper will lead the way when it comes to cutting-edge building design, as well as height, when it is completed in 2019.
“Consideration also has to be given to potential exposures such as flash flooding, which may pose a risk when initial building work starts on such projects because there will be large excavations in the ground,” Trencher adds. For example, Jeddah has a potential exposure to this risk [the city experienced flooding in 2009, in part due to inadequate drainage infrastructure] so a factor like this needs to be taken into account on the risk register.

The choice of building materials also poses challenges. Glass panels need to be thicker and more durable for the higher stories, while concrete mixes design also have to vary so they can withstand the differing buildings loads which vary with height. This is no easy feat.

Ahmet Batmaz, Global Head of Engineering Risk Consultants at AGCS, says “it is very difficult to pump concrete at this height – the high-strength concrete requires a specialized mix design to enable it to be pumped and it requires special equipment and pump lines as pressure can reach over 400 bar. It also creates some technical challenges during the stage where the concrete is mixed and placed as such concrete tends to set after two hours only.”

In addition to pumping and placing concrete at extreme heights other significant technical issues include craniege and lifting items to such heights; significant variation in wind speeds between ground level and higher levels – which affects design and construction.

Tall buildings in focus:
One World Trade Center

At 541m The Port Authority of New York and New Jersey and The Durst Organization-developed One World Trade Center is only just over half the proposed height of Kingdom Tower but is the tallest building in the Western Hemisphere and fourth largest in the world.

Featuring 3.5m square feet of space, the building alone, for which AGCS provided insurance, has an insured value of approximately $3.1bn. The exterior cladding of the building is composed of one million square feet of glass, similar to the amount it would take to cover 20 NFL football fields or 213 NBA basketball courts*.

Building materials included 200,000 cy of concrete, enough to build a sidewalk, four inches thick by four feet wide, from New York City to Chicago*.

One of the main risks associated with the construction of the tower is flooding, as demonstrated when the storm surge from Superstorm Sandy impacted the complex in October 2012, destroying walls and damaging builders’ equipment stored underground, resulting in insurance claims.

Indeed such flood losses prompted the insurance community to pay more attention to both its modeling results and policy wording, according to William Henthorne, Inland Marine Underwriting Manager, AGCS. “Many Sandy losses were caused by flooding rather than windstorm. Several large manuscript policies included tidal surge wording under windstorm rather than flood cover, which may have resulted in higher losses than expected, given the lower flood sub limits were no longer applicable.”

Based on available flood maps it is expected water on site from a 100-year flood event would reach the 10 foot level. The Port Authority reports the 100-year storm surge as 12.35ft and the 500-year storm surge as 15.85ft. Superstorm Sandy produced a surge reported by the Port Authority at 11.15ft. All first floor areas and below grade levels would therefore be expected to be inundated with water.

The Port Authority is working on extensive flood preparing planning and mediation methods via a multi-level approach. The first level is a Bollard Protection System (BPS) designed to cordon off the site in various “islands”. The second involves water intrusion protection systems which will be installed to protect individual objects.

* The Port Authority of New York & New Jersey World Trade Properties
works; maintaining verticality as the building height increases; elastic shortening of constructed building elements as the imposed weight from the completed building increases; maintenance and repairs of inside and external elements; and building services provisions - electrical, water and sewer disposal.

Fire risk in tall buildings, both during the construction and occupied phases, is a multiplied risk factor and represents a considerable challenge for designers and engineers.

Evacuation of a building which caters for multiple purposes like hotels, restaurants, residential areas, shopping centers and offices is crucial, especially considering the number of people to be evacuated within a short time period. Thus an enormous focus lies on the design of sprinkler systems, escape rooms and fire resistant structures at an early stage of design.

Unique projects

Although many of the technical issues that the latest high-rise building projects face may appear similar to previous supertall and megatall developments, AGCS experts advise against making assumptions that the same technical solutions can be used.

"Such constructions are unique projects facing unique risks. Every construction project faces challenges and the more ambitious and large-scale the project might be, the more challenges it will create," says Trencher.

"Each project has to be planned and assessed on its own merits and specific risks. While we may learn some techniques from the construction of other tall buildings, it would be wrong to assume that they can be fully risk assessed or planned just because they have been used on similar tall structures."

Photo: Adrian Smith & Gordon Gill Architecture
City in focus:
The Shard - continuing the transformation of London’s skyline

Recently voted the world’s best skyscraper out of 300 buildings by building information database Emporis the completion of the Shard last year ensured it became London’s tallest building (306m), transforming a city skyline which is relatively low-rise by international standards.

Although The Shard, for which AGCS acted as an insurer both during its construction and afterwards via its IDI protection (see page 14), represents a 25% increase in height compared with London’s previous tallest building, The Heron Tower [now The Salesforce Tower] (AGCS also led the construction all risks and delay in start-up insurance for this project), it is not even ranked in the top 80 tallest buildings in the world (83)*.

In fact London only just creeps into the top 50 cities in the world when it comes to number of skyscrapers with just 46* a legacy of the fact that height restrictions of under 100ft for buildings in the City were not removed until the early 1960s. By comparison Hong Kong boasts more than 1,250 multi-story buildings of 100m+ in height – literally the highest in the world.

Managing unique complexity

Another aspect of supertall and megatall building projects is their unique complexity. Such construction projects are time-consuming – spanning at least five years in the case of Kingdom Tower – and can, at times, involve as many as 10,000 workers and over 100 subcontractors working together.

Joint ventures, clients, consultants, subcontractors and suppliers need to work closely and act as a team. Organizing and managing subcontractors and suppliers requires a dedicated and highly experienced team. Strong management becomes vital for the success of such a project.

Regular and accurate management information on the building’s progress and any emerging risks is crucial. Batmaz says such information should be shared with all stakeholders.

"Projects of this scale will always involve changes. Risk levels on different aspects of the construction may fluctuate from low- to medium- to high-risk, depending on circumstances," he says.

They also need to be fluid, adds Stefan Atug, engineering underwriter at AGCS/Allianz Risk Transfer Dubai: "Timelines may extend, design plans may alter, engineering challenges may arise. Technical risks may need to be managed or mitigated in different ways."
“As a reinsurer, we need to be able to take a flexible approach and adapt our services to suit the client’s needs, which means forging as close a relationship as possible to be able to react to changing circumstances.”

There is no standard approach at the design stage nor during the construction phase of a supertall or megatall building. Current knowledge and state-of-the-art becomes irrelevant. In terms of technology this means innovative techniques and new technologies need to be applied. Design elements in respect of the behavior of the building especially in regard of strong winds are prototypical. Although extensive wind tunnel and material testing takes place during the design phase inherent risk becomes higher.

New challenges

And of course the risks don’t stop when construction is complete. New challenges continue to emerge as demonstrated by the recent case in London when the glare from the 37-floor skyscraper at 20 Fenchurch Street, more commonly known as the “Walkie-Talkie” impacted parked vehicles and shops.

As a result a permanent sunshade is now to be attached to the “Walkie-Talkie” to prevent reflected sunlight from causing further damage.

Such an unexpected consequence of building so high with such materials highlights the need for ongoing risk mitigation strategies. Appropriate insurance coverage is a key component of any holistic risk management strategy and as well as offering all risks building and construction protection, insurers such as AGCS can also provide after construction coverage, known as Inherent Defects Insurance (IDI).

This protects policyholders against physical structural damages arising from defects in design, materials or workmanship and is a first party insurance that does not require proof of negligence.

Insurers such as AGCS can also provide project-related third party liability insurance coverage, contractor plants and equipment insurance and advance loss of profits insurance, as well as after-construction coverage, known as Inherent Defects Insurance (IDI).

Close evaluation of past claims is essential in preventing potential future claims. AGCS subsidiary Allianz Risk Consulting conducts extensive pre-loss activities and joins underwriters when visiting large construction sites to assess and analyze risks.

London’s “Walkie Talkie” building is to attach a permanent sunshade

Photo: Thinkstock