WORLD
ECONOMIC
FORUM

COMMITTED TO
IMPROVING THE STATE
OF THE WORLD

Burj Khalifa

Constructing the world's tallest building and an iconic landmark leveraging innovation in building materials and techniques

Case Study prepared by the Boston Consulting Group as part of the Future of Construction Project at the World Economic Forum

The challenge

A record-breaking skyscraper, in keeping with the concept of a vertical city – the vision is one thing, but realizing that vision is another and requires both persistence and ingenuity.

When Emaar Properties acquired a site of abandoned military barracks to develop the 500-acre mega-project that is now Downtown Dubai, the vision was to "create one of the world's leading urban destinations", according to Robert Booth, Chief Executive Officer of Emaar Dubai Real Estate, at the time. The development as envisaged would take about 20 years of work, concluding in 2025, at an estimated cost of $20 billion. It was to have iconic architecture that would attract great admiration and boost real-estate value. And its centrepiece was to be a breathtaking super-high-rise building, the tallest skyscraper in the world.

The new building, as imagined by Mohamed Alabbar, the Founder and Chairman of Emaar Properties, would overtake the 449-metre record that was held by Taipei 101 in Taiwan. Alabbar's masterplan was for a mixed-use super-high-rise, incorporating hotel accommodation, private residential apartments and varied commercial premises – in short, an integrated vertical city, which would mark a new approach to the worldwide challenge of mass urbanization and megacities. And what a challenge that is: the outlook is that, by 2030, the world will have 41 megacities, each with more than 10 million inhabitants; and, by 2050, two thirds of the global population will live in cities. Urban centres are going to have to build high – even higher than today – to accommodate their workforce and residents. According to its advocates, the concept of vertical cities will become a widespread reality: vertical cities reduce traffic and urban sprawl, by combining different usages – living, working and leisure – within a single location.

The idea

Bring together an experienced team, work closely with suppliers, and engage government early on to build at top quality and dizzying heights.

When planning of the Burj Dubai tower (later renamed Burj Khalifa) began in 2002, it was already clear that many innovations would be needed in the design, construction and building technologies. The initial design brief was for a building of 550 metres. When the planned height subsequently increased to 750 metres, the innovation imperative became even clearer. And more so still when the main contract was awarded in 2004: the target height at that stage had surged again – with the encouragement of the visionary Sheikh Mohammed Bin Rashid al Maktoum, Vice-President and Prime Minister of the United Arab Emirates and Ruler of Dubai – and necessitated static recalculations of the foundations.

Three major themes characterized this flagship project: first, a highly experienced international team, allowing effective knowledge transfer, diligent front-loaded planning and optimized logistics; second, close and proactive collaboration with innovative suppliers; and third, early engagement with government and other major stakeholders.

The team
Regarding the first theme, the developer Emaar Properties put great effort into assembling a project team from across the world, with both experience and expertise in super-high-rise construction. The design was led by the Chicago-based design firm Skidmore, Owings & Merrill. The construction-management team from Turner International was brought onboard in 2003, very early in the planning process. Turner's main construction manager, David Bradford, had already been involved in the construction of Taipei 101, so was ideally positioned to plan and oversee the highly complex construction logistics of Burj Khalifa.

At the time, in the early 2000s, Building Information Modelling (BIM) was not in wide use and the Turner team leaders focused on an analysis of the project to avert the bottlenecks and obstacles they had encountered when working on Taipei 101 and similar projects. Their high-rise experience also helped them to split up the Burj Khalifa project into work packages that could be executed in parallel, to speed things up. Construction of the first levels, for example, began as early as 2004, while the design of the upper levels was still in progress.

Another key ingredient of the project's success was the detailed attention paid to the selection of consultants, contractors and suppliers. Turner managed all contracts centrally and included very detailed specifications and performance incentives, including penalties for delays. In total, more than 40 speciality consultants – experts in fire and safety, concrete-mix design, or lighting, for example – were hired early on to liaise with the relevant external stakeholders, in particular the suppliers and government authorities. Samsung, with its rich experience in superstructures, was selected as the main contractor and headed a group of contractors that included BeSix from Belgium and Arabtec from the UAE.

The project team also paid particular attention to logistics – a crucial emphasis, given that about 12,000 workers could be active at peak times. Prefabrication and lean construction methods were exploited to the full to keep on-site tasks to a minimum. Consider two contrasting examples. First, the approach to windows: in total, 26,000 panels were needed, involving 120 standard designs. The window panes would vary according to their destined position in the building, to suit the different wind speeds. The window panels were prefabricated and assembled off-site, then put in containers and transported to the site, lifted by cranes and slotted into place. Second, the workers' canteens: during the later phases, they were located temporarily on higher floors of the building to avoid the long travel times that a central ground-level canteen would require.

Collaboration

Close collaboration with innovative suppliers, the second theme, played a central role in the implementation of the various state-of-the-art innovations. The suppliers of building materials and technologies were invited very early on to provide their expert opinions. Even before the main contract was put out to tender, two leading formwork specialists – Doka and Peri – were consulted and their feedback prompted changes both to the architectural design and to the construction process. For instance, the project team decided to use poured concrete for the walls of the lift shaft to speed things along. Fortunately, the project team was experienced and flexible enough to accept suggestions from collaborators and to feel comfortable with ambitious innovations. Such a tall building would probably have been unrealizable without pioneering some of the very latest technologies. The GPS-controlled jump formwork is a case in point: to control for verticality as the building rose, conventional optical laser-based methods could no longer be relied on, so a new military-precision GPS system was adopted (and has now become standard practice in high-rise construction). Other innovative technologies included Favco's diesel-powered self-climbing cranes, which avoid the voltage drops plaguing normal electric cranes at such heights, and the special concrete pumps, which set new records in pumping concrete.

In fact, some expert observers consider the concrete technology to be the most innovative feature of the entire project. The concrete supplier, Unimix, contracted the German concrete-pumping specialist Putzmeister to develop, test, supply and install high-pressure pumps – able to reach a height of about 600 metres and withstand the required 200-bar pressure. The composition of the concrete mix was fine-tuned in extensive tests to guarantee fluidity and ultra-high strength, and to cater for different applications in the building's floors and concrete core. Construction often took place in extreme temperatures of more than 40°C, so the concrete mix would sometimes be cooled with ice rather than water, and the quality of each concrete batch would be rigorously tested.

Engagement

The third theme – close and early engagement with the government authorities and other key stakeholders – would prove a great help in converting the vision into a reality. Almost from the start, negotiations with the local authorities got under way. Local consultants, specially hired for the purpose, liaised with the Dubai municipality for building approvals, with Dubai Civil Defence for fire, live and safety protection, and with the local utility company for electricity.

The benefits of such prompt engagement can be seen vividly in two cases: the regulations regarding concrete and the electricity supply. The existing policy on concrete meant that each pouring of a concrete slab would have to be approved individually after an inspection on-site – hardly practicable in the context of a skyscraper with 200 levels, 160 of them habitable, and an ambitious timeline. The project team negotiated a solution with the municipal authorities: a specialist and properly certified consultant, jointly agreed on, would supervise the pouring of concrete and report to the municipality. As for the electricity supply, the conventional approach was again impracticable. Normally, transformers would be placed in the base of the building, but in the case of Burj Khalifa, the consequent voltage drops would be too severe, and daily operations would be jeopardized. The obvious solution was to locate transformers on floors throughout the building though the local utility company was uneasy about defying standard practice and feared complications if the transformers broke down. Both sides were committed to the collaboration, however, and eventually found a satisfactory compromise: transformers were placed on different floors and the design was adjusted to provide for a special lift large enough to transport a transformer up and down if it needed repairing or replacing.

The impact

Burj Khalifa has broken several world records for buildings, has indeed become an iconic urban landmark, and has tested and vindicated many innovations on the way.

Burj Khalifa is a project of superlatives and has broken numerous world records. At 828 metres, it is the world's tallest building and tallest man-made structure. It took less than four years from the first excavation works to reach level 141 and overtake Taipei 101 as tallest building, and just three years more to reach completion and be formally inaugurated, in January 2010. The building also has the world's highest aluminium and glass facade and holds the record for vertical pumping of concrete – 605 metres!

These and all the other records would have remained pipe dreams had it not been for a series of innovations in building materials, technology and techniques. The remarkable speed of construction was made possible by careful logistics planning, effective collaboration with specialist suppliers and experts, and up-to-the-minute technological advances. Thanks to the prefabricated and packaged window panels, for example, the site engineers managed to increase the installation rate from an initial 20-30 window panels per day to an impressive 175 panels per day. And thanks to a combination of innovative technologies and optimized planning, the concrete cycle of an entire floor could be completed in a mere three days.

Burj Khalifa has become an architectural icon of the modern world, attracting thousands of visitors every day and making Downtown Dubai a favourite urban destination. According to an Instagram analysis, Burj Khalifa now ranks third in the world on the ultimate edifice metric – selfie popularity – beaten only by the Eiffel Tower in Paris and World Disney World in Florida, but ahead of New York's Empire State Building and Big Ben in London.[1]

Tourists flock to the observation decks on levels 124, 125 and 148, travelling in one of the world's fastest lifts. Their enthusiasm is shared by the building's occupants, commercial and residential alike, and those of surrounding buildings: "view-premium" owners pay handsomely for an unobstructed view of the tower. As Emaar Properties had reckoned, real-estate value has indeed risen and the company's decision to invest only in top quality ($1.5 billion of investment, for Burj Khalifa specifically) has indeed paid off.

[1] The National (2015). *"Dubai's Burj Khalifa one of top selfie hot spots in the world"*. 2 November 2015. Retrieved 14 February 2017, from http://www.thenational.ae/uae/tourism/dubais-burj-khalifa-one-of-top-selfie-hot-spots-in-the-world.

The barriers to innovation – and the solutions

Scepticism in the construction industry can be overcome and unforeseen setbacks can be turned to advantage when offset by a clear and resolute vision, precise planning, and effective collaboration.

It comes as no surprise that the proposal to build this unprecedented structure was met with scepticism from planners, government officials and potential investors. Alabbar was undaunted and retained his vision – supported by the far-sighted ruler of Dubai, Sheikh Mohammed – not just of building Burj Khalifa but also of developing the entire site, however many years it would take. Strongly convinced that quality pays off in the long term, Alabbar resolved to invest upfront in world-class contractors and technology to turn his vision into a reality. He vetted many of the detailed decisions himself, including the design, the selection of artworks throughout the building, decor for the lobby, and furnishings in the apartments. Pre-selling 80% of the apartments helped to fund the project, with several down-payments linked to construction progress.

For Sheikh Mohammed and Alabbar, the sky was the limit (almost literally). When construction was already well under way, they pushed the team of designers and construction managers to increase the building's height. Fortunately, the design team from Skidmore, Owings & Merrill had incorporated a contingency buffer into their structural calculations, and, for instance, allowed for a giant damper at the top to absorb the movements of the building. It turned out, however, that such extra stabilization was not required, thanks to the wind-breaking properties of the building's Y-shaped cross-section, so the height of the building could be increased without too much trouble – by almost 200 metres beyond the initial brief. The unutilized space for the damper at the top was eventually converted into a private mosque – breaking another world record.

The most challenging moment for the project was when Schmidlin, the Swiss supplier of the window panes, declared bankruptcy in 2006, just nine months after it signed the contract. Schmidlin's joint-venture partner Arabian Aluminium would have to find a replacement supplier very quickly if it was to keep to the schedule. With the help of the project team and its international network, a high-quality supplier was soon identified, the Hong Kong-based Far East Aluminium. Initial testing confirmed the quality of the panes and quality control thereafter continued to validate their high standard: of the 26,000 panels delivered to the site during the construction phase, only 30 were rejected.

So Burj Khalifa's exterior cladding is the result of a cross-border supply chain and international collaboration. The glass panes were manufactured by Far East Aluminium and final assembly took place in the UAE, where the window panels were put in containers for delivery to the construction site. There the containers were picked up by cranes, dropped at loading areas on to the right floor, pushed on wheels by workers to the right location inside the building and lifted into place by a chain-hoist system. The actual installation was conducted by a team of international professionals, as the correct placement of the panels required considerable experience.

Lessons learned

- **Develop and maintain a vision to motivate everybody and to reject the status quo**
  By being personally involved in the project, proudly and prominently, Dubai's ruler Sheikh Mohammed and Emaar Properties chairman Mohamed Alabbar provided the requisite driving force behind the development of Downtown Dubai and the construction of Burj Khalifa. Their unwavering vision inspired the project team to go beyond the known limits – increasing the building's height and implementing still-unproven processes and technologies.
- **Assemble an experienced, best-in-class team to drive innovation**
  Alabbar had a long-term investment horizon as well as a long-term vision, and a determination not to compromise on excellence – a threefold motivation to assemble an expert team that had deep experience of super-high-rise structures. The formation of this team had the effect of maximizing knowledge transfer, enabling excellent upfront planning, optimizing logistics management, exploiting prefabrication to the full, reducing risks and facilitating collaboration with the technology providers and innovators.
- **Collaborate closely with suppliers to develop, test and implement innovations**
  Most of the project's innovations – notably, the concrete-mix design and pumping, the GPS-controlled jump formwork and the prefabricated window panels – were developed by suppliers, though it required close collaboration between contractors and suppliers to test and implement the innovations in Dubai's challenging physical environment. In many cases, the expertise of the various partners was invoked as early as the planning phase, to enable pre-emptive modifications and avert costly reworks. A striking example is Doka's recommendation to use poured concrete for the elevator shaft.
- **Engage regulatory authorities early on to speed up the approval process**
  For high-visibility projects, there is pressure to get things started (and completed) as soon as possible. All the more so in the case of Burj Khalifa – one of Dubai's flagship projects. The project team, being so experienced, knew the importance of early engagement with regulators and other enablers, and how best to go about it. The team promptly approached and negotiated with the relevant Dubai government agencies and utilities providers to expedite the official go-ahead and overcome any subsequent obstacles that might arise.

COMMITTED TO
IMPROVING THE STATE
OF THE WORLD

The World Economic Forum, committed to improving the state of the world, is the International Organization for Public-Private Cooperation.

The Forum engages the foremost political, business and other leaders of society to shape global, regional and industry agendas.

World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland
Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744
contact@weforum.org
www.weforum.org

World Economic Forum USA
3 East 54th Street, 18th Floor,
New York, NY 10022, USA
Tel.: +1 212 703-2300
Fax: +1 212 703-2399
contact@weforum.org
www.weforum.org