

Tomos Williams - 2319571

ACBA4006 - Material Science and Building Services

Assignment 1 – Construction Materials

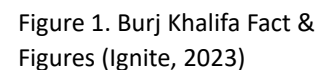


Concrete Framed Building - Case Study: The Burj Khalifa, Dubai, United Arab Emirates

Contents

Introduction.....	3
Original Design Planning.....	3
Construction Method.....	4
Social Impacts.....	4
Environmental Sustainability Impact.....	5
Environmental Conditions of the Site.....	5
Manufacturing Process of Concrete.....	6
Cement.....	6
Aggregates.....	7
Admixtures.....	7
Reinforced Concrete.....	7
Setting Concrete.....	7
The Environmental Impact of Producing Concrete.....	8
Frames Ease of Assembly.....	8
Provision of Building Services.....	8
Adaptability.....	9
Conclusion.....	9
Reference List.....	10

The Burj Khalifa is one of the most famous and extraordinary buildings in the world. Standing at a staggering height of 828 metres, making it the tallest building in the world. The construction of the Burj Khalifa is an iconic symbol of modern architecture and engineering. Reportedly amounting to \$1.5 billion (McLaughlin, 2022), the Burj Khalifa is an outstanding example of merging cutting edge design with the advancement of modern technology. This report aims to delve into the complexity of the framing structure, investigating the engineering principles, materials and construction methods that enables this incredible structure to stand at such heights.



The honour of designing the world's tallest building laid in the hands of Chicago architectural firm Skidmore, Owings & Merrill, who are specialists in ultra-tall structures. The aim was to design a structure that surpassed existing skyscrapers in height.

Figure 2. Burj Khalifa floor plan (McLaughlin, 2022)

Construction Method

Construction started in January 2004, and was completed 1,325 days later in January 2010. The whole construction used 330,000 cubic metres of concrete and 39,000 tonnes of steel rebar. (Burj Khalifa EMAAR, n.d.).

The foundation was a crucial aspect of the build. Engineers used a huge reinforced concrete mat, which was supported by 192 bored reinforced concrete piles. This mat was poured in four separate parts, it's 3.7 metres thick, and totals to 12,500 cubic metres of concrete. The piles required to be sunk to a depth of 43 metres, with a 3000-ton capacity for each pile (The Constructor, n.d.). The weight of the concrete poured for the foundation weighed more than 110,000 tonnes. The concrete used in the foundation needed to be high density, and low permeability as the groundwater it laid on was highly corrosive (Commercial Interior Design, 2023).

Three main cranes were placed at near the central core, each being able to reach different heights as required. Automatic self-climbing formwork was used to form the walls and perimeter of the building, and wall reinforcement was prefabricated on the ground. To transport materials and workers, high speed, high-capacity hoists were used. (Baker & Pawlikowski, 2015).

The central core and slabs were the first parts of the build to be cast in, in three sections. Next was the wing walls and their slabs, and lastly was the wing nose columns and slabs. Concrete was distributed to each part of the build as needed by using concrete booms, these were attached to the form work system. One of the most challenging issues of the project was to find a system and mix that was able to support pumping the high-performance concrete to heights of over 600 metres at a time (Baker & Pawlikowski, 2015).



Figure 3. Burj Khalifa under construction (Britannica, 2019)

Social Impacts

The construction of the Burj Khalifa made the local economy grow significantly by creating many job opportunities. Over 12,000 people worked on site every day (Commercial Interior Design, 2023). The building is used for residential, corporate and hospitality, creating even more jobs after construction was complete.

The Burj Khalifa has become one of the world's most visited buildings. Attracting tourists from across the globe to see this iconic structure. This has had a positive impact on the tourism sector of the country, boosting it significantly. The Burj Khalifa attracts an average of 4,000 visitors a day (Bundhun, 2011).

Environmental Sustainability Impacts

The process required huge amounts of raw materials such as concrete and steel. Extracting, transportation and processing of these materials contributed considerably to energy consumption and resource deficiency.

Significant amounts of energy was used, such as for machinery, lighting and water. The process reportedly used 250,000 gallons of water every day and 40,000 kilowatts of electricity (Answers, 2012). Consumption of this demand has significant environmental effects, especially if sourced from non-renewable sources.

Using heavy machinery for transportation of materials and for construction use would have an impact on air pollution, due to emissions being produced. Dust produced by excavation would have an impact on the surrounding area's air quality.

However, there are some positive impacts to be had. Such as the building's water system, which supplies 946,000 litres of water per day on average. Due to Dubai's hot climate and the building's cooling requirements, this produces a large amount of condensation which is collected and stored in a tank in the basement car park. Collecting around 15 million gallons of water per year (Commercial Interior Design, 2023).

Environmental Conditions of the Site

Dubai has a typical desert climate where it's very hot and humid. The UAE only has two main seasons, winter and summer. The mean temperature of the winter in Dubai ranges from 16.4°C to 24°C. The summer in Dubai can see extreme temperatures that climb as high as 50°C. Dubai sees very little rain fall with an average of 140-200mm of rainfall per year (Climate Knowledge Portal, 2021).

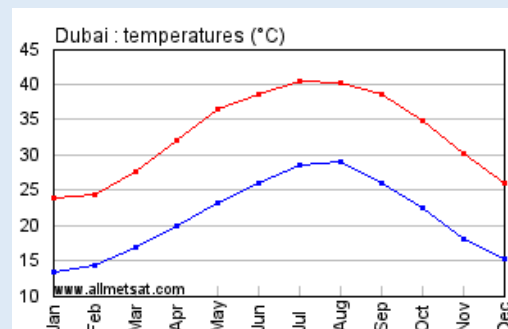


Figure 4. Dubai Temperature
(en.allmetsat.com, n.d.)

These extreme temperatures and little rainfall can make fires very likely. The framing material of the needed to be able to withstand extreme heats and fire risk. Concrete has a high resistance to fire and stops it from spreading, which makes it the ideal material for this kind of climate. The robustness of concrete reduces the chance of structural collapse during a fire (European Concrete Platform ASBL, 2009).

Concrete in a hot climate can have some negative effects such as a reduction in compressive strength. Pouring concrete in high temperatures can cause it to cure too quickly, which results in a decrease in strength and durability (Converge, 2023). This is why the concrete for the Burj Khalifa was poured at night due to lower temperatures, and they also added ice to the mixtures.

In hot weather concrete is more likely to crack, this is because of a rapid evaporation of moisture from its surface. As the concrete dries too quick, this can cause shrinkage and a build-up of internal stress which leads to cracks. This can have negative effects on the structures stability and may need repairs that can be expensive (Converge, 2023).

High temperatures can increase the permeability of concrete. This allows water and other liquids to pass through the concrete, which can lead to the corrosion of the steel reinforcement inside concrete (Converge, 2023).

Hot climates can accelerate the aging process of concrete, which then results in a shorter life cycle. Especially in a climate like Dubai's, where the structure is exposed to direct sunlight. The UV radiation from the sun can break down chemical bonds in the paste of the cement, which can cause the material to weaken over time (Converge, 2023).



Figure 5. Reinforced steel corrosion (RUSTX CCI, n.d.)

Manufacturing Process of Concrete

Concrete comes in a variety of different forms, from plain concrete to reinforced or precast concrete. Concrete is a blend of cement, coarse and fine aggregates, water and chemical additives, which hardens due to a chemical reaction by mixing the cement and water. The coarse aggregate acts as a filler, and fine aggregates fill gaps between the coarse aggregate. The mixture of cement and water then acts as a binder. The different components of concrete are as follows; up to 8% of air, 7-15% of cement, 14-21% of water and 60-75% of coarse and fine aggregates (Khatabook, n.d.).



Figure 6. Column failure due to inadequate amounts of fine aggregate (Articles, 2020)

Cement

Cement is a finely ground, non-metallic, inorganic powder. Cement is vital in the production of concrete as it glues all the ingredients together. Cement is a hydraulic binder, meaning it hardens when water's added. Portland cement is the most used type globally. Cement plants extract basic constituents of cement, limestone and clay, from raw materials supplied by neighbouring quarries (European Concrete Platform ASBL, 2009).

The manufacturing of cement is made up of two main phases. The first phase is where the raw material is delivered in bulk, crushed and homogenised into a mixture which is fed into a rotary kiln. The kiln is heated to 2000°C, and then the material is cooled quickly to around 100-200°C. Then four oxides: calcium oxide, silicon oxide, alumina oxide and iron oxide are used in the correct proportions to make the cement clinker. These are then mixed at 1450°C and combine to make the "raw meal" or slurry. New compounds silicates, aluminates and ferrites of calcium are then formed. The clinker is stored in large stockpiles (European Concrete Platform ASBL, 2009).

The last phase is when gypsum and blast furnace slag or fly ash is added to the clinker, and travels through a rotary grinding mill to produce the fine cement powder. This powder is either dispatched in bulk or bagged (European Concrete Platform ASBL, 2009).

Aggregates

Aggregates are an essential ingredient in concrete. Aggregates are inert granular materials such as sand, gravel or crushed stone. For a good concrete mix aggregates need to be clean, hard and free of organic impurity. Aggregates account for 70-80% of the total mix, a suitable material needs to be selected as it can affect the overall performance. Sources of aggregates vary such as naturally occurring aggregates from riverbeds or quarries, artificial aggregates as waste products from kilns or blast furnaces, and recycled aggregates from construction and demolition waste. Aggregates can reduce production costs of concrete by bulking the mix. The choice of aggregates can modify properties of concrete such as increasing durability and density or improving workability.

Admixtures

Most concrete contains one or more admixtures. Admixtures are chemicals that are added to concrete in small amounts to modify the properties of the mix. The content of admixtures can be as little as 0.2-2% in weight (European Concrete Platform ASBL, 2009). Most commonly used admixtures are air entraining agents, improving durability and workability, accelerators which accelerate the setting time in cold weather, retarders which decelerate the setting time in warmer conditions, water reducers allow low water to cement ratio but maintain workability, and super plasticizers or pumping agents which make increase the pumpability.

Reinforced Concrete

Reinforced concrete is a composite material which is a combination of concrete and steel. Concrete provides compressive strength, where steel gives its tensile strength by embedding reinforcing bars and mesh inside the concrete. Reinforced concrete is beneficial in areas that suffer from earthquakes, giving the material its ductile behaviour. Steel bars found inside reinforced concrete are made of carbon steel. Reinforced concrete is usually used for foundations, walls and columns that are under heavy loading. Combining both creates one of the most durable and economical composite materials used in construction (European Concrete Platform ASBL, 2009). These materials work well together as they have similar coefficients of thermal expansion.

Setting Concrete

These days mixing of concrete is a fully automated process, ensuring correct measurements of each material, consistency, and quality. Mixes are pre-determined amounts of different ingredients, perfectly measured and designed for specific jobs. All ingredients are combined in huge industrial mixers for around 60-90 seconds (European Concrete Platform ASBL, 2009).

Transportation of concrete is a vital part of production, as the mix can lose some of its properties during this phase. Concrete should be used as close as possible to the factory where it's produced. The lorry's drum rotates to ensure consistency. (European Concrete Platform ASBL, 2009).

Concrete is then poured or pumped on site to its required destination. After this its compacted by vibration to ensure no segregation and reduce air voids. Curing process of concrete takes 28 days to reach its maximum strength. Curing can be slowed down by spraying water on the concrete in hot weather, to avoid cracking. In cold weather, the concrete can be covered to avoid frost attack.

Environmental Impacts of Producing Concrete

Concrete is the most popular manufactured material worldwide, but this comes at a significant environmental cost. Cement is a main ingredient in the production of concrete, and “Cement production alone generates around 2.5 billion tonnes of carbon dioxide (CO₂) per year—about 8% of the global total” (Science Museum, 2021).

Such large-scale use is depleting supplies of resources across the globe, such as usable sand. In addition, concrete production “consumes almost 10% of the world’s industrial water supplies” according to (Science Museum, 2021).

Large concrete companies, such as LafargeHolcim, are working hard to minimise these environmental issues. According to (Ramsden, 2020) “The company has lowered carbon emissions by 25% since 1990 and has a goal to reach net-zero emissions soon”.

The CEO of the company says “we are accelerating circular and low-carbon solutions to lead the way in green construction” (Ramsden, 2020).

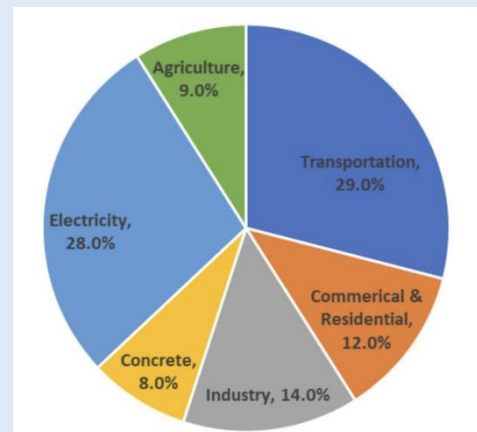


Figure 7. Global CO₂ emissions (Ramsden, 2020)

Frames Ease of Assembly

Concrete framed buildings ease of assembly is major advantage in its vast use in the industry. Concrete frames are not far behind steel frames in terms of construction speed. Use of modern formwork and precast concrete allow for quick construction speeds. It is now realistic to be able to produce speeds of 500 metres squared per week per crane (mpa The Concrete Centre, 2016). A well planned and detailed programme allows this.

However, concrete can have longer construction times than steel as it requires a lot of form work before pouring and needs to cure for 28 days to reach its maximum compressive strength. Whereas steel can be constructed and used pretty much right after erection.

Provision of Building Services

Mechanical and electrical services are an important part of construction. This can be an expensive element, as they need easy access for maintenance and repairs. Soffits of a concrete flat slab provides an uninterrupted zone where services can be easily run through and accessed, reducing efforts of the design team and risk of errors. Openings in slabs and secondary beams provide large areas for routes of services. These can be designed to suit during casting, or cut after, which allows flexibility and adaptability regarding building services (mpa The Concrete Centre, 2016).

Steel has more architectural diversity in shaping than concrete, in which openings can be easily provided in structural systems. This allows for easier installation of building services in steel structures when compared to concrete structures.

Adaptability

The industry is forever changing and developing, using materials which are easily changed or adapted to different needs without much effort are important.

The adaptability of a steel structure is much better than a concrete structure, as they are easier to dismantle. A concrete structure would require to be demolished, so has little to no adaptability. However, it is still possible to adapt a concrete framed structure to some extent. Holes can be cut through walls and slabs relatively easily, and the frame can be strengthened if needed (mpa The Concrete Centre, 2016).

Concrete frames usually last longer than steel structures as they are more durable, meaning there wouldn't be a need to adapt the building as it would last longer. Steel requires protective coating to protect it from corrosion. It also requires fire protection, whereas concrete has better natural fire-resistant properties without the need of extra protection. In case of fires steel is likely to buckle under high temperatures, but concrete can withstand higher temperatures better.

Conclusion

In conclusion, the Burj Khalifa stands as an architectural and engineering masterpiece. This iconic structure has not only redefined the Dubai skyline, but also set new challenges for the industry to replicate. It's record height is a testament to embracing modern construction methods, materials and maximising the potential of advancements in technology. This fine example of a concrete framed building promotes the material's endless possibilities, leaving an unforgettable mark on the global construction industry.

Reference List

- A guide to design and construction Concrete Framed Buildings CONCRETE FRAMED BUILDINGS 2. (n.d.). Available at: https://www.structuralprecast.org/Precast/media/BPMediaLibrary/Publications/MB_Concrete_Framed_Buildings_Feb16_1.pdf?ext=.pdf. [Accessed 4th December 2023].
- Agyekum-Mensah, G. (n.d.). CRITICAL ANALYSIS OF BUILDING PERFORMANCE BENEFITS AND COST COMPARISON OF REINFORCED CONCRETE, STEEL AND TIMBER FRAMED BUILDING. [online] Available at: <https://www.uk-bar.org/uploads/documents/originals/135658%20Steel%20Concrete%20Timber%20report%20%20A4%20WEB.pdf>. [Accessed 30th November 2023].
- Aldred, J. (2010). Burj Khalifa – a new high for high-performance concrete. Proceedings of the Institution of Civil Engineers - Civil Engineering, 163(2), pp.66–73. doi:<https://doi.org/10.1680/cien.2010.163.2.66>. [Accessed 28th November 2023].
- Answers. (n.d.). Did Burj Khalifa have a negative impact on the environment? [online] Available at: https://www.answers.com/Q/Did_Burj_Khalifa_have_a_negative_impact_on_the_environment [Accessed 5 Dec. 2023].
- Articles, P. in and Design, S. (2020). Types, Reasons & Prevention of Column Failures. [online] DECODE BD. Available at: <https://decode-bd.com/types-reason-and-reason-of-column-failures/>. [Accessed 6th December 2023].
- Baker, B. and Pawlikowski, J. (2015). The Design and Construction of the World's Tallest Building: The Burj Khalifa, Dubai. Structural Engineering International, [online] 25(4), pp.389–394. doi:<https://doi.org/10.2749/101686615x14355644770857>. [Accessed 28th November 2023].
- Britannica (2019). Burj Khalifa | skyscraper, Dubai, United Arab Emirates | Britannica. In: Encyclopædia Britannica. [online] Available at: <https://www.britannica.com/topic/Burj-Khalifa>. [Accessed 6th December 2023].
- Burj Khalifa (2019). Facts & Figures | Burj Khalifa. [online] Burjkhalifa.ae. Available at: <https://www.burjkhalifa.ae/en/the-tower/facts-figures/>. [Accessed 25th November 2023].
- Devant, L. (2009). Sustainable Benefits Of Concrete Structures. European Concrete Platform ASBL, [online] pp.6–34. Available at: https://www.theconcreteinitiative.eu/images/ECP_Documents/SustainableBenefitsConcreteStructures_EN.pdf [Accessed 1 Dec. 2023].
- Emaar (2009). Design | Burj Khalifa. [online] Burjkhalifa.ae. Available at: <https://www.burjkhalifa.ae/en/the-tower/design-construction/>. [Accessed 25th November 2023].
- en.allmetsat.com. (n.d.). Climate : Dubai, Dubai International Airport, United Arab Emirates. [online] Available at: <https://en.allmetsat.com/climate/asia.php?code=41194> [Accessed 6 Dec. 2023].
- Group, E.S.C. (2020). ESC Group. [online] esc-global-group. Available at: <https://www.escglobalgroup.com/post/steel-structures-or-reinforced-concrete>. [Accessed 5th December 2023].

Ignite, B.T. (2023). Learn in a Minute: Facts & Figures about the Burj Khalifa. [online] Medium. Available at: <https://medium.com/@be.the.ignite/learn-in-a-minute-facts-figures-about-the-burj-khalifa-571374dabe28> [Accessed 6 Dec. 2023].

Khatabook (n.d.). Understanding the 7 Essential Steps in the Concrete Manufacturing Process. [online] Khatabook. Available at: <https://khatabook.com/blog/concrete-manufacturing-process/>. [Accessed 30th November 2023].

McLaughlin, K. (2022). How the Burj Khalifa Redefined High-Rise Architecture. [online] Architectural Digest. Available at: <https://www.architecturaldigest.com/story/burj-khalifa>. [Accessed 26th November 2023].

Ramsden, K. (2020). Cement and Concrete: The Environmental Impact. [online] PSCI. Available at: <https://psci.princeton.edu/tips/2020/11/3/cement-and-concrete-the-environmental-impact>. [Accessed 3rd December 2023].

RUSTX CCI. (n.d.). RUSTX CCI : Concrete Corrosion Inhibitor. [online] Available at: <https://rustxcci.com/> [Accessed 6 Dec. 2023].

Science Museum (2021). Building the Modern world: Concrete and Our Environment. [online] Science Museum. Available at: <https://www.sciencemuseum.org.uk/objects-and-stories/everyday-wonders/building-modern-world-concrete-and-our-environment#:~:text=The%20environmental%20impact%20of%20concrete>. [Accessed 1st December 2023].

SOM (n.d.). Burj khalifa. [online] SOM. Available at: <https://www.som.com/projects/burj-khalifa/>. [Accessed 27th November 2023].

The Constructor (2017). Structural Details of Burj Khalifa - Concrete Grade and Foundations. [online] The Constructor. Available at: <https://theconstructor.org/structures/structural-details-burj-khalifa-concrete-grade-foundations/20512/>. [Accessed 27th November 2023].

The National. (2011). Burj Khalifa a towering tourism influence. [online] Available at: <https://www.thenationalnews.com/business/travel-and-tourism/burj-khalifa-a-towering-tourism-influence-1.471221>. [Accessed 29th November 2023].

Writer, S. (2016). UPDATED: How the Burj Khalifa was built (including design, foundations, cladding and urban myths). [online] Commercial Interior Design. Available at: <https://www.commercialinteriordesign.com/insight/updated-how-the-burj-khalifa-was-built-including-design-foundations-cladding-and-urban-myths>. [Accessed 26th November 2023].

Word count: 2657 (Excluding headings, table of contents and reference list)