

Assignment Title: Construction Materials

Module: Materials



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1. Executive Summary

This report examines two buildings constructed from two different methods of construction; One utilising a concrete frame and the other steel frame. Through independent research, the study identifies and discusses the differencing attributes both systems hold focusing on construction type performance through durability, social and environmental Impact and adaptability.

The report analyses both methods of construction focusing on the key elements below;

1. **Strength, Durability, and Climatic Resistance** – The suitability of each framing material concerning environmental exposure, assessing its ability to withstand climatic conditions and long-term durability.
2. **Environmental and Community Impact** – Evaluating the ecological footprint of the material production processes, including carbon emissions, resource consumption, and societal impact during construction.
3. **Adaptability and Assembly** – Reviewing the ease of constructing the frames and their flexibility for future modifications, assessing potential structural adaptations over the building's lifecycle.

A comparative analysis in tabular format summarises the advantages and disadvantages of concrete and steel framing, highlighting key differences in performance, sustainability, and functionality.

2. Findings

2.1 Concrete Frame Construction - Case Study A

I have identified the Burj Khalifa located in Downtown Dubai in the United Arab Emirates as being a great example to utilise as case study for concrete framing. Today, the building is surrounded by offices, shops, and restaurants and many more amenities.

The Burj Khalifa holds the title for the world's tallest skyscraper since it was first inaugurated in 2010. Built and managed by Emaar properties, it stands at an impressive height of 828m and is still considered a man-made acclamation and boosts the United Arab Emirates' economy. The total cost of constructing the Burj Khalifa amounted to an staggering \$1.5 billion. This eye-watering figure encompasses various expenses, including design, materials, labour, and project management. (Anon, 2020).



Figure 1 – Extract of Burj Khalifa

2.1.1 Strength and Durability

The Burj Khalifa's engineering is as groundbreaking as its height. At the core of its structural design is the Y- shaped floor plan, a simple yet powerful geometric form that optimizes the tower's stability and its ability to provide unobstructed views of the Arabian Gulf. The innovative shape also ensures that the building has sufficient space for residential and hotel accommodations, while minimizing wind forces at extreme heights. (ArchEyes Team, 2024)

Concrete is a material made up of cement, water, sand and gravel. It is widely used in construction due to its flexibility, strength, and durability. For the Burj Khalifa, concrete played an important role in the building's construction, as it was used to create the tower's foundation, columns, beams, and floors. (Lueste, 2024)

One of the most significant challenges during the construction phase was pumping concrete to heights that were never seen. In order to accomplish this, engineers developed a high-pressure pumping system that moved concrete vertically over 600 meters. To guarantee the integrity of the concrete during placement, this procedure needed exact timing and coordination. (Putzmeister, 2015)

The mixing process for the concrete has be itemised below;

1. **Raw Materials** – The concrete mix was composed of cement, water, fine and coarse aggregates, and chemical admixtures to enhance its properties.
2. **Mixing** – The materials were precisely proportioned and mixed in on-site batching plants to maintain consistency and uniformity throughout the construction process. (Lueste, 2024)
3. **Temperature Control** – Given Dubai's extreme heat, concrete pouring was conducted at night when temperatures were cooler. Additionally, ice was added to the mix to regulate temperature and prevent thermal cracking during curing. (Neenu S K, 2017)
4. **Pumping at extreme heights** – As briefly mentioned above, concrete was pumped to a record-breaking height of 600 meters using high pressure pumps. This required extensive planning and the development of unique pumping techniques to maintain flow and prevent blockages.

2.1.2 Social and Environmental Impacts

In most construction applications, the construction activity often impacts social and environmental values being positive or negative. During the construction of the Burj Khalifa, many sources online write about the impacts which have been touched on below;

Social Impacts

The construction of the Burj Khalifa's concrete frame had a significant positive economic impact, creating thousands of jobs. Sources online suggest that the project employed over 12,000 workers, including engineers, technicians, and construction labourers. The employment of 12,000 workers contributed to a total of 22 million hours dedicated to completing the skyscraper. However, many labourers faced extended working hours, low wages and the extreme heat, sources say labourers worked 14-hour shifts. (NORR)

Environmental Impacts

Many publications discuss the raw impact of concrete production to facilitate the build of the Burj Khalifa. This includes effects on the community through excessive traffic and HGV road use, effects to public health, local economies and social well-being. One of the biggest effects concrete productions has is air pollution, concrete manufacturing releases large amounts of carbon dioxide CO₂ into the atmosphere. This can lead to respiratory diseases and reduced air quality. Additionally, dust and pollutants from concrete mixing and transportation further degrade air quality, increasing health risks for local populations. (Environmental Impact of Concrete, n.d.)

A major environmental concern was water consumption and pollution. Concrete production requires large volumes of freshwater, straining natural water sources, especially in arid regions. Additionally, runoff from concrete mixing sites often contains highly alkaline substances, such as calcium hydroxide, which can alter the pH levels of nearby water bodies, harming aquatic life and making the water unsafe for consumption. (Yahaya, T. et al. (2024)



Figure 2 – Extract of air pollution

2.1.3 Adaptability / Assembly

The assembly of the Burj Khalifa was a complex and highly coordinated process that utilised cutting edge technologies and methods. The high strength reinforced concrete frame allowed the structure to withstand the immense vertical loads and lateral forces from wind and seismic activity. The concrete used in the construction was specifically formulated to handle the extreme conditions of the desert environment. (Lueste, 2024)

2.1.4 Evaluation of the Advantages and Disadvantages (Tabular Format)

Advantages	Disadvantages
Fire Resistance – Concrete is inherently fire resistant, offering better protection in the event of a fire.	Heavy Weight – Concrete is heavier than steel, putting more strain on foundations and requiring stronger structural support.
Durability – Concrete is known for its long-lasting nature, with a high resistance to wear and environmental conditions.	Longer construction time – Concrete requires time to cure, which can delay the construction process.
Lower Maintenance – concrete structures are less susceptible to damage over time, requiring less frequent maintenance compared to other materials.	Limited Flexibility – concrete is more difficult to modify or adapt once constructed limiting design change or conversions.
Good Sound Insulation – Concrete provides excellent soundproofing properties, reducing noise transmission between floors.	Cracking and Shrinkage – concrete is prone to cracking due to natural shrinkage or expansion, specifically in varying temperatures.

2.2 Steel Frame Construction - Case Study A.

An alternative method of construction is Steel Framing. The Willis Tower (formerly known as the Sears Tower) is a great example to analyse. The Willis Tower is a 108-story skyscraper in Chicago. The Willis Tower is considered a seminal achievement for engineer Fazlur Rahman Khan. The Willis Tower attracts more than one million people a year to its observation deck, the highest in the United States, making it one of Chicago's most popular tourist destinations. (Reaching New Heights,2021)



Figure 3 – Observation deck of Willis Tower

2.2.1 Strength and Durability

The Design of the Willis Tower incorporates an innovative structural system called the “bundled tube” system created by Fazlur Rahman Khan. This system has nine tubes locked together into a three-by-three grid, with some of the tubes stopping at different heights, thus giving a tapering shape to the tower. The bundled tube configuration minimizes the impact of lateral forces such as wind and adds more rigidity to the structure, which is very important owing to Chicago's windy climate. This also makes the design an economical one that permits the raising of skyscrapers without the expense of providing vertical concrete cores. The ability of the system to render stability contributed to the ability of Willis tower to endure the strong winds that are common in Chicago. (Osama Nasir, 2024)



Figure 4 – Construction of Willis Tower

The innovative design and construction techniques employed in the Willis Tower have had a lasting impact on skyscraper engineering. The bundled tube system has been utilized in numerous subsequent supertall buildings, demonstrating its effectiveness in combining height with structural efficiency (AISC, 2023)

‘Click Metal’ detail the steel making process with gathering the materials required: iron ore, coal and limestone. Iron ore is the main source

of iron, it is also the key material in steel. Coking coal is used to produce the heat required to reduce the iron ore into a usable form. Limestone then removes impurities such as silica, sulphur, and phosphorus during the process. The next step after gathering the raw materials, is coke making. This involved heating coal in a low oxygen environment, in a coke oven, to remove the volatile compounds. This then leaves behind coke, a rich in carbon fuel that burns hotter and cleaner than regular coal.

Once the coke is ready, the next step is to produce the molten iron in a blast furnace. The iron from the blast furnace is then taken to a basic oxygen furnace to be refined into steel, this process lowers the carbon content, making the iron stronger and more versatile. After the steel has solidified, it then goes through the shaping to create the final product, this is done through hot, or cold rolling. The final step in the actual steel production process is a series of finishing treatments, that prepare the steel for the use in construction. Before the steel is shipped out, it goes through strict quality control procedures to make sure the steel meets the correct mechanical properties. (Clickmetal, 2024)

2.2.3 Adaptability / Assembly

The Willis Tower is currently used for offices or rentable floor space. An advantage of steel frame construction is its flexibility, the Willis Tower has a bundled tube system, which consists of nine interconnected steel – framed tubes. This provided a column free interior space, allowing for easy change of use. Over the years, the Willis Tower has undergone several modifications to adapt to different and changing market demands. The steel frame system supports wide, open plan layouts, making it simpler to redesign floors for different uses, such as apartments, hotels, or offices. (SOM)

A great example of where transformation was possible due to steel frame would be the base of the Willis Tower, originally, the base was designed for offices, with minimal public engagement. However, with the changing market demands and urban planning trends,



Figure 5 – Extract of Willis Tower Conversion

the lower floors were converted into a five-story retail, dining and entertainment complex. This transformation was possible due to the open plan steel frame system, which allowed developers to reconfigure interior layouts and create public areas, without the need of additional support columns. (Osama Nasir, 2024)

2.2.2 Social and Environmental Impacts

Similar to concrete framing, Steel Frame construction poses many social and environmental factors both positive and negative. During the construction of the Willis Tower, many sources online write about the impacts which have been discussed below;

Social Impacts

The production of steel plays a huge role in economic development and job creation. Steel plants provide thousands of workers with employment in the manufacturing process as well as indirect job creation such as transportation, construction and maintenance.

Environmental Impacts

The construction of the Willis Tower had both positive and negative effects on the environment. On the positive side, the use of steel reduced the overall material waste compared to traditional concrete structures, as steel is recyclable and has a lower environmental footprint. (Klinger, 2021). On the other hand, a negative environmental impact was the disruption to local ecosystems during construction, as the large-scale excavation and the use of construction machinery affected nearby wildlife habitats and also the local environment. (Hines,2020)

2.2.3 Evaluation of the Advantages and Disadvantages (Tabular Format)

Advantages	Disadvantages
High strength to Weight ratio – Steel is incredibly strong and durable, making it very useful for high rise buildings where load bearing capacity is crucial.	Requires Fireproofing – Steel weakens at high temperatures, meaning it requires additional fireproofing methods.
Fast Construction Time – Steel components can be prefabricated off-site leading to faster assembly onsite.	High Initial Cost – steel structures can be more expensive to produce and assemble compared to concrete.
Flexible Design – Steels flexibility allows for easy alterations in the building's design or purpose.	Energy intense production – Steel manufacturing requires intensive energy, and this produces high amounts of CO ₂ .
Sustainability – Steel is highly recyclable, and much of the steel used in modern construction comes from recycled materials.	Rust and corrosion - steel can corrode over time if not properly treated, leading to deterioration of the structure.

3.0 Conclusion

Having considered both construction techniques, I have prepared the table below which compares the advantages and disadvantages of the two modes of construction focusing on the key criteria identified in the executive summary;

Factor	Steel Frame	Concrete Frame
Strength	High tensile strength, excellent for tall and long-span structures.	High compressive strength, ideal for heavy loads and stability.
Durability	Can corrode over time if not protected, requiring maintenance.	Very durable, with a long lifespan and minimal maintenance.
Climatic Resistance	Vulnerable to extreme heat (loses strength) and corrosion in humid or coastal areas.	Resists extreme temperatures, moisture, and harsh weather conditions better.
Environmental Impact	Highly recyclable, reducing material waste.	High carbon footprint due to cement production, but can incorporate recycled materials.
Social / Community Impact	Faster construction reduces community disruption; steel industry jobs support urban economies.	Slower construction may cause longer disruptions; widely used in local construction industries.
Adaptability	Easy to modify, expand, or repurpose with minimal structural changes.	Harder to modify; requires significant work to expand or repurpose.
Assembly	Prefabricated components allow for rapid installation with less on-site labor.	Longer construction time due to on-site pouring and curing of concrete.

To conclude, the report explores the key characteristics and applications of the two types of construction methods identified from two isolated case studies. Each method of construction offers distinct advantages depending on factors such as durability, sustainability and adaptability. The selection of the appropriate construction mode is crucial in ensuring structural integrity, efficiency and environmental responsibility. By understanding the different types of construction methods and their practical applications, construction organisations can make informed decisions that contribute to a safe, resilient and innovative construction project.

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