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Construction Materials

CONSTRUCTION MATERIALS (ACBA4016)
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Introduction

The evolution of building materials has significantly shaped modern architecture, with concrete and steel being two key framing materials. This report compares two habitable buildings—one with a concrete frame and the other with a steel frame—to explore the structural design and construction approaches. The first case study focuses on a concrete frame, known for its durability, thermal mass, and fire resistance. The second examines a steel frame, valued for its flexibility, strength-to-weight ratio, and fast construction. This analysis highlights the advantages and drawbacks of each material.

I will speak about the influence of both construction materials on the community and the environment during the production process, as well as how adaptable these structures are based on their shape and design. I've chosen two buildings for this:

Steel Frame – The Empire State Building (USA) Known for its Steel Frame structure



*Figure 1 – The Empire State Building
(Alltickets.com, nd)*

Concrete Frame - Marina Bay Sands (Singapore) -
Known for its **concrete** frame structure



Figure 2 - Marina Bay Sands (Austria-Forum.org, October 2018)

Concrete Frame

Introduction

Concrete is a widely used construction material known for its strength and durability. It is composed of three main ingredients: cement, water, and aggregates (such as sand, gravel, or crushed stone). When these components are mixed, they form a paste that binds the aggregates and hardens over time.

Concrete is versatile and can be moulded into various shapes, making it ideal for constructing buildings, bridges, roads, and many other structures. Its ability to withstand heavy loads and environmental conditions makes it a fundamental material in modern construction. (*Britania, 2025*) (*Concrete Network, nd*)

Globally, around 30 billion tonnes of concrete are used annually, making it the second most consumed material in the world, with water being the first. (*Nature; 'We use 30 billion tonnes of concrete each year — here's how to make it sustainable', 2025*)

Marina Bay Sands, Singapore

Marina Bay Sands is located in Marina Bay, Singapore. It was designed by Israeli-Canadian architect Moshe Safdie and opened in 2010, costing around 6 billion US dollars making it the most expensive building in Singapore, includes three 55-storey hotel towers topped by a 12,400m² SkyPark and the lotus flower-shaped Art Science Museum (Safdie 2011), it also includes retail shops, casino, nightclubs, entertainment facilities (Theatres, Museum) and is known for its unique structure. (*Insights.jonite.com - top 5 most expensive buildings in Singapore, nd*)

Marina Bay Sands is a concrete frame structure, where the two rows of shear walls in the north-south elevation split from level 23 to level 1 forming a high and grand lobby. The row at the west is straight and the row at the east has a gradient. Each of the towers has its own unique geometry. (*Weebly.com, Cive 2009*)

Concretes strength, Durability and climate resistance

Concrete's performance and longevity in a variety of environmental circumstances are mostly determined by its strength, resilience to weather, and durability. Depending on the kind of exposure the concrete will receive at the given site, these factors can change.

Strength

The mix, which includes the cement quantity, water-to-cement ratio, aggregate type, and curing conditions, is what mainly determines the strength of concrete.

Temperature - Moisture has a significant impact on concrete strength throughout the curing process. Lack of moisture or severe drying can cause inadequate hydration, weakening strength.

Moisture - High temperatures during curing may accelerate hydration, whereas freezing conditions can impede or prevent sufficient hydration, resulting in decreased strength.

Chemical Exposure - Chemical exposure (such as chlorides or sulphates) can damage concrete, particularly in harsh locations like coastal or industrial districts.

Singapore is humid country, when constructing and choosing to use a concrete frame, the temperature and moisture would have been taken into consideration.

Durability

Durability is the ability of concrete to tolerate different environmental conditions over time without deterioration.

Carbonation - Carbon dioxide in the air reacts with calcium hydroxide in concrete, reducing the pH and raising the risk of corrosion of implanted steel reinforcements.

Sulphate Attacks - Sulphate attacks in places with high sulphate concentration in the soil or groundwater can cause concrete to deteriorate, resulting in expansion and cracking.

Chloride Corrosion - Concrete exposed to seawater or de-icing salts may experience chloride-induced reinforcement corrosion, resulting in spalling and loss of structural integrity.

Climate Resistance

Temperature changes, humidity, rainfall, and UV radiation can all have a substantial impact on the performance of concrete.

Humidity – in places with high humidity, Moisture can infiltrate the concrete, causing freeze-thaw concerns or an increase in chemical reactions like sulphate attacks. Concrete must be built to withstand moisture penetration by reducing permeability.

Heat – High temperatures can speed up the setting and hardening of concrete, potentially leading to thermal cracks. It also causes more water to evaporate, which can have an impact on curing. Proper curing processes and mixing are required to avoid cracking.

Cold Climates – Refreezing and thawing cycles can cause damage because water expands in the concrete pores. In these areas, air-entrained concrete is commonly utilised, which contains small, stable air bubbles that allow water to expand without shattering the concrete.

Wind and UV Exposures - Strong winds and severe ultraviolet (UV) radiation can damage the surface of concrete, especially if it is not protected. UV light can break down the binder in concrete, causing surface scaling or discolouration. Protective coatings and surface treatments can improve durability under these situations.

Because of concrete's resistance to weathering, corrosion, and fire, the building can withstand Singapore's humid, tropical climate with little maintenance.

Production of Cement by the Dry Process

The diagram illustrates the production of cement by the dry process, showing the flow of materials and the sequence of operations:

- Raw Materials:** Quarry (ies) and Corrective Materials (from Feed Bins) are fed into the process.
- Crushing Plant (s):** Raw materials are crushed and fed into the Raw Materials Storage.
- Raw Materials Storage:** The crushed materials are stored before being fed into the Raw Mill.
- Raw Mill:** The raw materials are ground in the Raw Mill, which also receives input from the Electrostatic Precipitator.
- Rotary Kiln:** The ground raw materials are fed into the Rotary Kiln, which also receives input from the Coal Mill and the Hot Gas Generator.
- Clinker Cooler:** The output from the Rotary Kiln is fed into the Clinker Cooler.
- Clinker Storage:** The cooled clinker is stored in the Clinker Storage.
- Cement Mill:** The clinker is fed into the Cement Mill, which also receives input from the Mineral Gypsum Component.
- Filter:** The output from the Cement Mill is fed into the Filter.
- Bulk Dispatch:** The filtered cement is stored in the Cement Silo and can be dispatched in bulk.
- Packing Machine:** The cement is fed into the Packing Machine, which also receives input from the Bag Palletization.
- Bag Palletization:** The packed cement is stored in the Bag Palletization and can be dispatched in bulk or packed into bags.

<https://www.youtube.com/watch?v=8Qi00nO3thA>

Cement Production – the process of cement is liable for about 5-7% of the global CO2 emissions.

Air pollution – The process of making cement produces, sulphur dioxide (SO₂), nitrogen oxides (NO_x), and other pollutants that can harm air quality.

Resource Depletion - The extraction of raw materials for cement manufacture, such as limestone, clay, and sand, has the potential to deplete natural resources. Over-extraction can cause habitat degradation, soil erosion, and biodiversity loss.

Community Impacts

Social Disruptions – Cement plants and quarries can have an impact on the nearby communities due to the disrupt in social fabric.

Noise Pollution - Cement factories and quarries frequently generate high levels of noise, which can impact the quality of life for surrounding communities, contributing to stress, hearing damage, and sleep difficulties.

Land Use – Big scale cement plants or quarries may require large areas of land, resulting to displacing communities and disrupting agricultural land.

Concrete frames ease and adaption

The Marina Bay Sands in Singapore is an excellent example of how concrete frames can facilitate assembly and adaptation in the construction of a complicated, high-profile structure. The project made use of precast concrete pieces for quick on-site assembly, which reduced construction time and labour. Precast beams, columns, and slabs were manufactured off-site and brought to the construction site, which accelerated the process.

The flexibility of the concrete structure allowed the building to maintain its unusual, curved towers and expansive SkyPark, while its great load-bearing capacity ensured structural stability.

Steel Frame

Introduction

Steel is commonly used in the form of structural steel beams, columns, and reinforcements, within the construction industry. Steel is a versatile and important material used in the construction industry because of its strength, durability, and flexibility. Steel, which is largely made up of iron and carbon, can be easily shaped and sized, making it perfect for a variety of structural purposes.

Steel's high strength-to-weight ratio enables it to support significant weights while being relatively lightweight, allowing for easier transport and faster installation on-site. It's also favoured for its flexibility, as well as being a sustainable material.

The Empire State Building, USA

Completed in 1931, the Empire State Building is one of the most iconic steel frame buildings and skyscrapers in the world. Standing at 443 meters (1,454 feet) tall, it was the tallest building globally until the completion of the World Trade Center in 1970. The building's structure is primarily made of a steel frame, which allows for its enormous height and durability. It houses offices and observation decks.

During the time period of the construction of The Empire State Building, steel frame construction was fairly new. The use of steel allowed for the building to reach its towering height.

The building's frame is made of 60,000 tonnes of steel, which was used to construct beams, columns and girders. The steel frame was designed to maintain the building's weight while also providing immense open areas within the structure.

Steels strength, Durability and climate resistance

Steel is a highly adaptable material known for its strength, durability, and resilience to climatic conditions, making it ideal for a wide range of construction projects.

Strength

Tensile Strength - Steel is known for its great tensile strength, which means it can sustain large stretching or pulling pressures before breaking. This makes it an excellent choice for structural applications such as beams, columns, and frames in buildings, bridges, and towers.

Compressive Strength - Steel is also extremely resistant to compressive stresses, allowing it to withstand huge weights without deformation. This property is critical for large-scale construction, especially in high-rise structures and infrastructure projects.

Flexibility - Steel's strength and flexibility allow it to absorb and dissipate energy, making it resistant to dynamic loads such as wind, seismic pressures, and thermal expansion.

Durability

Corrosion Resistance - Corrosion can have an impact on steel's longevity, especially in situations with high humidity, moisture, or saltwater exposure (such as coastal locations). Modern steel alloys, such as stainless steel, are specifically developed to withstand corrosion. Galvanised steel, which is zinc-coated, also resists rust.

Lifespan - Steel constructions are noted for their extended lifespan, especially when properly maintained and protected against corrosion. Even in difficult locations, well-maintained steel structures can persist for decades with little damage.

Climate Resistance

Cold Temperature - Steel keeps its strength and integrity at extremely low temperatures, making it ideal for construction in cold climates. In truth, steel becomes stronger in cold weather, yet it can become brittle if exposed to temperatures below a specific point.

High Temperatures and Heat - Steel has a high melting point (between 1,370°C and 1,540°C, depending on the kind), making it resistant to high temperatures. However, thermal expansion at high temperatures can compromise steel's structural integrity, thus techniques such as fireproofing (intumescent coatings, concrete encasement) are frequently used in high-temperature situations to keep it strong during fires.

Steel Production Process

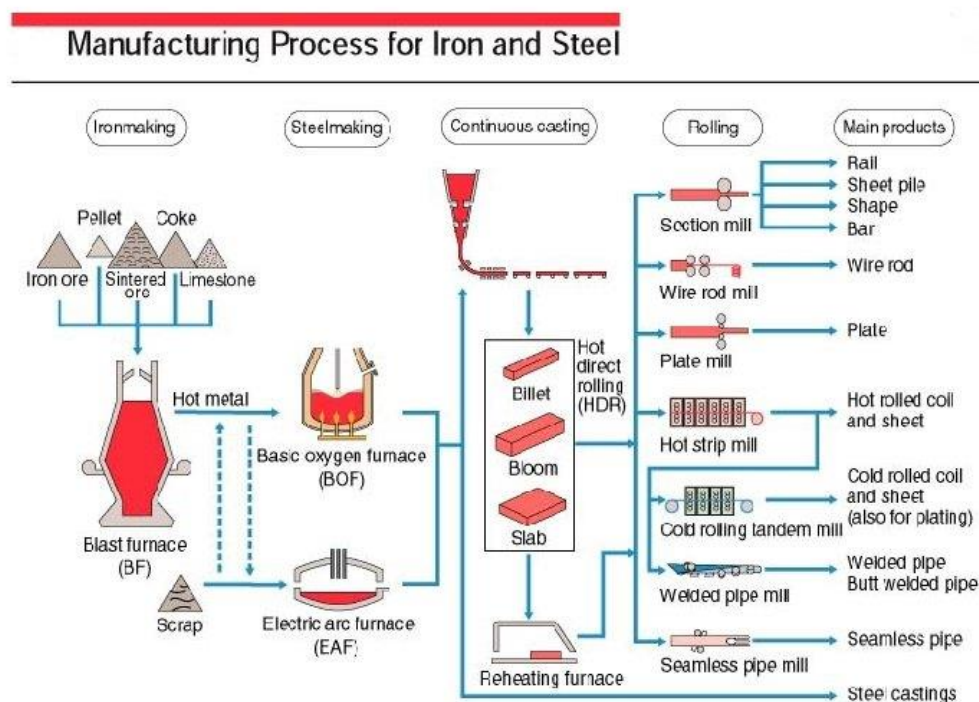


Figure 3 - Manufacturing process for iron and steel (www.researchgate.net, September 2018)

Below is a video on how steel is made:

<https://www.youtube.com/watch?v=eAbbSCG1aRE>

Impacts on the environment from the manufacturing process

The manufacturing of steel can have an impact on the environment as well as the community. Below are just some of the impacts:

Environmental Impacts

Air pollution - Steel manufacture is a carbon-intensive process that relies heavily on the usage of coal in blast furnaces. This causes the release of carbon dioxide (CO₂) and other greenhouse gases (GHGs), which contribute to global warming and climate change.

Air Quality – dust, soot and other particles are produced by the steel mills when producing steel, polluting the air and affecting the air quality.

Energy Consumption - Steel production is quite energy demanding, requiring a lot of electricity and fossil fuels. This leads to resource depletion and puts a burden on local energy supply.

Community Impacts

Healthy and Safety issues - Steel production facilities, particularly conventional blast furnaces, can be hazardous places to work and affect workers.

Job Opportunities - Steel production facilities offer job opportunities and can make major contributions to local economies.

Local Communities - Steel mills are frequently found near cities or in industrial zones, which can have a detrimental effect on the populations around them.

Steel frames ease and adaption

The Empire State Building was designed for adaptability, with prefabricated, modular steel beams that allowed for potential vertical expansion or modifications. This steel frame also made assembly easier, as components were fabricated off-site and then assembled on-site. The building's steel design supports multiple uses, with office spaces occupying most floors and observation decks for tourists on others

Advantages and Disadvantages of Concrete Frame

ADVANTAGES	DISADVANTAGES
Strength and Durability - Steel is incredibly strong yet lightweight, allowing for tall, sturdy structures with less material - Steel is durable and resistant to various environmental factors, such as rot, termites, and pests.	Corrosion - Steel is prone to rusting and corrosion when exposed to moisture or salt (especially in coastal or humid environments).
Flexibility and Adaptability - Steel frames can support various architectural designs, including complex shapes and open floor plans - Steel structures can be easily modified, expanded, or repurposed to meet changing needs over time	Insulation requirements - Steel is a poor thermal insulator, meaning buildings with steel frames may require additional insulation to maintain energy efficiency and comfort.
Faster Construction - Steel components are often pre-fabricated in factories, allowing for quicker on-site assembly and reducing overall construction time - Steel frames are modular and can be assembled quickly, which speeds up the entire building process	Cost - The cost of steel can be higher than other building materials, especially for high-quality steel.
Sustainability and Recyclability	Thermal

- Steel is highly recyclable, making it an environmentally friendly option as it can be reused in new construction projects, reducing waste - production and recycling require fewer natural resources when compared to some other materials	- Steel expands and contracts with temperature changes, which can affect the structural integrity of the building if not accounted for.
Fire Resistant - Steel is fire-resistant, although it must be properly treated with fireproof coatings for further resistance.	Sound Transmission - Steel structures can allow sound to travel easily, making soundproofing more challenging and potentially requiring additional acoustic treatments to ensure privacy and comfort.

Advantages and Disadvantages of Steel Frame

ADAVATANGES	DISADVANTAGES
Strength and Durability - Concrete is exceptionally strong in compression, making it ideal for foundations, walls, and structures that bear heavy loads - Concrete structures are durable and can last for decades or even centuries.	Heavy - Concrete is very heavy, which can make it difficult to transport and handle on construction sites.
Fire Resistant - Concrete is highly fire-resistant and does not burn, melt, or release toxic fumes in the event of a fire.	Water Absorption - Concrete is porous and can absorb water over time, which can lead to issues such as corrosion of steel reinforcement (rebar), mould growth, or water damage in structures.
Sound Insulation - Concrete is a good sound barrier. It effectively dampens noise, which is why it's commonly used in walls, floors, and ceilings in buildings like apartments, hotels, and offices.	Setting Time - Concrete requires time to cure and harden, which can delay construction, especially in projects requiring rapid assembly.
Low Maintenance - Concrete structures require minimal maintenance over time.	Strength - Concrete has poor tensile strength, which is why it's typically reinforced with steel rebar to handle tension forces.
Moulding - Concrete can be moulded into various shapes and sizes. This allows for flexibility in design, making it	Cracking - Concrete can crack due to shrinkage, temperature changes, or external stresses.

suitable for complex structures, curved shapes, and custom forms.	
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