

CONSTRUCTION MATERIALS REPORT

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Construction Materials

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INTRODUCTION

This report discusses the framing of two habitable buildings and the context of their original design and method of construction. The first building is the steel-framed Al Bahar Towers in Abu Dhabi, UAE. The second is the concrete-framed Marina City in Chicago, USA. A table in this report will advantages and disadvantages of the framing material's properties.

SECTION 1 – STEEL FRAMED

The Al Bahar Towers – Abu Dhabi, United Arab Emirates



Figure 1: Image of the Al Bahar Towers in Abu Dhabi (AHR, 2022).

1.1 - Original Design

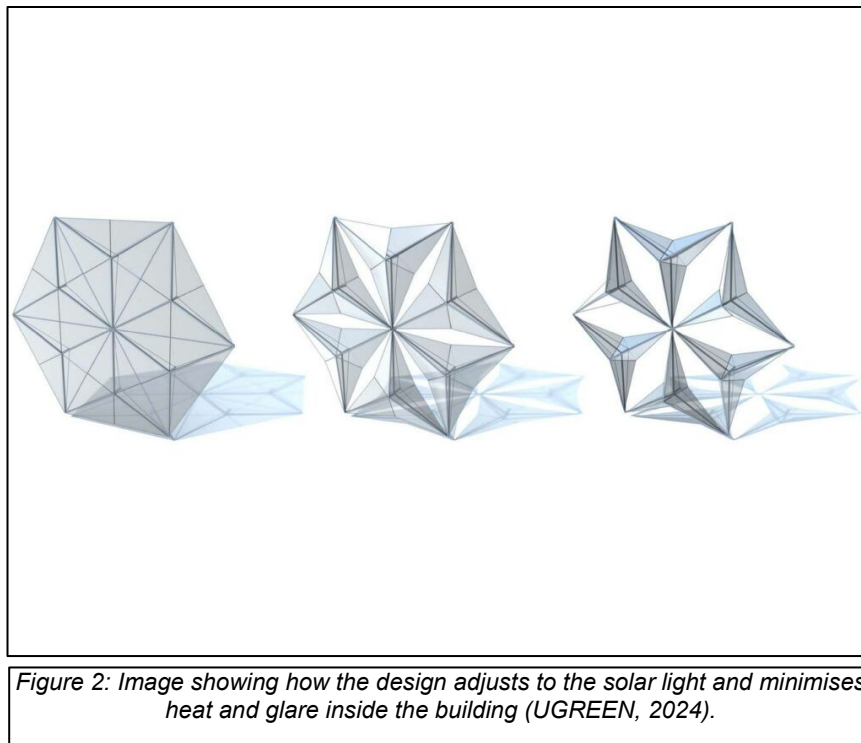
The Al Bahar Towers, Figure 1, are office buildings 145m in height with 25 storeys each. They combine modern design with Islamic tradition.

Steel-framed buildings that are typically covered in glass are usually unsuitable in hot climates due to creating a greenhouse-type effect. The designers countered this by covering the exterior in over 2,000 geometric patterns that act like individual ‘umbrellas’ that adjust to the sun to keep the interiors cool (Figure 2) (UGREEN, 2024).

Shape

Steel framing is very flexible and can be fabricated into any shape while maintaining its strength. It allows the building to have an aerodynamic shape, featuring a curved

angular façade that gives the building a higher wind resistance and ability to deflect wind and turbulence around the structure (Ulnagan, n.d.).



1.2 - Construction

Construction commenced in 2009 and concluded in 2012. Due to the towers' intricate cylindrical shape, extreme external climate, and steel framework, 3D modelling was used and proved effective. Applications were developed to simulate the movement of the façade in response to the sun's path (AHR, 2022).

Steel frame construction is rapid and is demonstrated by the main structural elements; the steel frame, concrete core, and floor decks being constructed simultaneously, rather than sequentially. This resulted in the basic structure and preliminary works being finished in just over a year (ARUP, n.d.).

The steel frame was constructed 6 floors behind the core construction. The decks were constructed four floors behind the steelwork, with concrete poured on top of the decks after the steelwork was completed (ARUP, n.d.). The steel decking acts compositely with the concrete to provide strength to the floor slab. This also doubles up as permanent formwork saving construction time by removing the need to dismantle

formwork. Prefabricated steel components allowed faster assembly and precision in construction (Ulnagan, n.d.).

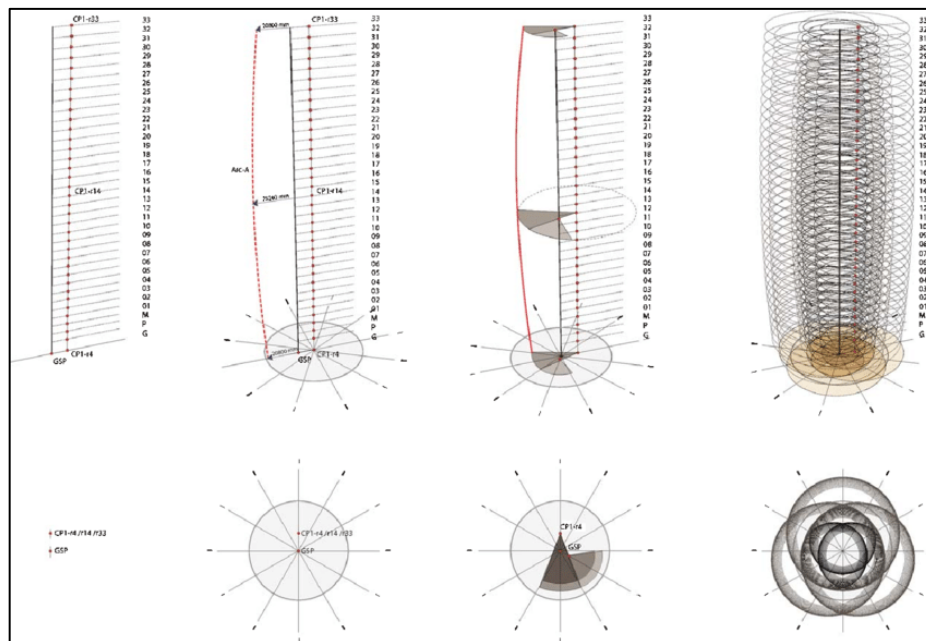


Figure 3: A model of the form and floor plates made from arrangements of tangential circles dictated by a radial grid underneath (Karanouh, 2015).

1.3 - Framing Material

Climate and durability

Abu Dhabi is a subtropical desert with high 46°C and high solar radiation all year. Steel framing is strong and durable and can withstand extreme environmental conditions. Earthquakes are less common in Abu Dhabi meaning less of a priority than wind action in structural design. The steel framing allows the towers to remain resilient and safe against high temperatures, harsh wind, and sand blizzards (EMIRFAB, 2024).

All main-fixed supporting components, such as the cantilever arms and brackets connecting the cladding system to the main structure (Figure 4), are made of Duplex Stainless Steel because of its high strength and resistance to corrosion in hot climates (Jambu, 2017).

Steel is fire resistant, however, at high temperatures, it will sustain heat damage and lose a lot of its structural ability. Therefore, the concrete core was designed to be fire-resistant - preventing rapid spread and assist in fire safety in stairwells and evacuation.



Figure 4: Image of the façade system's cantilever arms and brackets connecting to the main steel structure (Boake, n.d.)

Structural strength and stability

Steel has excellent strength in both tension and compression. The tube system, Figure 5, is a structural engineering system primarily used to resist lateral forces in high-rise buildings. It consists of using a perimeter frame that's made up of steel beams and columns that create a barrier around the towers. The steel columns are placed strategically at intervals to produce a strong frame and transmit forces from the frame to the pile foundation, then into the ground.

The exoskeleton's ability to be flexible and rigid, with the flexible connections between the floor and core, lets the towers move slightly from the seismic activity and maintain structural stability.

The steel beams create a network of structural connections that distribute forces evenly and enhance the shell's strength. A modular tubular design was used for the towers, which means it's constructed in a consistent, repetitive pattern that is flexible to scale up or down for the height of the building (Figure 6).

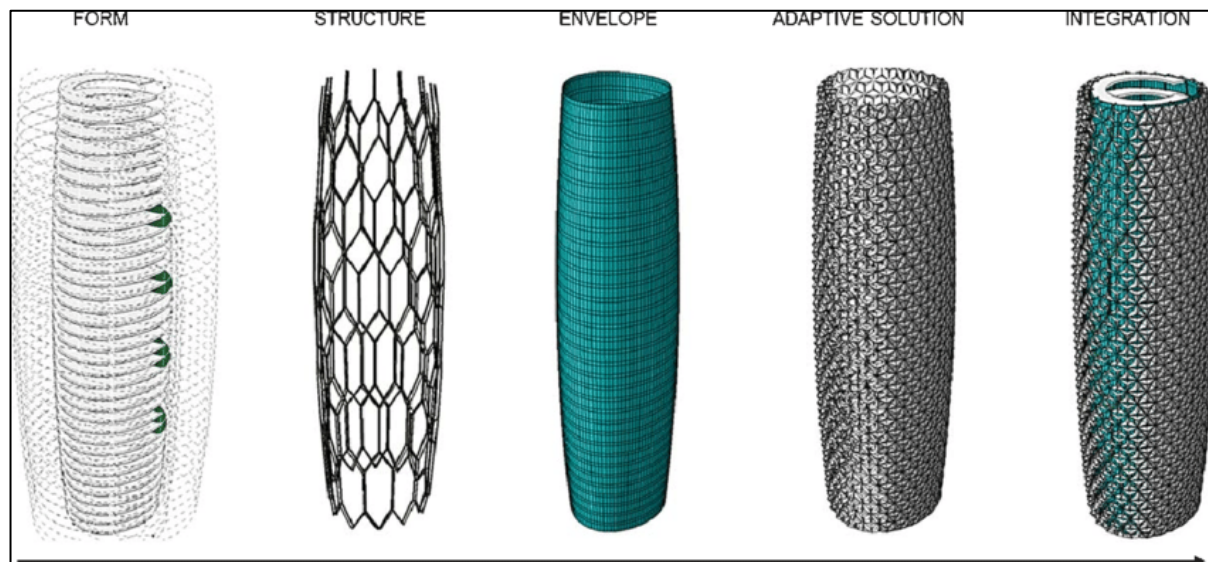


Figure 5: A model of the integration that was created through pre-rationalising the underlying towers geometric principles (Karanouh, 2015).

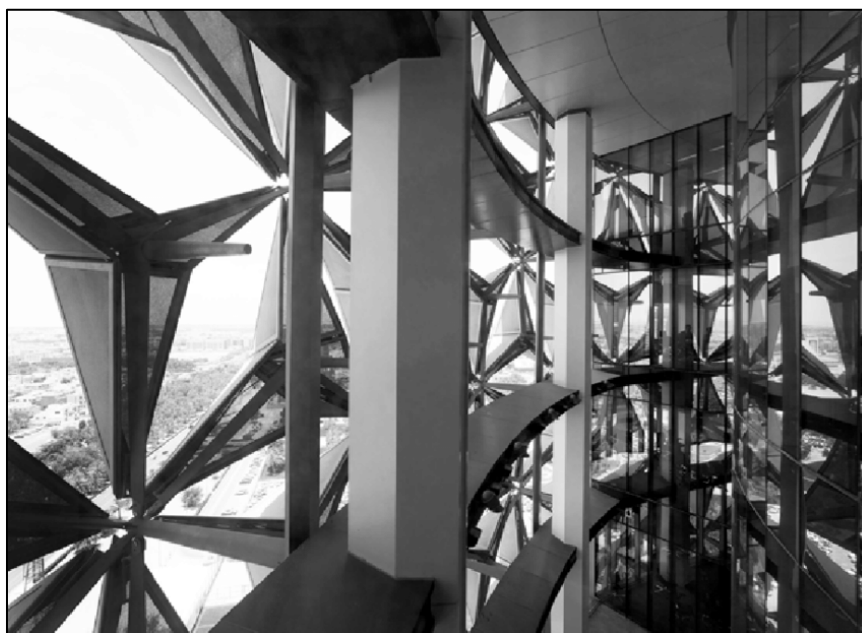


Figure 6: Image showing the integration between the mashrabiya and the perimeter frame (Karanouh, 2015).

The steel frame system reduced material usage because it is strong and stable, but lightweight relative to its height. This is more sustainable and beneficial to the community because it allows smaller foundations and fewer deliveries to the site. The need for excessive walls and internal columns is reduced - minimising the internal

mass and allowing more space for the final occupants and a lower construction cost (Ulnagan, n.d.).

A reinforced concrete core was used to provide structural stability of the steel against lateral forces such as wind and seismic forces causing deformation and torsions to the buildings. The core contains lifts, rooms, storage, plant and office use (Figure 7) (ARUP, n.d.).



Figure 7: A model of the Al Bahar floor plan and structural system (Wiki Architectura, 2024)

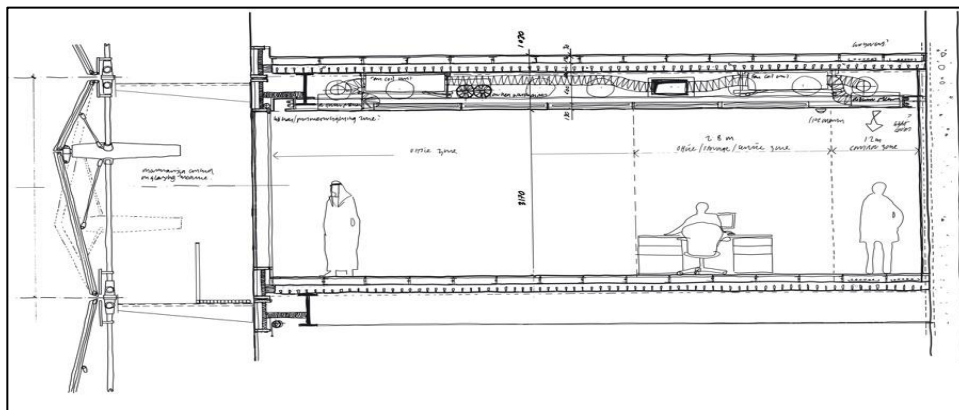


Figure 8: Cross-section through the south of the towers showing the connection between the façade and key building elements such as the structure and mechanical services (Karanouh, 2015).

Environmental impact

The steel framing was prefabricated off-site, and computer modelling before fabrication helped reduce the volume of scrap steel produced (*Jambu, 2017*). Any scrap produced can be recycled many times without detriment to its strength properties and used in other projects.

Adaptability

The Al Bahar towers are highly adaptable due to steel's longer structural spans allowing open floor plans meaning that the walls and partitions can be modified for different building uses.

SECTION 2 – CONCRETE FRAMED

The Marina City – Chicago, United States



Figure 9: Image of the Marina City Towers in Chicago (Chicago Architecture Centre, n.d.).

2.1 - Original Design

The Marina City Towers, in Figure 9, are two identical honey-combed-shaped towers that stand 180m tall and contain a mixture of residential and office units. They are the first in the US to feature a rigid concrete core and reinforced concrete columns (Sumini & Chesi, 2017).

Shape

The towers feature unique curvilinear designs with semicircular concrete balconies. Concrete has great versatility in design and construction, where unique architectural designs, like the towers, have been created using concrete as the main building material (Chicago Concrete Pros, 2023).

2.2 – Construction

The Marina City towers were designed and constructed between 1959 and 1967.

The columns and walls were constructed using in-situ concrete and consist of conventional aggregates with strengths that decrease from bottom to top. For horizontal elements such as beams and slabs, lightweight aggregates were used. Each parking ramp half-level consumed standard concrete for the vertical columns. Since the balconies and parking ramps were to be exposed to weather, lightweight aggregates were used for better durability.

The apartment floors were also cast in-situ (Figure 10) – including identical formwork, reinforcement techniques and concrete pouring processes (Sumini & Chesi, 2017).

Where concrete was cast in situ, work in the winter was lost when temperatures were very low. This reflects one of the common issues that come with the use of the concreting process in different weather conditions, which can lead to potential delays or compromised quality if not managed efficiently.



Figure 10: Image taken in 1961 during the construction of concrete being poured surrounding the concrete core (Chicago Old and New, 2019).

2.3 - Framing Material

Climate and durability

Generally, the climate of Chicago can be described as continental with warm summers, and cold winters – often experiencing short fluctuations in temperature,

cloudiness, wind direction and humidity. Concrete construction is the preferred choice in Chicago due to its versatility, durability and aesthetic appeal – allowing it to withstand challenges such as harsh weather, hurricanes and heavy rainfall.

However, high-rise reinforced concrete buildings constructed in the 1950s and 1960s are facing challenges from new structural design codes - specifically against seismic risk. Similar buildings built in seismic areas before the implementation of modern design codes, are vulnerable, with potential risk of demolition (Sumini & Chesi, 2017).

The cost of maintenance has been incredibly expensive. Since the construction of the towers, the concrete towers have had many issues with the material, Figure 11. Any deteriorated concrete, from high chloride content, for example, would be removed down to the reinforcing steel and then sandblasted, coated with epoxy and re-covered using concrete mixed with adhesive. Some residents had a polyurethane membrane over the concrete surface to help with protection. Ponding of the balconies has been a major issue too due to an error during construction - this could be a contributing factor for the concrete damage due to freeze and thaw attack (Chicago Old and New, 2019).



Figure 11: Image of concrete repair (WJE Projects, 2019).

Structural strength and stability

Concrete is great in compression and its flexibility and solid structure have supported many architectural styles and engineering methods. The towers' structural system consists of a rigid frame combined with a central core to resist lateral loads.

The walls of the towers vary in thickness - wider at the base and narrower at the top, to take the main load of the building. Inside the core are elevators, stairs, and utilities.

The foundation system of the buildings reaches 33.5m below the Chicago River located close and through soft Chicago clays, boulders, rocks and an abandoned rail tunnel (Sumini & Chesi, 2017).

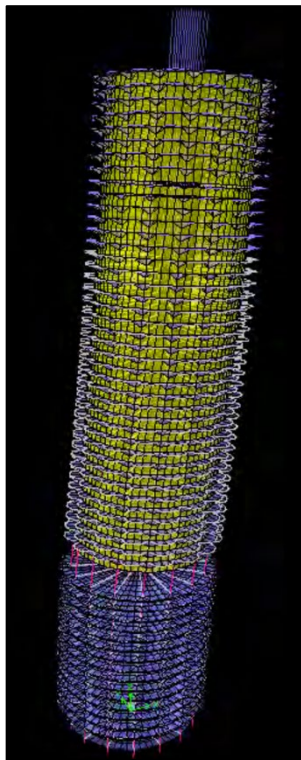


Figure 12: Model showing deformation of the structure due to wind loads with the spiral parking ramp maintaining stability at the base (Sumini & Chesi, 2017).

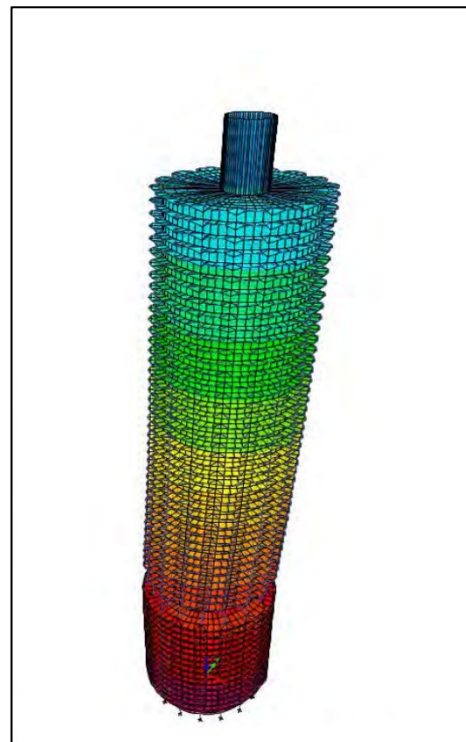


Figure 13: Model of resultant displacement of the structure due to seismic forces (Sumini & Chesi, 2017).

Environmental impact

The floor plans feature a high interior-to-external wall ratio, leading to substantial savings in both construction and long-term upkeep (Sumini & Chesi, 2017). Fly ash and ground granulated blast furnace slag are used in concrete mixtures to reduce environmental impact. Also, concrete's thermal mass properties help keep indoor

temperatures regulated and lead to less energy consumption and lower carbon emissions (Chicago Concrete Pros, 2023).

Adaptability

There is limited adaptability with The Marina City Towers due to the reinforced concrete frame, and cylindrical floors. Since concrete relies on load-bearing walls and cores, interior spaces cannot be reconfigured easily without reconstruction. Converting towers for a different use would be challenging due to the fixed column placements and limited floor plan flexibility. Major modifications would require breaking and replacing concrete. Adding additional plan floors or extending sections is nearly impossible, unlike steel, due to the need to reinforce the entire structure. Therefore, concrete is suitable for long-term stability but isn't great for adaptability.

SECTION 3 - TABLE COMPARISON

Properties	Steel Framed		Concrete Framed	
	Advantages	Disadvantages	Advantages	Disadvantages
Strength	- Stronger than concrete due to its high strength to weight ratio. - Eight times stronger in resisting tension and shear forces. - It tends to bend rather than crack, therefore more resilient. - It's ductile, making it's ideal	- Loses strength in fires if not protected.	- With steel reinforcement, it combines compression strength from concrete and tensile strength from steel (Buildings-uk, 2022). - Can withstand significant loads due to its	- Strength depends heavily on quality during the concreting process and variations such as aggregates, water and curing conditions. - It is weak in tension.

	for structures that experience dynamic forces like earthquakes and wind loads (Buildings-uk, 2022).		compressive strength.	
Durability	- Steel is more durable and bears advantages in seismic aspects because of its resistance to tension and deformation (RAHDA TMT, 2024).	- Unprotected carbon steels are prone to corrosion and section loss if exposed to moisture, chlorides and weather (SW Funk, 2025).	- It shows excellent durability if properly designed, cured, reinforced and maintained (SW Funk, 2025). - Highly resistant to corrosion.	- Can be susceptible to attack from sulphates, chlorides and freeze that attack. - Can split, crack, shrink or warp when exposed to elements.
Climatic Resistance	- Strong against fire (if suitably protected) and	- It can expand and contract with	- It can withstand harsh climates and extreme	

	adverse weather like heavy snow and strong winds. - It's better against earthquakes due to its ability to absorb impact and prevent collapse (Buildings-uk, 2022). - Most steel components are bolted together, leaving a slight deformation during earthquakes – allowing it to deflect and not	temperature shifts. - May require additional fire-resistant materials to improve fire safety properties (Lemen, 2023).	temperatures for an extended amount of time (RAHDA TMT, 2024). - It is naturally fire resistant (Lemen, 2023). - It's strong enough against fire and adverse weather conditions (Buildings-uk, 2022).	
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	collapse (RAHDA TMT, 2024).			
Environmental Impact	- Can be recycled and can be reused endlessly without the loss of strength. - The industry is working towards the installation of processes such as electric arc furnaces (Buildings-uk, 2022).	- It produces a lot of greenhouse gasses during manufacturing.	- Is a natural element and is viewed as sustainable.	- Not reusable and unrecyclable (RAHDA TMT, 2024). - The process of retrieving raw ingredients, making and disposing it is not seen as environmentally friendly. - Concrete has high embodied carbon in the cement, however partial cement replacements can be used.

				- The process of producing concrete and transporting it contributes to the air pollution (Buildings-uk, 2022).
Ease of Construction	- Mostly prefabricated off site, where various components can be made simultaneously in factory conditions allowing faster delivery and faster construction. - Being lightweight, steel		- Can be manufactured offsite by the pre-cast process – allowing for an efficient, durable and higher-quality concrete element.	- Size and shape (weight) of pre-casted concrete is limited due to transportation. - Usually constructed in-site, which consists of a slower process one step at a time, including 28 days of curing for desired strength (Buildings-uk, 2022).

	doesn't need as large foundations or doesn't require as many columns internally. - Allows bigger open spaces internally and suits a variety of uses for the structures (Buildings-uk, 2022).			
Adaptability	- Highly flexible and can be fabricated into different designs. - It has many different		- Can be moulded into any shape.	- Faces limitations in floor-to-floor construction heights and long, open spans (Lemen, 2023).

	aesthetic options (Lemen, 2023).			
Price	- Having a high durability means less maintenance and a reduced overall cost (RAHDA TMT, 2024). - Cheaper for framing in the UK as it requires less labour than concrete.	- Costs fluctuate.	- Used to be cost efficient and cheap to manufacture.	- Changes in manufacturing laws have made costs rise. - Long process and a lot of ingredients mean higher construction costs (RAHDA TMT, 2024). - More expensive in the UK due to higher labour requirement. - Requires ongoing maintenance and repairing (Buildings-uk, 2022).

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