

Assignment 1 Materials Science and Building Services

CASE STUDY: ANALYSIS OF BUILDING FRAME MATERIALS AND METHODS.

Ben Jeffs 2110628

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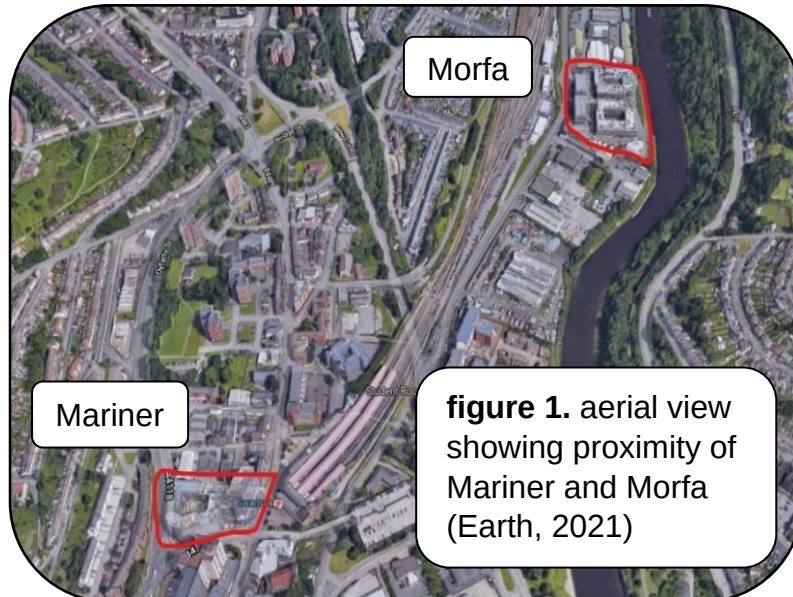
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1. Introduction

1.1. General

Framed buildings differ from traditional loadbearing structures in that the loads of the building are transmitted through the structural framework. The frame supports the



external weatherproof walling and roof, and also the internal walls and floors. Framed buildings are particularly suitable for medium to high rise structures. The material used to frame modern buildings is either reinforced concrete or steel. Mariner and Morfa

were completed in September 2021. Both are major student accommodation projects, just 1km apart, here at Swansea. Selecting recently completed projects allows easy access to modern public record keeping (Planning Portal, 2021).

Mariner Street Project (Mariner) is a £65 million recently completed development. It is 17 storeys tall at its highest and is now home to 780 students. There is also a gym, cinema, courtyard, and 2,000 square metres of commercial ground floor space. The buildings' frame is of reinforced concrete construction.





The Morfa Road Project (Morfa) is a £50 million recently completed development. It is 6 storeys tall at its highest and is now home to 706 students. The ground floor contains a cinema, library, gym and large recreation area. The buildings' frame is of steel construction.

1.2. Environmental Conditions

A review of the studies carried out by the Environmental Consultants at each site, see Table 1 below (Patrick Parsons, 2016) and (Ground Investigation, 2016).

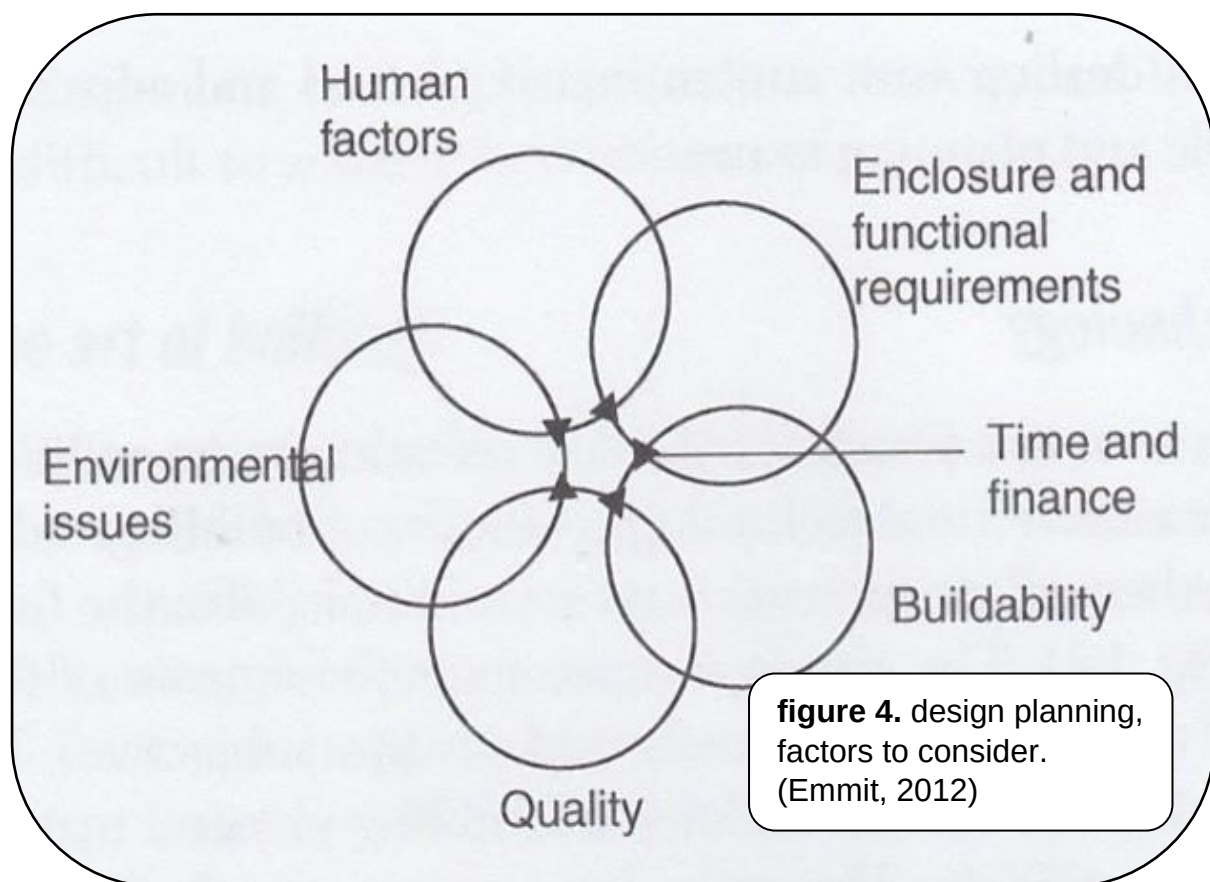
1.2.1. Table 1 Environmental Conditions

	Concrete framed building – Mariner	Steel framed building – Morfa
Location, aesthetics, social sustainability	Noisy, bustling, urban inner-city, residential and commercial. A unique form of design is needed to ensure this building blends into the city. Surrounding buildings mostly of brick or concrete construction.	Edge of inner-city, brown field riverside, some industry remains but fast becoming a residential area. Surrounding buildings mostly of low-rise steel frame construction.
Site history	Small commercial warehouse, hotel, shops, café.	Former riverside industrial zone.
Ground conditions	Made ground, medium density, bedrock at 20 metres, bored pile foundation is required. Ground slabs in limited load areas. No bedrock faults.	Made ground, medium high density, bedrock at 18 metres. Bored pile, ground slab foundation throughout. No bedrock faults.
Contamination and Radon	Some ground contamination, required capping. Radon levels are insignificant.	Significant ground contamination of arsenic and copper, required removal and capping. Radon levels are insignificant.
Flood risk, drainage	Low flood risk. Sustainable ground drainage is present.	Medium risk, within river flood plain. Sustainable ground drainage is present.
Mining records	No known historic or probable shallow coal workings.	
Climate	Temperate oceanic climate; Swansea has a significant amount of rainfall during the year. Winds are moderate but must be considered in developments over 6 storeys. Air has a high salt content.	

2. Concrete Framed Building – Mariner

2.1. Design Planning of Mariner

Fusion Students, the developer of Mariner, presented a 'Brief' to the designers, containing their conceptual ideas (Fusion Students, 2021). There were over 500 design planning documents submitted (Planning Portal, 2021). The Architects Design Development Plan outlined preferences for traditional methods of 'in-situ' concrete construction. (Day Architectural Limited, 2016). The designer matched up the clients' concepts with the reality of the design factors that must be considered. (Emmit, 2012).



Detail of how Mariner was constructed can be found in Appendix 1.

2.2. Materials Used in the Mariner Frame Construction

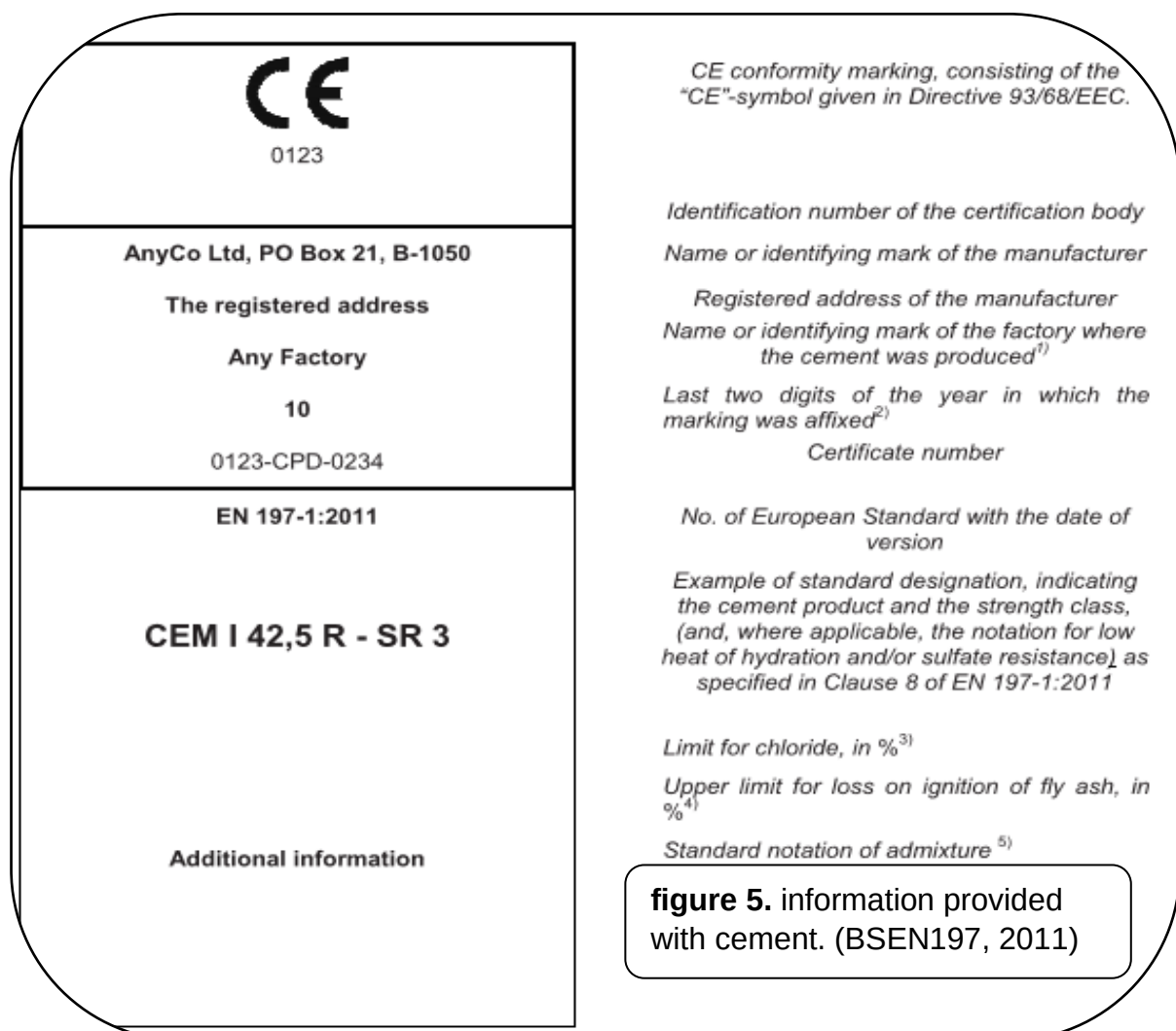
2.2.1. Concrete

The concrete used is a mixture of cement (approximately 10%), coarse aggregates and fine aggregates and water (sometimes small amounts of other additives).

2.2.2. Cement

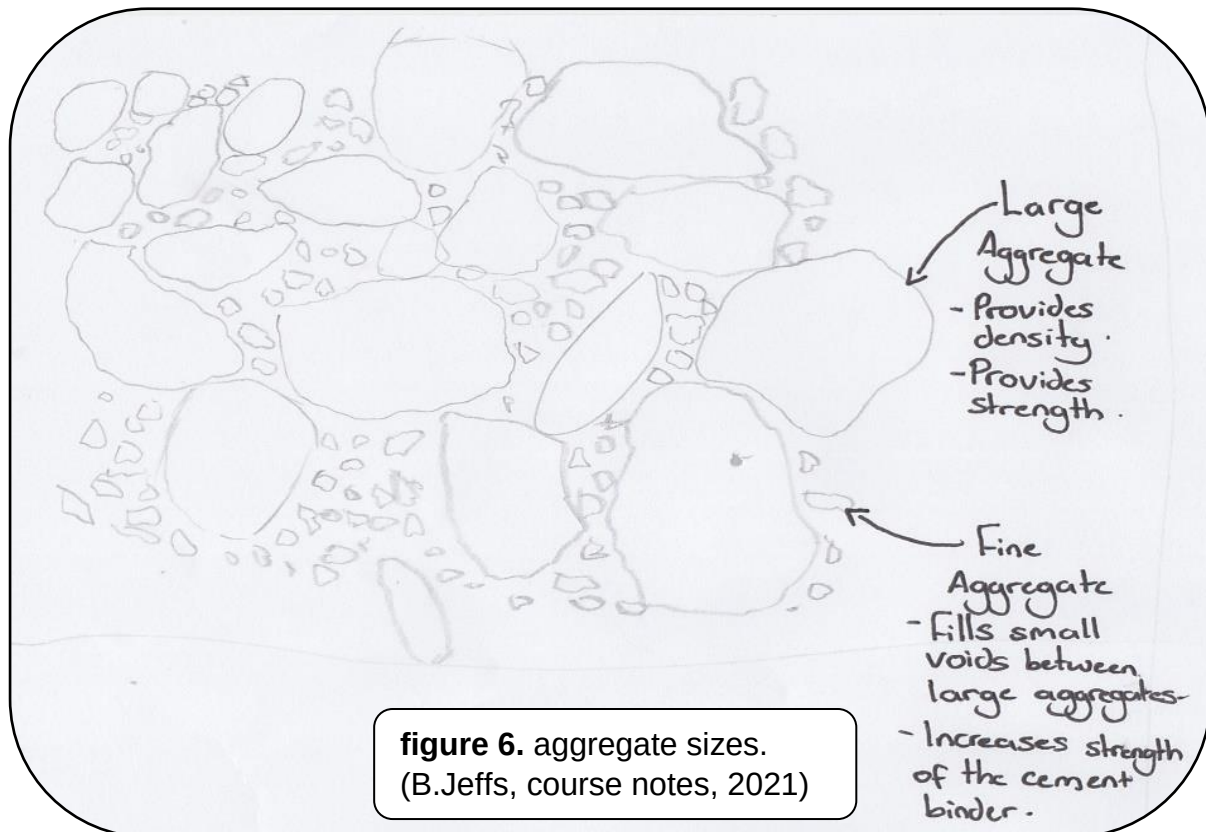
Cement ingredients are limestone, shells, and chalk or marl combined with shale, clay, slate, blast furnace slag, silica sand, and iron ore. Heating in a rotating kiln produces clinker, which is cooled and then finely ground to produce the powder we know as cement. (Marotta, 2005).

Portland Cement is the binder for concrete mix. Type strength is given, although once mixed into concrete, specific testing will be needed to determine qualities.



2.2.3. Aggregates

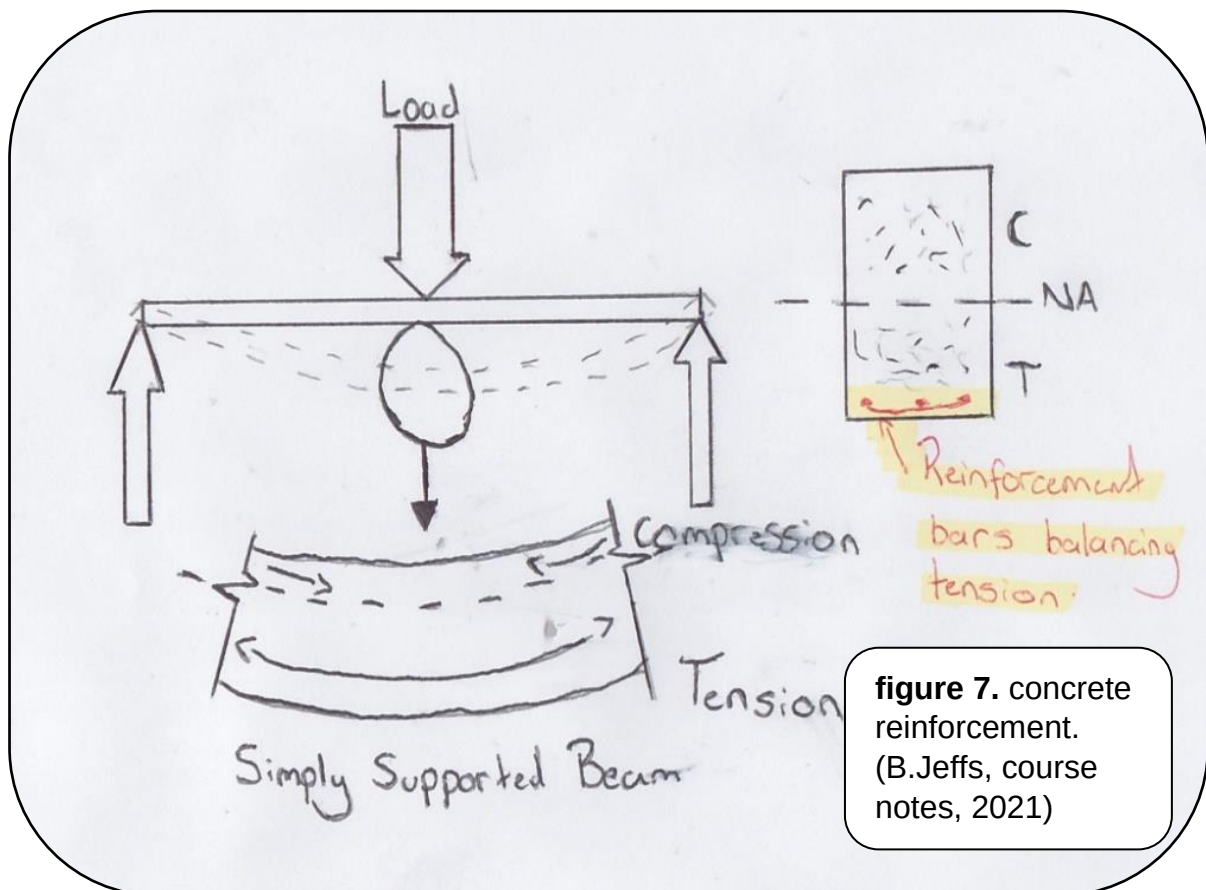
Aggregates are inert granular materials such as sand, gravel or stone. Sometimes they are artificial or even recycled materials. A uniform shape and rough texture is desirable. To allow flexibility in shaping of reinforced concrete, the size of large aggregates should be no greater than 20mm.



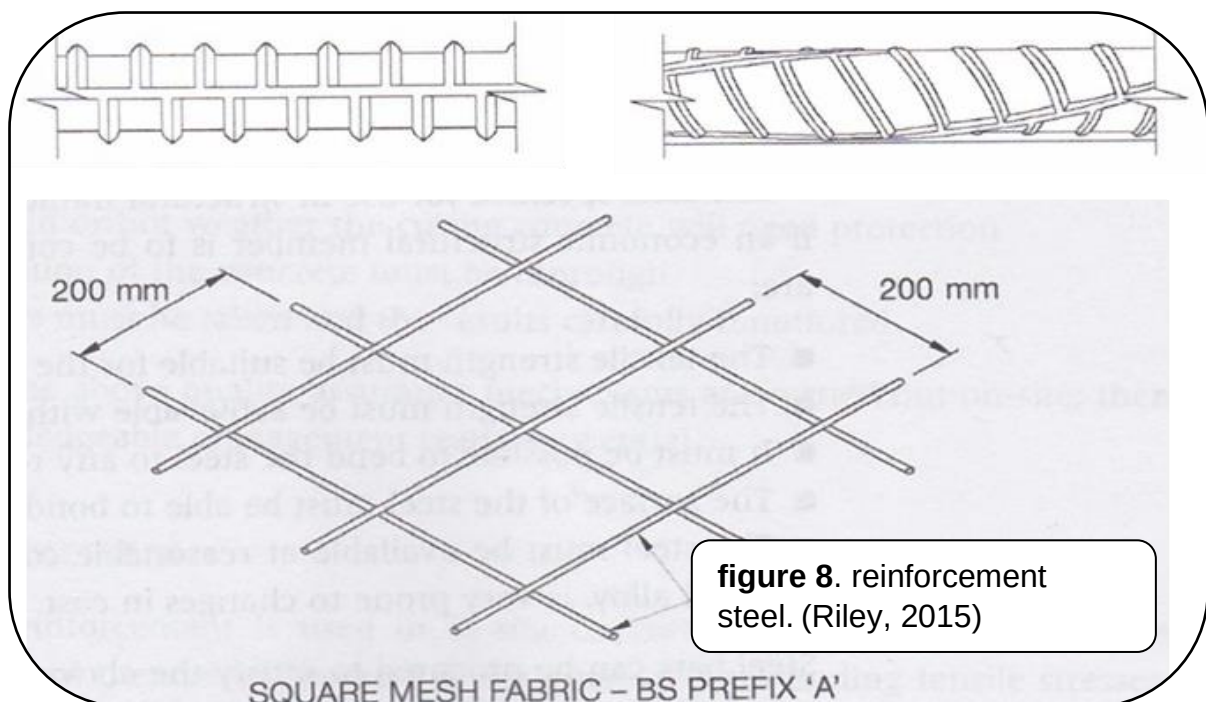
Aggregates are graded to ensure the optimum mix, they are quality tested at the concrete manufacturing stage for size, shape, dryness and density. (Nantel, 2020)

2.2.4. Reinforcement

Concrete is not good at withstanding tensile stresses so it has to be reinforced with steel. Bars are placed into the framework where tensile stresses will occur. Demonstrated in a simple beam under load the bars are placed at the bottom i.e., the point of tension, this balances the stresses.



Bars are used at various diameters, they may be ribbed or twisted ribbed. Steel mesh is used at the top of slab or beam sections, this prevents cracking of the concrete. (Riley, 2015).



3. Steel Framed Building – Morfa

3.1. Design Planning of Morfa

The Morfa Designers Philosophy Document provided an excellent example of how all the data collected is considered in plans (Powell Dobson Architects, 2017). The developers building history shows them specialising in steel framework buildings. (Create Construction, 2021).



figure 9. steel framework.
(Encyclopaedia, 2021)

Detail of how Morfa was constructed can be found in Appendix 2.

3.2. Materials Used in the Morfa Frame Construction

Structural steel needs to have desirable mechanical properties in:

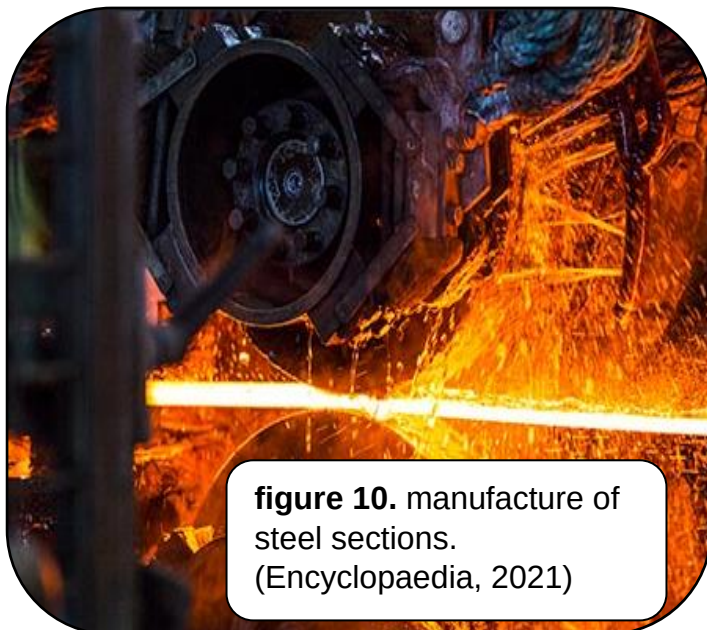


figure 10. manufacture of
steel sections.
(Encyclopaedia, 2021)

- Strength
- Toughness
- Ductility
- Weldability
- Durability.

These properties are derived from a combination of its chemical composition, heat treatment and manufacturing processes. The addition of very small quantities of other elements

such as carbon, manganese, phosphorus, sulfur, etc., can have a marked effect upon the properties.

The manufacturing process may involve combinations of heat treatment and mechanical working that are of critical importance to the properties and performance of the steel. (Marotta, 2005)

Structural steel sections are standardised. This makes them economical to produce and allows designers to adopt a standard approach, which is called 'limit state design'. Converse to concrete, structural steel has an excellent withstanding of tensile stresses but not compressive stresses. Therefore; sections tend to be over designed. Connections of structural steel by bolts, rivets or welding can be made in situ or at a factory. The method of connection must meet the required properties of the framework. (Riley, 2015).

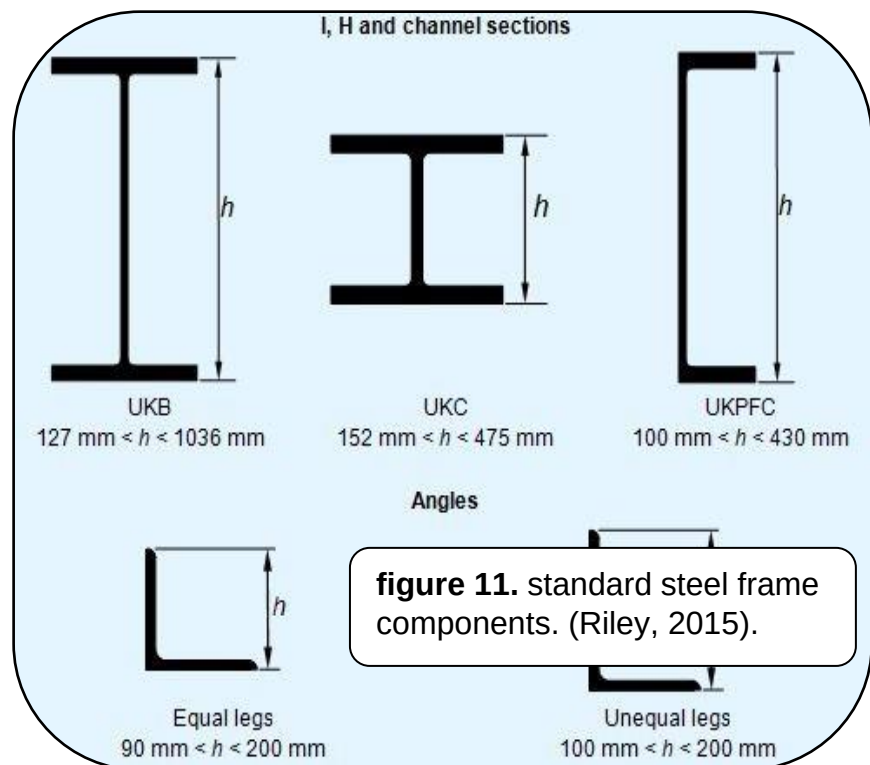


figure 11. standard steel frame components. (Riley, 2015).

4. Comparison and Analysis of Framing Materials

See tables below:

4.1 Table 2. Impact of the Frame Materials on the Environment.

Impact of:	Concrete framed building – Mariner	Steel framed building – Morfa
Raw materials	Resources are abundant for both concrete and steel, but still are finite. These huge mines are viewed as unsightly. High amounts of fuel is used with high potential of land/water pollution.	
Carbon dioxide (CO₂) footprint	Cement is the dirty ingredient of concrete. 1 tonne of cement = 0.62 tonne of CO ₂ . Contribution to global CO ₂ emissions is 7%.	1 tonne of steel = 1.85 tonne of CO ₂ Contribution to global CO ₂ emissions is 10%.
Fuelling production	35% of the cement footprint comes from the fuel combusted to heat the kiln.	70% of the footprint comes from the fuel combusted to heat the steel making furnaces.
By-products from chemical reactions in the production process	55% of the cement footprint comes from process by-product. Cement is composed of 60% lime, this is made from the decarbonisation of calcium carbonate (limestone) by heating to 1450°C. CaCO₃ (plus heat) → CaO + CO₂ calcium carbonate → lime + carbon dioxide.	20% of the footprint comes from process by-product. Heating to 1850°C, iron ore (iron oxide) and carbon to produce iron, with CO ₂ released as a by-product. 2Fe₂O₃ + 3C (plus heat) → 4Fe + 3CO₂ iron oxide + carbon → iron + carbon dioxide Other by products include slags, dust and sludge, all need to be recycled or disposed of.
Logistics and other	Remainder of footprint. Bulkier framework so there is more weight to transport, however; concrete components can be sourced locally.	Remainder of footprint. Fewer production centres, so has to travel greater distances. Long lengths increase transport needs.
At end of life	75% is downcycled to be used in alternative functions, 20% is recycled as aggregate and 5% goes to landfill.	Recyclability is far superior to concrete. 6% is re-used, 93% is recycled and just 1% goes to landfill.

4.2 Table 3. The Frames Durability.

Environmental and other influences:	Concrete framed building – Mariner	Steel framed building – Morfa
Forces acting on the building, load, weather, ground movement etc...	High compression strength, steel reinforcement increases tensile strength. Low toughness, high brittleness. Resistant to cyclic loads. High rise must take wind forces into consideration.	High strength to weight ratio, excellent toughness, stiffness and ductility. Greater spans are possible.
Space	Larger cross sections result in a bigger footprint. Offers more flexibility in the form of design.	A much smaller footprint than concrete means greater floor space and smaller foundation.
Above average rainfall and air salt	High resistance to corrosion. Excellent long-term durability in the harshest of conditions.	Corrodes, so must be shielded and protected with coating and cladding.
Varying temperatures	Good resistance to varying temperatures.	Some thermal expansion and contraction is possible.
Fire	Excellent fire resistance, retains properties under extreme heat before failing. Ideal for high rise.	Poor fire resistance, under high temps will melt. Must be protected by cladding.
Noise	Excellent noise insulation properties.	Can transfer structure-borne sound.
Finance	Overall considered less costly. Slower start to construction gives a more gradual cost/duration profile, this smooth's out project cash flow, which may be important.	In terms of floor area, steel is a more expensive method of construction. Although it is far quicker, so when a fast build is essential steel could prove more economical.

4.3 Table 4. The Frames Ease of Assembly and Adaption.

The frames ease of	Concrete framed building – Mariner	Steel framed building – Morfa
Design	Despite its bulk, has versatile design capabilities, allows free form layout. Particularly suited to non-standard shapes such as those seen at Mariner.	Can be made to standard lengths, widths and other specifications, this makes design simpler and quicker. Steel can span longer to make larger grids.
Assembly at site	More complicated so there is greater health and safety risk. Handling at site is difficult e.g.: formwork. High-skilled labour is needed. Quality control is difficult to achieve, with multiple continuous tests needed, there is more potential for problems. Weather dependent.	Materials lead-in time is long. Assembly is rapid in comparison to concrete. Handling is far easier and lower skilled labour used. Less equipment is needed and crane lifts are lighter. Generally, both quality and health & safety is easier to manage.
Maintenance	Low requirements. There may be some shrinkage or settlement that needs repairing.	Low requirements. Occasional inspection for corrosion.
Modification after construction	Once set, can't be reshaped. Modifications are difficult as they could compromise structural integrity.	Subtle changes are usually fine but larger modifications are difficult as they could cause structural imbalances.

4.4. Analysis

Mariner and Morfa have the same purpose, at a similar capacity and in the same city. The studies carried out at design planning stage, **Table 1**, show similar environmental conditions that presented no real barriers to the progress of either project.

Space and surroundings had a large bearing on the shape of these buildings and therefore, choice of framework material. Mariner had to go upwards to get its capacity whilst Morfa could spread itself out in grid-like fashion, both in-keeping with current surroundings. The temperate climate with moderately high winds of Swansea needed to be considered in the concrete design as did protecting the steel framework from sea air.

Neither steel nor concrete can be select as a preferred frame material based upon their impact on the environment, both make staggeringly high contributions to global CO₂ emissions. Steel creation burns huge amounts of fuel, this is shown in **Table 2**. Most countries continue to depend entirely upon coal for this, the use of natural gas has improved the situation in the UK somewhat, but cleaner fuels such as hydrogen are needed everywhere, as well as a continual improvement of processes. This won't help the dirty ingredient of concrete, which is cement. Large amounts of CO₂ is produced as a by-product from chemical reactions in the creation process, unfortunately these are effectively irreducible. A solution here would be to capture the CO₂ before it can enter the atmosphere, all possible, but at significant cost. Other by-products from steel creation include slags, dust and sludge, all need to be recycled or disposed of. The creation of concrete, or its dirty ingredient cement, has no other significant by-products.

By weight, concrete has the more favourable carbon footprint, but of course with a lower strength to weight ratio then more of it is needed. Steel has the further advantage of being largely recyclable, yet this is limited to producing only lower grade steels, and not beneficial enough to offset its massive initial carbon footprint.

The properties of steel do allow a smaller foundation and greater floor space than that of a concrete building although concrete offers much greater flexibility to the design shape. **Table 3** shows how both materials offer durability. Unlike concrete steel is susceptible to corrosion and must be protected, it must also be shielded from fire. Whereas a massive advantage of concrete is its fire resistance, a prime reason why

most residential high-rise in the UK are concrete framed buildings. The build cost profiles of each material differs and depending on the developers' circumstances, may have some influence on material preference.

Being city-centre meant Mariner needed to blend in, this inevitably resulted in a more demanding form of design. **Table 4** shows how concrete offers this flexibility, the price the developer pays for this is time, as concrete is the most complicated of builds and comes with many procedures and controls. Steel being simple and quick in comparison and despite the high cost of the material itself is still most widely used for out of town, more basic builds. Neither material takes kindly to modification afterwards, mainly due to structural integrity, it is of course possible but not easy.

5. Conclusion

Steel and concrete have certain key advantages over each other, in certain applications. Key advantages that make choosing a framework material easier:

- The lower cost, cash flow friendliness, design flexibility, fire resistance and durability of concrete make it the perfect choice for the unique, inner-city high-rise of Mariner.
- Just as the quick design, simple and rapid assembly, space saving of steel construction is perfectly suited to the cities edge, box shaped, mid-rise at Morfa.

The most suitable framework material for any building is determined by specific project needs.

6. List of References

(All references were accessed November 2021) (in alphabetic order)

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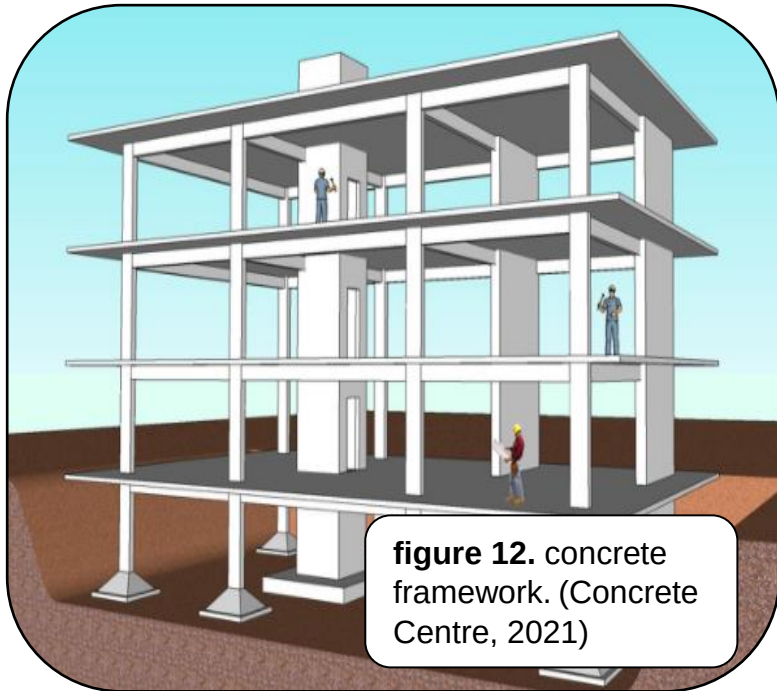
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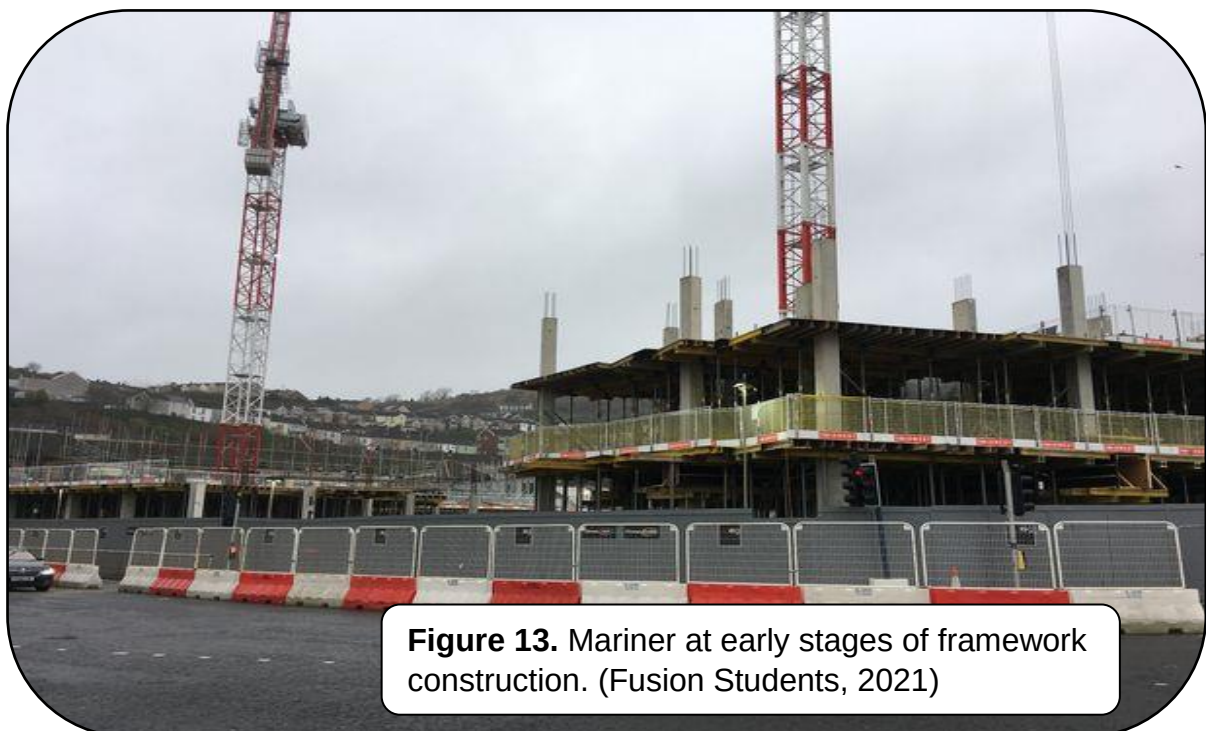
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Appendix 1 - Construction of Mariner

The design planning of Mariner arrived at a decision to create a reinforced concrete framework comprising vertical columns, horizontal beams and flat slabs. As a high-rise building, shear walls are included in the framework, these are essentially larger columns that help with horizontal forces on the building from high winds. Elevator shafts, which are essentially a concrete box, are also included in this design. The shaft helps with the frames' overall resistance to both vertical and horizontal loads.



Upon successful completion of ground preparation and foundations. The in-situ construction of the reinforced concrete framework components can begin.



Vertical columns, horizontal beams and flat slabs required the use of Formwork (or moulds). Concrete is poured into the formwork. (ISG Global Construction, 2019). System column formwork is used for vertical components whereas large table formworks are used to construct beams and slabs.

Vertical - System Column and Shear Wall Formwork



- The system column formwork are steel, modular and reusable they allow quick assembly and erection on-site.
- They are assembled and positioned over or enclosing the pre prepared reinforcing steel bar cage.
- The forms are positively restrained and braced using props.
- Concrete is poured, once hardened sufficiently the formwork is stripped and moved to the next position.

Horizontal - Beam and Flat Slabs Formwork

- Using large pre-assembled formwork, these are often called 'table forms', able to form a complete bay of a suspended floor slab and beam layouts.
- The assembled table formwork units are positioned by crane and sealed along the joints to form the floor to be cast.
- Steel reinforcement is fixed in place, rods are laid in ducts, to be stressed after laying the concrete, they are then anchored and bonded to the concrete. This is called post tensioning.
- Concrete is poured and cured.
- Once struck, the formwork units are lowered and removed from underneath the newly formed slab and placed at the next position or level.



figure 15. beam and slab table formworks.
(Concrete Centre, 2021)

Horizontal and Vertical – Lift Shafts

Are pre-factory cast. Positioned by crane, anchored and bonded to the framework.

Quality Assurance

The quality manager will slump test the concrete mix on-site, before making cubes to be sent for laboratory testing in accordance with the quality plan and standards.

Appendix 2 - Construction of Morfa

The design planning of Morfa decided upon a steel framework. As a six-storey building the method of building Morfa framework is relatively simple and quick, in comparison to Mariner. Fixed to a reinforced concrete foundation, the baseplates of the frames vertical columns were anchored and grouted in place. The framework is predominantly vertical H-beam and horizontal I-beam, the majority are of standard dimensions and fixed in-situ by bolts to specified torques. Some welding of non-standard features and some braced sections was carried out at the temporary fabrication facility. (Encyclopaedia, 2021)



figure 16. Morfa at early stages of framework construction. (Create Construction, 2021)