

Material Science and Building Services

Assignment: Case Study comparison between two residential buildings of Concrete frame and Steel frame in the United Kingdom.

Module Code: ACBA4006

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Introduction

Steel and Concrete currently dominate worldwide as principal construction materials for the built environment; an initial comparison of the properties of both these materials, along with respective strengths and weaknesses are presented in summary tables, together with mini case study profiles, in Section One as a point of reference for the main example case studies, concerning two residential buildings, both situated in the United Kingdom, which will be introduced in Section Two and the main points of their original design brief, construction methodology, and local sustainability impacts presented. The framework systems for each building will also be compared in terms of durability, resistance to the local climatic conditions, and in terms of embodied carbon levels arising from initial material production processes. Additionally the frames will also be assessed, regarding ease of adaptability needed for modifications, arising due to ongoing maintenance and/or repair requirements, or future changes of use. The level of recycling/repurposing that can be achieved, for each material, will also be considered at the end of the building lifecycle.

Why consider the sustainability and environmental impacts of materials?

Prior to embarking on the comparison of steel and concrete frameworks via selected case studies, I would like to emphasize why there is a general focus, throughout the construction industry, concerning sustainability and environmental impacts of materials and their place in the building lifecycle; consider the following quote, from the Ellen MacArthur Foundation website (Ellen Macarthur Foundation, 2019), in a section outlining the global need to look at adoption of the principle of a 'circular economy', a model proposed to replace our current 'linear' economic system, which relies heavily on continual supply and consumption of 'finite' resources, produced primarily using non- renewable energy resources such as coal and oil.

We must transform all the elements of the take-make-waste system: how we manage resources, how we make and use products, and what we do with the materials afterwards. Only then can we create a thriving economy that can benefit everyone within the limits of our planet.

A recent article titled 'Second Life' in Concrete Quarterly (Concrete Quarterly, 2019), identifies one of the many ways we could achieve this: "For buildings and structures, this can be achieved through demount ability and reuse elsewhere, or reuse of a structure in place – the latter being arguably a less energy-intensive activity. Both require some long-term thinking on the part of designers in the early decision stages."

The point I would like to emphasize is that during my research for this assignment, I observed that the construction industry uses many finite resources at all build stages, e.g. sand, a major constituent of concrete and non-renewable energy resources to produce materials such as coal, steel and plastics. Construction industry suppliers, contractors, designers, industry policy makers and construction bodies, such as the Building Research Establishment (BRE), all widely acknowledge that this needs examining, and has led to the industry as a whole working concertedly towards developing further tools and strategies, to enable our approach to be 'circular' and carbon zero' based, rather than 'linear' and 'finite' to provide environmentally resilient, and sustainability sound buildings for the 21st century. In the final section of this assignment I will briefly review the findings of my case study comparisons, considering which framework system would be considered best in this instance, in terms of a circular, carbon zero approach.

Section One

Comparing positive and negative physical properties for steel and concrete

Prior to examining the selected case studies, as a point reference summary tables are presented below to show positive and negative physical attributes, along with the most common applications in construction for steel (See Table One below) and concrete (See Table Two below)

Table One: Comparison of the positive and negative physical properties of Steel and summary of applications in construction

Positive Properties	Negative Physical Properties	Uses of Steel in Construction
High tensile strength	Can deflect and/or buckle with heavy loading. Cross bracing and other strategies, need to be employed to mitigate effects, may involve higher costs re requirement for more steel structures to provide bracing and extra labour and energy to be used to weld structures to the framework/supporting structure.	Rebar/cages/pre and post tensioning in concrete beams/structures sub and super structures Can be used to produce beams in buildings requiring long spans, which can allow for ease in over- all adaptability of the building regarding future modifications, potentially saving on material use and costs over lifecycle of the building.
Strong yet flexible,	As previous point	Popular with designers as can be used to accommodate curved

ductile.		facades. Also highly versatile material used widely to produce pre- fabricated structures i.e. infill panels and modular units. Unlike concrete there is no issue with waiting for steel to develop strength, it is a metal and as such density and integrity of the strength of the material does not vary on initial production (i.e. it maintains strength on casting and is ready to use without further modification post initial manufacture) Steelwork frames are also comparably lighter than reinforced concrete frames, requiring comparably smaller foundations to spread the load (subject to existing ground -site conditions)
Durable Does not rot/fire proof if protected.	Can corrode in certain environmental conditions, i.e. marine. Needs intumescent coatings to protect it from	Used externally and internally in a variety of low to high-rise building frameworks, internal beams, bracing, floor and roof structures..

	fire.	
Can be 100% recycled	A large amount of energy is used during extraction of the raw iron ore, blast furnace production processes to make pig iron Converted to steel in Blast Oxygen Furnaces and /or recovered from scrap sources in Electric Arc Furnaces More energy is then required to process the virgin steel into billets and the further energy is used in integrated steel mills to make structures such as large plates/rod/wires and pipes, ready to go to fabricators, manufacturers/ secondary processing into products / other applications. Results in a high-embodied CO2 value for steel manufacture and waste products from coke used in blast furnaces: Ground	End of life, recovered steel can be re- melted and integrated into new steel production, using a third of the energy required to produce virgin steel, in constant concrete is not renewable nor 100% recyclable.

	Granulated Blast Furnace Slag and Pulverised Fuel Ash, GBFS/FA can be utilised to as alternative constituents in concrete production offsetting some proportion of the contribution to emissions in hybrid systems.	
Lower thermal conductivity in comparison to other metals used in construction i.e. aluminium and bronze	Despite relatively lower thermal conductivity of stainless steel, requires insulation to prevent excessive heat loss in buildings, (unless paired with masonry) Expansion in high temperatures, this could be an issue with respect to framework structures and junctions/fastenings if not properly detailed to mitigate action of extreme heat.	Paring back the framework of steel frames allows for a variety of innovative insulation methodologies to be applied (see Red Bridge House example below) Precast slabs * can be used in conjunction with metal decking and left exposed to enable a certain degree of thermal mass to be achieved, using a steel framework and can contribute to net carbon emission savings over the life of the building, when considered with overall insulation and ease of adaptability, which use of a steel in the framework confers to the building, should future modifications

		be required. *Limitations are set on depth to relative value of 100mm, with the underside incorporating a faux covering for ceilings below, which reduces efficacy for heat absorption/release cycles.
Quick and accurate in assembly, can be bolted into place.	Heavy to handle may require heavy machinery, i.e. cranes. Expensive to transport.	Framework, panels and modular units can be CAD designed in a factory setting off site accurately and safely, to produce structures with minimal waste, from virgin manufactured steel. Crucially aligned holes for services can be designed with precision, saving time on site regarding co-ordinating other trades, during the build (and materials can be incorporated at the same time to prevent thermal bridging where there are junctions) Steel products above are also deliverable ready for assembly on site /require no 'wet' trades, which could involve weather, temperature dependencies (and possible delays),

		as many of these elements can be bolted together on site.
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Table Two: Comparison of the positive and negative physical properties of Concrete and summary of applications in construction.

Positive Properties	Negative Physical Properties	Uses in Construction
Strong: High in Compressive strength.	Weak in tension, low tensile strength, can mitigate with reinforcement with steel bars, cages and/or pre/post-tensioned rods.	Beams, blocks, columns, sub structure, frameworks, and facades of low and high -rise buildings. Can be cast in situ or precast and placed on site to make efficiency savings in programme/build time on site, e.g. for vertical elements/ other flat work forms.
Flexible: Concrete can be poured/pumped into formwork/moulds	Time-consuming process mixing and casting into formwork/shuttering, affected by water and temperature during the process, as strength is	Popular with designers due to its compressive strength and ability to be cast into many shapes/forms. Also highly versatile material, which can be adapted to offsite

and form wide variety of shapes. Adaptability useful for in situ casting (e.g. if concrete can be designed in mix ration to enable it to be pumped at height during construction of tower blocks, or to be pumped into complex formwork for beam or solid wall panel construction.	determined by water to cement ratio: Does not reach full strength until 28 days, after initial set, also can be restricted by weather conditions onsite with respect to placement, regarding temperature and moisture conditions. Admixtures/changes of water ratio required to produce concrete for adapting to different on - site requirements or environmental conditions (e.g. extreme heat or cold, which can affect setting and curing)	production i.e. pre-, fabricated floor slabs and composite beam structures. Probes can be used, to mitigate and monitor values for strength in cast concrete, to enable compressive strength to be determined as early as possible, to help with programming/ faster build progression.
Durable: Does not rot and is naturally fire resistant.	Can corrode in certain environmental conditions, i.e. in presence of extremes of acidity or alkalinity, e.g. foundations cast in soil with high levels of hydrocarbon/sulphate contamination, requires	As per previous point: used externally and internally in a variety of low to high-rise buildings, due to longevity and natural fire resistance.

	admixtures or other, to prevent conditions such as concrete 'cancer' Can also suffer from cracking if reinforcement eventually fails or from damage/inappropriate building load/shear force over building lifecycle.	
Good Thermal Mass: Concrete combines high storage capacity, density, and a moderate thermal conductivity.	Large amount of energy is needed to heat, a mixture of the Limestone and other raw materials in cement kilns, to temperatures of over 600 °C (1,112 °F) achieving fusion at temperatures of about 1,450 °C (2,640 °F) to produce the clinker required to make Portland Cement: Requires further energy input for in grinding mills, to	Concrete is widely used in substructures, frameworks and internal beams, wall and floor structures not only due to it's compressive strength and durability but also because of it's ability to confer good thermal mass: Due to possessing high storage capacity, density and a moderate thermal conductivity, concrete allows to absorption and release of heat over the course of a day, within a building: Can further allow moderation of internal temperature changes in a

	be then mixed with gypsum to make cement powder ready for concrete production. This results in a high-embodied CO2 level for concrete, regarding inclusion of cement as a major component although waste products: from steel production; Ground Granulated Blast Furnace Slag and Pulverised Fuel Ash, can be utilised to a certain extent as alternative constituents in concrete production offsetting some proportion of the contribution to emissions.	building and so enabling less energy over the life cycle of the building to be used to power heating and cooling systems to ease internal climate conditions.
Reduces noise and vibration	-	Important consideration in managing acoustic quality and privacy within buildings.

Section Two

Introduction to example case studies:

Case- Study Profile One: to illustrate properties and applications of Steel in construction:

(Smerin Architects, 2014)



Figure 1: Rear elevation view of the Red Bridge House, Crowborough

(Crocker, 2019)

The Red Bridge House (steelconstruction.info, 2019) was commissioned as a new build to be, at the outset, not only original in design but to also to minimise its impact with respect to the immediate environment during construction, and to have consideration to long term sustainability. It is set in a woodland location in the East Sussex countryside, and occupies three floors, with the upper /middle storeys comprising living and sleeping accommodation and the lower storey a swimming pool.

The new build is situated on the footprint of an original dwelling, minimising the impact of casting a new extended substructure, it also steered the decision to incorporate the balcony, which extends beyond the original perimeter boundary of

the former, in brief the steel frame comprises a cantilevered structure, with stainless steel tensioning rods on the outer edge of the balcony as a mitigation measure against buckling.

In Fig One and Two, we can see how the steel frame work was designed to appear minimal and to allow for efficient incorporation of insulation into the external envelope of the house, which also incorporates a timber clad finish on three sides and glazing on all four elevations to access views of the surrounding countryside.

Overall it demonstrates many applied uses for the strong, flexible and high tensile properties of steel; the main framework facilitated a 15m span to be accommodated for construction of the ground floor swimming pool, also incorporating a two story 'Vierendeel truss' to allow for 'floor to ceiling openings' on the upper floors.

The latter includes a wrap around veranda, stabilised by a series of stainless steel hanging rods, supported by the overhanging steel beams (see Fig One) Externally the aesthetic properties of steel have been further utilised by use of weathered steel to construct the steel plate bridge providing access to the front door (See Fig Two)

Being in a ecologically sensitive site (ancient woodland), with reduced access, and where proximity to the ancient woodland necessitated additional fabrication and/or welding needed to be restricted, the choice of steel for framework was obvious in this case as it could be produced offsite into smaller, deliverable units, to enable efficient, accurate reassembly, using simply detailed connection systems; furthermore each floor is essentially a single modular unit allowing for numerous future reconfigurations, and is completely recyclable at the end of the building's life cycle.



Figure 2: Front elevation of the Red Bridge House Crowborough

(Crocker, 2019)

Table 3: Summary table to show key criteria for framework choice for Case Study One

Key Comparison Criteria for the Red Bridge House	Location restrictions/project restraints	Observations regarding framework choice
Durability and climatic resistance	The met office notes that Sussex is one of the sunniest counties in the UK, enjoying sunshine averages of up to 1800 hours, with 1550-1600 hours being, typical, with mild wet winters and moderate winds, due to its sheltered location. (metoffice.gov.uk, 2020)	Steel framework is minimised to accommodate external insulation and cladding. Weathered external steel cladding is not only aesthetically pleasing, but is also a sensible choice, in the mild, wet and humid climatic conditions

Impact of Steel work Frame re: original production process on environment	Production of steel, uses a large amount of energy, using coke in the initial stages to produce pig iron, which is used to make virgin steel (See Table One, Section One)	The framework suppliers, for this build are local (Southern Fabrications Sussex Ltd), which though not a replacement for the embodied CO2 levels in steel works to offset some of the carbon footprint accumulated by reducing transportation costs to site.
Ease of Assembly of framework	The framework was broken down into small units, for easy delivery and erecting onsite, to avoid use of heavy onsite machinery in such a sensitive setting	Steel is a versatile, ductile material, which lends itself to off site fabrication, and the mode of fixing, being essentially a 'dry' process, enables accurate, precise construction and placing of services.
Ease of Adaptation of framework	The design is modular where each floor is essentially a single unit, allowing easier future modification and/or with the removal of external cladding and glazing , openings can be changed without causing	The high tensile strength in steel enabled a 15m span to be achieved to enable the inclusion

	major structural changes.	of the swimming pool 'floor to ceiling openings' on the upper floors, crucially the properties of steel in this instance supported a longer span, supporting the application of a modular design, to enable future change of use
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Case Study Profile Two to illustrate properties and applications of Concrete in construction:



Figure 3: The Concrete House, view of the front elevation

(cemex.co.uk, 2020)

The 'Concrete House' (cemex.co.uk, 2018) (see Fig 3) is as in the former case study, located in East Sussex, Lewes but nearer the coast, rather than in woodland, and is an unusual self-build, consisting essentially of a series of interlocking, connected concrete modules, covering 250sq/m less than four different concrete design mixes (provided by the supplier: Cemex UK) to achieve the correct strength for the structural walls, floors and roof and sub-structure and to counteract any heat losses arising from junctions between joints in the previously described structural elements. Table 3(see below) summarises the mixes used and their properties and functionality with respect to this particular build.

In the interests of saving programming time, and to improve efficiency in pouring the design mixes, the client worked with another supplier: Peri UK who used the project as a test case for Duo®: a patented, a plastic formwork system, which the client describes on his own website (cite) as being a 'technopolymer' and 'is fully recycled, fully recyclable, and no element weighs more than 25kg. It can be used in both vertical and horizontal forms creating simplicity on site' .In brief being light and easily assembled by novice builders, this avoided the need for use of heavy machinery to lift concreted sections into place, avoided wasted materials from discarded wooden formworks, and saved overall on project time and costs.

In addition, (referring to Table 2 above), we know that concrete has good thermal inertia and we would therefore infer that this design has a good built in 'thermal

envelope' and would work well to naturally control daily temperature fluctuations for the inhabitants. The density of the concrete forms also confer durability with respect to the local climate, which as in case study one, is made up of wet, humid summers and relatively mild but stormy winters, but relatively sheltered from excessively high winds and precipitation.

Considering carbon foot print impact of the frames original production process, referring back to data in Table 2, Section One, we observed that concrete, however innovative the mix, in the first instance embodies a large amount of carbon, due to the high energy requirements (currently most industrial production is powered using non- renewable sources) We could infer therefore that the overall Carbon footprint of this project is proportionally high, although this may be offset by the long term thermal efficiency of the design, as a result of the high storage capacity of concrete, also with savings made by reducing the amount of steel reinforcement and raw materials required for formwork, during in situ casting of the sub and superstructure of the building.

Table 4: Summary Table to describe CEMEX design mixes used and their functionality/properties

Cemex product	Type	Properties
Resilia HP	Fibre-Reinforced Self Compacting Concrete	Used for walls and horizontal elements, self-compaction quality allowed. Allowed 60% less steel to be used as reinforcing agent- reduced programming time as a result due to less steel needing to be fixed. Highly ductile, allowing for

		thinner sections of cement to be cast
Insularis,	Designed to form 'thermal break' in concrete structures.	Possesses low thermal conductivity in relation to traditional concrete mixes. Enables concrete applications to be continued through junctions, whilst maintaining strength and avoiding need for insertion of plastic/other component types to act as thermal breaks In concrete house build-formed kickers at the base of the external walls to combat heat loss.
Resilia Conventional mix,	Standard concrete in Cemex range.	Used to form ground slab & up stands between the changes in ground level with the different modular component structures of the building
Evolution F Self Compacting Concrete (SCC)	Concrete for floor applications, self compacting	Flexible mix that allowed application across all the different floor levels and to accommodate under floor heating, due to

		admixtures, which allowed for a flexible pre-set mix that could be worked to achieve the high quality finish required for the internal floor specifications.
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Finally, with respect to future modifications, the modular design, may enable reconfiguration to a certain extent but having chosen concrete as the main framework material, changes, would still involve some demolition and recasting, with further imports of the primary framework materials and possible costly rerouting of services, e.g. with respect to re routing the under floor heating services.

This overall would add to the total carbon cost of the building, but again could be offset by the longevity of concrete as a material, minimising future repairs and renewals.

Section Three

Summary of case studies:

Comparing the frameworks in both case studies, which share the same climatic conditions, both steel and concrete, would prove durable and able to withstand the relatively mild, wet winters and hot humid summers that occur in East Sussex. It was not in the scope of the assignment to go in to all of the ramifications of climate change with respect to the location for both case studies and what this would mean regarding, required adaptations for both building, in case of extreme weather events, e.g. flooding. In both instances however it could be considered that the properties of both steel and concrete would withstand some of these events and allow the buildings to be recoverable.

In terms of the environmental impact, caused by the production of both types of frameworks, it is a fact that both materials require large amounts of energy during manufacture and fabrication, (aside of transportation to site and energy used to incorporate the materials within the build and any further energy use arising from future adaptations to the building/modifications and eventual demolition at the end of the lifecycle)

Accurate assessment of the carbon foot prints of these buildings could be obtained by running the production and design specifications through 'a carbon footprint' tool such as that referred to in the Tata Steel document 'Steel Construction: Embodied Carbon' (www.steelconstruction.info, 2014) (this particular tool was developed in conjunction with PE International and Jane Anderson lead author of BRE's Green Guides to Specification)

It can be used to run building data at the start of design planning, to allow evaluation of the use of different material specification scenarios. The results are expressed as single CO2 emission figures and also provide a bar chart showing contributions of all the elements of the building.

Despite the compelling case for concrete, regarding innovation in cement production see as detailed in a recent publication authored by MPA: the Concrete Centre (MPA

The Concrete Centre, 2019) the case comparison studies detailed in the Tata Steel document 'Steel Construction: Embodied Carbon' (www.steelconstruction.info, 2014) makes an equally compelling argument for use of steel and indicates that overall use of steel is more sustainable in application to whole life cycle thinking (from 'cradle to cradle') and future adaptability of buildings.

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