CRITICAL ANALYSIS OF BUILDING PERFORMANCE BENEFITS AND COST COMPARISION OF REINFORCED CONCRETE, STEEL AND TIMBER FRAMED BUILDING

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The British Association of Reinforcement (BAR) is the trade association of UK manufacturers and fabricators of steel reinforcement products including cut and bent and mesh. BAR aims to add value to the UK reinforcement industry through market and product development, promotion of good industry and health and safety practices and forwarding the development of the reinforced concrete industry as a whole. All BAR members are audited and approved by recognised industry accredited quality schemes.

TABLE OF CONTENTS

List of Tables, Figures and Equations

Welcome from the British Association of Reinforcement

Whilst there have been a number of cost comparison studies comparing the costs of concrete, steel and timber construction there has never been a comprehensive study of the costs of additional finishes for long-term occupational performance.

There is much anecdotal evidence and understanding of the inherent performance benefits of concrete construction. Fire resistance, flood resilience, sound insulation, vibration damping, thermal efficiency and robustness are all provided free-of-charge. There have been few specific studies that examine the financial and environmental advantages of these inherent concrete benefits of the extra costs for the additional finishes necessary for steel and timber construction.

With this in mind, the British Association of Reinforcement invited the University of Greenwich to undertake independent research to determine if the supposed inherent performance benefits of concrete construction translate into real economic advantages over steel and timber.

The research findings make interesting reading. They underline the need to include performance benefits when determining the real overall cost of a building's construction. It seems that the anecdotes have a concrete reality.

Stephen Elliott
Chairman
British Association of Reinforcement

Executive Summary

Most construction cost studies are focused on initial capital and construction costs, they do not address the additional costs of a building's performance in terms of acoustic, fire protection, and thermal insulation, insurances, vibration performance and robustness. This study aims to address this and examine the differing performance and operational cost between concrete, steel and timber framed construction.

A systematic cost analysis was performed on an identical building, using different concrete and steel construction techniques. Following on from that, critical documentary analysis was used to compare the actual cost of construction using data from the RICS BCIS. and the data was then analysed statistically and discussed.

It was found that concrete construction provides many inherent performance benefits such as acoustic, fire protection, thermal insulation, insurances, vibration performance and robustness. The free cost of these benefits are generally not considered in cost comparison literature. It was found that when they are considered concrete construction is lowest in cost compared to steel and timber framed building.

This study adds to the library of construction cost studies by contributing to the cost of construction technology debate. In particular, the operational and the costs for additional finishes. It recommends that performance costs should be considered both explicitly and implicitly as part of a building's overall cost.

Dr George Agyekum-Mensah
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1.0 Introduction

True cost comparison details of construction materials are scarce. Previous studies on cost analysis are mainly focused on the independent cost of construction without critical comparisons and without considering the performance benefits such as acoustic, fire protection, thermal insulation, insurances, vibration performance and robustness. Therefore, the main aim of this study is to provide a comparative cost and examine the performance benefits of concrete structures, steel, and timber framed construction. The main objective of this study is to compare the overall cost of preparing identical buildings using different techniques of construction materials and determine whether although some building techniques may be considered quicker and cheaper than others, the overall cost, with the necessary additional performance costs, might favour a different construction method.

Schneider (2017) conducted a study in the USA and reported that concrete frame is less expensive, compared to other competitive methods. He recommended that studies be undertaken to evaluate the use of similar construction techniques and their associated construction cost impact on other typical building types such as, schools, retail establishments, and commercial office buildings.

2.0 Critical discussion of construction techniques and cost elements

Concrete Frame

Concrete is a material that is often locally sourced; thus, typically requires minimal energy to transport to building sites. Concrete possesses unique durability and flexibility (in fact, it is argued that one can shape anything out of concrete). Concrete has the capacity to carry high compression loads but weak in tension (International Atomic Energy Agency, 2002). It is also asserted that public and private developers should also realise that using cast-in-place reinforced concrete to frame a high-rise office building would yield more rentable space because of lower floor-to-floor heights. Concrete can be off site construction (precast) or on-site construction (in-situ). The latter presents a major advantage for concrete frame especially for very restricted construction site where there is very little space for pre-fabrication storage. Usually the rebar for reinforced concrete is produced from recycled steel (International Atomic Energy Agency, 2002; Cao et al, 2019). At the end of its functional life, concrete can be crushed and recycled but one can argue that the recycled material may not be used for new building concrete. However, up to 95% of the reinforced concrete is recyclable for use in road and runway sub-bases. In the UK, 25% of its aggregates supply comes from the recycled aggregates (The Concrete Centre, 2016).

Concrete can endure very high temperatures from fire for a long time without loss of structural integrity. Therefore, concrete requires no additional fireproofing treatments to meet stringent fire codes and performs well during both natural and manmade disasters (The Concrete Centre, 2016). Insurance companies recognise the benefits of a cast-in- place reinforced concrete office building because the benefits of increased safety and structural integrity; reduce liability on their part and therefore, attract lower premiums. The cost of ready-mix concrete remains relatively stable, even the increase in the cost of steel has had a minimal effect on reinforced concrete building projects. While cast-in-place concrete construction can be pricier on the front end, the return on investment achieved can lessen the cost differential.

Steel Framed

Steel's strength and ductility, combined with solid engineering and design, make it a safe choice in seismic zones. The inherent redundancy of the steel frames can prevent structure's collapse. Steel framing does very well under high wind loads because it is ductile, which means it has the ability to bend without breaking and can absorb energy. Steel can soften and melt with exposure to extremely high temperatures. However, with the addition of passive fire protection, such as spray-on fireproofing, buildings constructed of structural steel can sustain greater temperatures and therefore, provide additional safety (Brockenbrough, 1999). Apart from the aforementioned properties, the most important behaviour of the stainless steel is its ability to resist corrosion (Total Materia, 2020); yet this is hardly used in construction. Perhaps, this is due to the cost stainless steel as it is very expensive.

Timber Framed

Timber framed structures have been gaining relative coverage in the construction technology discussion in the last few decades. It is argued to be preferred to other competitive materials due to low CO^2 cost compared to other construction materials such as steel and concrete. Timber frame is a structure that transfers vertical as well as horizontal loads to the foundations. (Timber Frame Suppliers 2020). Timber frame building possesses other inherit advantages including energy efficiency performance, recycling and re-use of wood and wood products, and using recovered wood for energy generation.

Timber is natural organic material which is environmentally friendly and renewable. It can last for many years given the right conditions for preservation; however, the natural durability of timber is mostly questioned. Natural durability refers to the natural resistance of timber or wood against biologic degradation such as fungal decay and insect attacks (EN 350, 2016). Other than in the cases of fire, fungal and insect attack, timber is an extremely resistant and durable material. The most important characteristic of timber is that it is sustainable because the stock can be replenished.

There is much misconception about the ability of timber to perform under harsh conditions; however, the correct choice of product, good design and the help of technology mean that almost any end-use can now have a timber-based solution. However, durable construction timbers take between 15 to 20 years and over 25 years respectively to mature. The reduced availability of durable construction timber due to growth maturity years removes timber from true construction cost comparisons. Therefore, the next section will focus on concrete and steel comparison.

3.0 Comparison of concrete and steel framed building

Table 1 presents the key factors between concrete and steel framed construction that inform their choice as it is discussed in literature.

Table 1: Comparison of concrete to steel framed building

Factors	Concrete structure	Steel structure
Durability	Concrete structures have high integral durability	The durability of steel structures can be adversely affected by weather conditions and rusting
Scrap value	The scrap value of concrete is good considering the increased costs of aggregates and landfill	The scrap value of steel is good for recycling
Strength	High compressive strength but lacks tensile strength. Needs steel reinforcement to increase tensile strength, ductility and elasticity	Extremely strong, high stiffness
Foundation	Greater foundation required for the heavier weight of concrete structure	The steel structure can be made with minimal foundations. Example, simple warehouse
Construction time	Concrete structures generally need 28 days before they are ready for use	Steel structures are fast to erect and can be used soon after erection. However, prefabrication time must be considered
Labour	Requires less skilled labour	Requires more skilled labour
Flexibility	Can be in situ or pre-fabrication and can be formed into any shape. Can be use on congested urban sites	Usually, prefabricated and erected on site. Difficult to use on congested urban sites
Cost	The cost of construction is less expensive; since the material prices are relatively constant	The cost of construction is more
Joining	Joints such as construction joint, expansion joint, contraction joint, etc are needed in concrete structure	The steel component is joined by using rivets, welding, nuts & bolts, etc. in steel structure
Sustainability	Concrete may be crushed and used for future and can be 100% recycled. Reinforcement is manufactured from 98% recycled steel	Steel is almost 100% recyclable; up to 90% of all structural steels are manufactured from recycled steel

Cost of Steel and Concrete framed building

Even though costs of materials significantly fluctuate over period of time, there is no significant difference between the frame costs for concrete and steel.

A cost comparison conducted by the Concrete Centre (see below) showed that construction costs for concrete and steel frames are very similar – with concrete being slightly cheaper.

Table 2: Comparison of concrete and steel frame costs

6 Storey office	RC flat slab	£26,224,107
	Steel composite	£26,619,649
3 Storey office	RC flat slab	£6,525,807
	Steel composite	£6,601,819

Source: (The Concrete Centre, 2014)

4.0 Performance analysis and cost

Tables 3 and 4 present the performance analysis of the three main different framed construction. Eight main factors were considered which have significant cost to the structure. It is established that concrete framed has several inherent performance cost benefits compared to steel and timber framed buildings. A further analysis on the usage on building types illustrates that the usage of concrete frame cut across all the building types which could be attributed to these inherit performance cost benefits.

Earlier studies suggested that concrete can have a higher initial cost [Hicks et. al. 2004], although Goodchild [1993] argued otherwise. Recent studies such as Schneider [2017], and VanderWerf and Haidari [2017] showed that concrete construction is less expensive when other factors such as operational performance and insurances are taking into account. Tables 3 and 4 present the performance cost factors analysis in relation to the true cost for different construction building technologies for steel, timber, and concrete.

Table 3: Performance analysis

Factors	Concrete Framed	Steel Framed	Timber Framed
Acoustic insulation	High - This is an inherent property	Poor - Additional provision should be allowed	Poor - Additional provision should be allowed
Fire protection	Provides high level of inherent fire protection	Low level of fire resistance. Requires additional fire protection finishes	Very low level of fire resistance. Requires additional fire protection finishes
Thermal insulation	High thermal insulation inherent	Low – additional provision should be made	Medium – additional provision should be made
Insurances	Low insurance	Medium Insurance	High insurance
Vibration performance	High vibration performance	Medium vibration performance	Low vibration performance
Energy Efficiency	High energy efficiency	Medium energy efficiency	Medium energy efficiency
Maintenance	Low maintenance	High maintenance	High maintenance
Robustness	Resistance to rusting and does not get corroded by the action of termites	Corrosion or rusting	Termite and rot prone

Table 4: Performance Benefits Analysis

Factors	Concrete Framed	Steel Framed	Timber Framed
Acoustic insulation	No[1]	Yes[2]	Yes
Fire protection,	No	Yes	Yes
Thermal insulation,	No	Yes	Yes
Insurances,	Low	Medium	High
Vibration performance	No	No	Yes
Energy Efficiency	No	Yes	Yes
Maintenance	Low	Medium	High
Robustness	Low	Medium	High

1 No means no additional cost needed
2 Yes, means addition cost is needed

Acoustic and thermal insulation

Acoustic and thermal insulation play major role for occupant comfort and energy efficiency. Concrete frames are known for providing the inherent benefits of excellent acoustic and thermal mass at no extra cost. Timber frames provide medium level of acoustic and thermal proof in relation to steel. In steel framed building, additional acoustic and thermal construction is needed at extra cost. It might not be surprising that steel is not often used for residential buildings.

Fire protection

In terms of fire safety, the International Building Codes (IBC), ensure that fire resistance is provided on steel although it is inherently a non-combustible material. However, when heated to extreme temperatures, its strength can be significantly compromised. Similarly, timber is less fire resistance unless additional materials of fire resistance is needed. However, concrete is inherently fire resistance, therefore, there is no additional protection needed. For example, when the 28 story Windsor Tower in Madrid collapsed in 2005, the reinforced concrete inner-core survived but the surrounding steel framework collapsed (Montalva et al, 2005).

Insurances

A study conducted by VanderWerf and Haidari (2017) stressed on the importance of cost insurance and its impact on building. This comprehensive study covered many locations in the USA and the quotations were for builder's risk insurance and commercial property insurance based on a 100,000 square-foot, 4-story apartment building comprising 8 two-bedroom and 14 one-bedroom apartments per floor. It was observed that concrete framed buildings were less expensive in comparison to timber buildings. From their analysis, it was established that savings on concrete buildings are averagely, 47% and 40% for builder's risk and commercial property insurances, respectively. A further probing into the reasons behind the significant difference, one factor that stood out was fire resistance or hazard. VanderWerf and Haidari (2017) asserts that this difference in price will continue to grow over the next few years.

Energy Efficiency

With Early Contractors Involvement or Contractor Design Portion, most of this different construction methods should provide excellent energy efficiency. However, it is safe to say that due the inherit acoustic, and thermal resistance in concrete combined with the thermal mass it provides energy efficiency at no additional cost (Schneider, 2017).

Maintenance

Maintenance is relatedly needed for any type of construction although materials are more expensive to maintain than others. It is established that timber framed requires higher maintenance costs. However, it is arguably depending on the type and age of the timber used. Fungal and insect attack, as well as water contact can cause problems with timber construction. Equally, water or in scientific term oxidation is fundamental problem for steel, leading to corrosion and consequently reducing the main benefit of steel construction which is its tensile strength. Hence, appropriate, and professional care is needed for steel in order not to compromise with the security, safety, and longevity of the building. All these additional costs are rarely examined when considering the literature for the cost of buildings. Concrete on the other hand will not corrode naturally however, with reinforced concrete, it should be ensured that appropriate cover is given to the rebar so that they are not exposed during construction. Ageing maintenance cost should be allowed on concrete buildings but it is reasonably low when compared to steel and timber.

Robustness and vibration performance

It has been reported that concrete is more durable and adaptable in its many forms such as in-situ, precast and pre-stressed concrete (Concrete Framed Buildings). Equally, the robustness of steel cannot be discounted as the load carrying capacity of steel structure is excellent. Timber on the other hand is not as robust compared to its competitors. Schneider (2017) simply summarised and emphasised that concrete construction methods result in a safer, far more durable building that is more inexpensive to insure and very cost competitive to build. Concrete and steel provide resistance to mould or fungi growth, resistance to damage from vandalism, and minimal damage vibration performance.

5.0 Study Methodology

This study adopts a critical review on existing performance cost analysis of concrete, steel and timber framed building. A systematic analysis used to ensure a structured approach to the discussion was presented. Knight and Ruddock (2009) stressed on the usefulness of critical and systematic analysis of the field of study which ensured present state of knowledge as well as establishing gaps in knowledge. This was followed by three stages statistical cost data analyses.

Stage 1 – Systematic Review

The first stage of the study was to provide critical review and systematic analysis on performance cost analysis of the three main construction technology for building, steel, concrete and timber. The analysis led to the production of many comparative tables and discussions to understand the present state of knowledge on the performance benefits analysis. Tables 1 to 4 presented important comparative approach, which was a snapshot of the similarities and differences. This led to the stage 2 of the study as presented below.

Stage 2 - Documentary Analysis – BCIS

A systematic cost analysis was performed on an identical building using different techniques of construction so and the data discussed. This cost analysis and discussion was conducted on three different types of concrete framed buildings and steel framed buildings. A total of 6 options were considered mainly three options each for steel and concrete frame building. The options were based on general usage and design of concrete and steel framed buildings and Table 6 provides the details. The overall building costs per meter square (£/m^2) was estimated for each option.

Stage 3 – Systematic Cost Analysis

This stage of data collection focused on a documentary analysis on data from Royal Institution of Chartered Surveyors (RICS) Building Cost Information Service (BCIS). BCIS is a cost data-based system which collates past project analyses of UK projects. It also provides data to enable cost forecasting and cost planning which is maintained by renowned professional institution, RICS. In this study, however, past cost data were examined for two main objectives.

1. To establish the frequent use of concrete, steel and timber framed for five main categorises of building types.
2. To analyse the average cost per meter square of concrete, steel and timber.

Objective 1 was address by general analysis of the BCIS data system whilst objective 2 data focused on from 2015 to 2020. The latter ensures that recent cost data were included in this study as well as to establish current cost per m^2.

The cost data was collected by going through the BCIS Online cost analyses with the aim of identifying and categorising into concrete, steel and timber framed buildings. The relevant information was inputted on a spreadsheet and further analysis was conducted to establish the average cost per m^2. Regarding the average cost, the Location Factor (LF) as well as the Tender Price Index (TPI) adjustments were considered to ensure a forecast to a same place and time for fair comparison.

Stage 4 – Synthesis

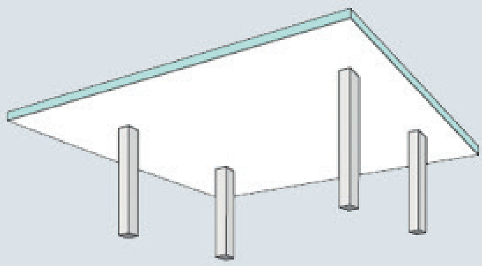
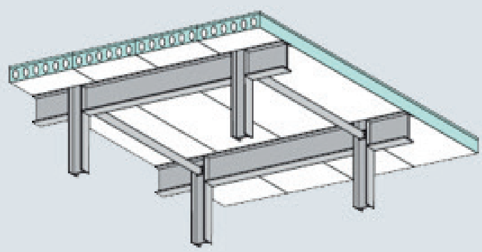
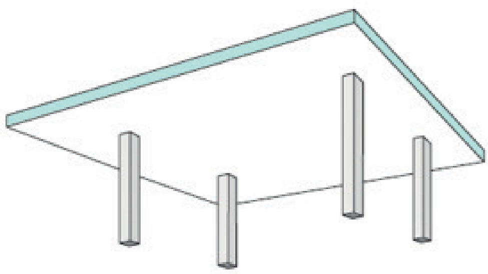
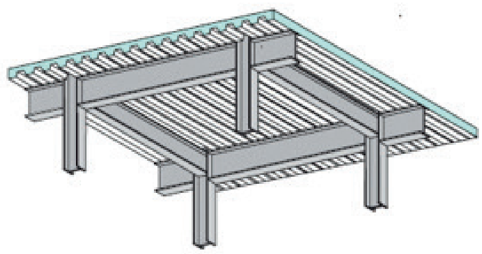
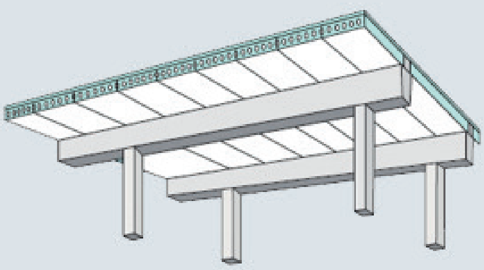
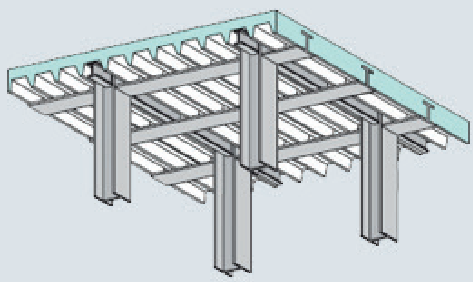
The final stage of the research process was to provide synthesis of stages 1, 2 and 3. This allowed the critical discussion of the various results with the literature to draw robust conclusion.

6.0 Results, Analysis and Discussion

Comparative cost analysis for concrete and steel framed buildings

Cost analysis of identical buildings with different techniques of construction for concrete and steel framed building were presented and discussed. This cost analysis focused on a total of six options, of which three were concrete framed and three were steel framed buildings. Details of the design and techniques of construction are considered in Table 6. The options were professionally designed for identical projects to ensure fair comparison. In the cost analysis, performance cost was not factored or considered; it was mainly elemental cost method. Additional consideration was given to time or proposed duration from specialist constructors.

Table 5: Analysis for different steel and concrete framed building (designed for identical buildings)

Option	Concrete Framed	Steel Framed
Option 1	Post-tensioned (PT) flat slab – Post tensioned in-situ concrete flat slab and reinforced in-situ concrete columns 	Steel and hollowcore – steel beam acting compositely with precast concrete hollowcore floor slab and in-situ topping. Steel columns 
Option 2	Flat slab – reinforced in-situ concrete flat slab and columns 	Composite – steel beams and metal decking both acting compositely with in-situ concrete floor slabs. Steel columns 
Option 3	In-situ and Hollowcore – reinforced in-situ concrete beams and columns with precast concrete hollowcore floor slabs and in-situ topping 	Slimdek – slimdek system comprising asymmetric steel beams and composite metal decking both acting compositely with in-situ concrete floor slab. Steel columns. 

Source: The Concrete Centre 2008a and 2008b

Detail Cost Analysis - Overall cost analysis per m^2

A detailed cost analysis was conducted on each option and the overall building cost was then estimated as per meter square (m^2). It was evident that there is not significant difference in terms of cost per m^2 except with the Slimdek Steel frame which is on the higher side. This was consistent wth literature as presented in Table 2. It was estimated that PT Flat slab of concrete framed is the lowest cost whilst as mentioned Slimdek of steel framed is the highest. Generally, the increase between the two PT flat slab concrete framed building and Slimdek steel framed building is 7.2%.

Table 6 shows the overall building cost per m^2 for hospital project which demonstrates that the highest cost for concrete framed (option 3 – PT flat slab - £2,129.20) is less expensive than that of the lowest cost of steel framed option (Option 1 - Steel and Hollowcore - £2,171.40). This represents 2% drift. One may argue that this is not significant; however, it might make a significant difference in large areas. This is consistent with literature asserting the concrete frame is less expensive to construct than steel. In addition, the average overall building cost for the three options for concrete framed building is £2, 108.43 whilst the corresponding of the steel framed building is £2,197.52. This present 4.2% drift or increase on the concrete framed building. Table 6 presents Overall building costs details in £/ m^2 for hospital projects. Details of the cost data can be found in The Concrete Centre (2008a)

Table 6: Estimated overall building cost per m^2

	Concrete framed		Steel framed	
Option 1	PT Flat Slab	£2,088.00	Steel + Hollowcore	£2,171.40
Option 2	Flat Slab	£2,108.10	Composite	£2,182.45
Option 3	In-situ + Hollowcore	£2,129.20	Slimdek	£2,238.72
Average		£2,108.43		£2,197.52

Source: Davis Langdon LLP in Concrete centre (2008b)

Figure 1: Overall cost analysis per m^2

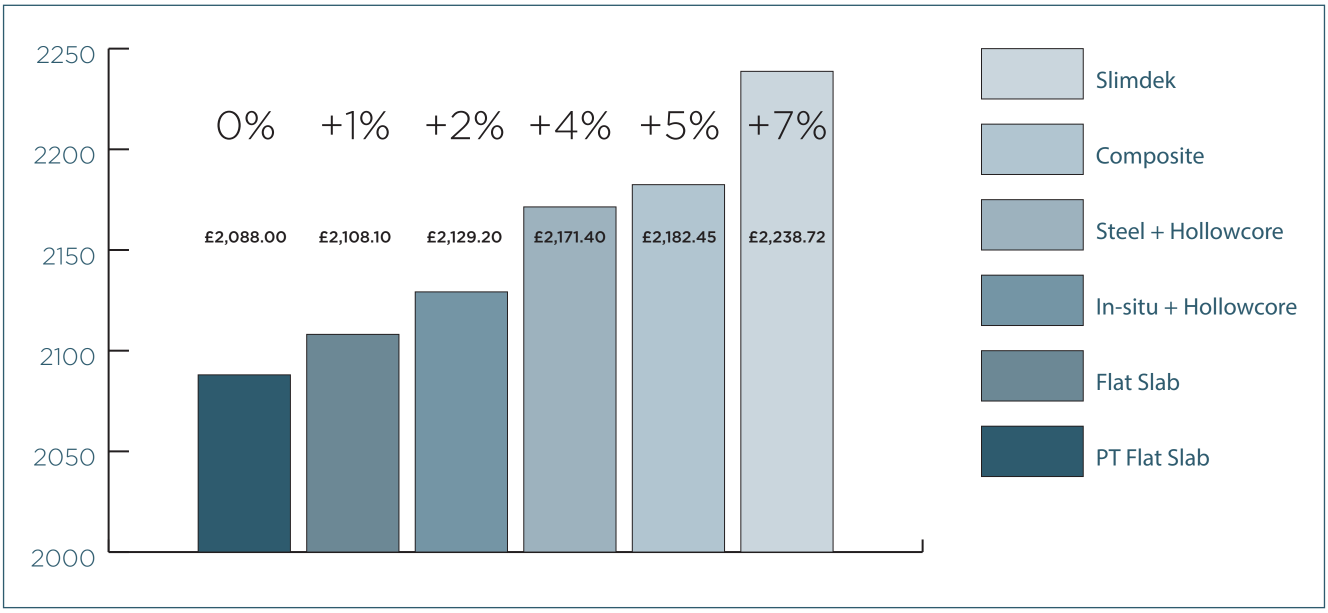


Figure 1 is graphical representation of the overall cost per m^2 of all the options. The concrete framed options are the shade of blue with the black line borders, whilst the shade of grey with red line borders presents the steel framed buildings. The figure also illustrates a drift or increase of the options showing 2% between the concrete framed but 7% for the steel framed building.

Another interesting comparison in this study is the concrete framed – in-situ and Hallowcore and steel framed – steel and Hallowcore shows the latter is 2% higher than the former. It is therefore safe to conclude that overall building cost of concrete framed building is lower than steel framed building. This finding which evident concrete framed has overall building cost lower than steel framed is consistent with the literature (See Table 2).

Table 7 presents the cost analysis of school project with different framed design (concrete and steel). Similar findings as presented in Table 6. Therefore, it is safe to conclude the concrete framed is less expensive regardless the type of building although the difference is not significant. The Concrete Centre (2008b) presents the details of cost data.

Table 7: Cost Data per m^2 for School project

	Concrete framed		Steel framed	
Option 1	PT Flat Slab	£1,459.00	Steel + Hollowcore	£1,492.00
Option 2	Flat Slab	£1,491.00	Composite -	£1,501.00
Option 3	In-situ + Hollowcore	£1,488.00	Slimdek -	£1,588.00
Average		£1,479.33		£1,527.00

Source: Davis Langdon LLP in Concrete Centre (2008b)

7.0 Documentary Analysis - Stage 3

In this section, the analysis of cost data obtained from RICS BCIS is discussed. The main focus is to analyse the average cost per meter square of concrete, steel and timber framed building

Comprehensive Cost Analysis per m² for concrete, steel and timber framed buildings

The cost per m^2 of each building type is analysis from documentary data from BCIS. Data was restricted to projects in and after 2015. This ensured that only relatively recent data are captured in the analysis. The search for the project information ensured that projects which are clearly labelled concrete framed, steel framed and timber framed for main construction methods were selected for this study. The data considered include project reference, location, year of construction, storey height and cost per m^2 at the time of construction. A further analysis was conducted to stimulate if the projects were to be constructed in December 2020 (4Q 2020). Therefore, there was adjustment to the Tender Price Index (TPI) to ensure all data are updated to December 2020 (4Q 2020). Similarly, due to the different locations of the existing projects, adjustments were made using UK mean. This assumes the project would be constructed in the same location. Equation 1 represent the formula used for the updated cost per m^2 – LFc stands for Current Location; LF e is for Existing Location Factor, TPI c represents Current Tender Price Index and TPI e denotes Existing Tender Price Index. Adjustment Factors such as contractor selection and building height were not considered as the impact on the outcome will be insignificant.

Equation 1: Cost update formula

$$\text{Updated Cost/m}^2 = \frac{\text{Cost}}{\text{m}^2} \times \frac{\text{LF c}}{\text{LF e}} \times \frac{\text{TPI c}}{\text{TPI e}}$$

The cost analysis for concrete, steel and timber framed building are depicted in Tables 8, 9 and 10 respectively. Table 11 presents the summary of the average cost. There were many projects in the last five years for concrete framed buildings. The average for the existing cost per m2 was £1,782.54 whilst the after the adjustment to the current date produced an average of £2,039.94. There are varieties of storey height for concrete framed building spanning from 2 to 26 floors with an average of 9 storeys. The data from Table 8 shows that the projects are spread across the UK, indicating the acceptability for concrete framed for all types of building type.

Table 8: Analysis of Cost per m² for concrete framed building

Concrete framed							
Existing Data					Adjusted [4Q 2020] Data		
Item	Location	Year	Storey	Cost/m²	LF	TPI	Cost/m²
33046	London Borough of Barking	Mar-16	26	£1.958.00	0.85	1.19	£1.973.08
33331	Forest HIll, Lewisham, London	Jun-16	6	£1,700.00	0.83	1.16	£1,629.15
33042	Erdington, Birmingham	Jun-15	3	£1,324.00	1.04	1.20	£1,658.04
33626	Ballymena	Nov-18	4	£1,914.00	1.89	0.99	£3,578.49
33351	Lewisham, London	Jan-16	7	£1,621.00	0.83	1.19	£1,592.99
33356	Purley, Surrey	Dec-15	4	£1,395.00	0.88	1.21	£1,482.02
32424	Kensington, London	Feb-16	5	£2,402.00	0.75	1.19	£2,131.49
33726	North West Region	Nov-17	16	£1,786.00	1.03	1.03	£1,899.32
31432	Cwmbach, Aberdare, Mid Glamorgan	May-15	2	£1,343.00	1.03	1.20	£1,664.50
32597	Dalston, London	Jan-15	15	£2,491.00	0.80	1.23	£2,449.80
31665	Belfast	Mar-15	10	£1,123.00	1.69	1.23	£2,339.88
33727	London	Jan-19	5	£2,461.00	0.83	0.99	£2,026.05
32634	West Midlands	May-15	18	£1.655.00	1.05	1.20	£2,094.37
	Average		9	£1,782.54			£2,039.94

From Table 9 below; the steel framed building had existing average cost per m^2 of £3,355.00. However, this cost was reduced after the updated or adjustments to £2,977.19. The average story height is 3 storey. It was also noted that all the steel framed building from the data collected were in the South of England, mainly, in London area. This could be due the advantage of steel framed construction site duration as most elements are pre-fabricated. However, one may also argue that it might be expensive to be use in rural construction.

Table 9: Analysis of Cost per m^2 for steel framed building

Steel framed							
Existing Data					Adjusted (4Q 2020) Data		
Item	Location	Year	Storey	Cost/m^2	LF	TPI	Cost/m^2
33763	London	Oct-18	3	£4,148.00	0.83	0.99	£3,425.24
32080	Abbotswood, Stelling Minnis, Kent	Nov-15	4	£2,490.00	0.92	1.21	£2,766,67
34014	London NW7	Apr-19	3	£4,216.00	0.83	0.98	£3,439.70
33763	London	Oct-18	3	£4,148.00	0.83	0.99	£3,425.24
33081	Lower Brailes, Banbury, Oxfordshire	Apr-17	2	£2,761.00	0.96	1.07	£2,827.76
33215	Golders Green, London	Jan-18	2	£2,367.00	0.83	1.00	£1,978.55
	Average		3	£3,355.00			£2.977.19

Table 10 presented that of timber framed building. The timber framed construction was also assessed although there were relatively lower projects fully constructed as timber framed from the data collected. All the projects were two storey which is consistent with the literature which suggests timber is used for mid-rise buildings. The average cost per m^2 was £2,375.09 which was adjusted to £2,149.33. The increase after the adjustment supports the fact that most of the projects are in the rural districts.

Table 10: Analysis of cost per m^2 for timber framed building

TImber framed							
Existing Data					Adjusted [4Q 2020] Data		
Item	Location	Year	Storey	Cost/m^2	LF	TPI	Cost/m^2
34113	Wendens Ambo, Saffron Walden, Essex	Mar-19	2	£3,626.00	0.97	0.99	£3,477.85
32053	Armadale, Highland, Isle of Skye	Aug-15	2	£1,479.00	1.11	1.21	£1,982.92
31432	Cwmbach, Aberdare, Mid Glamorgan	May-15	2	£1,343.00	1.03	1.20	£1,664.50
	Average		2	£2,149,33			£2.375.09

Summary Average Cost Analysis

Table 11 illustrate the average cost per m^2 for the construction of concrete, steel and timber framed as presented earlier. Significantly, it shows a cost drift of 31% cheaper for concrete framed and 20% cheaper for timber as compared to steel framed construction.

Table 11: Summary of Average cost of per m^2 for each construction frame

Average Cost per m^2			
Construction Type	Existing Cost	Adjusted [4Q 2020] Data	Percentage Drift
Concrete Framed	£1,782.54	£2,039.94	-31%
Timber Framed	£2,149.33	£2,375.09	-20%
Steel Framed	£3,355.00	£2,977.19	0%

8.0 Synthesis and Conclusion

This study discussed the performance benefits and empirical detail cost analysis of concrete, steel and timber framed buildings. It was established that concrete framed has inherent performance benefits such as acoustic insulation, fire protection and thermal insulation. Other qualities are low Insurances, minimum vibration, energy efficiency and lower maintenance. This can relatively reduce both the construction and ongoing costs of a building.

The comparative analysis of cost of concrete and steel framed building illustrated that concrete framed is lower in overall cost when compared to steel framed for the same type of building design. Further cost analysis conducted by adopting documentary analysis using data from BCIS cemented the fact that concrete framed is actually less expensive followed by timber framed. This study is arguably the first study providing detailed cost comparative analysis and detailed discussion on the performance benefits of different construction framed buildings.

The study contributes to the construction cost literature and cost of construction of technology debate and recommends that the additional cost of finishes necessary for a building's operational performance - that are otherwise inherent and free-of charge for concrete construction - should be fully considered.

9.0 References

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