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Sustainable Construction by Means of Improved Material Selection Process

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Abstract

Whilst sustainable construction relates to both a building's structure and the use of proper life cycle processes, the selection of the most appropriate material/s is deemed a considerable undertaking. Throughout a building's life-cycle that extends from design, construction, operation, maintenance, renovation, until demolition, the selection of sustainable material/s is a particularly crucial task for the development and establishment of such structures. Traditionally, there are three main materials for general construction: (1) Steel, (2) Concrete and (3) Timber. These materials not only influence the function within the structure, but also affect the operation cost and energy usage. Operation cost reduction and energy savings are typically elements of the sustainable construction sphere. However, in developing countries, there is a variety of highly critical factors, which can impact material selection as well as the long-term sustainability of the structure, including: Fire Performance, Environmental Impact, Structural Performance (strength and durability), and Functioning Capabilities. Accordingly, this paper will first compare the sustainability of these three key materials and then converse with appropriate processes for material selection. Attention will be given to the sustainable construction recompense associated with the different material selection factors. Doing so ensures a more sustainable built environment by means of an improved material selection process.

1. Introduction

Whilst sustainable construction relates to both a building's structure and the use of proper life-cycle processes, the selection of the most appropriate material/s is deemed a considerable undertaking. The suitability of building materials for various practical uses is determined by their particular properties. Timber, concrete and steel are the most commonly used structural materials in the built environment, and they typically behave quite differently under various loads (Gharehbaghi, 2015).

The following factors (either taken individually or in combination) form the basis for various systems of classification of sustainable materials (Gharehbaghi, 2014):

-The chemical composition of the material, that is their chemical makeup.
-The material mode of occurrence in nature, organic and macrobiotic systems.
-The refining and manufacturing processes, including costs, to which it must be subjected to, before it gains economic importance.
-The material internal (atomic and crystalline) structure.
-The industrial uses and purpose of the materials.

As already stated, there are three types of materials commonly employed in sustainable construction practices; these are:

-Steel: Conventionally steel is an alloy of iron and other material elements combined. Due to its tensile strength, steel is commonly used in construction. Steel can be molded into different shapes and compositions with sufficient heat. In the construction practice, steel is generally used not only in reinforcing components but also to build beams and other structural components.
-Concrete: Concrete, is in essence, a composite material that is extensively used throughout the construction industry around the world. Most concrete mixes use Portland cement and different types of aggregates. Recently, there have been many new developments in reusing recycled concrete as a material aggregate.
-Timber: Timber is one of the oldest materials used throughout the construction industry. Although its use has been slowly reducing, in particular for high-rise construction, timber has been processed into beams and other load bearing structural components over the past. In recent times, timber usage has been mainly for fit-outs and non-load bearing structural components.
These three materials, whether used individually or in combination still provide the primary source for the sustainable construction of the built environment (Gharehbaghi, 2015). Collectively, they almost provide 90% of all the materials used throughout the construction industry (Gharehbaghi, 2015). Hence, the selection of the most appropriate material/s to use in a particular setting is a considerable undertaking from a sustainable construction standpoint. Although there are various methods available to utilize in material selection, processes are not universal and the importance of factors that are to be accounted for differs according to the country of location. As Allwood et al. (2012) correctly conversed, there are multiple hurdles to incorporate sustainability into material selection practices such as overall cost, material's behavior and various design limitations and requirements.

2. Sustainable Construction Materials

A main source of environmental impacts associated with greenhouse emissions comes from the mining of raw materials and their production (Goodhew, 2016). However, Gajanan (2012) argued that the embodied energy for production of buildings was still small in comparison to the embodied energy used for the operation during the building's life. Furthermore, Halliday (2012) correctly claimed that whilst approximately 90% of a structure's CO_2 emissions are a result from the energy consumed during its life, there is much that can be done to reduce that 10% associated with its construction.

Most materials –in particular concrete– is the primary starting point for CO_2 emissions reduction, since it is responsible for approximately 10% of global CO_2 emission's. In addition to concrete, steel and its production processes also produce some CO_2 emission, but not as much as concrete (Woosik et al., 2015). Conceivably, the most emission-less material is timber, since there is not that much pollution produced during its production.

More sustainable forms of materials can exist where recycled aggregates are used in their composition. For example, crushed glass or wood chips can be added, as the basis of concrete aggregates (Khouli et al, 2015). Recently, innovative engineering materials, such as recycled concrete, have emerged with the potential to influence the future of an environmentally sustainable construction product industry.

Steel, concrete and timber are unequivocally the three most commonly used materials in sustainable construction practices. To fully comprehend sustainable construction material selection prcoesses, the commonly used materials need to be thoroughly investigated. For such purpose, three buildings were selected and carefully analyzed. The three buildings were traditional high rise (approximately 18 levels) residential structures in Sydney, Australia. Their age is less than 20 years whereas their material composition consisted of Concrete, Steel and Timber. Nonetheless, the main structural elements of the said buildings were a combination of concrete and steel, with timber being utilized for low load bearing structural elements. All three structures were constructed on deep concrete footing and reinforced foundations of end bearing piles (with some friction piles utilized as well). The analysis of the three buildings was based on the specific materials which were actually used in these three independent sites. Since steel, concrete and timber were the major materials used in these structures, their particular usage and convention require careful analysis. Subsequently, to further demonstrate the utilization of these three materials, tables were developed to exhibit their usage as shown hereinafter. As a basis of comparison, Material Selection Factors [MSF] were utilized.

2.1. Steel

As already discussed, due to its tensile strength, steel is mainly used in construction. Moreover, steel usage in sustainable construction practices is due to (Kibert, 2016):

-Adaptability: Steel can be modified for many requirements, for example, I-beams, continuous beams, structural joints, and so on. This capacity to acclimatize to changes allows for easier development, at the same time assists to extend the lifespan of the structure.
-Ductility: Steel structurally does not distort, rotate, clink, warp or splinter. However, through proper fabrication it can be rolled or cut and turned into a variety of sizes and shapes, all without varying its composition or physical property.
-Durability: Steel can endure extreme forces, such as sturdy winds, earthquakes, hurricanes and heavy snow. Steel is also defensive to rust with the appropriate coating and, unlike timber, is not affected by termites, bugs, mildew, mould and fungi. Besides, steel is more fire-resistant with cement coating compared to timber.

Table 1. Steel usage in construction.

Material Type	Use	Grade	Internal Forces	Structural Use	Joining and Linkage	Composition
Reinforcement Used in Footings						
Mesh	Reinforces footings	SL102	Adds tension to the footing system	Reinforces footings	Held in concrete once set	Steel
REO	Reinforces footings	4L12TM	Adds tension to the footing system	Reinforces footings	Held in concrete once set	Steel
REO	Reinforces footings	6L12TM	Adds tension to the footing system	Reinforces footings	Held in concrete once set	Steel
Reinforcement Used in Concrete Slab						
SL82 Mesh top 25 cover	Used to reinforce concrete slabs	SL82	Mesh provides the concrete with tension and thus prevents it from cracking throughout its life	Used to strengthen concrete slabs	Mesh chairs hold mesh in place temporarily until concrete sets around mesh holding it permanently in place	Steel
Reinforcement Used in Precast Concrete Panels						
RL718 Mesh	Reinforces concrete panels	RL718	Mesh offers the concrete with tension and thus preserves its durability	Reinforces panel	Held in concrete via mesh chairs	Steel

Continued on next page

Table 1 continued

1N16 Perimeter Bar	Extra reinforcement for panels	1N16	Perimeter bars are good in tension and offer this component to concrete	Provide extra REO to slab	Held in concrete once set	Steel
1N16 Trimmer Bar	Extra reinforcement for panels	1N16	Trimmer bars are ideal to provide extra tension to concrete	Provide extra REO to slab	Held in concrete once set	Steel
Edge Beams						
REO	Reinforces beams	3L12TM	Adds tension	Reinforcement	Held in place temporarily by bar chairs & ligatures. Then permanently by the concrete	Steel
Roof Framing						
Roof Beam	Supports roof and passes loads down	250 UB31	Good in tension and compression	Support roof and pass loads down	Plate cleat and cap plate bolted to column from beam	Steel
Roof Beam	Supports roof and passes loads down	310 UB40	Good in tension and compression	Support roof and pass loads down	Plate cleat and cap plate bolted to column from beam	Steel
Wall Tie	Tying walls to frame	PFC	Good in tension and compression	Tying walls to frame	Bolted	Steel
Wall Plate	Aids in lifting panels into position	F17KDHW	Compression and tension	Aids in lifting panels into position	Fixed to panels with M12Trubolts	Steel (240x45)
Bracing	Extra support	16Dia Rod Bracing	Tension	Extra Support	Nails	Steel
Purlins	Support loads from roof	Z20024 Battened Purlins	Compression and tension	Supports loads from roof	Plate cleat bolted in	Cold formed Steel

Continued on next page

Table 1 continued

Purlins	Support loads from roof	Z10015	Compression and tension	Supports loads from roof	Plate cleat bolted in	Cold formed Steel

Table 1 provides a typical example of steel usage in construction. As it can be noticed, although steel can be utilized for beams and other structural elements; generally due to its tensile strength, it is used as a reinforcement constituent, in particular, in conjunction with concrete.

2.2. Concrete

In terms of volume, twice as much concrete is used around the world in construction than all other building materials combined including timber, steel, aluminum and plastic (Gharehbaghi, 2015). Presently, concrete is one of the most versatile and effective building materials on the market. Meanwhile, Portland Cement is considered the most widely used type of cement for daily use in many parts of the world; it is the main ingredient of mortar, concrete, stucco and most grouts. The most common construction material that accounts for the majority of materials used in high-rise construction is concrete. According to Bribian et al. (2011), the contribution of primary energy demand in the manufacture of concrete, excluding aggregates and additives, is 11% increasing to 30% when adding the contribution of CO_2 emissions associated in the manufacture of the concrete. The following table provides an example of concrete usage in construction.

Table 2. Concrete usage in construction.

Material Type	Use	Grade	Internal Forces	Structural Use	Joining and Linkage	Composition
Concrete Slab						
150mm thick RC slab	Provides a stable base and floor for the construction	32MPa	Slab is good in compression but bad in tension. Top & bottom reinforcement provide sufficient tension to the slab. Shrinkage occurs whilst curing and cracks will develop if concrete is not cured properly.	Used as flooring as well as a base. Helps pass loads down.	Starter bars join the RC slab to the panels.	Cement, water and aggregate
Precast Concrete Panels						

Continued on next page

Table 2 continued

150mm RC Precast Concrete Panel	Walls	40MPa	PC Panels are excellent in compression due to the concrete and the reinforcement makes it good in tension as well. Shrinkage occurs whilst curing at the factory and cracks may occur if not properly transported to site.	Supports roofs and ceilings and separates the external environment from the internal environment	Cast in ferrules are embedded in the precast panels. The starter bars from the slab penetrate into the cast-in ferrules and join them sufficiently.	Cement, water, aggregate
Reinforced used in Footings						
Concrete	Provides support and passes loads down	15MPa Blinding Concrete	Great in compression but lacks in tension	Provide support and pass loads down	A piece of rebar rises vertically out of the footing and is bent at a 90° angle into the slab. This is known as a slab dowel and is tied directly to the slab rebar mat.	Cement, water, aggregate
Edge Beams						
Concrete	Provides support & increases the load bearing capacity of the structure greatly	25MPa	Great in compression but lacks in tension	Provide support and passes loads down	Held together by chemical bond	Cement, water, aggregate
Roof Framing						
Column	Passes loads down through structure	125x125x6.0 SHS Column	Concrete component adds compression & reinforcement adds tension	Passes loads down	Dowel bars connected to column and footing	Concrete and steel

Table 2 provides a typical example of concrete usage in construction. As it can be noticed, concrete as a composite material is generally utilized for footings, panels and frames. Steel is particularly used as a reinforcement constituent in conjunction with concrete.

2.3. Timber

As Mouton (2011) correctly discussed, there are many advantages to using timber in the sustainable construction practices. These advantages are:

-Uncomplicated to use. Timber is versatile material, and it can be used in a wide variety of ways and purposes. Timber is easy to install and can be worked with simple equipment. This ease of work reduces the overall energy required for construction.
-Excellent insulator. Since timber is a natural insulator, it helps reduce the overall energy required especially when utilized in windows, doors and floors.
-Minimal production energy. Timer is perhaps the lowest energy-demanding material to be produced. This transfers to very low embodied energy.
-Natural organism. Timber is a natural building material, readily available, non-toxic, and does not leak chemical vapor into the buildings and their occupants. Furthermore, when timber ages, it does so naturally and does not dissect into environmentally damaging materials.
The following table provides an example of timber usage in construction.

Table 3. Timberusage in construction.

Material Type	Use	Grade	Internal Forces	Structural Use	Joining and Linkage	Compo-sition
Roof Framing						
Outrig-ger	Supports awnings	UC15	Tension & Compression	Supports awnings	Bolted	Timber
Fascia	Supports gutters	PFC	Used only for aesthetic purposes	Supports gutters	Nails	Timber
Window Header	Provides extra support above openings	F17 KDHW	Compression and tension	Provides extra support above openings	Nails	Timber (90x45)

Table 3 provides a typical example of timber usage in construction. As it can be noticed, timber is generally utilized for low load bearing structural elements. Although timber has the ability to withstand low-to-mid-range loading, for high-rise construction, its usage has been mainly for fit-outs and non-load bearing structural components.

3. Key Factors in Selecting Suitable Sustainable Materials (Material Selection Factors [MSF])

Generally, buildings expend great quantities of materials, energy and other resources. This produces momentous environmental impacts during construction, operation and the eventual demolition. The main aim of environmentally sustainable and responsible materials is to consume fewer resources, particularly less energy, and to diminish unfavorable environmental impacts (Miller and Kenneth, 2013). At present, the construction and building industry is seeking and moving towards sustainable materials. Utilizing sustainable materials is not only due to the market demands, but also because of potential cost savings (Montoya, 2010). Trying to define sustainability is a difficult task, and one will find as many varied classifications as possible. There are some key points that tend to overlap to provide a workable definition from which to start, and balancing these factors is the key to a sustainable approach.

Traditionally, operation cost reduction and energy-saving benefits are important considerations for sustainable construction. Accordingly, sustainable materials should consider an environmental aspect, such as, CO_2 production, environmental deterioration and so on. In addition, sustainable materials should also consider economic issues, such as, the overall costs, long-term sustainability/longevity, productivity and economic growth, and so on. The latter factors are quite important for the construction of buildings, particularly in developing countries. Collectively, key factors in selecting suitable sustainable materials (i.e. Material Selection Factors [MSF]) can include (Natee et al., 2016; Tucker, 2015):

1.Environmental Impact. Traditionally, to analyze the environmental impact of building materials, the life-cycle of the different materials should be considered. This life-cycle consists of the extraction of the raw materials, the manufacturing, construction, use and demolition.

2.Fire Performance. How a material performs during fires can be assessed through various building codes and test standards. Various Australian codes and standards exist such as AS1684 Residential Timber-Framed Construction. The categories for a material's fire performance typically include:

- Combustible materials, for example explosive and burnable materials such as steel and timber.
- Non-combustible materials, for example non-explosive and non-burnable materials such as concrete.
- Fire-resistant materials.
- Ignition-resistant materials.

3.Structural Performance (Strength and Durability). The strength of a structure/material is simply the load which will break the structure and/or materials (Gharehbaghi, 2014). The durability, for example the life span of a material, is its resistance to deterioration. Deterioration may occur due to physical, chemical or biological factors. Durability is important for structural materials because they are expected to last a long time. Sometimes materials need to be treated in some way to improve their durability. The suitability of building materials for various structure uses is determined by their particular properties. Timber, concrete and steel are known to behave quite differently under load.

4.Functioning Capabilities. The material's functioning capabilities not only include improved Load Bearing Capacity (LBC), but also enhanced stress and strain potential (Gharehbaghi, 2014). Stress strain curve is a behavior of material when it is subjected to load. Structural failure refers to loss of the load carrying capacity of a component or member within a structure or of the structure itself. Structural failure is initiated when the material is stressed to its strength limit, thus causing fracture or excessive deformation. The ultimate failure strength of the material, component or system is its maximum load-bearing capacity.

In addition to these four key factors, other areas, e.g. economics, ease of construction, etc., can also be considered to ensure informed decisions are made when selecting suitable sustainable materials. Different decision making models have been used in construction-related problems in the past, e.g. Georgy and Barsoum (2005), Georgy et al. (2005), and others.

In the herein study, to account for the different factors of concern, e.g. environmental impact, fire performance, etc., a simple additive scoring method is employed to estimate the score of a construction material (MSFi) based on a number of factors (j).

$$MSF_i = \sum_{j=1}^{n} w_j * s_{ij} \tag{1}$$

As described above, 4 factors are taken into account. The score or rating of a material with respect to a particular factor (s_{ij}) is contingenct upon how such material fares in this particualr domain. For instance, concrete is known to perform better than steel in case of fire, while both concrete and steel perform significantly better than timber. This means that the individual score (s_{ij}) for concrete will be greater than steel whereas the lowest score will be given to timber. The weight (w_j) reflects the relative importance of a certain factor comapred to others. When the individual scores/ratings are added up using the given weights, materials can be compared to one another based on the estimated MSF_i scores.

There are two types of additive scoring methods; they are: (a) the weighted scoring models, and (b) the unweighted scorning models. In the latter case, which admittedly is much less common, the different factors are considered to be equally important. For illustration purposes, this will be assumed in this paper.

4. Results and Discussion

Below table provides a comparison amongst the three key construction materials while accounting for the Material Selection Factors (MSF) discussed above. This MSF setting is a vital component in selecting the suitable material for sustainable construction.

Table 4. Materialselection factors (MSF) matrix.

Material	Environmental Impact (1-5)	Fire Performance (1-5)	Structural Performance (1-5)	Functioning Capabilities (1-5)	Overall Rating (/20)	MSF Rating (Percentage)
Steel	4.0	2.0	4.5	4.0	14.5/20.0	72.5%
Concrete	2.0	4.5	4.0	5.0	15.5/20.0	77.5%
Timber	4.5	1.0	1.5	1.0	8.0/20.0	40.0%

As noticed, concrete has the highest MSF rating/score, which is slightly better than steel. On the other hand, timber has a significantly lower MSF, and accordingly it is less likely to be used in demanding areas such as high seismic activity zones. This ranking is based upon an assumption that all the four MSF have equal relative importance. If the relative weights amongst the 4 MSF change, a different ranking may emerge. For instance if environmental impacts are highly regarded due to the sensitivity of area where structure is to be constructed, timber may come at the top due to its excellent environmental impacts rating.

5. Concluding Remarks

Although sustainable construction typically relates to the building's structure and the use of proper life-cycle processes; the selection of the most appropriate material/s to employ is also a significant consideration. This paper focused on the three main conventional materials for general construction: Steel, Concrete and Timber. As discussed, whether used individually or in combination, these three materials provide a foundation for a sustainable built environment. Also, they collectively constitute almost 90% of all the materials used throughout the construction industry. Therefore, the selection of any of these three materials is one of the most important factors that impact the sustainability of buildings. As a part of the material selection process, there are many factors that require careful deliberation. These factors were referred to as Material Selection Factors (MSF). Paper particularly focused on four specific factors, which could affect the material selection. These factors included, Environmental Impact, Fire Performance, Structural Performance (Strength and Durability), and finally Functioning Capabilities. In addition, while the four factors were carefully considered, the three main materials (Steel, Concrete and Timber) were also compared via the MSF equation. Subsequently, it was demonstrated that the concrete and steel are the most sustainable materials for demanding situations, where, structural performance and functional capabilities are of essence. While timber was not collectively highly ranked, it still performed admirably with respect to environmental impacts (higher than steel and concrete). Conversely, timber performed poorly with respect to fire performance, while in such situation concrete performed as the best sustainable material. In conclusion, the MSF ranking was based upon an assumption that the four factors had the same level of importance. Nonetheless, if a different weighting scale is used, the MSF ranking will ultimately shift. Therefore, additional research may be required with different MSF rankings and values to further examine the overall performance between steel, concrete and timber.

6. References

1. Allwood, J, Cullen, J and Carruth, M. *Sustainable materials with both eyes open*, UIT Cambridge; 2012.
2. Bribian, IZ, Capilla, AV, Uson, AA. Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential, *Building and*

Environment, 2011, **46**:1133(8).

3. Gajanan, M. *Green building with concrete sustainable design and construction*, Hoboken: Taylor and Francis; 2012.

4. Georgy, M and Barsoum, S. Artificial neural networks model for parametric estimating of construction project costs, *Journal of Engineering and Applied Science* 2005, **52**: 1050.

5. Georgy, M, Chang, L, Zhang, L. Utility-function model for engineering performance assessment, *Journal of Construction Engineering and Management* 2005, **131**: 558-568.

6. Gharehbaghi, K. Advancements in concrete technology in Australia: geo-polymer concrete, *International Journal of the Constructed Environment* 2015, **7**: 19-29.

7. Gharehbaghi, K. Material advancements for high-rise construction, Proceedings of the 5th International conference on the constructed environment, 16-17 October 2014, Philadelphia, USA.

8. Goodhew, S. *Sustainable construction processes: a resource text*, Hoboken: John Wiley and Sons; 2016.

9. Halliday, S. *Sustainable construction*, Hoboken: Taylor and Francis; 2012.

10. Khouli, S, Viola, J, Zeumer, M. *Sustainable construction techniques: from structural design to interior fit-out: assessing and improving the environmental impact of buildings,* München: Institute of International Architecture Documentation GmbH & Co.; 2015.

11. Kibert, J. *Sustainable construction: green building design and delivery*, Fourth Edition, Hoboken: John Wiley and Sons; 2016.

12. Miller, A, Kenneth, A. *Sustainable construction materials, sustainability, energy and architecture: case Studies in realizing green buildings*; 2013.

13. Montoya, M. *Green building fundamentals: a practical guide to understanding and applying fundamental sustainable construction practices and the LEED green building rating system*, Prentice Hall; 2010.

14. Mouton, Y. *Organic materials for sustainable construction*, London: Wiley; 2011.

15. Natee, S, Low, SP, Teo, E. *Quality function deployment for buildable and sustainable construction,* Springer eBooks; 2016.

16. Tucker, L. *Sustainable building systems and construction for designers*, London: Fairchild Books, an Imprint of Bloomsbury Publishing Inc. Second Edition; 2015.

17. Woosik, J, Hyun-Woo, Y, Seung HH. Quantitative decision making model for carbon reduction in road construction projects using green technologies, *Journal of Sustainability* 2015, **7**:11240-11259.