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A systematic review of green buildings as a tool towards a sustainable construction industry

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Abstract
"Green" has become the stenography term for the concept of sustainable development when applied to the construction industry. Sustainable; or green buildings are developed with aims to reduce the negative environmental impacts and to improve construction design, and operation systems. The last decades have perceived a massive number of researches and studies in sustainable buildings. The objective of this paper is to present a critical review of literature related to sustainable buildings. The major aspects are scope and definition of green buildings considering the three sustainability bottom lines, with various accomplishment approaches. Moreover, assessment tools of green buildings which are seen as a way to increase the demand for sustainable buildings. It is found that the majority of studies focused on environmental aspects whilst other aspects are commonly overlooked. Occupants' satisfaction requirements and the associated measures are briefly reviewed. The findings emphases the importance of the life cycle assessment approach, and also indicated that there is a transfer to widen the scope from only directing and focusing on the building itself to the linkage between building and its users.

Keywords
building performance, energy, environmental aspects, sustainability, and user satisfaction.

1. Introduction

Global CO2 emissions track an upward trend and expected to keep on growing. Construction industry has a massive and increasing impact on the environment; globally, 40-60% of total energy consumption results from building construction, operating; heating, lighting, ventilating, maintenance, and servicing which results in high energy cost for both individuals and business levels, as indicated by, Zhou et al., (2014) and Hoseini et al., (2014). Additionally, buildings generate massive amounts of Greenhouse Gas emission (GHG), which makes them a major responsible for the global warming, Zue and Zhao (2014) and Green et al, (2015), in the time when climate change has become one of the most critical problem, Ji et al., (2009) and Ruparathna et al. (2016).

Green et al. (2015) noted that buildings have a significant contribution to the value and the stability of the economy. The construction industry constitutes around one-tenth of gross domestic product (GDP) worldwide. Nonetheless, it is a significant employment generator and provides work to almost 7 per cent of total employment population globally, Pearce and Ahn (2012).

Buildings consume large quantities of resources and have a major impact on our health, wealth, and environment. Buildings are critical to our success as society, as Green et al., (2015) pointed out that we spend, in average an amount of time in buildings that deserves to ensure that the indoors and outdoors environment meet our physiological and psychological needs, Ruparathna et al., (2016).

In view of these findings, Ries et al. (2006) and Shafaghat et al. (2016), argued that investigations into sustainability are increasing with a significant demand for low embodied energy and low carbon energy efficient buildings, ensuring generating minimum waste, considering the whole lifecycle of buildings counting renovation and deconstruction, required by all participants which representing a major opportunity to implement sustainable development in the construction industry, Yuan et al. (2013).

The aim of sustainability is to allow people to achieve their needs and enhance their wellbeing, while conversing and protecting the ecological system and its diversity, considering current and future generations. According to Zue and Zhao (2014), Chatterjee (2009) and Gluch (2006), green or sustainable building is a significant measures put forward to mitigate significant impacts of the building stock on the environment, society, and economy, reflecting the efforts put forward to apply sustainability in building manufacturing, by developing green building strategies, designs, standards, and assessment tools. Zue and Zhao (2014) go further and defined four pillars of green buildings, highlighting the associated social impacts rather than the environmental and economic ones, e.g. enhancing occupants and local community health conditions whilst discussing the turn on investment to developers.

The paper aims to critically review and discuss green buildings, and organised as follow; first, definitions, and major aspects concerning green buildings and their implementation strategies, then, discussing the environmental, economic evaluation, and social aspects considering user's concerns and satisfaction issues. Followed by; challenges to their accomplishment, reviewing how to overcome these barriers. Moreover, the assessment tools of the green buildings and how they can influence the sustainable development in the construction industry.

2. Sustainable/ Green building definition

According to Lützkendorf and Lorenz (2007), Kibert (2008) and Robichaud and Anantatmula (2010), a sustainable building can be defined as a building characterised with features and aspects engaged with sustainable growth whilst enhancing its performance and functionality. Sustainable buildings should be associated with better aesthetics quality and minimization of lifecycle cost, thus requires a comprehensive application of strategies and innovative tools enhancing protection of the capital cost value, reducing the land consumption, protecting and minimise the demand for the threatened resources; decreasing of negative effects on the environment, ensuring security and wellbeing of workers, users, and community, moreover, when appropriate to protection of national heritage.

On the other hand, Lützkendorf and Lorenz (2007) and Chatterjee (2009) defined green building as a building which is restricted to the idea of ecologically conserving building, not necessary to fulfil all sustainability aspects or requirements; the writers limited the definition to cover environmental and energy efficiency aspects only, and how these features can affect people health and wellbeing is neglected.

Whilst Pan et al. (2011) stated that a sustainable building is a consequence of the design viewpoint which emphases the improvement of efficiency of resources and materials expenditure. However, Deuble and de Dear (2012) took issue with the contention that sustainable buildings are those including natural ventilation features, with low or zero energy consumption. Zue and Zhao (2014) are more critical in their definitions, and defined green building as: "… healthy facilities designed and built in a resource-efficient manner, using ecologically based principles."

Lützkendorf and Lorenz (2007) summarised that, there is still overlap between the concept and characteristics of green buildings and sustainable buildings boundaries, and sometimes sustainable buildings are termed green, highlighting that the absence of a robust definition generates more difficulties in delivering a successful implementation.

3. Green buildings and the environment

In their integrated analysis of sustainable buildings Zue and Zhao (2014) indicated that sustainable building trend is essentially based on environmental concerns of sustainability, which was further declared by Samer (2013), that in recent decades, we are threatened by the rising problems of natural resource depletion and shortage of energy resources, concurrently with global climate change issue which cannot be overlooked. In similarity with Wu and Low (2010) study which argued that the main source of GHG emissions around the world is the Construction industry, thus, made the move into sustainable buildings a major requirement and developed the crucial drivers in the construction industry. Furthermore, de Wilde and Coley (2012) explained the ecological impacts might influence and cause problems even for the buildings that operating efficiently.

On the other hand, Xing et al. (2011) stated that burning finite resources such as fossil fuels generates CO2 emissions, added that develop more energy efficient techniques to combat global warming is a major contributor to cope with this problem, as stated in the government paper for energy efficiency best practice programme. Generally, most of the construction materials affect the environment somehow, mainly through their construction and transference to site, that which highlighted the attention to embodied energy consideration in green building strategies.

However, Elattar and Ahmed (2014) suggested many strategies in selecting building materials, and recommended minimizing the use of non-renewable construction materials whilst maximizing the use of recycled ones. Isolation materials produced using chlorofluorocarbons (CFCs) or hydro chlorofluorocarbons (HCFCs) which deplete the ozone layer, should be interchanged by other sustainable or recyclable materials e.g. recycled cellulose, or mineral fibre, in addition to using locally grown timber rather than steel as argued by the government paper for energy efficiency best practice programme.

In their detailed investigations Chang et al. (2011b) and Xing et al. (2011) specified that the energy usage in the buildings can be minimized with significant amounts by following a range of strategies for building renovation; e.g. sensible and smart positioning for air conditioning devices , applying enhanced energy efficient features, and practice of energy maintaining behaviors.

Dammann and Elle (2006) concluded that environmental indicators for buildings can work as a technique to create observable patterns to the environmental impacts of buildings to the concerned participants; however, they are more accepted when they are not mandatory, but are to be used in flexible manners. This study uses the terms sustainable or green buildings referring to the same connotation.

4 Green buildings human aspects

4. 1. Thermal comfort/ indoor environmental quality (IEQ) and user satisfaction

Green *et al*. (2015) debated that human benefits of green buildings are as important as environmental and economic related aspects, based on the notion that people spend a considerable volume of time in buildings which impacting their health, wellbeing, and success. Along the lines of that, Zue and Zhao (2014) indicated that generally, sustainable building outstripped conservative ones. See figure 1

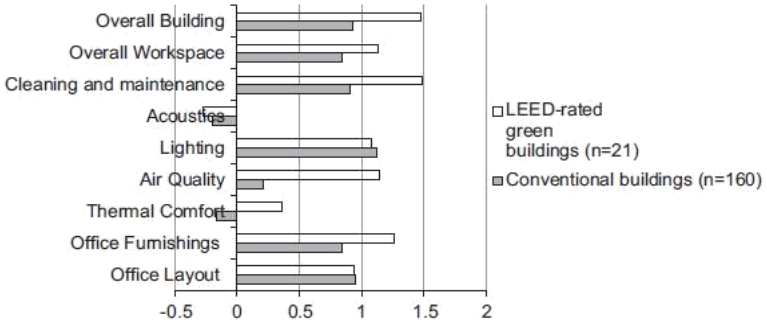

Figure 1: Levels of users satisfaction on IEQ between a Green and convensional buildings Sourse: Zue and Zhao(2014)

Thermal comfort is one of the major factors affecting users satisfaction, with focus on both temperature and humidity levels. However, it should be noted that, psychological, physiological, cultural, and social aspects may influence thermal comfort conversion. Many studies have been carried out and a range of required room temperature could be proposed as a result. Zue and Zhao (2014) and sicurella *et al.* (2012). In line with what discussed above, Lee and Guerin (2009), Gou *et al.* (2012) and Ries *et al.* (2006) emphasised other aspects and indicated that IEQ plays a critical role in user's performance, health and productivity rather than their satisfaction. On the other hand, Zue and Zhao (2014) and Leaman and Bordass (2007) study observed a notable point; that users tend to be more tolerant in green buildings in terms of indoor IEQ.

Then again, green building can be associated with many dissatisfying concerns observed by Abbaszadeh *et al*. (2006) that regarding layout, light, and sound aspects, not enough daylight, reflections in computer screens, and people talking in neighbourhood areas. Hauge *et al.* (2010) stated that investigating the suggestion that sustainable buildings are more convenient, and provide a better quality of life and healthier workplace, will require conducting many case studies. The findings by Heerwagen (2005 and 2009), and Paul and Taylor (2008) are controversial. Heerwagen indicated that green buildings increase associated with more comfort, and better living and work productivity, although Paul and Taylor (2008) did not mention any remarkable variances.

Hauge *et al.* (2010) makes further attempts to determine the underlying causes of the alterations in findings; suggesting two major factors; buildings structures and landscape, in addition to as user's cultural backgrounds and characteristics.

4.2. Technical operation

Hauge *et al,* (2010) stated that, users are the main factor influencing buildings performance; a possible explanation for this might be that occupants are the direct operators of the innovative systems and the lack of information provided to them could result in frustration of achieving the anticipated results. A likely explanation by Deuble and Dear (2012) suggested that in order to achieve efficient performance for green buildings, more effort should be allocated in occupants' knowledge and education.

In their study investigating the user satisfaction differences in sustainable and traditional buildings Leaman and Bordass (2007) indicated that occupiers are more indulgent and accepting when they have

more lead and control, added that their attitudes depend on the extent to which they aware of how these buildings work.

Isaksson (2009) and Isaksson, and Karlsson (2006) studies indicated that users generally are not interested in reading difficult instructions, and highlighted the idea that users understanding of warming devices as a major issue.

The studies and investigations carried out only on a few number of buildings which cannot guarantee realistic results. Nonetheless, future researches covering a larger sample of buildings are required to recognize how tenants' environmental beliefs impact their acceptance of sustainable buildings, given the urgency to mitigate global warming Isaksson, (2009) and Hauge *et al*. (2010)

5 Economic Aspects of Green Buildings

Thus far, several studies have indicated that sustainable construction can give rise to major financial savings by enhancing the productivity, due to further returns of better health and safety conditions, less energy consumption and less operational and maintenance charges, providing financial rewards for building owners, operators, and occupants, Eichholtz *et al.* (2015), WGBC (2013), and Zue and Zhao (2014).

However the results of many studies showed that the initial costs of sustainable buildings are higher than the conventional buildings, as argued by Ross *et al.* (2007) study which specified that LEED certified building will experience approximately 10% of additional budget, see Figure 2. WGBC (2013) and many other researches argued that by introducing more innovative techniques and applying improved and comprehensive designs, the initial budget of a sustainable building can maintain the similar as, or lower than, that of a conventional ones, WGBC (2013) and Ries *et al.* (2007).

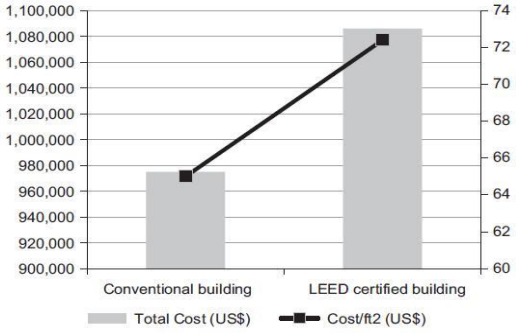

Figure 2: Total cost and cost per unit floor area, conventional and LEED certified building
Sourse: Zue and Zhao (2014)

The report by WGBC (2013), Popescu *et al*. (2012) & Ries *et al*. (2007) pointed to an increasingly compelling business case for green buildings, counting risk mitigation, increasing asset Value, decreases operating Costs, enhancing workplace productivity and Health highlighting the potential to reduce the payback period of investment for energy efficiency measures and the lifecycle cost typically lower than the cost of more traditional buildings. See Table 1.

According to a new research from the British council of shopping centres (BCSC), reveals that energy efficiency can increase the value of shopping centres by over 5% (BSEE, 2015). In line with Turner and

Frankel (2008) study which showed that the LEED certified building can realize up to 28% of energy savings in comparison to the estimated levels, see figure 3. Nonetheless, the BSSC added that, Securing finance is always seen as one of the most significant barriers to sustainable developments, as in a recent survey, 62% of companies cited lack of access to finance and capital as their biggest barrier to progressing energy- saving upgrades.

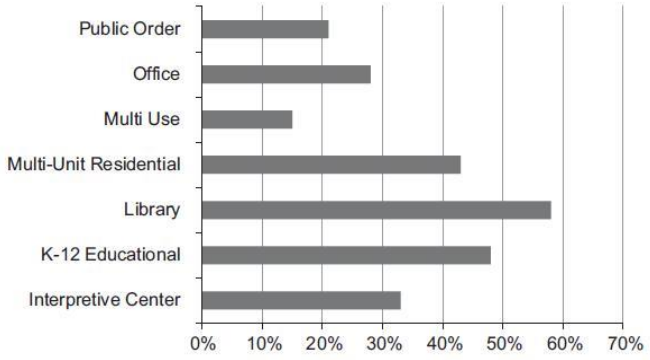

Figure 3: Energy savings from LEED certified building
Sources: Zue and Zhao (2014)

On the other hand, Chau *et al*. (2010) argued that end-user behaviours plays a vital role on green building successes and that the sector development is mainly driven by market demands, in light of that; studies found that end-users do not mind to expend higher charges if they will benefit the ecological performance in sustainable building growths.

Table 1: Potential savings from health and productivity benefits; Source: Ries et al. (2006)

Source of productivity gain	Potential annual health benefits	Potential annual savings or gains
Reduced respiratory illness	16 to 37 million avoided cases of common cold or influenza	$6–14 billion
Reduced allergies and asthma	8 to 25% decrease in symptoms within 53 million allergy sufferers and 16 million asthmatics	$1–4 billion
Reduced sick building syndrome symptoms	20 to 50% reduction in health symptoms experienced frequently at work by ~15 million workers	$10–30 billion
Improved performance from thermal and lighting changes	Not applicable	$20–160 billion

6. How to achieve sustainable buildings

Zue and Zhao (2014) specified three critical and interactive factors should be addressed in order to achieve a successful green building, counting technological, managerial, and behavioural aspects.

6.1. Technological aspects

Using renewable energy and technological innovations is an essential aspect for achieving sustainable buildings as stated by Shi *et al.* (2013), whilst Berggren *et al.* (2013) and Marszal *et al.* (2011)

highlighted the importance of allocating a number of related credits in assessment tools, hence, the result anticipated is the reduction of energy consumptions and emissions. On the other hand, Praene *et al.* (2012) and Yuan *et al.* (2013) suggested some common renewable energy sources to use in green building; including: solar and wind energy technologies.

In their review; Zue and Zhao (2014) argued that construction and demolition (C&D) waste regulator is a key contributor in achieving sustainable buildings. Whereas, similarly, Weishenglu and Vivian (2013) argued that reducing resources consumption, recycling and reuse of C&D waste are also major approaches to reduce environmental impact.

6.2 Managerial aspects

In their analysis of successful achievement requirements, Häkkinen and Belloni (2011) indicated that, ensuring specific project management skills; covering project level, company level and market level, whilst adopting assessment tools, and providing employees with the required training and education are significant factors.

6.3 Behavioural aspects

Hoffman and Henn, (2008) claimed that obstacles facing sustainable buildings development are no longer economic or technological, instead they are social and psychological, therefore, educating and rising the standard of knowledge for all shareholders, including end-users and customers, engineers and contractors, is a major step towards sustainable development. This view is supported by *Kato et al.* (2009) who concluded in their research that, green workplace offers greater psychological benefits, e.g. taking pride of the workplace environment, to occupiers than physical developments including health and productivity advances.

7 Constructions and strategies of sustainable buildings

Sadineni *et al.*, (2011) and Aksoy and Inalli (2006) defined different components in the green building, counting; walls, roofs, foundation, thermal isolation, thermal mass, exterior covering schemes etc. as important parts of any building and emphasized the passive strategy features such as building system and alignment. In the same vein Sadineni *et al.*, (2011) added that currently a renewed interest in environmental-friendly passive energy strategies are seen, intended to act as a practicable solution to the concerns of energy crisis and environmental pollution.

7.1 Green building and energy

Much of the current literature on sustainable development emphasis that green buildings are designed to reduce energy consumption and costs, considering sustainability economic and environmental issues, hence, lessen emissions and waste (Jiang and Rahimi-Eichi, 2009). Larsson (2004) suggested that a sustainable building energy scheme varies from low energy, zero, or passive energy, but overall it must involve renewable energy usage, energy storing and energy controlling.

More recent attention has focused on the provision of low energy buildings suggested that many interventions are needed to improve energy systems efficiency whilst promoting renewable energy resources, combined with applying a variety of measures including; applying active or passive energy effectual approaches, enhancing warming, cooling and airing schemes, etc. can be characterized as active techniques, whereas, developments to building covering components can be categorized as passive or

inactive ones, Kylili and Fokaides (2015), Yuan *et al.* (2013) and Zuo and Zhao (2014). Likewise, Crawford *et al.* (2011) suggested an inclusive standard for reforming less energy building proposal to minimize the whole building's lifespan energy usage.

According to the recast of the Directive on the energy performance of buildings (Directive 2010/31/EU) Zero energy buildings (ZEBs) represents a major contributor towards the achievement of the future smart cities, which is described as buildings that have zero carbon emissions on an annual basis while, Sartori *et al.* (2012), argued that a yearly weighing scale is not enough to guarantee a Net ZEBs. Kylili and Fokaides (2015) argued that this is achievable by reducing the energy demand and developing Renewable Energy Sources (RES). Santamouris (2014) also suggested green rooftops as submissive cooling techniques that work to protect the building and to stop the inward solar energy, thus provides both aesthetic and environmental benefits.

7.2. Construction materials of green buildings

Achieving a sustainable building requires emerging sustainability concepts through the whole life cycle analysis (LCA) of the building, using less, durable and recycled materials whilst designing for reusing, WGBC (2013). In an attempt to guide decision-makers to choose and indicate best materials, a study by Castro-Lacouture *et al.* (2009) suggested an integer approach covering project restraints, whilst achieving better (LEED) rating system credits. Chatterjee (2009) also argued that the LCA and sustainable building laws can act as a major factor in appraising building materials and retaining sustainability in the construction field.

Hosseini *et al.* (2011), Yen *et al.* (2011) and Damtoft *et al.* (2008) claimed that the cement and concrete manufacturers can enhance the Climate Change action by increasing the use of bio-fuels and alternative materials which reduces the CO2 emission from cement production.

However, Cautions selection of materials can also benefit reduce the waste to the landfill, e.g. using fly ashes as structural components of green building design, as suggested by Zue and Zhao (2014) and Drochytka *et al.* (2012). Similarly, Jaillon *et al,* (2009) added the use of precast or prefabrication technologies helps to reduce construction and demolition waste to a great point.

7.3 Green buildings assessment tools

Wei *et al.* (2015) pointed out that sustainable building certifications aim to achieve buildings that are healthy, energy-saving, and environmentally friendly. Zue and Zhao (2014) went further and declared that recognizing the social and economic aspects of sustainability is reflected in the development of sustainable buildings assessment tools.

Alyami and Rezgui, (2015) argued that despite the existence of a range of assessment tools which are valued from designing standpoints, they are hardly take into account post occupancy evaluation and end users perspectives, thus they need to allocate more attention to users contribution to ensure and not only to focus on technical and before occupancy phases, also to recognise what perform best in reality, Nicol and Roaf (2005).

Nevertheless, Reith and Orova (2015) and Wangel *et al.* (2016) pointed out the crucial need to introduce new forms of the assessment tools rather than the leading ones; e.g. LEED, BREEAM. This new

developments should essentially be combined with further studies and researches support the decision making practice and provide with the required criteria.

Challenges and Solutions

The Bond and Perrett (2012) and WGBC (2013) defined many barriers and challenges facing the sustainable development implementation, including; the absence of knowledge and awareness, lack of leadership, fears and resistance to change, and further risk of poor application, however, most of the barriers are addressable through practice and good adoption of planning strategies and innovative solutions (Yudelson, 2010).

The WGBC (2013) suggested leading thorough investigations and surveys, combined with proposing workshops, and user guides as key solutions. Whilst Lützkendorf and Lorenz (2007) identified many approaches can be employed to boost the demand for sustainable buildings, including; development of suitable financial instruments, changing societies' values and concerns, in addition to the developing the CO2 certificate trading schemes. Nonetheless, incorporation of sustainability in building sector in courses and programs of higher degree studies.

Sustainable buildings and Building information modelling, (BIM)

Sustainable Building aspects comprise building performance, economic, environmental, and social aspects. In addition to innovative designs and whole life cycle managing tools of buildings, which in turn require innovative forms of information in comparison to conventional building. All these associated features and the huge amount of information needed, drive the need to BIM to support the integrated information management through the construction Life Cycle (Häkkinen and Kiviniemi, 2008).

8.0 Conclusion

This study carried out a critical review of sustainable buildings, reviewing the notion of applying sustainability techniques and principles in the construction industry. The outcomes indicated that these studies investigated major issues regarding sustainable development, e.g. the explanation of what are sustainable buildings; environmental, economic, and social aspects of sustainable buildings; methods to accomplish them; followed by strategies for construction of green buildings, assessment tools, and the barriers and challenges to the implementation of sustainable buildings and suggested solutions.

The comprehensive critical review reveals that most of sustainable building researches emphasis the environmental aspects of sustainability focusing on energy usage and carbon emissions issues; proposing some ideas to handle and cope with them. Whilst, identified big gaps regarding social and economic facets of sustainability. The findings also emphases the importance of the life cycle assessment approach, and recognised the trend from concentrating on building itself to the importance of exploring the link between building and its occupants. However, it should be noted that the majority of existing studies on green building are based on the current weather data and current occupancy pattern which may not be sufficient as trends may change. In general, the extensive review found that a little research has been carried out to investigate occupant satisfaction which clarifies a need for specific further studies targeting the extent to which users are satisfied and the factors affecting their decisions in order to gain enhanced understanding.

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