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Abstract:
Awareness and significance of sustainable development (SD) has been growing around the world for the last few decades. Sustainable construction is now considered a way for the construction industry to contribute to this larger effort. It is clear why the construction industry must respond accordingly and focus its attention on developing more sustainable buildings - not least because of its huge size, the vast amount of resources it consumes and its major impact on the built and natural environments. This research work therefore aims to examine the concept of sustainability, investigate the costs related to producing sustainable buildings and the relationship that exists between these costs. A review of the literature showed that the concept of sustainability is broad but the economic, social and environmental aspects, which are inextricably linked, remain the three fundamental pillars of sustainability. Initial construction cost (IC), cost-in-use (CIU) and carbon cost (CC) were revealed as monetary means of appraising economic and environmental criteria. According to the review, social criteria are drivers: subjective and human factors, which affect the other two factors, directly or indirectly. It is concluded that inverse relationship often exists between IC and CIU but the movement of CC in relation to this is still unknown, being a new concept. Further stage of the research work will explore this grey area and consequently model through quantitative analysis the relationship that exists between IC, CIU and CC.

Keywords:
Carbon cost, construction industry, cost-in-use, initial construction cost, sustainability

1 Introduction

Awareness and significance of sustainable development has been growing around the world for the last few decades (Khalfan, 2006). Sustainable construction is now considered as a way for the industry to contribute to this larger effort of achieving sustainable development (Ding, 2005; Majdalani *et al.,* 2006). The construction industry in the UK remains one of the most critical sectors for the adoption of sustainable development principles because of its size which accounts for 8% of Gross Domestic Product (GDP), the enormous amount of the resources it consumes, and the major impact of its products on the built and natural environments in particular and the society at large (Spence & Mulligan, 1995; Raynsford, 1999; GCCP, 2000; BERR, 2008).

In lieu of the above, Myers (2008) opined that sustainability is another concept that has come to stay in the UK construction industry whilst developing more sustainable buildings continues to be one of the top government priorities (DECC *et al.,* 2008). This is because sustainable development involves meeting the needs of the society without depriving future generations of theirs by taking a long-term view amidst the often dominant short-term returns (WCED & Brundtland, 1987; Meckler, 2004; Flanagan *et al.,* 2005; Hertwich, 2005; DTI, 2007). The private sector is also not left out in the process as they strive to incorporate sustainability into their services and products not least because it is the right thing to do but because of the inevitable government legislations and economic policies driving the sustainability agenda.

It is clear why the construction industry must respond accordingly and focus its attention on developing sustainable projects which are economically viable, socially acceptable and environmentally friendly. Taking into consideration sustainability during the cost estimating process is vital for the successful integration of sustainable features within a construction project (Essa & Fortune, 2008). This research therefore aims to examine the concept of sustainability and investigate the relationship that exists between the costs related to producing sustainable buildings through the review of literature carried out in the first few months of this doctoral research work.

At a later stage in the research work, quantitative data analysis will be used to model the relationship that exists between the costs of producing sustainable buildings. The model will thus be used to verify the earlier review. The resulting index will be internally validated with the costs data used in its development and externally validated with a new set of data obtained from carefully selected sustainable projects. Case study of a selected group will be used to test the acceptability and usability of the index before making it public. Public educational buildings and PFI school projects will be carefully selected when collecting data for the study because of the central role of the government in achieving the sustainability agenda.

The research examines the monetary means of appraising economic and social factors. It acknowledges the third aspect: the social factors, which is beyond the scope of this research project for various reasons. The research looks at the economics of sustainability and aims to model the relationship that exists between the costs of sustainability. Moreover, social factors are more or less seen as drivers that can change based on context. It is also not the aim of this research to replace the non-monetary tools that measure the more subjective and human factors such as Design Quality Indicators (DQI) for appraising social aspect, for instance. Nevertheless the research encourages the holistic approach for optimising sustainability criteria in a construction project by combining monetary appraisal methods with non-monetary tools.

This paper reports the work done in the initial 6 months of the doctoral work. According to the review done so far, sustainable development is inevitable. It is a means of meeting the current needs without jeopardising the ability of the future generations to meet theirs. Economic, social and environmental factors were identified as the three fundamental principles of sustainable construction, which are inextricably linked. Whilst social factors are seen as human factors, initial construction cost (IC), cost-in-use (CIU) and carbon cost (CC) are shown as monetary means of appraising economic and social sustainability. The research concludes that an inverse relationship often exists, or perhaps seen to exist,

between IC and CIU but the direction of CC in relation to this is still unknown. Further research work will shed more light on this and consequently model through quantitative analysis the relationship between IC, CIU and CC, to verify the review.

2 Literature Review

In 1987, the United Nations Brundtland Commission offered what may be the definitive explanation of the term sustainable development (Mills, 2010). According to the report of the World Commission on Environment and Development, Our common future, it is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED & Brundtland, 1987). Several global events have since taken place with debate on topical issues including sustainability. Amongst these are the Earth Summits in Rio de Janeiro 1992, New York 1997 and Johannesburg 2002, the Conference of the Parties to UNFCCC (UN Framework Convention on Climate Change) in Kyoto, 1997, and possibly the awarding of the Nobel Peace Price to Al Gore and the IPCC (Intergovernmental Panel on Climate Change) as highlighted by Barkemeyer *et al.* (2009). A common trait of these notable events has been the ability to trigger and/ or alter the debate around sustainability and maintain its importance as ever when the word was first coined. In effect, on a global level, sustainable development continues to grow in awareness. This seems to be of an incremental nature, perhaps due to these distinctly associated events. The assertion that only very few truly global events can be identified that triggered a substantial amount of media coverage globally, tells a lot about the supreme importance, sustained level of interest and growing concerns associated with the subject matter of sustainable development (Barkemeyer *et al.,* 2009).

In recent years, after the publication of the Brundtland Report, the term sustainability has been widely adopted by both the public and private sectors. According to Barkemeyer *et al*. (2009), the coverage of sustainable development seems to have reached the mainstream public arena, in the local, national and on a global level. These terms are now in common use in scientific papers, monographs, textbooks, annual report of companies, government policy usage, and the media (Glavic & Lukman, 2007). In fact, it is so overused that it has given birth to new lexicons, with words such as greenwashing, green supply chain management, greenbuildings, etc. becoming commonplace and gaining currency to describe the many attempts to co-opt the issue (Mills, 2010). The overuse of the term may have contributed to the increase in its awareness, which is a good thing in one respect. On the other hand, the confusion that comes with this is worrying as the term could be used to imply what it is not, in order to gain competitive advantage in the marketplace.

Given sustainability's broad meaning, it has been subjected to a range of interpretations. Thus, it is paramount to look at the fundamental concept of the term sustainable development (SD), commonly and simply referred to as sustainability. The different definitions of SD imply that application of the term depends on their designation and recognition in different disciplines of human endeavour. However, the domain concept remains the same and must not be misplaced not least because it helps avoid much confusion about their usage. But it also helps to achieve better and easier understanding. In lieu of this, Glavic & Lukman (2007) suggested that sustainable development should

be supported by a common, unambiguous, fundamental concepts, applicable to real-world problems no matter the discipline.

The WCED & Brundtland (1987) stated categorically that the interventions needed to achieve sustainable development must be conceived and executed by processes that integrate environmental, social and economic considerations which are the fundamental principles. SD is not only a new name for environmentally sound management: it is a social and economic concept as well, according to the report. In a recent study, having analysed fifty-one definitions from diverse sources, Glavic & Lukman (2007) concluded that the environmental/ecological, economic, and societal principles are connected to all dimensions of sustainable development. The authors noted further that all the definitions examined have interconnections between environmental protection, economic performance and societal welfare. Numerous definitions have emerged over the years and various applications of sustainable development are attainable in this present era but in principle, they remain similar to the one from 1987 (Glavic & Lukman, 2007).

Following on from the above, the concept of sustainability is broad and has been used in different context, but the economic, social and environmental aspects, which are inextricably linked, remain the three fundamental pillars that must always be appropriately addressed (Kunszt, 1998; Ding, 2005; Matar *et al.,* 2008; Jones *et al.,* 2010). Traditionally, the construction industry has often explored the single state sustainability (1st order as shown in Figure 1) within the economic dimension which explains why most times projects are awarded to the contractor with the lowest tender (Edum-Fotwe & Price, 2009). In the past, tenders have been based solely on economic factors which measure short-term returns at the detriment of social and environmental issues which consider long-term benefits of an asset (OGC, 2007). Thus there is need to examine ways of incorporating other factors which have not always been considered in the past. Using this holistic approach to select the best option among alternatives at an early stage of a development is vital in promoting sustainable practices in construction (Lippiatt, 1999; BERR, 2008; Essa & Fortune, 2008; Zavrl *et al.,* 2009) and achieving this will mean looking for a way of measuring these three pillars of sustainability in monetary terms when proposing a new development or retrofitting the existing stock.

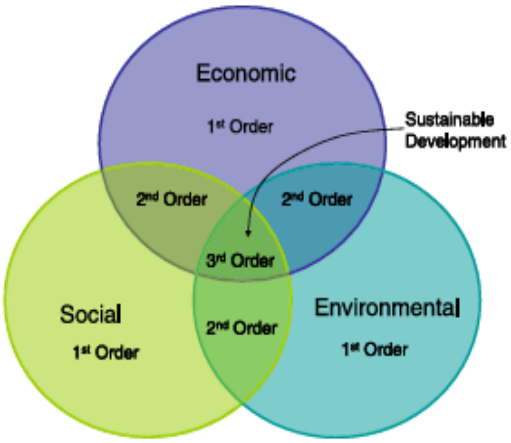

Figure 1. The Three Fundamental Principles of Sustainability
(Source: Edum-Fotwe & Price, 2009)

The economic sustainability of a project which looks at the short-term benefits and the effective use of limited resources has long being judged using initial cost of construction (IC) and in more recent times with cost-in-use (CIU) as value for money, that is, cost-benefit analysis of an asset over its entire life, is gradually becoming the norm (Myers, 2008; Barsuk, 2009). Using whole-life appraisal, it is an effective tool now used to measure sustainable building performance as it considers the long-term benefits that can be accrued and the costs that will be incurred (Flanagan *et al.,* 2005).

On the other hand, it could be difficult to fully measure the social sustainability of a development in monetary terms due to its greater proportion of human and subjective factors. Design Quality Indicator (DQI) is one of the contemporary tools that have been recently developed to take care of these difficult to measure criteria. In addition, social factors are drivers that often have direct or indirect impact on economic and environmental factors. Thus, this research will be focussing on the monetary measures of economic and environmental criteria (2^{nd} Order as shown in Figure 1).

Carbon equivalent (CO_2e) which now has cost implications known as carbon cost has been recently developed as a more specific measure of environmental criteria (DTI, 2007; DECC, 2009). Sustainability revolves around minimising the detrimental effects of development on the built and natural environments through the reduction of greenhouse gasses and the transition to a low or zero-carbon economy (Price *et al.,* 2007). Given that 86% of the greenhouse emission is carbon related, CO_2e has been developed for the remaining 14% composed of methane (CH_4), nitrous oxide (N_2O) and refrigerant gases to enhance uniformity of measurement (DECC *et al.,* 2008).

Although CIU can be used to measure a building's environmental performance during operation as it takes into account energy usage (Davis Langdon, 2007), it does not measure the environmental impact of construction, hence the importance of the carbon cost (CC) measure. As the UK construction industry consumes a vast amount of resources, assessing the CC of producing a building can make the difference between choosing a sustainable design that minimises environmental impact and an unsustainable one that wastes the limited available resources and as well degrade the built and natural environments. The importance of CC measure which has been neglected in the past cannot be overemphasised in achieving sustainability agenda as it is now a legal obligation for the UK Government to reduce carbon footprint by whatever means possible (Lohnes, 2008; BIS, 2010; Jones *et al.,* 2010).

Taking into consideration sustainability during the cost estimating process is vital for the successful integration of sustainable features within a construction project (Essa & Fortune, 2008). There are costs implications attached to producing sustainable buildings as explained earlier, using whole-life appraisal to evaluate the economics of sustainability. They include IC and CIU for appraising economic factors, and CIU and CC for measuring environmental impacts (Lowe & Zhou, 2003; Edum-Fotwe & Price, 2009; Zavrl *et al.,* 2009). Considering these costs and seeking the optimum balance in the relationship that exists between them during the early stage of a development will promote the 2^{nd} Order level of sustainability. And even the 3^{rd} Order level when used with other non-monetary measures such as DQI for instance, as opposed to the 1^{st} Order still prevalent in the industry (Sorrell, 2003).

Research has revealed that a reduced IC will in many cases have to offset an increased CIU such as increased cost of operation and maintenance perhaps due to poor quality design (OGC, 2007). On the other hand, using renewable materials in a building could also imply higher IC due to the costs associated with new technology and invention, but lower CIU due to less energy consumption and carbon footprint for instance (Matar *et al.,* 2008; Nalewaik & Venters, 2008; BIS, 2010). However, no known research has been found to date and if available not popular, explaining the movement and/or behaviour of the CC in relation to IC and CIU components despite its importance in achieving environmental sustainability. This has been largely attributed to the newness of CC as a measure of environmental impact.

In summary, it is logical to believe that in practice, achieving a direct relationship between IC, CIU and CC may not always be achievable as any construction investor would want it. Whilst reducing the CIU and CC is greatly desired, sustainability comes with a price often reflected in the IC in terms of high up-front expenditure (Davis Langdon, 2007). The different research works examined above have shown that optimising the CIU component which is far greater than the smallest amount IC will often lead to better overall savings over the building life. This implies that a trade-off in constituent costs is absolutely necessary for a sustainably-designed building but at what point is it most advantageous is what the subsequent phase of the research work will explore. The movement of CC in relation to IC and CIU is another indecisive area to be examined. The further review to be conducted, the cost data to be generated and the quantitative analysis to be performed at a later stage in the research process will help to model a cost relationship index that achieve optimum balance between these three costs.

3 Research Methodology

In order to achieve the aim of this research, the following strategies and research methods have and will be employed to capture, analyse and present relevant knowledge.

3.1 Published sources

A review was conducted to explore and understand the concept of sustainable development in general and the role of the construction industry in achieving sustainability agenda. Further review will be conducted at a later stage to identify the various sustainability assessment techniques and the current practice of appraising building projects.

3.2 Data collection

To provide quantitative data for the model to be consequently developed, relevant cost information of some sustainable projects selected with de facto sustainability assessment techniques, will be sourced through appropriate means. Some of the data to be collected include initial construction costs (IC), cost-in-use (CIU) such as operational, maintenance, replacement and disposal costs, and carbon costs (CC) earlier identified in the review. It is rational to believe that some of this costs information will have to be generated. Such include CIU as most property owners do not have detailed record of this recurring expenditure over the entire life of the building. CC will also have to be computed in most cases using appropriate formulas. In contrast, getting IC is presumed to take less effort because of its one-off nature and straightforward approach.

3.3 Data analysis

Relevant statistical inference tools and techniques will be used on the costs data generated above to model the relationship that exist between IC, CIU and CC which will lead to the development of an optimum balance index that serves as a single sustainability indicator.

3.4 Index validation

The index to be developed at a later stage of the research work will be validated through appropriate means such as quantitative data testing to prove that it can be harnessed for wider use. One way that would be considered in the validation process will be to analyse the IC, CIU and CC of a notable project, built to a high sustainability code, in relation to the optimum balance index developed. The index will be internally validated with the costs data used in its development and externally validated with a new set of data obtained from carefully selected sustainable projects.

3.5 Model concept validation

Case study will be used to test the acceptability and usability of the new index: one of the main outputs of the doctoral research work. This method will be facilitated with the development of a web interface to showcase this output. The web interface will also be used to present and conduct the case study. This research strategy will test the acceptability and usability of the index using a selected case study group.

4 Findings and Discussion

Sustainable development (SD) otherwise referred to as sustainability is a concept that continues to grow in awareness and importance. Many definitions have surfaced over the years in the hope of trying to make meaning of the term but the definition once given in the Brundtland report in 1987 remains the underlying benchmark. It is interesting to see that all the reviewed literature on the subject matter have all used Brundtland's definition as a basis for making their case and this research is no exception though the boundaries were pushed forward.

Following on from the above, one begins to wonder what makes the Brundtland's definition of SD so unique, commonly referred to and universally accepted. The simplicity, fairness and modesty of the definition could have played a major part in this, perhaps? According to the report, sustainable development is the development that meets the needs of the present without compromising the ability of the future generation to meet their own needs. Whether we can effectively achieve what was proposed in the Brundtland's report in a timely fashion is undoubtedly questionable.

There is now a pressing demand for the construction industry to lean towards this direction and follow the path of sustainability not least because of its size, the share volume of the resources it consumes and the huge impact of its products on the built and natural environments. According to the review, developing more sustainable buildings has thus become one of the top government priorities. Sustainable construction is now seen as inevitable in the short and long run and hence pursued with relevant legislations and economic policies. The economic, social and environmental factors are said to be

the three fundamental pillars of sustainable construction. These key criteria kept reappearing in all the various definitions examined. The significance of this could be that the so called three pillars of sustainability are in reality inextricably linked and must at least be appropriately addressed irrespective of the field of human endeavour to achieve the minimum standard of sustainable development.

The construction industry, however, is often accused to be exploring part of the economic factors (short term view of awarding project based on initial cost) without full consideration of the equally important social and environmental criteria (long term benefits of project over its entire life), based on findings from the literature. The temptation to award projects to the contractor with the lowest tender, which is apparently often done at the expense of all other factors, has been explained as one of the most popular reasons for this. Apparently, there will always be more tenable reasons caused by the complexity and reality of the market place. A typical example of awarding project based on the lowest bid from government perspective will be the need to ensure accountability and fairness in the tendering process, may be?

Nevertheless, taking into consideration sustainability during the cost estimating process is vital for the successful integration of sustainable features within a construction project (Essa & Fortune, 2008). The implication of this would be that it is high time the design team started considering at the early design stages other cost aspects of sustainable development which have otherwise been neglected in the past. It is no doubt that this practice will further the course of the sustainability agenda. Hence, exploring the costs associated with sustainable development must certainly be a step in the right direction.

The costs related to producing sustainable buildings were revealed in the review. In identifying the monetary implications of a sustainable development, social factors were excluded and beyond the scope of this research work, because of their humanistic and subjective nature which cannot easily be captured in monetary terms. The argument that they are social drivers that impact (directly and/ or indirectly) on the other factors means that they are not exclusively left out. Of course, some proponents of cost benefit analysis would argue that it is a monetary tool that could be used for social assessment though in a subjective manner. For these reasons, the research focussed on the more objective monetary means of appraising economic and environmental factors.

The review showed that initial cost (IC) and cost-in-use (CIU) are monetary tools now being used to appraise the economic sustainability of a project over its entire life based on whole-life appraisal. CIU and carbon cost (CC) are other measures gaining popularity as a means to measure the environmental impact of construction. Whilst inverse relationship is often seen to exist between IC and CIU, rightly or wrongly, the influence on CC is yet to be determined as there happens to be no known literature on this at the moment. As evident from the literature, however, a reduced IC will in many cases have to offset an increased CIU such as increased cost of operation and maintenance perhaps due to poor quality design, and vice versa.

Whether this is often the case in different contexts and based on different design options and decisions are matters open to further debate and interpretation. More so, the inconclusiveness of the direction of CC in relation to IC and CIU according to the review is that borne out of CC being a new concept used to determine environmental

impact. It is no doubt that further research is needed in this area. Firstly, to probe the relationship that exists between IC and CIU in different contexts and based on different design choices. And secondly to establish the relationship that exist between IC, CIU and CC, when the third aspect of CC is introduced.

5 Conclusion and Further Research

Awareness and significance of sustainable development continues to grow around the world. Sustainable construction is now seen as a way for the construction industry to contribute to this inevitable agenda. Taking into account sustainability during the cost estimating process is vital for the successful integration of sustainable features within a construction project. This research work therefore examines the general concept of sustainability, investigates the costs of producing sustainable buildings and the relationship that exists between these costs through review of the literature.

According to the findings, sustainable development (SD) is a term with several definitions but that provided by Brundtland report in 1987 is still widely adopted. It is the development that meets the needs of the current without compromising the ability of the future to meet their own needs. The economic, social and environmental factors are identified as the three pillars of sustainable construction, which are inextricably linked.

Examining SD over its entire life, initial construction cost (IC), cost-in-use (CIU) and carbon cost (CC) were identified as monetary implications of economic and environmental factors. Social factors were seen as human and subjective factors that cannot really be quantified in monetary terms but which influence, either directly or indirectly, the other factors. The review concluded that inverse relationship often exists between IC and CIU but the direction of CC in relation to this is still unknown, owing to CC being a new concept.

This paper reports what has been achieved in the initial six months of the doctoral research work. Thus further review of the literature is needed to examine other sustainability assessment techniques. The existing relationship between IC and CIU in various circumstances will be explored further and CC will also be put into context. At a later stage, relevant costs data will be collected to model the relationship between the three cost components and the results used to verify the findings from the literature.

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