Title: Dynamic Relationship between Embodied and Operational Impacts of Buildings: An Evaluation of Sustainable Design Appraisal Tools

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Abstract

Purpose: Buildings and their construction activities consume a significant proportion of mineral resources excavated from nature and contribute a large percentage of CO2 in the atmosphere. As a way of improving the sustainability of building construction and operation, various sustainable design appraisal standards have been developed across nations. Albeit criticism of the appraisal standards, evidence shows that increasing sustainability of the built environment has been engendered by such appraisal tools as BREEAM, Code for sustainable homes, LEED and CASBEE, among others. This study evaluates the effectiveness of the appraisal standards in engendering whole lifecycle environmental sustainability of the built environment.

Design/methodology/approach: In order to evaluate the adequacy of sustainability scores assigned to various lifecycle stages of buildings in the appraisal standards, four case studies of a block of classroom were modelled. Using Revit as a modelling platform, stage by stage lifecycle environmental impacts of the building were simulated through Green Building Studio and ATHENA Impact estimator. The resulting environmental impacts were then compared against the assessment score associated with each stage of building lifecycle in BREAAM and code for sustainable homes.

Findings: Results show that albeit the consensus that the appraisal standards engender sustainability practices in the AEC industry, total scores assigned to impacts at each stage of building lifecycle is disproportionate to the simulated whole-life environmental impacts associated with the stages in some instances.

Originality/Value: As the study reveals both strengths and weaknesses in the existing sustainability appraisal standards, measures through which they can be tailored to resource efficiency and lifecycle environmental sustainability of the built environment are suggested.

Keywords: *Sustainability, Simulation, Lifecycle Analysis, BREAAM, CO2 emission, Global Warming Potential.*

1.0. INTRODUCTION

In addition to its consumption of largest proportion of mineral resources excavated from nature (Anink et al., 1996), building and construction activities contribute large percentage of CO2 in the atmosphere (Baek et al., 2013), and produce the largest portion of waste to landfill (Oyedele et al., 2014). Due to this, it has often been argued that the sustainability of the built environment is indispensable to achieving the global sustainability agenda (Anderson and Thornhill, 2002). Since the initiation of official movement for sustainability was raised through Brundtland Report, concerns raised by the awareness of climate change has become an important political priority across the globe (O'Neill and Oppenheimer, 2002; Brundtland, 1987). Consequently, building performance, green buildings, eco-labelling, lifecycle impacts, sustainable building and environmental impacts, among others are some of the concepts that have changed, and are continuously changing, the teaching and professional practices within the built environment (Ding, 2008; Ajayi et al., 2014; Ortiz et al., 2009).

Congruently, the governments and other concerned bodies across the globe have introduced the concept of sustainable design appraisal frameworks, which are being used to engender sustainable design and construction of built infrastructures (Kajikawa et al., 2011). Due to the need of the diverse group of stakeholders involved in building lifecycle process, including owners, construction professionals, designers and users, the development of the assessment framework is a complex task (Cole, 2005). This is as a result of conflicting priority among the different groups of stakeholders, with the government usually being the major driver of the sustainability agenda. Nonetheless, since the introduction of the UK Building Research Establishment Environmental Assessment Method (BREEAM) in 1990, buildings environmental performance assessment frameworks have become rife within the construction industry (Cole, 2005). These sets of frameworks include the US Leadership in Energy and Environmental Design (LEED), the Comprehensive Assessment System for Built Environment Efficacy (CASBEE), the Code for Sustainable Homes (CfSH), Comprehensive Environmental Performance Assessment Scheme (CEPAS), and many others (Poveda and Lipsett, 2011; Cole, 2005). These performance assessment tools require that social development, environmental protection and economic development should be appropriately considered in the decision about locating, designing, constructing, operating as well as the end of life deconstruction or demolition of the buildings. As such, scores were assigned to various aspects of project lifecycle in a bid to calculate the overall sustainability of the buildings.

Evidence suggests that significant progress made in driving environmental sustainability agenda is majorly due to the implementation of the sustainability appraisal frameworks (Ding, 2008; Ajayi et al., 2015). Albeit this success, claims have been made that wide acceptance of the framework is not necessarily due to its effectiveness but largely due to the legislative requirement for its implementation (Cole, 2005; Poveda and Lipsett, 2011). Scores are often assigned to the different aspects of design and construction processes, but there is lack of study that evaluates the overall effectiveness of the sustainable design appraisal tools in engendering sustainability of the whole built processes throughout the building lifecycle.

Based on this gap, this study evaluates the effectiveness of the appraisal standards in engendering whole lifecycle environmental sustainability of the built environment. The study estimates the total environmental weight assigned to different lifecycle stages of buildings in the UK BREAAM and CfSH. The proportional weight per building lifecycle stages was then compared with simulated environmental impacts of individual lifecycle stage, which were assessed using Lifecycle Assessment (LCA) methodology. The study offers insights into changes required of the sustainable design assessment frameworks for increased efficiency. It also suggests the aspects of the built processes that are expected to be further targeted by the sustainable design appraisal tools.

2.0. LITERATURE REVIEW

The construction industry is one of the least sustainable industry, accounting for about half of all non-renewable resources consumed by mankind (Edwards, 2014). This is especially as all other human activities are built around buildings and other constructed infrastructures such as roads, bridges, etc. Apart from its consumption of the substantial proportion of resources excavated from nature, and the subsequent CO2 emission and materials depletion (Dixon et al., 2018), the industry also accounts for various other environmental impacts. These include energy consumption, agricultural land loss, air pollution, waste generation, use of CFC generating materials, deforestation and water consumption, among others (Säynäjoki et al., 2017; Soares et al., 2017). With all these impacts contributing to climate change, the construction industry has remained under considerable pressure to improve its sustainability profile (Ajayi and Oyedele, 2017).

In line with the global sustainability agenda, as entrenched in “Our Common Future”, sustainable construction has become the buzzword that is driving the activities of the industry towards achieving the social, economic and environmental sustainability (Brundtland Commission, 1987). The impact of the construction industry touches the three pillars of sustainability, which are economic, social and environmental. For instance, the UK construction industry contributes about 6–10% of the nation’s GDP and provides employment for over 3 million people (Edwards, 2014; ONS, 2017). At the environmental level, the industry is responsible for almost half of carbon emissions, generates large portions of waste to landfill, and consumes about half of mineral and water resources (Edwards, 2014; Säynäjoki et al., 2017). The social significance of the industry is also evident in terms of its significance in enhancing the quality of life in terms of housing, workspace, utilities and transport infrastructure. As such, a truly sustainable construction project should address the environmental, economic and social pillars of sustainability at all stages of the building lifecycle. According to Halliday (2008), a sustainable construction enhances biodiversity, support communities, uses resources effectively, minimizes pollution, managed responsibly, energy efficient and creates healthy environments. Such construction project would aim at providing a building that is affordable, accessible and environmentally conscious, covering the three pillars of sustainability (Dixon et al., 2018; Chong et al., 2017). In addition to the traditional project performance indicators – cost, time and quality – sustainable construction adds sustainability as another key project performance indicator.

Apart from the sustainability of the actual construction process, the sustainability of the building is essential to achieving the sustainability of the built environment (Chong et al., 2017). The lifecycle of a typical building is divided into various stages, covering raw materials and manufacturing, construction, operation and maintenance (Ajayi et al., 2015). Out of all these stages, the operational stage of the building accounts for the larger impacts of the entire lifecycle (Soares et al., 2017). Depending on building use, construction techniques, materials used and reuse, among others, operational impacts of buildings could account for about 60% to over 90% of the total lifecycle impacts (Zhan et al., 2018; Soares et al., 2017; Ajayi et al., 2015). These impacts are specifically due to energy used for building operation, maintenance and management of conventional buildings (Soares et al., 2017). As such, the use of renewable energy system (Chong et al., 2017), as well as the changing use pattern and user behaviour are essential to minimizing the overall impacts of buildings on the environment. This has become the main focus of the legislation, with various new ways of efficiently operating buildings being innovated.

In order to drive the sustainability of the built environment, including the building and its construction process, various policies, legislation and targets have been set. Some of these targets and mandates are in response to meeting the international targets for carbon emission and global warming, and they remain the major driver of sustainability within the built environment (Ajayi and Oyedele, 2017). These legislative requirements and targets have been developed into standards that are fast becoming a requirement for every construction project. Examples of such legislative measures include the EU Renewable Energy Directive (2009), Energy Performance of Buildings Directive EPBD (2002/91/EC), Sustainable and Secure Buildings Act (2004), Waste (England and Wales) Regulations 2011 with (Amendment) 2012 and continuous revision to the part L of the Approved document, among other provisions (Edwards, 2014; Dixon et al., 2018)

In addition to the legislative provisions, sustainable design appraisal systems have been developed to drive the sustainability of the built environment. Across the globe, considerable effort has been made to develop various building performance assessment standards (Sharifi and Murayama, 2013). These sets of building assessment standards benchmarks various elements of building design and construction activities to award performance grade to the building (Ding et al. 2008). Following the introduction of the UK BREEAM in 1990, various other assessment standards have been developed across the globe (Illankoon et al., 2017). These include the LEED in the US, BEPAC in Canada, CASBEE in Japan, Eco-Quantum in Netherlands and GreenStar in Australia, among others (Ding et al., 2008; Sharifi and Murayama, 2013; Doan et al., 2017). According to Ding (2008), only Eco-Quantum is based on the whole building lifecycle

While some of these standards consider sustainability at the holistic level, covering social, economic and environmental aspects, some of them focussed on the operational energy efficiency of buildings without considering the embodied impacts of the materials and the environmental impacts of the actual construction process (Doan et al. 2017). With the exception of a few, most of the sustainable design appraisal systems have largely focused on the environmental pillars of sustainability (Illankoon et al., 2017). Notwithstanding this, evidence suggests that the sustainable design appraisal systems have been effectively doing what they were designed to do by driving sustainability of the built environment (Doan et al., 2017; Büyüközkan and Karabulut, 2018). Nonetheless, continuous improvement and updating of the sustainable design appraisal systems are essential to its effectiveness in driving the sustainability of the built environment (Doan et al., 2017; Illankoon et al., 2017).

Lifecycle assessment considers the whole life impacts of a product, covering its materials extraction, transportation, processing and manufacturing (Khasreen et al., 2009). In the case of a building, its lifecycle analysis covers all the processes involved from cradle to cradle, in case of its materials reuse or recycling, or from cradle to grave (Ajayi et al., 2015). Since the LCA covers the entire lifecycle of buildings, aligning the sustainable design appraisal tool with the LCA is essential to assigning appropriate environmental weight to various stages of the building lifecycle.

2.1. ENVIRONMENTAL SCORES PER LIFECYCLE STAGES OF BUILDINGS

Various sustainability assessment frameworks are being used for weighing the sustainability of building design and construction activities. Detailed analysis of some of these frameworks is available in Ding (2008), Cole (2005), Sharifi and Murayama (2013) and Kajikawa et al. (2011). In this study, the effectiveness and appropriateness of the UK BREAAM and CfSH were evaluated based on the environmental weight assigned to different lifecycle stages of buildings. The two frameworks were selected as the study is based in the UK. Although the sustainability assessment frameworks address the social, economic and environmental aspects of sustainability, this study is limited to the environmental aspect of sustainability. This section presents a brief overview of the assessment framework and summarises the scores assigned to different sections of the framework.

2.1.1 BREEAM

BREAAM is the first and world’s leading environmental assessment method for building. Its aim is to give environmental labelling to buildings by considering the best environmental practices that are incorporated into the planning, design, construction and operation of the buildings (BREEAM, 2014). The assessment framework covers various building schemes, which includes offices, retails, industrial, education, healthcare, multi-residential, court and prisons, among others (Kajikawa et al., 2011).

In BREEAM, buildings are assessed on nine key categories of performance, including energy, management, health and wellbeing materials, waste, pollution, and so on. As the 10th category, an additional score is assigned to a project, where stakeholders can demonstrate another innovative approach than those included in the assessment framework. The total number of points or credits gained in each section is multiplied by an environmental weighting factor, which considers the relative importance of each of the total 10 sections (BREEAM, 2014).

BREEAM consists of 5 categories of grades, which are a pass, good, very good, excellent and outstanding, depending on the overall score achieved by a project. Based on the provisions of BREEAM and scores assigned to different building performance indicators, Table 1 shows a breakdown of scores assigned to different lifecycle stages of buildings. Since the BREAAM considers social and economic aspects of sustainability, scores assigned to activities that do not directly fall under any lifecycle environmental impacts of buildings are classified as "others" in table 1. After multiplying the scores by the environmental weight assigned to each category of building performance indicator, the overall score per lifecycle stage is put in the bracket in the table.

2.1.2. Code for Sustainable Homes

The Code for Sustainable Homes is another environmental assessment rating method for new homes that assessed the environmental performance of residential buildings at the design and post-construction stage. It benchmarks building performance in nine categories of performance indicators, which include energy and carbon emissions, water, health and wellbeing, materials, waste and pollution, among others. Based on an analysis of a building proposal, and depending on the overall score, a building could be scored from level 1 to level 6, with level six being the highest achievable standard. Before it was repealed in April 2015, every new build in England and Wales is expected to achieve code level 4 before it could be granted a building control approval. Its provisions have now been incorporated into the building regulation as the new national technical standard, which is set at the equivalent of a code level 4. Although the code is not based on building lifecycle stages, but rather on the nine categories of measures, a thorough analysis of the code for sustainable home was carried out to determine the total score assigned to different stages of the building lifecycle. The result of the analysis is presented in Table 2.

Table 1: A breakdown of environmental impact weight per lifecycle stages in BREEAM

Categories/considerations	A	B	C	D	Others	Weight	Total Credit
1. Management		6 [0.72]			16[1.92]	0.12	22 [2.64]
2. Health and wellbeing			4 [0.60]		6 [0.90]	0.15	10 [1.50]
3. Energy			25[4.75]		5 [0.95]	0.19	30 [5.70]
4. Transportation					9 [0.72]	0.08	9 [0.72]
5. Water			6 [0.36]		3 [0.18]	0.06	9 [0.54]
6. Materials	10[1.25]		1[.125]	1 [.125]	0 [0.00]	0.125	12 [1.50]
7. Waste	1[0.075]	4 [0.30]	1[.075]	1[.075]	0 [0.00]	0.075	7 [0.525]
8. Land use and ecology		1 [0.10]			9 [0.90]	0.10	10 [1.00]
9. Pollution			7 [0.7]		6 [0.60]	0.10	13 [1.30]
10. Innovation					10[1.00]	0.10	10 [1.00]
Total	1.325	1.12	6.61	0.2	7.17	-	16.425
Percentage impacts per lifecycle stage	14.3%	12.1%	71.4%	2.2%	-	-	100%

**A = Embodied energy and Products manufacturing stage; B = Construction and replacement stage; C= Operational (use) stage; D = End of Life stage*
**Percentage per impact considers the proportion of points assigned to each stage per total proportion for the whole lifecycle stages (excluding "others")*

Table 2: A breakdown of environmental impact weight assigned to lifecycle stages in CfSH

Categories/considerations	A	B	C	D	Others	Total Credit
1. Energy and CO2 emission (ECO 1 – 9)	2	-	23	-	4	29
2. Water (WAT 1 – 2)	-	-	6	-	-	6
3. Materials (MAT 1 – 3)	24	-	-	-	-	24
4. Surface Water Run-off (SUR 1 – 2)	-	-	-	-	4	4
5. Waste (WAS 1 – 3)		2	5		-	7
6. Pollution (POL 1 – 2)	1		3			4
7. Health & Wellbeing (HEA 1 – 4)			7		5	12
8. Management (MAN 1 – 4)		4			5	9
9. Ecology (ECO 1 – 5)	1	3			5	9
Total	28	9	44	0	23	104
Percentage impacts per lifecycle stage	34.6	11.1	54.3	0	-	100%

3.0. METHODOLOGY

The overall goal of this study is to assess the sensitivity of the sustainable design appraisal tools to the lifecycle impacts at the different stages of the building lifecycle. In order to achieve this, score assigned to the different lifecycle stages in BREEAM and Code for sustainable homes were calculated. A full lifecycle analysis was carried out for four typologies of a modelled classroom to determine the lifecycle impacts of different stages of the building. The percentage of stage-based impacts were then compared with the percentage points associated with each of the stages in the sustainable design appraisal tools. The comparative analysis provokes some thoughts on the strength and weaknesses of the sustainable design appraisal tools and the needs for continuous improvement, as the use of renewable technologies increases.

3.1. LIFECYCLE ANALYSIS OF FOUR TYPOLOGIES OF A BUILDING CASE STUDY

Lifecycle Analysis (LCA) is a globally recognised approach for estimating whole lifecycle environmental impacts of products (Khasreen et al., 2009). It is performed within the framework of ISO 14040, utilizing four established phases, which are goal and scope, inventory analysis, impact assessment and interpretation (Ooteghem and Xu, 2012). A block of classroom was modelled as a case study using one of the widely used BIM tool, Revit. The lifecycle assessment process, case study model and the analytical process are discussed in this section.

3.1. The Case study

A case study of a block of classroom was modelled in Revit. The building consists of 2 floors with a total Gross Floor Area (GFA) of 1233m^2. Details of the case study model are as given in Table 3. In order to estimate the average lifecycle impacts of the building, irrespective of the materials of construction, materials used for the building were varied across four typologies. This is further referred to as sensitivity analysis in other parts of this paper. Typology 1 was modelled as a traditional British brick and block building, typology 2 is a timber building, typology 3 is a steel structure, while typology 4 was modelled with Insulated Concrete Forms. Inventory of total materials required for each typology is estimated in Revit, while operational impacts of the building typology were estimated using Green Building Studio (GBS) and energy analysis function of Revit.

Table 3: Specific characteristics of the baseline design used for the study

Building system	Specific characteristics
Exterior walls	100mm facing brick, 110mm cavity filled with polystyrene insulation, CMU inner wall with 12.5mm plasterboard finish and partly curtain wall.
Interior walls	Cavity masonry units filled with sound barrier.
Structure	Self-sufficient brick/block component served as structural support.
Ground floor	Composite hollow core floor finished with synthetic resin
First floor	Timber boards with I-section timber frames and synthetic resin floor finish
Windows	Aluminium-frame, double-glazed, argon-filled, U-value 1.55 W/m^2 K
Roof	Slate roofing sheet with wood frame
HVAC	Gas fired boiler, steam from Central Powerplant
Electricity	100% from external regional utility
Ceiling	Suspended gypsum ceiling with steel grid
Column	Pressure treated sawn hardwood – free from Copper Chromium Acetate(CCA)

3.2. Lifecycle Assessment (LCA) Framework

Goal and Scope

The scope of the LCA is limited to a two-floor BIM-modelled block of classroom with sensitivity analysis of material specifications, to determine the effects of each specification over the building's lifecycle. Also known as "what-if scenario", a sensitivity analysis was used to hypothesise alternative materials that could be used for the building. In line with Saynajoki et al. (2012), a period of 30 years was used for the LCA analysis of the building typologies. This is also partly due to the provision of 30 years available in GBS, which was used for evaluating the operational impacts of the buildings.

Inventory analysis

The LCA inventory analysis was estimated using the volume estimate capacity of Revit. The total volume of materials required by different typologies was entered into ATHENA impact estimator (IE), an LCA tool that takes in data from building materials and operation and converts it into various impacts categories such as Global Warming Potentials (GWP), acidification, etc. The inventory of energy need of the different building typologies was also estimated using GBS and Revit energy analysis. The results were also entered into IE to calculate the lifecycle impacts of the buildings.

Impact Assessment

In line with Hamilton et al. (2007), the most potent environmental impacts of building on the environment are its tendency of increasing GWP. As such, the impacts of the buildings were evaluated in terms of their tendency for GWP by calculating the quantity of carbon produced by each typology over the entire building lifecycle in KgCO2.

Interpretation

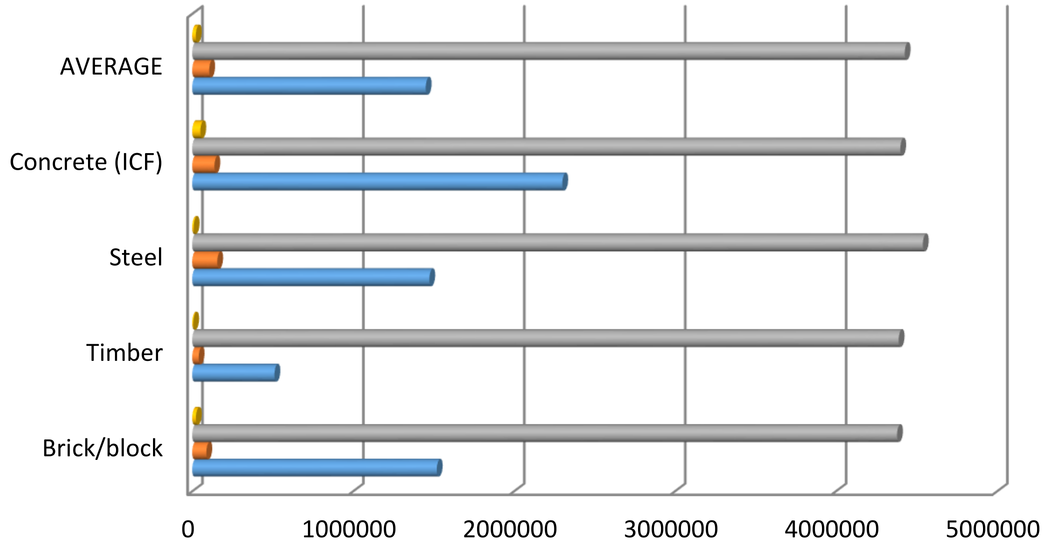
The overall goal of the whole life building LCA was to calculate an average impact per lifecycle stage of buildings. As such, the sensitivity analysis provided an avenue for finding the average impacts of the four typologies considered in the study.

4.0. FINDINGS AND DISCUSSION

This section presents the findings of the LCA for the building typology, and the corresponding impacts of each stage are compared with the proportional score assigned to the stages in BREEAM and CfSH.

4.1. Environmental impacts per lifecycle stages of buildings

As presented in Figure 1, the GWP of the buildings varied with the types of materials specified for their construction. The findings show that the order of environmental friendliness of the building typologies ranges from timber, brick/block, steel to concrete, where concrete buildings have the highest negative environmental impacts. Considering the lifecycle stages, the operational stage has the highest impacts on the environment. This was followed by the materials/product stage, construction and replacement stage and end of life stages respectively for all the building typologies. Figure 1 presents the average impacts of all the typologies over each lifecycle stage in KgCO2 that would be emitted by the buildings. AVERAGE represents the average impact per lifecycle stages for all the four typologies.



	Brick/block	Timber	Steel	Concrete (ICF)	AVERAGE
🟨 End of life Impacts	23200	6840	9760	50900	22675
◼ Operational Impacts	4380000	4390000	4540000	4400000	4427500
🟧 Construction Impacts	88240	40294	156000	138424	105739.5
🟦 Embodied Impacts	1520240	511285	1474000	2300224	1451437.25

Figure 1: Impacts of all the typologies (in KgCO2) over each lifecycle stage of buildings

4.2. The environmental weight assigned to different lifecycle stages of buildings in BREAAM and CfSH

As earlier presented in table 1 and 2, operational impacts of buildings were assigned with the highest environmental weight in BREEAM and CfSH with 71.4% and 54.3% respectively. This was followed by the embodied impact, which has 14.3% and 34.6% for BREEAM and CfSH respectively. Construction and end of life-related impacts were assigned 12.1% and 2.2% (respectively) in BREEAM. While the CfSH sets no direct measure for the end of life-related impacts, construction-related impacts have a proportional weight of 11.1%. Figure 2 presents the proportional environmental weight assigned to the different lifecycle stages.

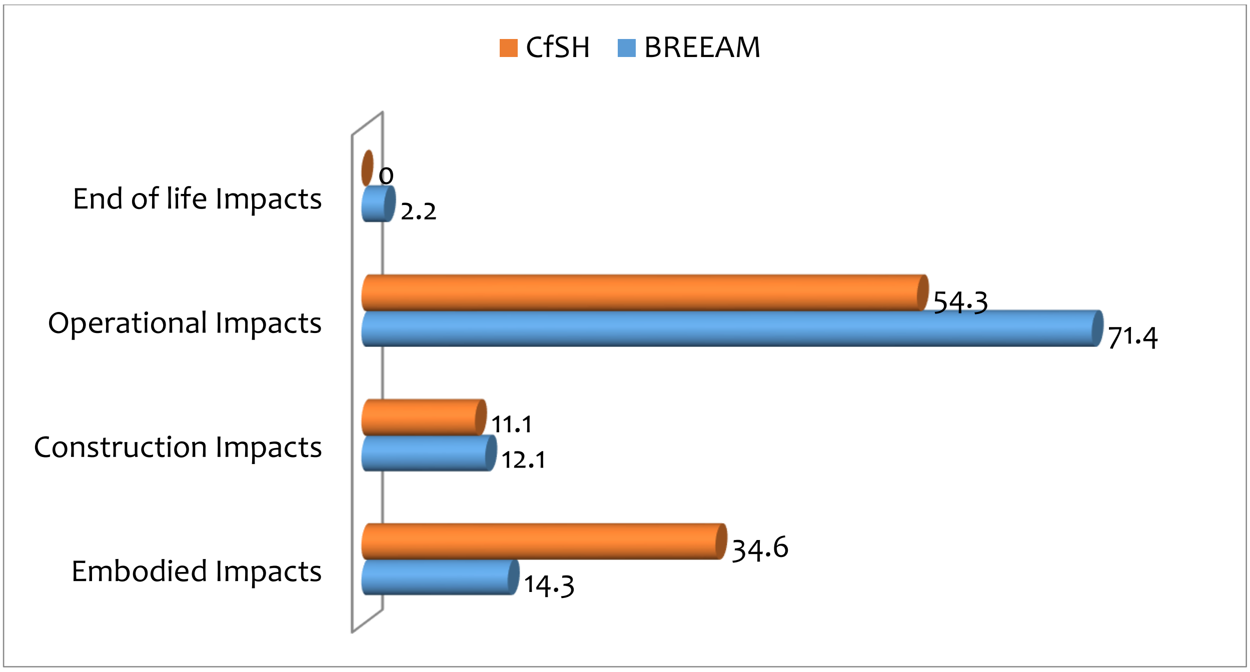
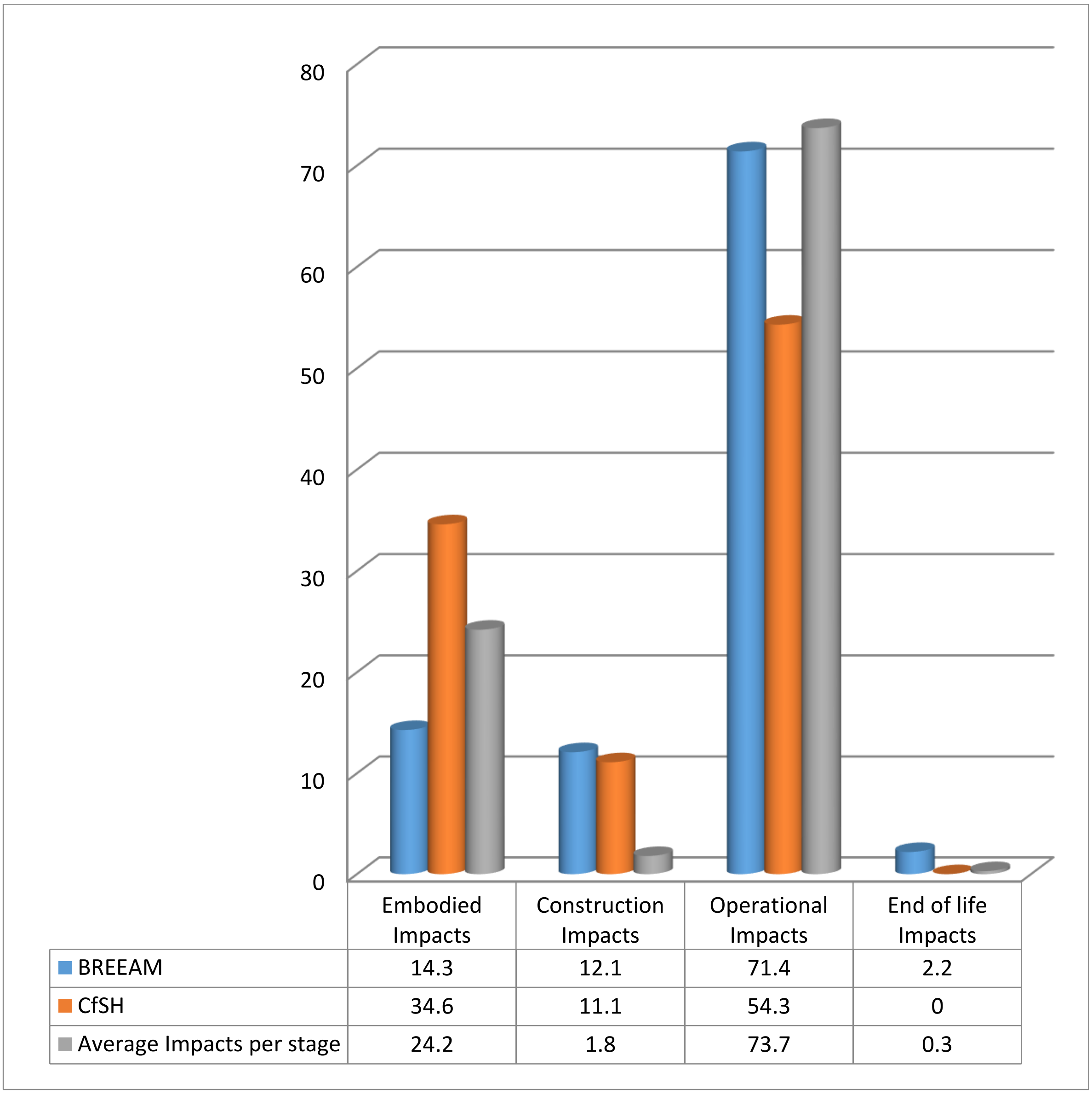


Figure 2: Environmental weight assigned to different lifecycle stages of buildings in BREAAM and CfSH.

4.3. Comparative analysis of Simulated and assigned lifecycle environmental impacts

Figure 3 compares the percentage impacts of buildings over their entire lifecycle with the proportion of scores assigned to each stage in BREEAM and CfSH.



	Embodied Impacts	Construction Impacts	Operational Impacts	End of life Impacts
🟦 BREEAM	14.3	12.1	71.4	2.2
🟧 CfSH	34.6	11.1	54.3	0
⬜ Average Impacts per stage	24.2	1.8	73.7	0.3

Figure 3: Comparison of simulated impacts with CfSH and BREEAM weightings

Note: "Average impacts per stage" refers to average simulated impacts for all the four building typologies as presented in figure 1.

The figure suggests that on average, BREAAM perform fairly well in terms of the proportional scores assigned to the different lifecycle stages of buildings, when compared to the CfSH. For instance, while average operation impacts of buildings stand at 73.1%, a total impact weight of 71.4% is assigned to the stage of the building lifecycle. This fairly represents the significant impacts of the operational stage of buildings (Zhan et al., 2018), suggesting that the sustainable design appraisal methodology is effective in driving the sustainability of buildings at the operational stage. Nonetheless, the embodied impacts of materials are underscored, while impacts of the construction processes are scored far higher in BREAM than its simulated impacts. This suggests the need to reconsider the environmental weight assigned to the raw materials processing and production in the widely used environmental assessment method. This is particularly important as there is an increasing recognition of the economic benefits of the operational stage (Ajayi et al., 2015). Based on this, there is an increasing decarbonisation of national mixes and the use of fossil energy for building operation is decreasing (Malmqvist et al., 2018). This means that legislative provisions and environmental assessment tools are required to give more weight to the embodied impacts of the materials used in construction. Although more significance has also been assigned to the end of life stage than the simulated impacts, the assigned proportion still fall within the range of the simulated impacts of 1.5-4% depending on the materials used. As the BREEAM weighting assigned to the operational impacts reflects the simulated impacts of the stage, the most important improvement requirement for the BREAAM is to redistribute the importance index assigned to the construction and embodied impacts. This has the tendency of driving the use of environmentally friendly materials for building construction.

Unlike the BREAAM, CfSH attached more importance to the embodied impacts of the building, while the significance attached to the operational stage is lower than the simulated impacts. Although the code has ceased to operate, the concern raised by this comparative analysis is very important for the building regulation, into which the provision of the code has been integrated. While the simulated lifecycle operational and embodied impacts of buildings cover about 73.7% and 24.2%, 54.3% and 34.6% have been allocated to the two stages respectively. In addition, no significant provision has been made for the end of life of the building, which contributes about 0.3% with the tendency of contributing between 1.5 and 4% when brick and concrete are used for construction. This requirement is in line with Akinade et al. (2015) who opined that significant proportion of construction waste and its associated environmental impacts could be prevented by considering the end of life in the sustainable design appraisal tools.

5.0. CONCLUSION AND IMPLICATION FOR PUBLIC POLICY

Sustainability appraisal frameworks have received both praises and criticism in terms of their effectiveness in engendering sustainability of the built environment. In order to contribute to the ongoing debate and determine the effectiveness of the appraisal framework concerning whole life performance, this study compares simulated lifecycle impacts of buildings with the environmental weight assigned to the lifecycle stages in BREAAM and Code for Sustainable Homes (CfSH) as case studies. The comparative analysis suggests that while BREEAM has adequately assigned weight to operational stage of building lifecycle, scores assigned to embodied and construction impacts are disproportionate to their simulated lifecycle impacts. Code for Sustainable Homes, on the other hand, attached more importance to the embodied impacts of the building, while less significance is attached to the operational stage. It also makes no significant provision for end of buildings' lifecycle, which could have significant environmental impacts on the built environment.

This study has an implication for improving the effectiveness of the sustainability appraisal framework. The deficiency in BREEAM provision requires that more weight should be given to embodied impacts, while points assigned to construction-related impacts requires reduction. These require re-consideration of the scores assigned to materials, waste and management aspects of the appraisal methodology. Although the CfSH has ceased from being a requirement for new homes, its integration into building codes means that weights assigned to different lifecycle stages require revision. This could be achieved by increasing the total weight associated with the operational stage while reducing the weight associated with the embodied impacts.

Notwithstanding this present change requirement, continuous improvement of the total weight associated with different lifecycle stages is required for the effectiveness of the appraisal framework. Similarly, increasing recognition of the economic benefits of buildings operational effectiveness means that other stages could be further driven by the sustainability appraisal framework. This is particularly important, as buildings that are based on renewable technology over its lifecycle could possess higher embodied impacts than operational impacts. Thus, with increasing energy efficiency of buildings, there is a need for a stepwise increment of the proportional importance assigned to embodied and end of life impacts of buildings.

As this study is limited to a case study of a block of the classroom, other studies could evaluate the effectiveness of the sustainability appraisal framework using a case study of other building use types such as residential, offices, retails and industrial buildings among others. Similarly, the effectiveness of other internationally recognised sustainability appraisal framework, such as LEED and CASBEE among others, could be evaluated in terms of their proportionality to real lifecycle impacts of buildings. Although the Green Building Studio and ATHENA impacts estimator have been widely approved and used for building simulation, the accuracy of the simulated results largely depends on the tools.

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