Lifecycle Environmental Performance of Materials Specifications: A BIM Enhanced Comparative Assessment

Abstract

The study aimed at evaluating the extent to which different building materials specifications affect building lifecycle environmental performance, using a Building Information Modelling (BIM) enhanced lifecycle assessment (LCA) methodology. A combination of Revit Architecture which is a BIM based design and analysis tool, an energy simulation tool known as Green Building Studio (GBS) and LCA tool known as ATHENA Impact Estimator were used for the assessment. The LCA was carried out on a life case study of a 2100m^2 one-storey school building as well as its variability analysis, by varying materials specifications in terms of whole building materials. The lifecycle performance of the buildings was primarily evaluated in terms of its Global Warming Potential (GWP) and Health Impacts.

The findings of the study show that irrespective of materials used, buildings that are based on renewable energy perform better than those based on fossil fuels over its lifecycle. In terms of building materials, both environmental and health preference of buildings congruently range from timber, brick/block, steel, to Insulated Concrete Foams, in a descending order. The study suggests that as buildings become more energy-efficient during operational stages, serious attention needs to be given to their embodied impacts.

The study lay out a methodological framework that could be adopted by industry practitioners in evaluating lifecycle environmental impacts of different BIM modelled materials options at building conception stage. This has the tendency of ensuring that most lifecycle environmentally beneficial materials combinations are selected during specification and construction.

Keywords: Lifecycle Assessment; Building Information Modelling, materials specification; Global Warming Potential; Health Impacts.

1. Introduction

The building sector is the largest consumer of energy in the developed nations, in terms of energy requirement for materials manufacture, construction and building operation [1]. The sector has become a major target for environmental improvement as it accounts for more than 40% of total energy consumption and natural resources, with about 33% of global CO_2 emission coming from the sector [2] Whilst these alarming figures point out to a need for holistic efforts towards investigating and preventing environmental impacts due to buildings, fortunately, Life Cycle Assessment (LCA), which involves cradle to grave analysis of products, is arguably the best method of evaluating impacts of a particular product on the environment [3] Nonetheless, despite the claim that clear interaction between buildings' lifecycle stages calls for such global methodology like LCA [4], it has been rather applied to other products, with little application to whole building analysis. This is due to the complex nature of buildings' inventory analysis, inadequate inventory data, its long life span, and so on [3, 5]

Previous research efforts towards estimating building lifecycle impacts have been dedicated to individual buildings in forms of offices, residential and industrial buildings [6, 7, 8, 9]. While these set of studies have set some frameworks for whole building lifecycle assessment, lack of global benchmark for comparing lifecycle impacts of each building [10], as well as failure of the studies to consider alternative materials specifications, have questioned the ingenuity of their findings. Other set of studies have been carried out to evaluate how materials configurations affect energy efficiency of buildings using various sensitivity analysis and "what if scenarios"; these among others include, Ceranic [11] Azhar et al. [12] and Autodesk [13]. Again, apart from showing impacts of using different building materials specification over its energy performance, these set of studies are limited to operational stage of building, thus leaving out environmental impacts of buildings during other stages - material manufacture, transportation, construction, maintenance and demolition stages. Although the studies provided rich information about impacts of materials specifications on operational energy performance, industry practices still lack knowledge of cradle to cradle/grave environmental impacts of different materials specifications.

As the year 2016 has been earmarked as the period when BIM would be fully adopted for public procurements in the UK, with further cut down in emission target [14, 15], a number of studies have highlighted the potential benefits and possibility of using BIM for lifecycle environmental assessment of buildings [7,16,17]. However, despite the growing adoption of BIM across the UK and increasing call for early stage simulation of different design and construction options to predict their environmental impacts, before actual site works, there has been no standard guideline for implementing whole building lifecycle assessment with the aid of BIM. Bulks of research efforts and software designs have been focussed on building energy performance during operational stage, thus leaving out all other lifecycle stages, which are very important for curtailing environmental impacts [18]. It is on this basis that this study emerges with an overall aim of determining the extent to which building materials specifications affect its lifecycle environmental performance. The study fulfils the following objectives:

1. To determine impacts of materials specification on lifecycle Global Warming Potential (GWP) and health impacts of buildings.
2. To comparatively evaluate lifecycle impacts of buildings based on fossil fuel and those based on renewable energy.
3. To compare health and environmental impacts of operation stage and other lifecycle stages of building.
4. To determine whether environmental friendly buildings are really healthy.

The findings of this study would furnish industry practitioners with the knowledge of whole life impacts of different materials specifications. The successful integration of BIM with LCA tool signifies the possibility of design stage simulation of whole lifecycle environmental impacts of buildings, thus advancing current industry practice beyond its focus on operational stages.

2. Existing Literature on BIM and LCA

LCA is an internationally standardized technique for evaluating environmental impacts of a product, process or system throughout its life cycle. It covers extraction and transportation of its raw materials, manufacturing, transportation and distribution, use and re-use, maintenance, recycling and final disposal [19]. It is a holistic approach that considers all materials and energy inputs and flows throughout the life span of a product in question, in order to analyse the environmental aspects and potential impacts of the product [20]. Techniques and approaches adopted in carrying out LCA vary from one study to another. Nevertheless, LCA is generically carried out within the framework of ISO 14040 which consists of four main phases [3].

Goal and scope definition is the first phase of LCA where purpose and objectives of the study is defined, assumptions and simplification used is made known, the limit (boundary) of the system is stated, the necessary data is identified, functional unit is defined and the target audience is spelt out [4, 21]. This is followed by the inventory analysis stage where accounts of input and output flows of energy, water, material, emission and pollutants are made [4]. It is often referred to as data collection and calculation phase [21]. The next stage is referred to as Impact Assessment, which involves evaluation of the results obtained from the previous phase and characterisation of the result into more meaningful environmental impact such as global warming, toxicity and so on [4]. This precedes the last stage known as the interpretation phase where the results from the inventory analysis and impact assessment are all considered based on the goal of the study, in order to establish conclusion and recommendations [21].

Implementation of LCA is usually time-consuming as it takes a lot of time and effort to compile and manually input life cycle inventory data for every material used in the building; thus limiting its application in AEC industry [22]. Integration of BIM and LCA software therefore is a solution to the problem as quantity take-offs and material specifications are already included in BIM platforms. Various constraints of BIM based LCA has been identified over the years. For instance, inaccessibility and complication of LCA tools, inefficiency of data input into LCA programmes and problem of data interoperability exist [23]. It is expected that BIM and LCA tools are interoperable and compatible for future LCA to be effective in AEC industries. For implementation of LCA to be eased, there would be need for improving data exchange between different programmes or LCA tools are built-in for BIM software [24].

Nonetheless, several studies have been carried out on the concept of whole building LCA, with each having different techniques and approaches, as well as varied goal and scope [2, 6, 7, 9, 25, 26]. Some of the studies address the use of BIM for LCA [16, 17]. For instance, Wang et al [16] demonstrated how BIM supports implementation of LCA. The building model was prepared with Revit architecture, and Autodesk Ecotect was used for simulating the operational energy used through an easy file transfer between the two BIM tools. LCA of other stages of the building was carried out through combination of other external analysis tools and databases. Stadel et al. [17] point out the main obstacle in the use of BIM for LCA. They stressed that although recent development in BIM platform (especially Revit architecture) has allowed material take-off and estimates/schedule, there is still need to disaggregate individual material under the same family.

Whole building Life Cycle usually cover five stages, raw materials and manufacturing, construction, operation, maintenance, and demolition stages [8, 16]. As a result of simplifications suggested for successful implementation of LCA, some studies neglect one stage or the other. Nevertheless, all studies identify material and manufacturing, construction and operation stages as crucial stages of buildings LCA. Other stages covered or omitted in each study would therefore be determined by the goal and scope of the study [27].

In implementing whole building LCA, a combination of LCA tools and other external analysis tools were used in different studies as a result of growing list of computer programmes suitable for the assessment. For instance, Ooteghem and Xu [6] combined ATHENA Impact Estimator and eQUEST. The former was used for other stages of building life cycle than operation stage while the latter provided information about operation stage of the case study used. Ghattas et al. [25] argues that ecoinvent is one of the commonly used data source for LCA. Various database along with several mathematical analysis for summing up overall embodied impacts have been developed and used in previous studies [28]. For instance, Baek et al. [2] used inventory prepared by Japan Building Construction; Wang et al. [16] used Finnish building classification, while some other studies also used the Bath University Inventory of Carbon and Energy (ICE) to estimate embodied impacts of various building materials [29]. These thus suggest that although all LCA studies are carried out within the framework of ISO standards, simulation, database and analytical tools vary from one study to others.

3. Methodology

A building that is regarded as zero energy or carbon neutral/negative during its operational stage is possibly constructed of materials with high embodied energy or construction techniques, which also have hazardous environmental effects. Therefore, this study is aimed at examining the impacts of commonly used materials specifications on life cycle environmental performance of buildings using a BIM enhanced approach. Based on American Institute of Architect (AIA) standard, the BIM model is produced at Level of Detail 200 (LOD 200) as the approximate quantities, size, shape, location, and orientation are required for both energy analysis and quantity estimation required. This section describes the methodological framework, case study model, research instruments and detail approach used in the study.

3.1. Life Cycle Methodological Framework

LCA is performed within the framework of ISO14040 [6] considering its four established phases [7, 30]. This study is carried out within the framework provided by the standards and considered all the phases as described below.

Goal and Scope: The scope of this study is limited to a single storey BIM modelled primary school building with variability analysis of materials specifications, to determine effects of each of the specifications over the building's life cycle. A short lifecycle period of 30 years was taken after Saynajoki et al. (2012 in [25]), and in consideration of years considered in Green Building Studio which was used for simulating operational energy of the building

Inventory Analysis: The life cycle inventory of material input were computed using volume estimates capacity of Revit. The quantities were entered into ATHENA Impact estimator which in turn estimates the impacts of the building using database of impact categories associated with unit of the material specified, and the type of construction. The inventory of energy use during the operational stage was made using Revit Architecture with its powerful link to Autodesk Green Building Studio (GBS). The estimate was made for each of the design specifications used in the study. The result from Revit Architecture and GBS were ultimately entered into ATHENA impact estimator which finally converts the unit of gas and electricity used into different impact categories such as climate change potential, acidification, eutrophication, and so on.

Impact Assessment: Two primary impact categories assessed in the study are Global Warming Potential (GWP) and Human Health particulates (human toxicity). The GWP was considered as a result of highest impact rating given to it by the BRE [31]. Human Health particulate (HH impacts) was given a special consideration as a result of its potential for health deterioration and impacts on respiratory system which may result in such diseases as asthma, bronchitis and acute pulmonary diseases [32].

Interpretation: Variability analysis was used to evaluate impacts of different design specifications on the buildings' LCA. The impact of the main case study was interpreted for the whole building and alternative configurations/specification so as to set basis for comparing commonly used building specifications.

3.2. Process Description

For a typical LCA of each of the typologies used in the study, a BIM model of the building is generated using Revit. Material take-off of the building is estimated to determine volumes of each of the materials that contributed to the building as a single entity. Excel sheet was used to segregate each of the building components so as to determine materials that contributed to each components; for instance, walls made of timber are separated from those made of steel within the same building. Operational energy required for the building is determined with the aid of Revit and Green Building Studio, and the results are then entered into the Impact Estimator along with the quantities of each of the materials to determine the life cycle environmental impacts of the building. The procedure is repeated for other design specifications, and their impacts are comparatively evaluated to achieve the aim and objectives of the study.

3.3. Case Study Design

In this study, case study approach was adopted, with variability analysis carried out to fulfil the goal of the study. The case study used for the study is a two-floor primary school building located in Canada. Table 1 gives a brief description of the building, and Table 2 provides inventory of material specifications for all design options used in the study. The model is detailed at LOD 200.

Table 1 : General building characteristics
Building type: Primary school,
Number of floor: 2
Ground Floor area 1319m^2
First floor area :938m^2
Lighting control: All manual
Green roof area: 258m^2
First floor roof area: 1050m^2
Low level roof: 183m^2

Table 2*: Material specifications for the typologies*

Building system	**Specific characteristics**
Exterior walls	**A**. 100mm facing brick, 110mm cavity filled with polystyrene insulation, CMU inner wall with 12.5mm plasterboard finish and partly curtain wall. **B.** Cladded timber cavity wall filled with cellulose insulation. **C.** ICF with expanded Polystyrene. **D.** Gypframe steel framed wall with polystyrene insulation. **E.** Brick/block cavity wall**.**
Interior walls	**A.** Cavity masonry units filled with sound barrier. **B.** Timber cavity with cellulose insulation. **C.** Cavity CMU with polystyrene insulation. **D.** Timber/steel cavity with cellulose insulation. **E.** Timber cavity with cellulose insulation.
Structure	**A**. Self-sufficient brick/block component served as structural support. **B.** Hardwood structural post as main beam, and glue lamp as secondary frame. **C.** Reinforced Concrete column structure **D.** Steel frame **E.** Hardwood structural post as main beam, and glue lamp as secondary frame.
Ground floor	**A**. Composite hollow core floor finished with synthetic resin **B.** Timber raised floor insulated with blown cellulose, on CMU structure. **C.** Timber raised floor insulated with blown cellulose, on CMU structure. **D.** Steel plate raised on CMU, and finished with synthetic resin **B.** Timber raised floor insulated with blown cellulose, on CMU structure.
First floor	**A**. Timber boards with I-section timber frames and synthetic resin floor finish **B.** Timber frame and timber board finished with synthetic resin **C.** Precast concrete floor D. Gypframe steel flooring
Windows	**A**. Aluminium-frame, double-glazed, argon-filled, *U*-value 1.55 W/m^2 K **B.** Timber-frame, double-glazed, argon-filled, *U*-value 1.55 W/m2 K **C-E.** Aluminium-frame, double-glazed, argon-filled, *U*-value 1.55 W/m2 K
Roof	**A**. Slate roofing sheet with wood frame **B.** Insulated timber plate flat roof with EPDM cover **C.** Reinforced concrete flat roof with 40% GGBS/recycled aggregate

	D. Insulated steel plate flat roof covered with EPDM **E.** Slate roofing sheet with wood frame
HVAC	**A-D**. Gas fired boiler, steam from Central Power plant **E.** Renewable source with lower percentage of fossil fuel.
Electricity	**A-D**. 100% from external regional utility **E.** renewable/non-renewable sources
Ceiling	**A-E.** Suspended gypsum ceiling with steel grid
Column	**A**. Pressure treated sawn hardwood – free from Copper Chromium Acetate(CCA) **B.** Pressure treated sawn hardwood – free from Copper Chromium Acetate(CCA) **C.** Pressure treated sawn hardwood – free from CCA **D.** Steel column. **E.** Pressure treated sawn hardwood – free from CCA

*Note: **A** is a typical Brick/block building, **B** is a timber structure, **C** is Insulated Concrete Form building, **D** is a steel structure while **E** is also a Brick/CMU like A, but based on renewable energy sources.*

3.4. Sustainable Alternatives and LCA of Required PV Panels.

LCA was carried out for energy efficient alternatives for the typology A. The required electricity and fuel was estimated for different building requirements such as space cooling, fans, lighting, heating, miscellaneous equipment and so on, using Energy End-use Chart of Green Building Studio. LCA was estimated for required PV panel to power lighting, miscellaneous equipment and fans based on earlier studies [33, 34, 35]. The estimated LCA was added to the original LCA value for the embodied and construction impacts of the buildings while electricity and fuel requirement was only estimated for other facilities that are not powered by the PV panel. The embodied CO_2 for PV panels found in literatures are 14.65g/Kwh_e, 34.3 g/Kwh_e, 44g/Kwh_e 50 g/Kwh_e, 60 g/Kwh_e, 280 g/Kwh_e based on the years covered by the study, with recent years producing less CO_2 emission per KiloWatt hour of electricity generated [33, 36]. Therefore, an average of 60gCO_2/Kwh of electricity on a life cycle of 30years was used in the study.

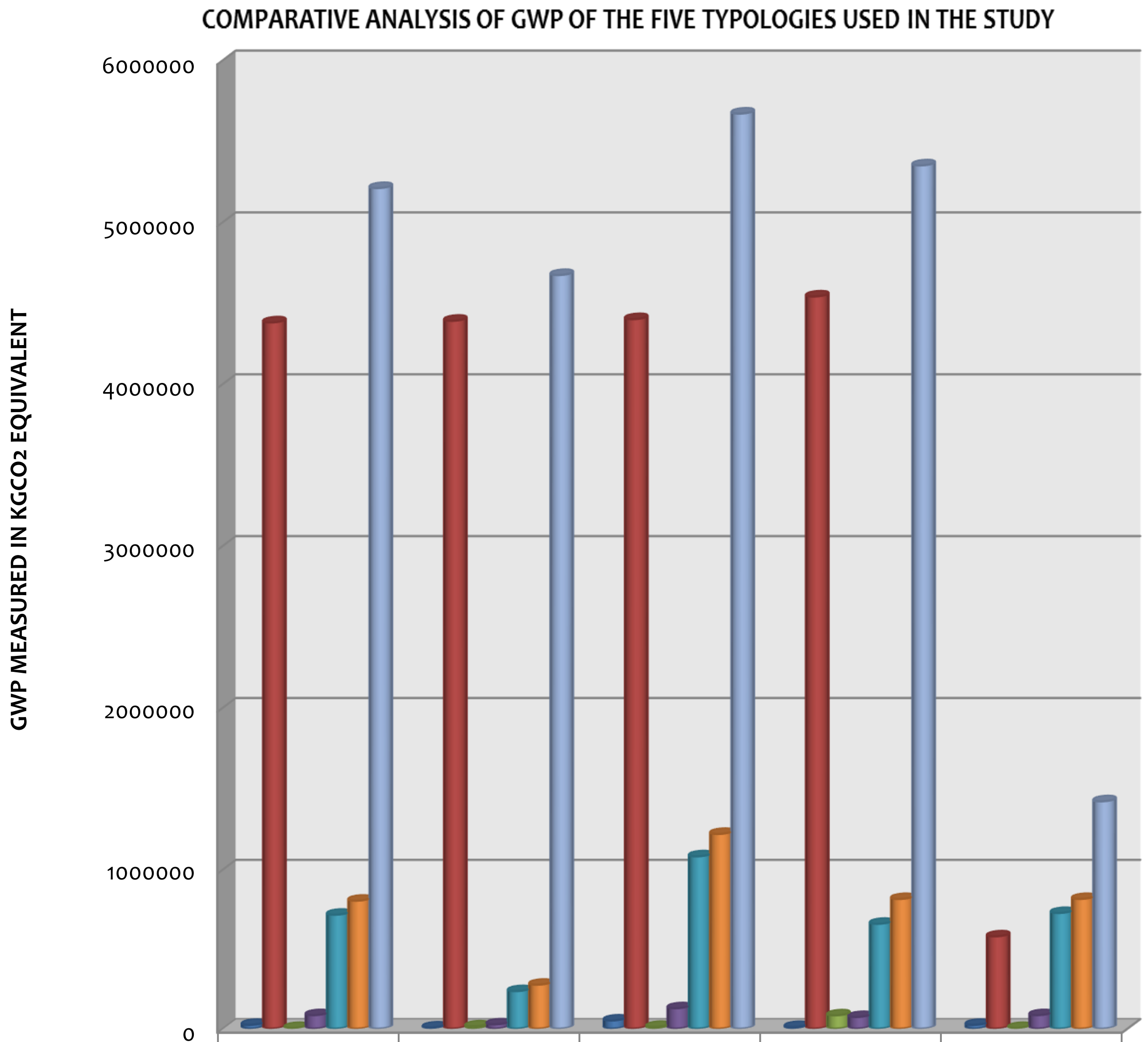
5. Findings and Discussion

This section analyses the findings of the comparative analysis and discusses its implications, so as to draw meanings from the findings. It comparatively evaluates the results of the findings and follows it up with discussion of the comparative analysis. The discussion is based on relevance of each buildings' life cycle stages, materials specifications, GWP, health impacts, and so on.

5.1. Comparative Analysis of GWP of the Design Typologies

The figure below comparatively evaluates GWP of all design typologies used in this study over the life cycle of the buildings. In terms of the four conventional typologies (A, B, C and D), ICF building has the highest GWP of 5,670,000kgCO_2 equivalent of which amount to annual journey of about 573SUVs over the entire life cycle of the building, or 19SUVs/year. The steel building has the second highest impact of 5,350,000kgCO_2 equivalent; which equals 540SUV/year over the entire life cycle of the building or annual journey of 18SUVs. Brick/block building has the third highest GWP of 5,210,000kgCO_2 equivalent, an annual journey of 526SUVs over the entire life cycle of the building which could also be expressed as 17.5SUVs/year. Timber structure has the lowest GWP among the four typologies. It has a total GWP of 4,672,625kgCO_2 equivalent, which equals annual journey of about 472SUV over the entire life cycle of the building, the same amount as about 16SUVs/year.

The low energy typology suggests that a decision that has to do with reduction in operational energy is more important than material selection in building. Comparing typology A and E, the use of PV panel to compliment electricity resulted in a decrease of 3,788,973kgCO_2, equivalent to annual journey of 383SUVs or a save of up to 13SUVs in a year. Total impact of using PV panel contributed only 11027kgCO_2 equivalent which is less than annual journey of 2SUVs over the entire life cycle of the building, or 0.04SUV/year. Echoing findings by Dodoo et al. [37], the study suggests that the more the reduction in operational energy, the less the GWP of the building typology.



	BRICK/BLOCK	TIMBER STRUCTURE	ICF BUILDING	STEEL BUILDING	LOW ENERGY BUILDING
END OF LIFE	23200	6840	50900	9760	23200
OPERATIONAL	4380000	4390000	4400000	4540000	580000
REPLACEMENT	3840	13745	10424	83200	3840
CONSTRUCTION	84400	26540	128000	72800	84400
PRODUCT	716000	235500	1080900	659000	727027
EMBODIED IMPACTS	804240	275785	1219324	815000	815267
TOTAL IMPACTS	5210000	4672625	5670000	5350000	1421027

Figure 1: Comparative evaluation of GWP of the five building typologies

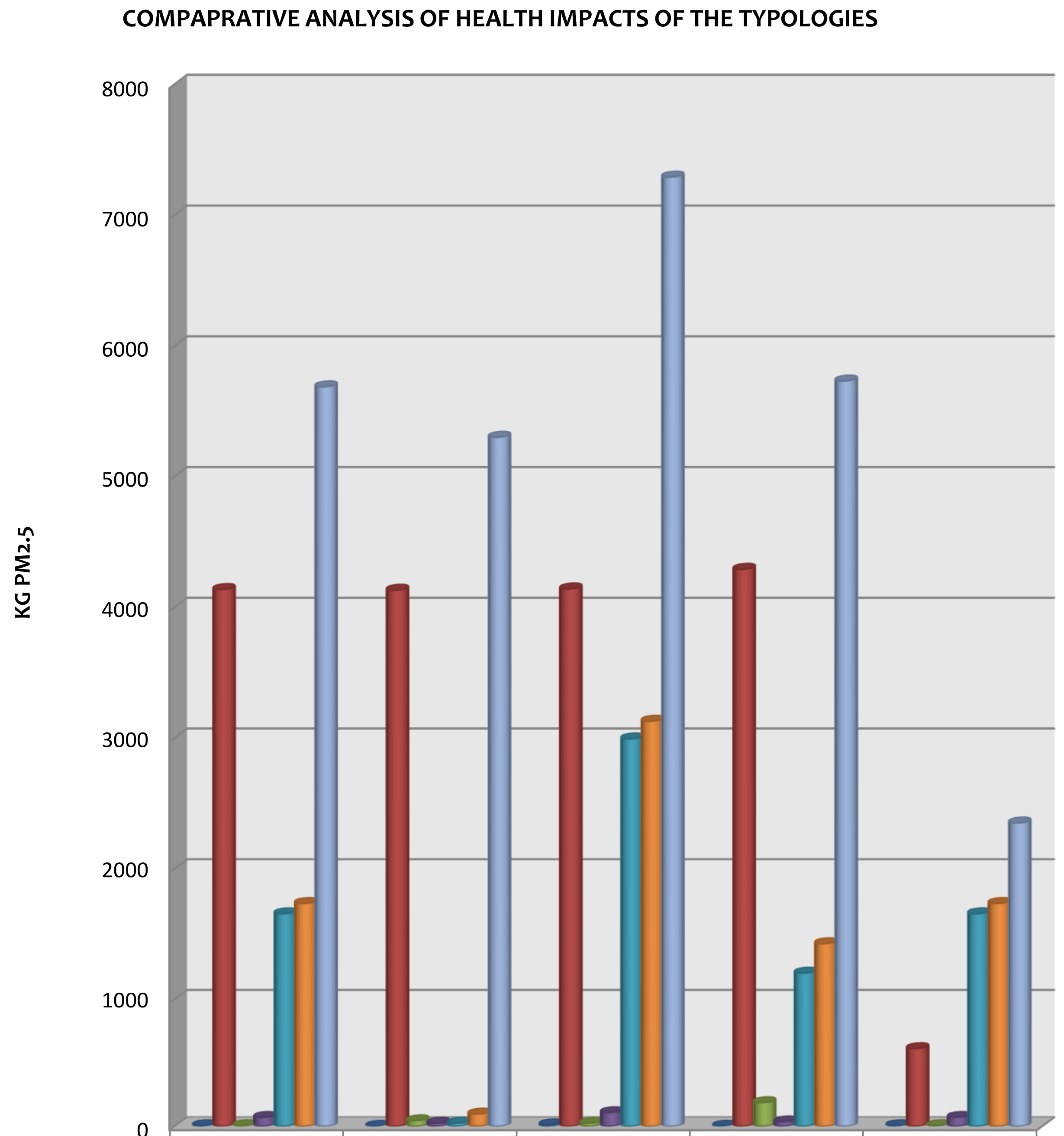
5.2. Comparative Analysis of Health Impacts of the Design Typologies

Similar to GWP of the building typologies, the health impact varies from one building to another. Figure 2 shows HH Criteria measured in terms of $kgPM_{2.5}$ of particulate matter that would be present in the air as a result of material manufacturing and transportation, construction, replacement, operation and end of life impacts of the buildings.

The Figure 2 shows that after the low energy building, timber building has low health impacts over the life cycle of the building. Surprisingly, the product, construction, replacement and end of life stages of the timber building have insignificant impacts when compared with operational stage. This means that by further reducing the operational energy requirement of the timber building, it would have almost no health effect throughout the entire life cycle of the building. ICF building produced the highest $KgPM_{2.5}$ of fine particulate matter, followed by steel building and then the brick/block building. The result based on low energy building suggests that unlike timber building, reducing operational energy for a brick/block building, ICF or steel structure does not entirely reduce their health impacts as the product stage also contributed significant health effects. Although, operational stage has the greatest health effects compared to other stages.

5.3 Relationship between GWP and Health Impact

This study shows a direct relationship between GWP and health impacts of the buildings. Both the GWP ranges from ICF building, then the steel building, brick/block building and timber building in descending order. From their relationship, it can be concluded that the greener a building in terms of GWP, the healthy the building. This suggest that to make a building healthy for both the occupants and construction workers, the use of energy efficient, greener, renewable and local materials becomes important as they results in low GWP which in turns results in less health effects.



	BRICK/BLOCK	TIMBER STRUCTURE	ICF BUILDING	STEEL BUILDING	LOW ENERGY BUILDING
END OF LIFE	7	2	14	3	7
OPERATIONAL	4135	4130	4140	4290	612
REPLACEMENT	7	46	26	188	7
CONSTRUCTION	72	26	109	37	72
PRODUCT	1655	26	2993	1201	1655
EMBODIED IMPACTS	1734	98	3128	1426	1734
TOTAL IMPACTS	5686	5300	7290	5730	2350

Figure 2: Comparative evaluation of human health impacts of the five building typologies

5.4 Design Specifications and Embodied Impacts

Embodied impacts vary from one building design specification to another based on the findings of this study and similar findings [16, 27]. As represented in Figures 1 and 2, the ICF has highest GWP and health impacts compared to other building typologies. The brick/block building has the second highest in terms of both impacts; steel building is next to the brick building while timber building has lowest impacts compared with other buildings. While there is much gap between ICF and brick/block buildings in terms of embodied GWP, – up to 440Mg, an equivalent of up to annual travelling distance of 44SUVs – there is little difference between brick/block and steel building – just about 20Mg (annual travelling distance of approximately 2SUVs). Total GWP saving as a result of the use of timber compared to steel or brick/block building amounts to 527Mg. This shows that there is direct relationship between embodied GWP and embodied Health impacts in a similar relationship with total GWP and total Health impact. The building with highest embodied GWP has the highest embodied health impact and vice versa.

5.5. Design Specifications and Operational Impacts

The findings suggest that the higher the energy requirements of a building, the more would be the GWP and health impacts associated with the operational stage of the building. Unlike embodied impacts where ICF building has highest GWP and potential health impacts, steel building uses more energy than ICF and other building typologies, thereby having the highest GWP and health impacts due to operational stage of the building. The next highest impact at the operational stage after ICF (which is next to steel) is due to timber building which is slightly higher than that of brick/block building. This suggests that massive cavity walling system reduces operational impacts of buildings much more than thinner walling frame. However, when insulation pattern of the timber building was improved, it led to reduction in both GWP and health impacts due to operational stage, while it insignificantly added to embodied impacts of the building. These results suggest that when evaluating LCA of a whole building as an entity, thickness and efficiency of insulation is a very important element that can go a long way in reducing life cycle impacts of buildings. This is because, the thicker/more-efficient the insulation, the lesser the operational energy requirements and the potential impacts due to the operational stage. Even as timber is proved to be more environmental friendly in this study, poor insulation to a timber building would have far more environmental impacts than ICF or well insulated brick/block buildings.

5.6. Comparative Analysis of Conventional and Low Energy Typologies

The more the renewable technology used in a building, the less would be the environmental impacts due to the building. This conclusion is reached as a result of direct comparison between building typology –A which is a brick/block building and its alternative typology –E which is based on combination of electricity and PV panel. As shown in the figures, the building based on renewable energy technology has very low GWP (about one fourth), when compared to the same building that is based on fossil fuel. Although embodied impacts would increase when using renewable technologies, it has insignificant effects compared to resulting impacts of electricity and fuel. As the health impacts also varies significantly with GWP of buildings as earlier discussed, the building based on renewable technology has lesser health impacts compared to its conventional alternative.

5.7. Relevance of Each Stage to Environmental Impacts of Buildings

Building types and its materials specifications determine the stage that is more relevant when carrying out LCA of whole buildings. For a building that is based on electricity and fuel, operational impacts is the most impactful stage in terms of whole lifecycle analysis of a building, with product stage being the next important stage for such a building. However, for a building that is based on renewable technology, product stage has more impacts than all other stages. Construction stage closely follows either of the two stages depending on the sources of energy used in running the building. Similarly, materials used in the building determine the relative importance of replacement and end of life stages. For buildings with massive walling system and less tendency for reusability of the materials, end of life impacts is more than replacement impacts. This applies to buildings constructed with brick/block and ICF. However, this is contrary for steel and timber structure as their end of life stage has less GWP and health impacts than the replacement stage.

Summarily, this means that a general conclusion regarding the relevance of replacement and end of life stages could not be made. The reusability/recyclability of the building components determines their relative importance just like source/means of energy use in building determines the most impactful between operational and construction stages.

6. Implication for Practice

Currently, reducing the demand for operational energy is the most important factors to be considered in achieving buildings that would have low impacts over its lifecycle. Therefore, both the designers and policy makers should concentrate their efforts on reducing operational energy requirements of buildings. This would not be limited to the use of renewable technologies for building operation; it would involve selection of appropriate insulation materials to reduce outdoor impacts on the building as discussed in the findings of timber structure with varied insulation efficiency.

Meanwhile, as demonstrated by renewable alternatives of buildings, embodied impacts increase when building uses renewable technology. As such, designers are encouraged to improve the use of environmental friendly materials such as timber, especially for internal partition so as to reduce environmental impacts due to building materials. Also, when using timber or steel walling system, there would be more need to improve the thickness of insulation materials much more than what would have been used if the building were to be constructed with bricks and blocks. This is because; finding showed that the timber and steel walling system requires thicker insulation than what is been used for brick cavity walling. Doing this would prevent the reduced negative impact avoided from embodied energy from being lost to operational energy. This is needed, as the operational energy becomes more when insulation is not efficient.

As a result of economic aspects of sustainability, it may not be easy to prevent the use of such materials as Portland cement – which is the main element that contributed to high impact of ICF. However, assigning eco-points to different materials may be a great way of addressing embodied impacts of materials. This could be done in such sustainable design appraisal tools as the UK BREEAM and the US LEEDS. In that wise, the designers would be able to trade off among all stages of building rather than the current practices which only concentrate on operational impacts. This is expected to be the next line of action; especially as continuous awareness and stringency of legislations reduces operational impacts, thus calling for more concern about embodied impacts.

7. Conclusion

The study was carried out to determine the impacts of materials specifications on life cycle environmental impacts of buildings with the aid of BIM enhanced LCA methodology. It clearly shows the relevance of LCA and its need in holistic evaluation of environmental impacts of buildings from cradle to grave/cradle. The study carried out to determine implementation of whole building lifecycle analysis showed that the life cycle standard – ISO14040 – which is the internationally standardized LCA methodology can also be applied to whole building in similar way to products. This may be done in order to determine relative importance of building components, lifecycle stages, or comparing different building typologies/specifications, with the aid of what if scenarios or variability analysis.

Resolutely, to benefit from LCA methodology in mitigating the environmental and health impacts of building right from design stage, Revit material take-off with combination of other tools used in the study has demonstrated that, future integration of BIM platform with LCA tools would assist in early stage assessment of buildings' lifecycle impacts. This would be necessary, as the studies along with BIM platforms analysis showed that, until now, not a single BIM tool or platform has incorporated enough intelligence for whole building LCA studies. Presently, recent assessments as well as this study use combination of different tools, with this study using Revit, Green Building Studio, excel sheets and ATHENA Impact Estimator.

Irrespective of materials specifications, the study showed that buildings that are based on renewable energy are environmentally preferable to those based on fossil fuels over its lifecycle. This is because; operational stage contributes far more impacts than all other stages over the lifecycle of buildings. As such, attempts to reduce operational impacts or use renewable energy significantly reduces lifecycle environmental and health impacts of buildings. However, despite the significant nature of the operational impacts, embodied impacts due to material selection, construction and end of life is far from being trivial. As codes are becoming more stringent, environmental awareness and demand for operationallyenergy efficient building is increasing. This result in the use of renewable technologies, such as PV panel, ground source heat pumps, and so on for building operation, thus resulting in reduced operational impacts. Therefore, optimization of embodied impacts becomes imperative as other stages are becoming the most important stage to be considered in LCA of buildings.

Considering the environmental and health impacts of buildings based on design specifications used in the study, buildings constructed with Insulated Concrete Forms has more negative environmental and health impacts than steel building which also has more negative effects than brick/block buildings. Timber structure is the most environmental friendly of all the typologies used in the study. However, there is need for efficient insulation system in a timber building so that environmental and health impacts prevented due to embodied energy would not be lost to higher operational impacts. Improving insulation to buildings constructed with steel also has a tendency for shifting its impacts below those constructed with brick/block cavity walling system as operational impacts was the main factor that contributed to its higher impacts than those constructed with brick/block at the same level of insulation.

Direct relationship was also established between GWP and health impacts of buildings. The more the potential of a building for global warming, the more likely the building is to affect human health. This shows that the greener a building in terms of environmental impacts, the more healthy and breathable the building becomes.

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