Research Article

BIM-based LCA and energy analysis for optimised sustainable building design in Ghana

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Abstract
Integration of Building Information Modelling (BIM) and Life Cycle Assessment (LCA) is regarded as useful for making design decisions regarding the environmental and health impacts of building products and materials. This research aimed at studying the process of BIM-LCA integration to assist designers in making sustainable material and product selection decisions in Ghana. A guidance framework for implementation of BIM-LCA supported by energy analysis has been developed to aid optimisation of sustainable design solutions based on simulations using Autodesk Revit as a BIM authoring tool, Green Building Studio and Tally to perform energy and LCA simulations on a hypothetical two-bedroom single-family house. The research considers both operational and embodied carbon effects of the design solution. The framework aligns with the RIBA Plan of Work 2013 Stages 0–2 (i.e. Strategic definition, Preparation and briefing, and Concept design) and presents a systematic approach for BIM-based LCA estimation for the early design stages using the Business Process Modelling Notation. The paper proposes a generic approach which has the potential to incorporate LCA as an integral part to the BIM-enabled design development process. This assists designers in decision-making that consider environmental impacts of materials and energy consumption as part of sustainable building design considerations.

Keywords Sustainability · Environmental impact assessment · Building information modelling · Life cycle assessment · BIM-LCA integration · Energy analysis

1 Introduction

Designing buildings to respond to the wide and amorphous scope of sustainability requirements is challenging. The design of new buildings presents an opportunity for designers to make sustainable decisions to reduce environmental impacts and enhance human health. Consequently, designers have taken on a difficult, but important role, which requires in-depth knowledge on the environmental impacts of materials [1] as analysis of building performance has significantly become more complex at the early design stages [2]. Decisions made must be informed to make the process fluid and efficient. Assessment methods such as Building Research Establishment Environmental Method (BREEAM), Leadership in Energy and Environmental Design (LEED), and the Sustainable Building Tool (SbTool) among others, have been developed to guide designers in providing environmentally friendly solutions [3]. However, these assessment methods do not offer guidance on the incorporation of sustainability considerations as an integral part of design delivery. Such tools revolve around the descriptors of sustainability, among which are the United Nations Sustainable Development Goals (UN SDGs). The UN SDGs 11 and 13 obligate Ghana, like many other developing countries, to work towards building of

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sustainable cities and communities by 2030 and make efforts to reduce adverse effects of climate change [4]. Tackling climate change requires responsible action towards carbon and greenhouse emissions. Increasing urbanisation in Ghana is however accompanied by a lack of awareness of sustainability principles [5] and a struggle to match growing technological advancement of the global industry to meet such needs [6]. Largely, efforts to meet these goals are government driven through institutional arrangements on climate change and other sustainability goals. Furthermore, residential development dominates Ghana's building stock, accounting for over 78% of building development [7]. Nonetheless, there is an estimated deficit of 1.7 million houses [8] and a growing residential development market led by the private sector [8]. A 'Government-driven approach' presents a lengthy and high-level roadmap to realising these goals as housing development is growing in the face of increasing housing deficit [9]. Ultimately, designers of these buildings need to be equipped with decision-making support tools and guidance to minimise the impact on the environment in line with global trends and help meet the SDG goals.

Computational tools with the capacity to simulate building data in relation to climatic conditions help to make refined decisions during design [10]. This study focuses specifically on facilitating the adoption of BIM-based Life Cycle Assessment (LCA) and energy analysis as a suitable approach to achieving optimal sustainable design solutions in Ghana, emphasising on the process of assessment and the information requirements for an efficient process. BIM-LCA integration has been described as an optimal procedure in achieving sustainable development through empowerment of decision-making during design [11] as LCA helps discriminate between materials and products based on their environmental impacts [12, 13]. Architects, engineers and other built environment professionals have a distinctive opportunity to lessen environmental impact of buildings at the design or development stage [14]. The functions of these professionals are vital to achieving SBD targets, and as such, their roles properly defined and supported [2]. This makes a strong case for adopting performance-based approaches to achieving SBD. This paper reports on the findings of a broader study within the theme of sustainability and building design and the context of Ghana through the concepts of sustainable building design (SBD) and lifecycle thinking. This research aimed at studying the process of BIM-based LCA and developing a guidance framework to enable its application in Ghana to optimise Sustainable Building Design (SBD) with an emphasis on the organizational relationships, information requirements, and process.

2 Overview of sustainability and the built environment

The built environment is central in the efforts to achieve sustainable development due to its direct influence on habitats, humans and natural resources [14–16]. The industry is widely held to be responsible for up to 60% of natural resource consumption and at least 39% of global carbon emissions [13, 17–19]. Consequently, international organisations and national governments have acknowledged the need to assist the industry to be more responsible. This has led to the notion of sustainable design and construction, reflecting in ensuring provision of current built environment needs without compromising on the resource requirements to meet the future needs [20]. Hill and Bowen [15] argue that for sustainable building objectives to be realised, the effort needs to begin from the planning stage (design) and continue through the whole life cycle.

2.1 Sustainable design and construction in Ghana

In executing its responsibility, the Ghanaian construction industry causes significant environmental impact [6, 21, 22]. Developing countries that contribute a lot to environmental degradation are least able to prevent and withstand the effects of climatic conditions resulting from global climate change [23]. Ofori-Kuragu et al. [21] argue that Ghana is one such country where environmental considerations are generally weak. Ghana ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1995, 2000 and 2011. However, greenhouse gas emissions increased by 107% from 1990 to 2006 [24] resulting in political attention to the issue. In spite of the efforts of Ghana's Environmental Protection Agency (EPA) to safeguard the environment from activities of the construction industry such as building and road construction, most industry players do not consider environmental sustainability principles, and there is a general lack of knowledge about them [22]. Environmental Impact Assessments (EIA) carried out for many projects in Ghana often lack scientific data and baseline information [25]. Predictions of impacts tend to be based on generalisations with little or no relation to the project environment and potential adverse effects of projects and alternatives are ignored or given scanty attention [26]. EIA reports are mostly requested on large projects, or as determined by the Environmental Protection Agency and the EIA laws, are quite vague about SBD. Djokoto et al. [5] posit that this low uptake of sustainable design and construction has strong cultural linkages, especially with material preferences. Ghana's building industry is dominated by the use of cement, concrete and steel with the contribution of concrete twice the total of all other building materials put together [5]. According to [5], designers exhibit confidence in their ability to access and use information relevant to design, but this confidence drops when it comes to matters of sustainability. Ametepey et al. [27] call for appropriate guidance for designers in implementing SBD. Table 1 presents a summary of the barriers to sustainable design and construction in Ghana identified from literature.

2.2 BIM and SBD

The graphics and digital information of components in BIM, enable a function of analysis and control which can be linked to SBD [29]. The functional support of BIM for SBD reflects in the ability of BIM tools for energy modelling and sustainable material selection to reduce environmental impact [30]. Linking BIM to sustainable design analysis (SDA) tools facilitates the comprehensive environmental trade-off evaluations during early design stages [31]. By this, BIM, when paired with dynamic performance analysis software tools, can provide quantifiable measures such as operational energy consumption, carbon emissions, waste management, which are fed back into the decision-making. This approach deals with the calculation aspect of SDA as outlined by Ceranic et al. [32]. Zanni et al. [2] has examined the scope of considerations for SBD and has aligned these to the RIBA Plan of Work 2013 stages 0, 1, and 2. Sustainability considerations need to be expressed qualitatively at stage 0, then, quantified (through metrics and benchmarks) at stage 1, and finally, tested and defined explicitly at stage 2 (see Fig. 1). Feasibility of the sustainability criteria is the basis for optimising the design, by performing iterations at Concept Design (stage 2). The standardised process developed has aligned the RIBA Plan of Work with defined Level of Development (LOD), and non-graphical information to regulate the information exchanges between the project team participants. The LOD, i.e. modelling detail and information requirements are treated as critical to the analyses for optimising the design solution. Therefore, modelling detail and assumptions on materials specifications and performance used for energy simulations are constraints for the SBD optimisation (see Tables 1, 2).Ideally, the modelling detail at Stage 1 must provide an outline which includes site location, layout and massing. This helps optimise the design solution against criteria such as solar radiation studies and estimated energy consumption. At Stage 2, the focus shifts to performance. Here, the model must have sufficient and valid geometric detail and initial services specifications along with material specifications, U-values, capital cost, etc. This enables optimisation of the design against criteria including embodied carbon, toxicity, CO_2 emissions, etc.

2.3 BIM-LCA integration

LCA helps identify impacts associated with different stages of the building lifecycle [12, 13]. It covers extraction and transportation of raw materials to factory, manufacturing, transportation, and distribution, use and reuse, maintenance, recycling, and final disposal. These define the boundary conditions of LCA. Traditional LCA is complex and tedious due to the required data [33], and is often avoided by designers. Recent efforts to simplify this

Table 1 Summary of barriers to sustainable design and construction in Ghana

Authors	Barriers
Djokoto et al. [5]	Cultural barriers (particularly material preferences) Lack of sustainability measures by stakeholders Lack of demand by clients Financial barriers—perceived high cost of investment Lack of capacity to implement sustainable principles Lack of methods for measuring sustainability
Ametepey et al. [28]	Absence of legislation and government commitment Low desire of stakeholders to be committed to sustainable design Low awareness and knowledge of sustainable design Higher cost of investment for sustainable design A lack of appropriate guidance for designers in implementing sustainable design
Ametepey et al. [27]	Lack of client demand Lack of government commitment Fear of investment cost
Ofori [6]	Low level of Information and Communications Technology (ICT) application (specifically BIM) Absence of appropriate technologies, methods, and equipment for sustainable design Low numbers of knowledgeable clients who desire high standards

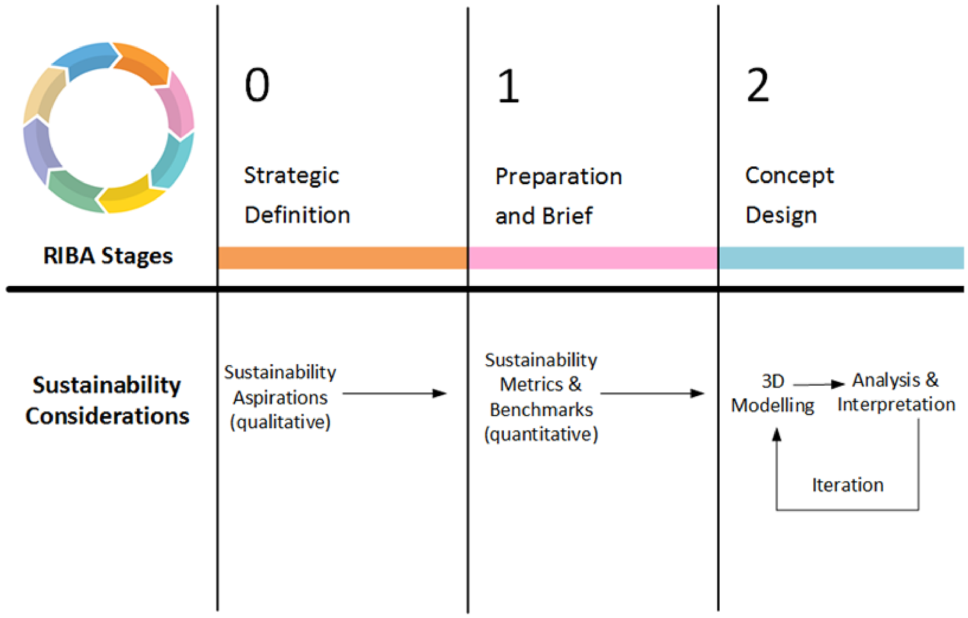

Fig. 1 Sustainability definition aligned with the RIBA plan of work 2013

process for application to design have attempted to incorporate LCA and BIM focusing on intelligent technologies, performance methodologies and investment evaluation analysis [34]. Analysis of buildings using BIM-LCA integration is considered advantageous if the amount of data, assessment processes, and the results are user-friendly and simplify LCA application [35]. BIM-LCA integration in Autodesk Revit has demonstrated to offer the advantage of automated material take-offs and extraction of component data from the BIM without necessarily entering data manually [36]. There are a few BIM-LCA tools on the market with varying levels of complexity, outputs and performance. Tally, Athena Impact Estimator (ATHENA IE), and One Click LCA (OCL) are notable examples which have been used in sustainability analysis bordering on material and building product choice [37, 38]. A. Schultz et al. compared Tally and ATHENA IE and found that Tally performed better at allowing users to. Tally's ability to identify the impact of specific materials in a building and an itemised list of quantity of each material used in the project as an appendix to the impact report [39] makes it a suitable tool for architects to perform LCA analysis. Some BIM-LCA studies have incorporated energy analysis tools such as GBS and IES-VE to capture operational energy data for whole building analysis [12, 36, 37]. GBS has been found to have a seamless interoperability with Autodesk Revit. However, the organizational readiness and standardization of the interaction between project team members is yet to be highlighted. With designers being the focus, coupled with the advantages mentioned above, Tally was selected for this study because of the advantages above. GBS was selected for energy analysis due to its native compatibility with Revit. Tally, however, was found to be geographically designed for the USA. To address the impact of this on the boundary conditions, transportation data were edited for each material to reflect prevailing practice, and power grid mix assumed to be one of the default options to obtain comparable results. Impact categories reported by Tally are acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone depletion potential (ODP), smog formation potential (SFP), primary energy demand (PED), non-renewable energy, and renewable energy. These characterisation factors help quantify the potential impacts of the materials, in terms of emissions and releases into the environment. These relate closely with waste reduction and maximisation of reuse, prevention of pollution, avoiding environmental health problems, minimisation of resources consumption, acidification, water resource depletion and toxicity as SBD considerations relatable to Ghana [18, 22].

3 Methods

This research acknowledges that working towards an enhanced SBD regime is dependent on multiple factors and by extension multiple realities. As such, combining the experiences or viewpoints of individuals engaged in the activity of designing buildings was deemed critical. The study was, therefore, designed to achieve four specific objectives as illustrated in Fig. 2. The first stage involved a detailed literature review on SBD and BIM-LCA which has been presented earlier in this paper. Following the exploratory stage, a survey was conducted as a cross-sectional data collection instrument with a sample size of 246 architects drawn from the Ghana Institute of Architects

Table 2 Information requirements for SBD

RIBA stages	Modelling detail	Specification assumptions	Optimisation criteria
1. Preparation and brief	Site location; preliminary positioning; preliminary massing; layout (locate rooms and volumes)	Spatial requirements; performance standards (natural ventilation, temperature range); schedules; statutory requirements; user profiles; site conditions; topography	Overshadowing analysis; maximum building height; solar radiation studies; estimated energy consumption of scheme designs
2. Concept design	Geometry; dimensions; elevations; massing; size; form; volumes; orientation; master plan; glazing ratio for facades; shading depth and height; preliminary services specification	Preliminary material specification; target insulation values (U-Values) for walls, windows, roof, and ground floor; thermal mass; information on materials; preliminary code compliance	Embodied carbon and toxicity of materials; recycled materials; preliminary heating impact and overheating; estimation of heating and cooling loads; preliminary life cycle carbon; preliminary energy consumption; water consumption; air flows; CO_2 emissions

(GIA). Treating the membership of the Ghana Institute of Architects as a cohort afforded the benefit of looking back on how the practice of SBD has evolved over the period prior to this research [40]. This was achieved through strong connections to literature and the lead author's experience of working as an architect in Ghana. Overall, the survey was aimed at providing enough context of the design practice, how it approaches sustainability assessment, and how this practice could be improved through BIM-LCA integration. The research adopted the haphazard sampling method [41] and made it voluntary for members of the population to participate. This aimed at increasing the response rate [42]. A unique URL was shared with an open invitation to all members in the closed WhatsApp and Telegram group. Table 3 details the outline of the survey questionnaire.

3.1 Action case study

A hybrid between action research and case study research (action case study) was adopted in Phase 3 of this work. Action case study combines components of both, action research, and case study to support abduction-based research [42]. The process of action case study consists of interpretation, gaining understanding, logical reasoning, and qualitative data and the reflective aspects of action research to create change [42]. In a typical action case study, it is common to have several iterations which can be untidy [43] even when experienced professional researchers are involved. This results in two outcomes that are in line with abductive logic [42]. First, results that are beneficial to concerns of practice or organisations and secondly, contribution to theory. The action case study model adapted for this research is illustrated in Fig. 3.

4 Results

4.1 Survey findings

The survey recorded a 12% response rate. For a web-based survey of this scale, the threat of validity of the results because of nonresponse bias is small when response rates are as low as < 10% [44]. Thus, the results presented here are viewed as reflective of current practice, but not entirely representative of the design practices in Ghana. Parts 1 and 2 of the survey are presented under the theme of 'readiness for BIM-based solutions for sustainability assessment'. Part 3 is broken into two aspects i.e. 'consideration of sustainability as a key design requirement' and 'current sustainability assessment practice'. Part 4 of the survey is presented under theme of 'remedies to address barriers to SBD and assessment'.

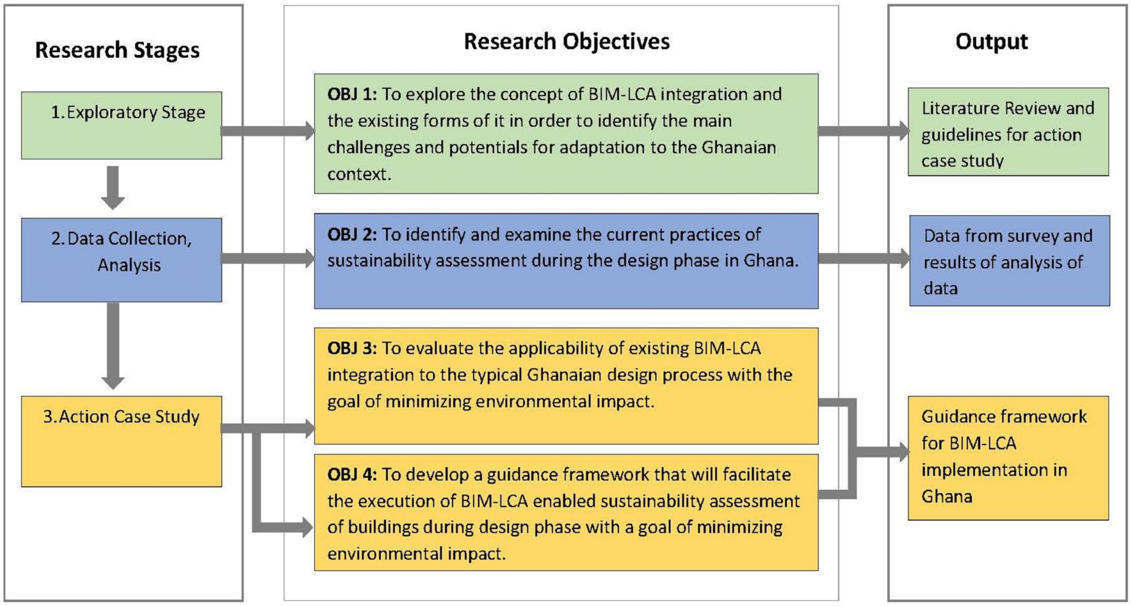

Fig. 2 Detailed research design

Table 3 Outline of survey questionnaire

Part	Focus	Data expected/objective
1	BIM process awareness	Roles of participants; BIM maturity; BIM software used; applicable BIM standards
2	Relevant project experience	Most common type of building designed; application of RIBA Plan of Work 2013
3	Sustainability awareness and application	Level of uptake of sustainability assessment; major drivers and barriers using a ranking scale; performance review of current sustainability assessment practices in connection to LCA
4	Future improvement	Measures to overcome barriers to sustainable design and sustainability assessment

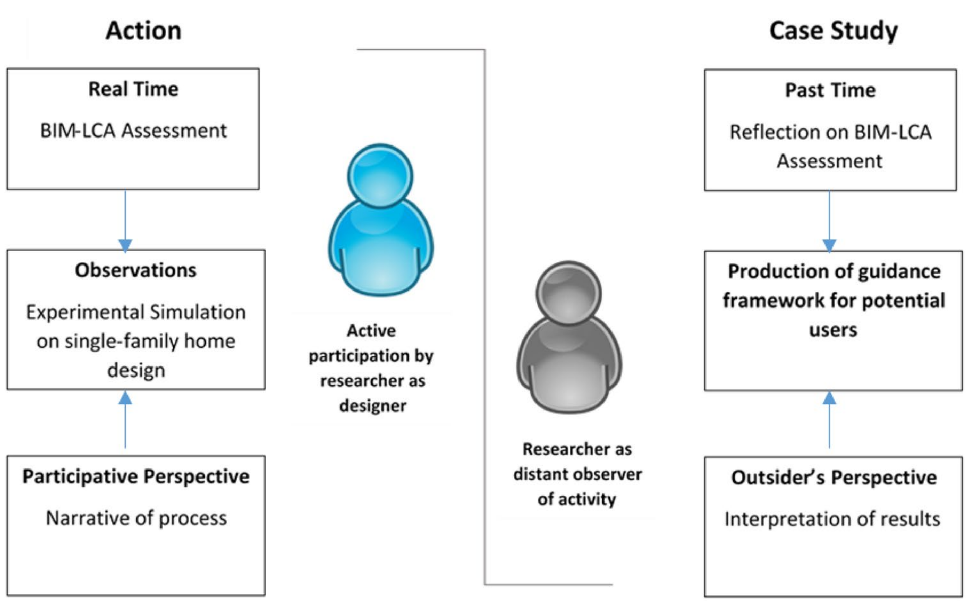

Fig. 3 Action case study model adopted for the project. Adapted from Halecker [42]

4.2 Readiness for BIM-based solutions for sustainability assessment

BIM process awareness, identification of predominant primary BIM authoring tools, standards application to BIM implementation, and relevant project experience were assessed to determine readiness for acceptance of the proposed framework. The survey established that there is sufficient readiness in terms of the technical infrastructure and skills for BIM-based solutions with 70% of respondents operating at BIM Level 1 maturity and predominantly using Autodesk Revit and AutoCAD (83.3%) for executing design activity. Most designers (66.7%) reported they applied their preferred tool predominantly to residential designs and had experience of the RIBA Plan of Work 2013 stages. Ninety-three per cent (93%) of respondents reported they applied no standards when working in a BIM environment. Of this group, 60% explained their non-application of standards as resulting from lack of awareness of CAD/BIM standards. Furthermore, 40% stated there were no CAD/BIM standards. The 6.7% who reported that they used standards cited the BS 1192 series that is used in the UK (now superseded by ISO 19650). Markedly, the practice lacks a common standard and guidance for implementing BIM to its full potential. Hence, it is inferred that there is significant readiness for a BIM-based proposal which is integral to the design workflow as designers are skilled at using Revit, and other BIM tools and well versed with the design process of producing project information in line with the RIBA Plan of Work 2013. However, a standard process to guide its application is required.

4.3 Consideration of sustainability as a key design requirement

It was found that 63.3% of the respondents considered sustainability as a requirement in their designs mainly due to personal motivation. Elaborating on their inclusion of sustainability into design, cost, energy, and environmental effects were reported as the underlying reasons for considering sustainability as a key design requirement. Twenty per cent (20%) of the respondents reported they do not consider sustainability as a key design requirement. They stated lack of educational training on sustainable design and sustainability and lack of awareness of statutory regulations on EIA as the reason for their decisions. Table 4 shows designer's ranking of the influence of drivers and barriers to sustainability consideration as a key design requirement.

4.4 Current sustainability assessment practice

Manual calculation was reported by 53.6% of respondents as the predominantly used method for assessing designs against sustainability goals. This process is self-administered. Twenty-five per cent (25%) reported they used self-administered computer-based environmental impact simulations which were targeted at energy analysis, mainly for energy analysis. *Ecosoft, Ecotect, EnergyPlus, Designbuilder*, and *Exotic* were mentioned as the tools utilised. Three per cent (3%) stated they used the LEED rating scheme to assess their buildings. The remaining did not specify any method or tools. The methods employed for analysis and interpretation varied among respondents with 78.6% of those who carried out any assessments not applying any standards. Assessments were found to be biased towards the operation and maintenance stage (85.2%) with operational energy as the focus. Analysis on the construction stage (63%) of the building life cycle was the next highest focal point for assessments. None of the respondents indicated their analysis covered six stages of a building's life cycle. As such, the boundary conditions for current assessments do not typical reflect a cradle to grave or cradle to cradle analysis. The benefit of analysis for decision-making assistance during design stage appeared low as 80% of respondents reported that they validate

Table 4 Designers' perspectives of drivers and barriers to consideration of sustainable design principles ranked by level of influence

Drivers	Rank
Client interest	3rd
Personal Motivation	1st
Educational training on sustainable design/sustainability	2nd
Statutory regulations on EIA	4th
Barriers	**Rank**
Low client Interest	4th
Lack of personal motivation	3rd
Lack of educational training on sustainable design/sustainability	2nd
Lack of awareness of statutory regulations on EIA	1st

their analysis based on improved actual performance of building. This could be inferred to be a result of the lack of scientific data and standardised methodology, for SBD assessment with defined feedback mechanisms during early design stages, leading to missed opportunities to optimise building performance.

4.5 Remedies to address barriers to SBD and assessment

Respondents ranked six proposed remedies based on the perceived influence in overcoming the barriers identified in Sect. 4.3. The responses of respondents were evaluated using the relative importance index (RII) [45] and are summarised in Table 5. From this, architects hold that enhanced education and training on SBD and sustainability assessments is the most important, followed by strict statutory regulations and its enforcement as well as incentives from government to encourage sustainable building solutions. Investment in software tools that integrate sustainability assessment with CAD was ranked as the third most important factor.

4.6 BIM-LCA + energy analysis for SBD guidance framework

This study identified that cost, energy, and environmental impact analyses are key considerations for SBD in Ghana. Nevertheless, a standardised approach, which is integral to the design process, is currently missing. Also, a need for enhanced education and training is highly ranked by designers to overcome the current SBD barriers. Though designers ranked investment in tools that integrate sustainability assessments with CAD highly, there is little evidence of application of such tools in Ghana now. Additionally, it would be vital for clients and architects to have quantifiable values of a building's sustainability performance to access any government incentives. Therefore, this study sought to make a practical proposal to meet this need, while informing the theory around SDA and SBD. For this purpose, simulations were iteratively performed on a hypothetical two-bedroom single-family residential building (Fig. 4) using Autodesk Revit, GBS and Tally to demonstrate optimisation of SBD, leading to the development of a proposed guidance framework. The iterations of the design towards optimisation focused on the building fabric and the HVAC mechanisms for energy analysis and subsequently LCA (Fig. 4).

4.6.1 Application of tools

Autodesk Revit, GBS and Tally were used in an action case study to test the optimisation criteria and information requirements needed for the proposed framework. Figure 5 details the process of applying the tools, showing the inputs, processes, outputs, decision points and workflow for the application of tools. GBS is placed in a dotted box as it is web-based and not a native offline application within Revit. The hypothetical building was modelled in Revit. Responding to the modelling detail and information requirements for Stage 1 of the RIBA Stages, the site location was specified, using GPS coordinates to connect the model with local weather data. In line with Stage 2 of the RIBA Plan of Work, the geometry of walls, roofing, floors, doors, and windows were defined resulting in Option 1. A gbXML file was generated for a web-based energy analysis in GBS before an individual full building LCA (with cradle to grave boundary) was performed in Tally.

4.6.2 Energy analysis

The annual energy use intensity (EUI) was used as the benchmark for optimising the building. Option 1 had 150 mm thick CMU walls (painted white), aluminium framed windows and aluminium roofing sheet and mechanical cooling. The mechanical cooling and vent fans recording a significantly high EUI. In the second iteration, the optimisation focused on changing the building fabric. Walls were changed to 102.5 mm thick brick walls, windows were also altered to have wood frames. Roofing was not changed but the building was made to rely on natural ventilation only. Though the EUI reduced, there was a marked increase in the EUI for area lighting and miscellaneous equipment. Option 2 was modified to have 225 mm thick hollowcore CMU. Natural ventilation was maintained. The EUI reduced significantly, with the area

Table 5 Architects' perspectives on remedies to SBD barriers

Proposed remedies	RII
High client interest and investment	0.593
Improved educational training on sustainable design and sustainability assessment	0.680
Investment in software tools that integrate sustainability assessment with CAD	0.640
Technical guidance on operating software tools for sustainability assessments	0.526
Strict statutory regulations and enforcement	0.646
Government incentives (e.g. tax waivers, subsidies on software, awards, etc.)	0.646

Fig. 4 Layout and 3D views showing design options of case study building

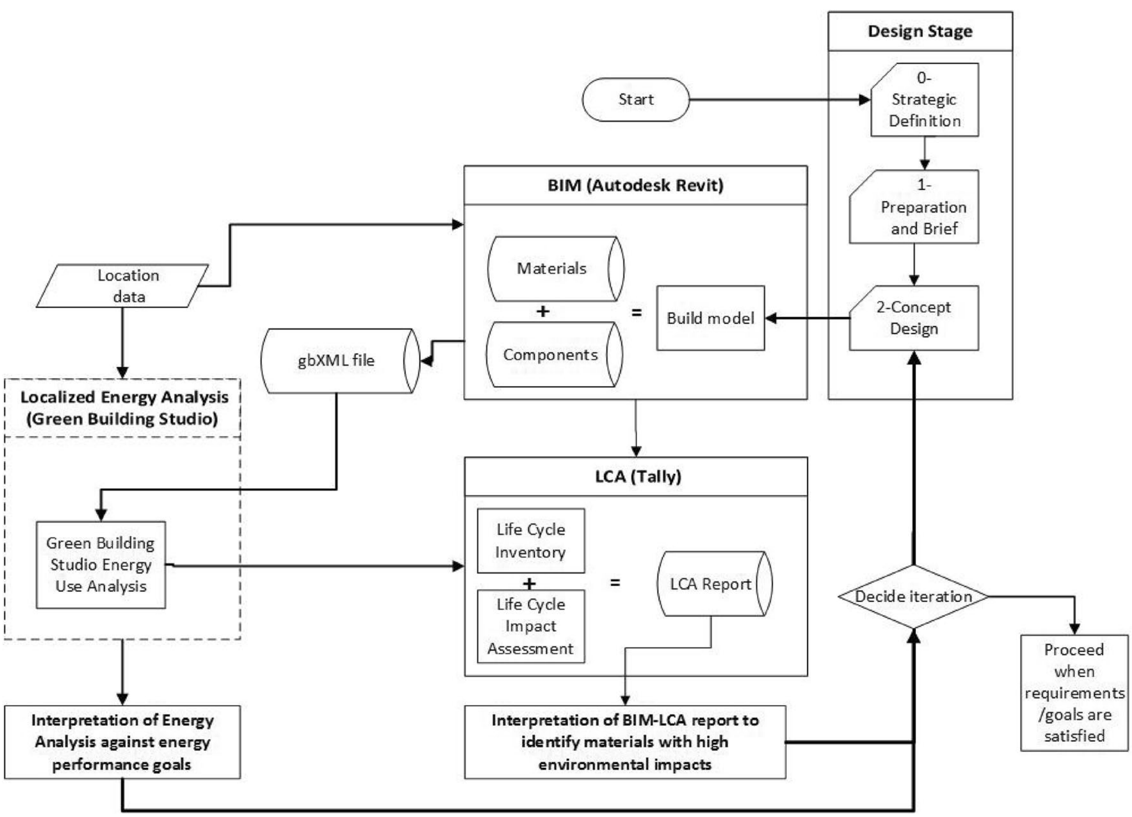

Fig. 5 Process of BIM-LCA + energy simulations used in action case study

Table 6 Parameters used in energy analysis

Category	Parameter	Value			Units	Criteria
		Option 1	Option 2	Option 3		
Space	Condition type	Cooled	Naturally vented	Naturally vented	N/A	Always
Space	Space type	SingleFamily	SingleFamily	SingleFamily	N/A	Always
Space	Lighting power density	4.84	4.84	4.84	W/m^2	Always
Space	Equipment power density	4.63	4.63	4.63	W/m^2	Always
Space	Area per person	20.5	20.5	20.5	m^2/person	Always
Space	Sensible heat gain	250	250	250	BTU/person	Always
Space	Latent heat gain	250	250	250	BTU/Person	Always
Space	Design temperature	25	N/A	N/A	°C	Always
Space	Cooling on setpoint	26.7	N/A	N/A	°C	Always
Space	Cooling off setpoint	24	N/A	N/A	°C	Always
Space	Outside air per person	15	15	15	CFM	Always
Space	Infiltration flow	N/A	0.5	0.5	ACH	Always
Zone	HVAC equipment	4 No. 10.8 EER AC Units	N/A	N/A	N/A	Always

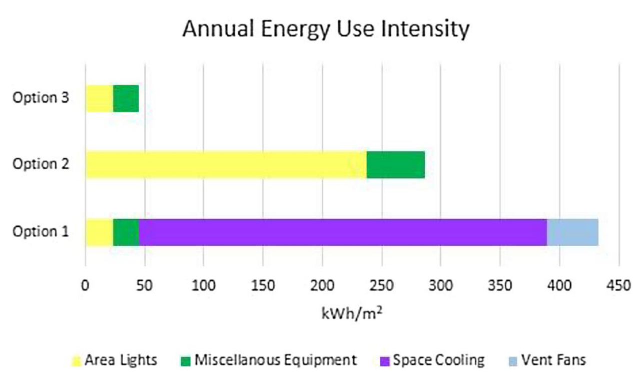

Fig. 6 Annual energy use intensity options 1–3

lighting and miscellaneous equipment EUIs same as that of Option 1. The assumptions and parameters used for the Energy Analysis are presented in Table 6. The 2009 edition of the ASHRAE handbook was consulted in making these assumptions. Figure 6 presents a summary of the EUIs of the three options. Even though strict thermal conditions are not met (for Options 2 and 3), this strategy is considered acceptable as several studies have found that occupants are more tolerant towards "green" buildings [46, 47].

4.6.3 LCA

LCA simulation in Tally afforded comparison of the three different options across five impact categories as shown in Fig. 7. Here, the decisions made during the energy analysis regarding the choice of wall material were validated. Comparing the options on greenhouse emissions (GWP) i.e. the measure of greenhouse gas emissions, Option 2 recorded the highest values followed by Option 1 and Option 3. This result validated the choice of CMU for the third iteration as it has a lesser impact compared to brick. In terms of the acidifying effects (AP) to the environment, which could lead to effects such as forest decline and increase in hydrogen ion concentration in water, Option 2 recorded the highest measure with Option 1 slightly higher than that of Option 3. Again, CMU as a wall material performed better, validating the choice made during the energy analysis. Option 1 recorded the lowest EP, meaning that it was less likely to cause excessively high levels of nitrogen and phosphorus in the ecosystem as compared to Option 3 and Option 2, respectively. As before, the CMU specified in Option 3 had the least impact. Option 2 recorded the highest SFP, followed by Option 2 and Option 3, respectively. This meant that Option 3 has the least potential in contributing to ground level ozone which could lead to a variety of respiratory diseases. The non-renewable energy consumption of brick is high compared to CMU. Using hollowcore CMU as in Option 3 has a lesser non-renewable energy consumption. Overall, the LCA validated the choice of settling on a hollowcore CMU as the wall material. This satisfied the optimisation criteria of lowest possible environmental impact and least EUI. Key assumptions made in the LCA are detailed in Table 7. It is worth noting that transportation distances for materials were edited in Tally to reflect common trends in Ghana. Steel, glass and tiles are common materials imported from China. This was a key assumption in the simulation. All other materials were edited to be sourced within a 100–400 km radius.

4.7 Towards improved SBD in Ghana

Designers play a critical role in reducing environmental and health impacts of the buildings they design. As such,

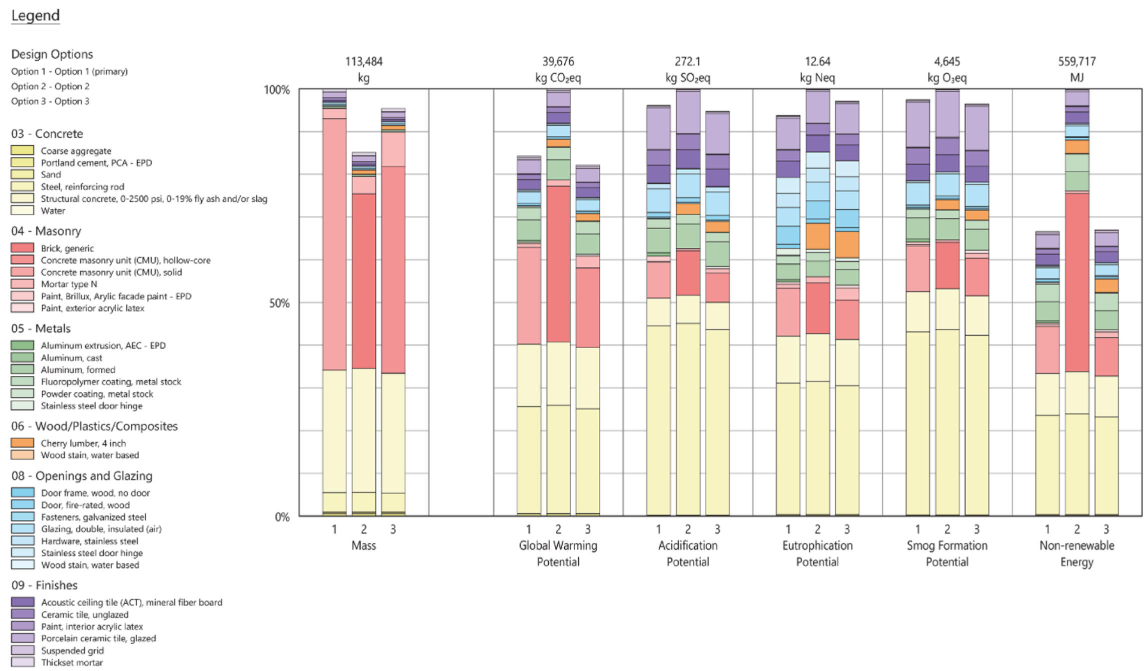

Fig. 7 LCA results itemised by material

their roles in SBD must be properly defined and supported [48]. For designers to develop solutions that meet the social, economic, and environmental sustainability requirements, as identified in the survey, the approach needed to be structured and ingrained into the design development process. Besides, the move towards BIM-enabled design environments as established by the survey, means that the sustainability requirement and goals, would have to be clarified and simplified in the context of BIM to provide the necessary guidance on meeting SBD goals. The reflections from the action case study provided insights on: (1) clear definition of sustainability goals, (2) frequent feasibility checks on model for assessments, and (3) clear rules that govern the process (i.e. sequence of activities, design considerations, critical decisions). Consequently, a framework comprising a guidance matrix and workflow process for implementing BIM-LCA enabled sustainability assessment is proposed to provide this guidance. The framework focuses on addressing the energy, health, and environmental sustainability requirements during early design stages. Within the guidance matrix, critical activities required to achieve the objectives could be identified and their input and output requirements recognised. The workflow process describes the iterative information flows within and between the activities depicted and the decision points (hard and soft) identified to address the weaknesses. To adapt this to the Ghanaian context, two of the four barriers identified in the survey i.e. '*Lack of Educational Training on Sustainable Design/Sustainability*' and *'Low client interest'* are addressed primarily in this work. This is done to respond the focus of the study on clarifying the process of assessment and the information requirements that can be integrated into the design process. The barrier associated with the *'EIA regulations'* is treated as external to the framework. *'Lack of Personal Motivation'* is indirectly addressed as designers are expected to be driven to change if the status quo of not performing sustainability assessments is disrupted by availability and widespread acceptance of adequate tools and legislation. However, future investigation on contributing factors to the lack of personal motivation is necessary. The framework is developed based on reflections made on the simulations and the broader survey context.

4.8 Guidance matrix

The first part of the framework, i.e. the Guidance Matrix (GM) provides guidance on critical tasks, information requirements, sustainability criteria and aligns them with the early design stages (see Table 8). The actor codes are defined in Table 9 using the R-A-C-I method [49]. This acts as the foundational component of the framework as it establishes a condition precedent for operationalising BIM-based LCA. The GM identifies three actors for BIM-based SBD as contextualised in this study. These are the Architect (Designer/Design Team), the Client, and an Expert (a Sustainability, LCA, or Energy Consultant).

Table 7 Schedule of project data and SBD goals for simulations

Project data sheet	
Project location	6.6798, – 1.5803
Floor area	82 m^2
Number of occupants	4
Building life cycle	50 years
Source of energy	Average UK grid mix (close to Ghana's mix)

Energy optimisation criteria: least possible EUI

Environmental impact goals: lowest possible environmental impacts and enhance human health

Material and components

Materials	Option 1	Option 2	Option 3
Walls	150 mm thick solid CMU blockwork	102.5 mm thick brick wall	225 mm thick hollow core CMU blockwork
	Finished with acrylic paint on both sides	No finish applied	FINISHED with acrylic paint on both sides
	Mortar Type N (1:1:6) for bonding	Mortar Type N (1:1:6) for bonding	Mortar Type N (1:1:6) for bonding
	No reinforcement	No reinforcement	No reinforcement
Windows	Aluminium framed sliding windows with double glazing	Timber framed sliding windows with double glazing	Timber framed sliding windows with double glazing
	Cast Aluminium panel with powder coat finish	4-inch cherry lumber finished with water-based wood stain	4-inch cherry lumber finished with water-based wood stain
	Double glazing, insulated (air)	Double glazing, insulated (air)	Double glazing, insulated (air)
Roofing	24-gauge aluminium roofing sheet	24-gauge aluminium roofing sheet	24-gauge aluminium roofing sheet
Ceiling	Mineral fibre board	Mineral fibre board	Mineral fibre board
	Suspended grid	Suspended grid	Suspended grid
	Acrylic paint finish	Acrylic paint finish	Acrylic paint finish
Internal doors	800 mm and 900 mm wide flush doors	800 mm and 900 mm wide flush doors	800 mm and 900 mm wide flush doors
	Wood door frame with steel fasteners	Wood door frame with steel fasteners	Wood door frame with steel fasteners
	1-h Fire rated door	1-h Fire rated door	1-h Fire rated door
	Finished with water-based wood stain	Finished with water-based wood stain	Finished with water-based wood stain
	Stainless steel hardware	Stainless steel hardware	Stainless steel hardware
	No door closers	No door closers	No door closers
External door	Aluminium frame with single glass	Wood frame with single glass	Wood frame with single glass
	Cast Aluminium panel with powder coat finish	4-inch cherry lumber finished with water-based wood stain	4-inch cherry lumber finished with water-based wood stain
	Double glazing, insulated (air)	Double glazing, insulated (air)	Double glazing, insulated (air)
	Stainless steel accessories	Stainless steel accessories	Stainless steel accessories
Floor slab	150 mm thick in situ concrete slab	150 mm thick in situ concrete slab	150 mm thick in situ concrete slab
	1:2:4 mix	1:2:4 mix	1:2:4 mix
	Welded steel mesh reinforcement	Welded steel mesh reinforcement	Welded steel mesh reinforcement
Floor tiles	Porcelain tiles and Ceramic tiles	Porcelain tiles and Ceramic tiles	Porcelain tiles and Ceramic tiles
Concrete steps	1:2:4 mix	1:2:4 mix	1:2:4 mix
	16 mm reinforcement	16 mm reinforcement	16 mm reinforcement

Expert involvement is treated as optional as it is dependent on the Client's priorities and capacity to hire one. However, it is recommended that an Expert is appointed to further enhance the outputs and interpretation of results.

4.8.1 Stage 0: strategic definition

Here, the Architect and Client are responsible for defining the overall sustainability aspirations of the project, e.g. electricity consumption and environmental impact benchmarks. Additionally, the Goal and Scope of the

Table 8 Guidance matrix

Legend: R- Responsible; A- Accountable; C- Consulted; I- Informed (* Denotes Optional)

RIBA Plan of Work 2013 Stage	Activity/Task	LCA mode	LCA Phase	Sustainability criteria	Information requirement	Expert Involvement	Designer/ Design Team	Client
0-Strategic definition	• Make decision to consider sustainability • Agree on the useful life cycle of building	Screening	Goal and Scope Interpretation	Overall sustainability aspiration	Team members and responsibilities	C*	R	R
1-Preparation and brief	• Prepare material specifications • Specify sustainability criteria • Finalize Scope of LCA study	Screening	Goal and Scope Interpretation	Estimated energy consumption; renewable and non-renewable resource consumption; pollution data	Environmental & Energy Performance standards	C*	R A	I
2-Concept Design	• Create building model. • Undertake Sustainability assessments for EIA	Screening	Inventory Analysis Impact Assessment Interpretation	Global warming potential; Ozone depletion potential; acidification potential; eutrophication potential; smog potential; primary energy consumption; non-renewable energy; renewable energy	Material U-values; material dimensions; site location; resource sourcing data Include exterior and interior walls, glazing, windows, roofs, ceilings, foundations, columns, and finishes.	C* I* A*	R A	I

Table 9 R-A-C-I definitions

Code	Meaning
Responsible	Actor who performs task
Accountable	Actor who owns task (approving authority)
Consulted	Actor whose input is required for task to be signed-off.
Informed	Actor that needs to be updated on progress

LCA and interpretation methods must be discussed. The Expert may be consulted if agreed by the Client. Key tasks to be undertaken are: (1) decision to consider sustainability as a key design requirement and (2) agreement on useful life cycle of building. These give a baseline for specifying components and materials to meet the benchmarks defined in the sustainability aspirations. The information required here is to name all team members and define their responsibilities in terms of data management and SBD tasks to be described in subsequent sections.

4.8.2 Stage 1: preparation and brief

Having identified the baselines for building specifications, the Architect is responsible and accountable for preparing the brief, specifying in detail the sustainability criteria, and finalising the scope of the LCA study. The Expert may be consulted if involved in the project. The Client must be informed on the outcome of these tasks. The sustainability criteria cover estimated energy consumption, renewable and non-renewable resource consumption, and pollution data (mainly emissions and releases into the environment by materials). Environmental performance standards, such as permissible quantities and assembly of certain materials, are a key requirement. This could be expanded to meet other issues such as financial analysis provided there is baseline data. Such a scenario will require additional software tools and skills other than those described in this framework.

4.8.3 Stage 2: concept design

This stage involves the creation of the building model in a BIM authoring tool (e.g. Revit) and undertaking energy analysis and LCA. The Architect is responsible and accountable for this stage. Where an Expert is involved, they are to be consulted during simulations and informed of the progress of model authoring and simulations. They are accountable for the simulation and review of its outcomes. The Client must be informed. Here, the sustainability criteria are more specific and can be grouped into two mutually dependent categories. The first category is Energy Performance Goals: i.e. energy consumption, energy use intensity. Environmental impacts such as GWP, ODP, AP, EP, SFP, PED, non-renewable energy, and renewable energy consumption make up the second category. Material U-values, accurate quantities, location data, resource sourcing data are key information requirements.

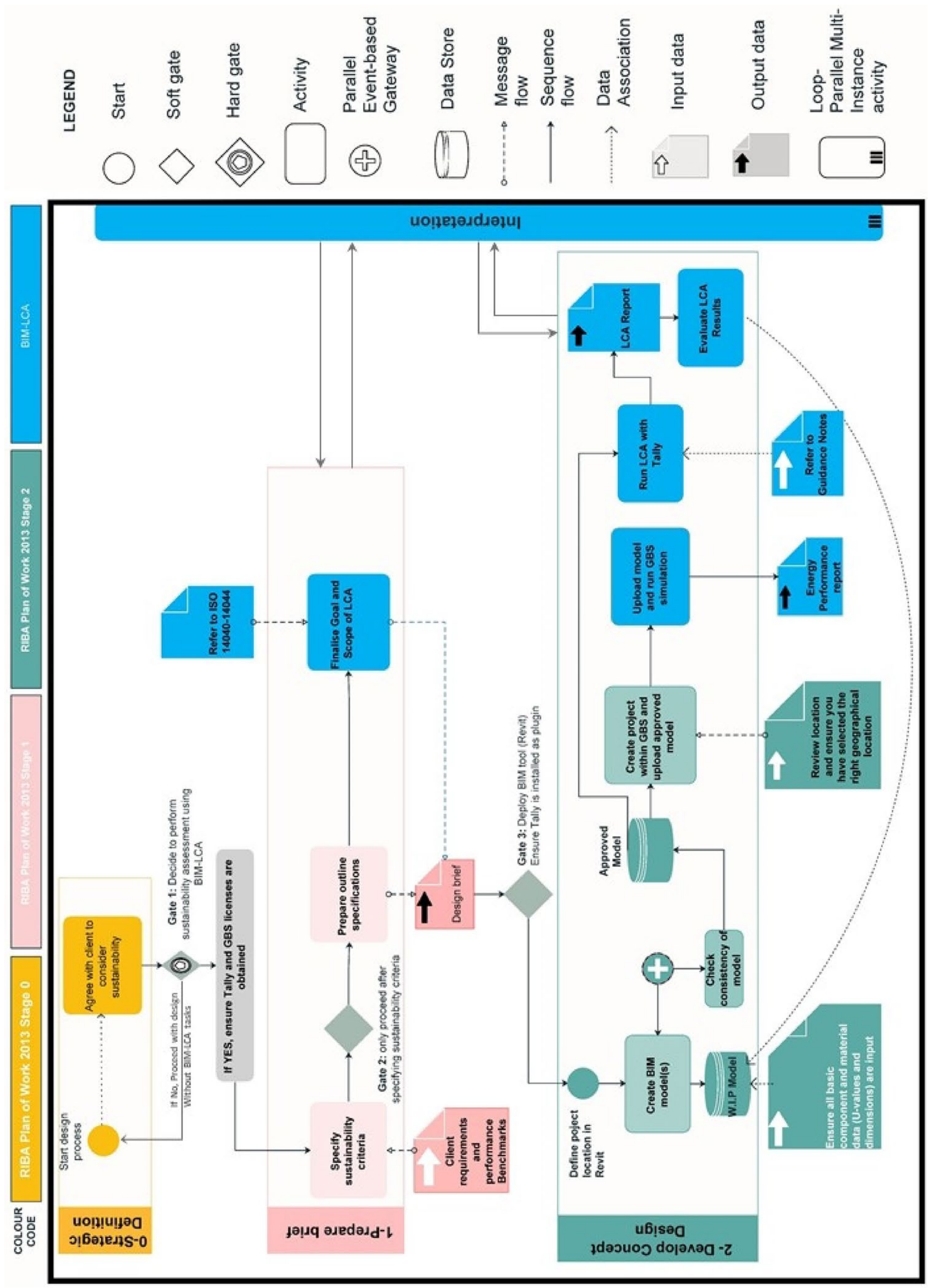

Fig. 8 Workflow process for BIM-LCA enabled sustainability assessment during early design stages

4.9 Workflow process

The workflow process describes in graphical detail the stepwise method for executing BIM-LCA enabled sustainability assessment using the Business Process Modelling Notation (BPMN), as shown in Fig. 8. The process has been organised into 'swim lanes' which correspond to the RIBA Plan of Work 2013 Stages 0–2 that define manual and automated tasks required for BIM-based LCA and energy analysis. The Architect, Client and Expert are the human actors involved in this process. The Architect, and where applicable the Expert, interact with software tools (such as Revit, GBS and Tally) to deliver an optimised building design using the energy performance and environmental impact goals. At the Start point, the Architect will have to secure consent from the Client (at Gate 1) to make sustainability a key design consideration for the system to proceed to the second lane. Once consent has been obtained, overall sustainability aspirations on energy and environmental impacts based on Client requirements and performance benchmarks, must be set prior to preparation of outline specifications. The transition from specifying sustainability criteria to preparation of outline specifications (Gate 2) is not a prerequisite as it is deemed that brief preparation is a fluid activity. Where consent is declined, the process fails to meet the condition precedent for the framework. The Client and the Architect are responsible for this action. Where an Expert is involved, the Architect-Client pair would have to consult the Expert in setting sustainability goals. The Client's priorities are to be considered and synthesised accordingly. It is advisable to start defining the goal and scope for the LCA from this point including the various interpretation mechanisms. This forms the basis for developing the design brief. Development of the design brief links the second and third lane via Gate 3. Lane 3 details the BIM-LCA + Energy simulations. To describe this further, a use case scenario is presented in the next Section.

4.10 Use case scenario

This Use Case Scenario (illustrated in Fig. 9) presents an ideal general course of interactions that correspond to the Preparation and Brief (RIBA Stage 1) and Concept Design (RIBA Stage 2) of the proposed workflow process. A precondition of this process is that the Client would have reached an agreement with the Architect to consider sustainability as a key design requirement. The Architect and Client are responsible for developing the brief, this may be in consultation with an Expert one has been appointed to the project. The brief must include a finalisation of the scope of the LCA and specifying of the sustainability criteria (energy and environmental performance goals).

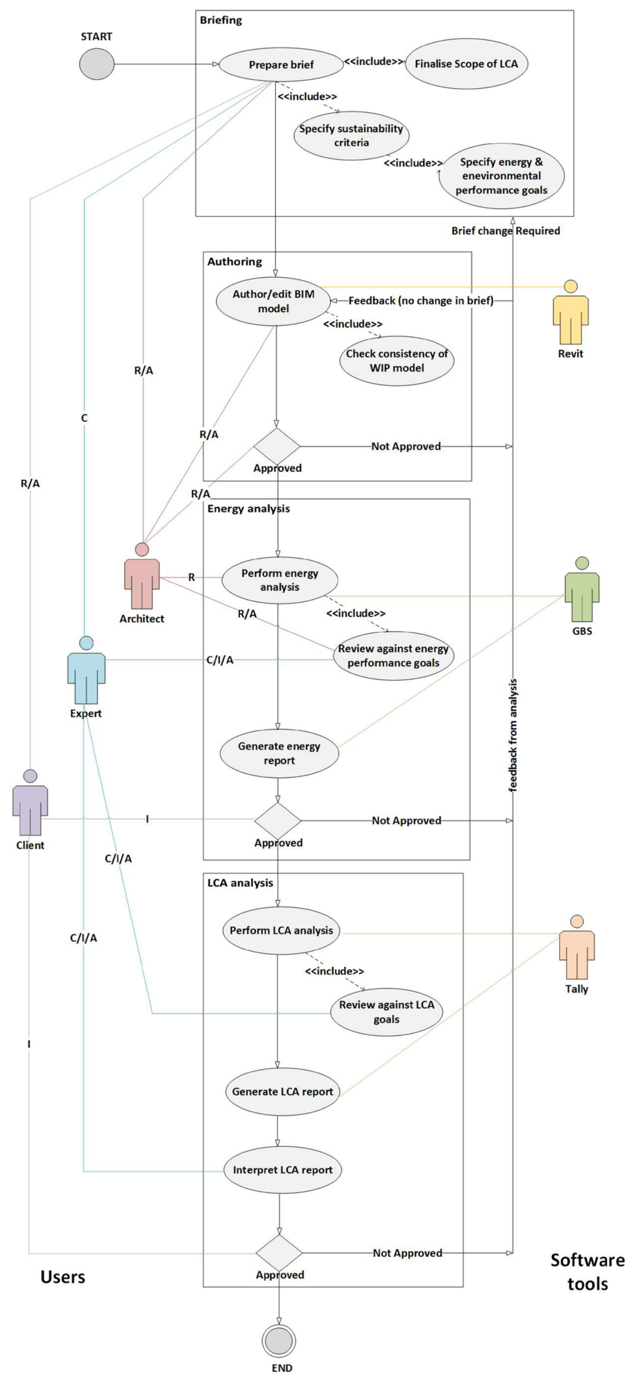

Fig. 9 Use case scenario of BIM-LCA enabled sustainability assessment

Subsequently, the Architect authors the Work-In-Progress (WIP) model using Revit and checks it for accuracy of physical and analytical properties (e.g. U-values, R-values) of materials and components as authoring progresses. Consultation with the Expert may be done to ensure accuracy of physical and analytical data. WIP model must be passed for energy analysis by the architect following a thorough check for consistency. Where issues persist, they are fed back into the authoring process for editing. Where a change of brief is necessary, the feedback goes to the first level. An approved model is used to generate an energy model for energy analysis in GBS.

The Architect performs the energy analysis, which includes reviewing initial results against the energy performance goals. The Expert takes part in the review when they are involved in the project. A report is subsequently generated which requires Client approval before the LCA analysis is carried out. An iteration involving a change in brief or editing of the model may be required if the goals are not satisfactorily met. LCA analysis commences when energy analysis outcomes are approved. Utilising the Revit plug-in Tally, the Architect can perform the LCA analysis. Data input must be carefully reviewed against LCA scope and goals. This is done by the Architect and an Expert, where such an arrangement exists. Tally produces a report, which must be interpreted by the Architect with or without an Expert. It is necessary that the Client is kept informed of the outcomes (insights on material and product impacts on the environment) so a decision as to whether or not to proceed or review the design, can be made. Where it is decided to make alterations to meet goals or redefine goals to match new priorities, the process is repeated from the briefing level with feedback from the analysis. The burden of data re-input in Tally is significantly reduced as changes made to the model are automatically reflected in Tally due to enhanced interoperability. Tally's integration with Revit picks up changes to model automatically and updates quantities as necessary.

5 Conclusions and discussion

This study sought to demonstrate that BIM-based LCA and Energy Analysis can facilitate SBD in Ghana. Emphasizing on the process of assessment and information requirements, a framework which incorporates a guidance matrix and a workflow process has been proposed. First, the guidance matrix clarifies the critical components of SBD (goals, responsibilities, methods, and deliverables) for RIBA Plan of Work 2013 Stages 0-2 (i.e. Strategic definition, Preparation and briefing, and Concept design). Then, the workflow process describes a sequence of actions between the identified actors (i.e. human and software tools) to provide optimised design solutions. It is acknowledged that the proposed framework is by no means a comprehensive solution to SBD in Ghana. Also, it suggests a process for SBD which may not be adequate for all kinds of projects without some adjustments. Nevertheless, this study provides an apt response to two of the main considerations of Ghanaian designers as found in the survey (i.e. energy and environmental impact analysis). The implications of this work relate to the following:

- Actors involved in domestic building design;
- The traditional design and sustainability assessment processes;
- Technology for SBD; and
- Policy.

These are discussed in the following sections.

5.1 Implications on actors

Regarding the relationship between actors, the proposed framework potentially does not pose a disruption to the status quo. Typically, a client will commission an architect to design a home for them, playing little to no part at all following the development of brief. This framework proposes an inclusive design process to stimulate client interest in sustainable decision-making while defining the roles and responsibilities. Some actors (i.e. stakeholders) play a critical role in influencing whether or not sustainability goals are met. Client is one such role that has influence on the outcome. This research revealed that, in Ghana, there has been a low client interest in sustainable design solutions. It is well documented [26] that this practice has led to design solutions with adverse environmental impact. Client buy-in and early client involvement are thus critical if the SBD goals, are to be achieved. This research proposed a framework for BIM-based LCA and energy analysis. It encourages early engagement of Architects, Clients and Experts (e.g. sustainability consultants) at the briefing stage of the RIBA Plan of Work, so environmental sustainability goals are understood and captured early in the design process. By explicitly defining the roles, responsibilities, and interactions between these actors, a structured and guided approach is proposed to accommodate the iterative nature of SBD. The proposed framework encourages Clients, Architects and Experts to make sustainability a key design requirement. Together, they specify the sustainability goals and work in a coordinated manner to optimise a design solution. The Use Case Scenario (in Sect. 6.2.1) describes this process. This joint execution of SBD holds the benefit of ameliorating the persistent low client interest in sustainable design solutions. Perceived high investment costs, cultural linkages to material preferences and a lack of scientific data to show clients the impact of materials and products perpetuate this barrier. Having the benefit of scientific data on environmental impacts of materials and products could convince clients to invest in more environmentally sustainable options. Thus, opportunities for making responsible and cost-sensitive decisions are not missed. Furthermore, Architects stand to have a confidence boost in dealing with matters regarding sustainability. Thus, providing a potential remedy to the lack of confidence on the part of Ghanaian designers regarding sustainability reported by [5].

The success of this framework however relies on the availability of some skills on the part of Architects, who are the main drivers of the proposed BIM-based LCA + Energy analysis processes. It was found that designers are reasonably experienced with using digital technologies such as BIM for design development. This presents an opportunity to extend their capabilities to tackle issues of SBD. The proposed framework attempts to extend these capabilities by integrating BIM-based LCA + Energy analysis tasks into the design process. What remains is getting up to speed with LCA and energy analysis as they are a departure from the manual calculations predominantly used currently. The framework offers guidance tailored to the inexperienced Architect considering that there is a lack of training on SBD. This however does not assure of quality analysis. It is therefore necessary that training on the use of these tools be undertaken to obtain maximum benefits. Additionally, the involvement of Experts in LCA, Energy Analysis, and the wider issues of Sustainability, is encouraged to realise the full benefits promised by this framework. Their involvement brings deeper knowledge of the information requirements and interpretation of results. Ultimately, this provides richer insights that can be used to make design variations that lead to meeting SBD goals.

5.2 Implications on traditional design and sustainability assessment processes

Optimising SBD has implications on the traditional design process. This research proposes an approach that encourages concurrent interactions between actors in 'integrated' environments, earlier in the process compared to its traditional counterpart. The proposed changes necessitate a rethink of how, the new integrated processes are delivered, and roles and responsibilities redefined, so environmental sustainability could be achieved. Integrating previously disparate processes requires new interactions between actors, that were not necessary in the traditional sense. Thus, a re-engineered approach may be desired. Re-engineering the traditional design process to achieve optimal SBD requires: (1) clear definition of sustainability goals, (2) frequent feasibility checks, and (3) clear rules that govern the process (i.e. sequence of activities, design considerations, critical decisions). Utilising a transparent process that follows clear patterns could minimise fragmentation and improve communication amongst project team members. The proposed framework introduces value-adding tasks to Stages 0–2 of the RIBA Plan of Work 2013. This value is realised in dimensions of definition of roles, information requirements for SBD, enhanced information exchange and time for sustainability assessments on energy and environmental impact of building materials and products. Definition of roles is guided by the guidance matrix and its operational essence, illustrated with a Use Case Scenario. To make the integration of SBD clearer and coordinated, the specific sets of tasks to be performed are detailed along with the required information for performing the task.

It is proposed that the Client appoints an Architect right from the Strategic Definition (Stage 0). Together with the Client and any appointed Experts, the Architect defines the overall sustainability aspirations of the project. This makes explicit the information that needs to be assembled much earlier and establishes sustainability as a key consideration right at the inception of the project. The traditional task of brief preparation is expanded to include LCA scoping in addition to specification of sustainability outcomes (definition of energy and environmental performance goals). Additionally, information required for analysis are assembled before the development of Concept Design (Stage 2). This has the potential to eliminate time wasted on looking for such information while developing designs.

The process of sustainability assessments is also impacted by the proposed framework. Though the existing practice of manual calculations has its advantages, the complexity of data requirements and accessibility for analysis pose the disadvantage of prolonged design durations and possible human errors which cannot be easily and timely fixed. Integration of BIM with LCA and Energy analysis tools reduces the burden of rework when iterations are made to the design to meet sustainability, offering a just-in-time assessment. For example, changes made to the building model are reflected automatically in Tally for example. This reduces the time previously spent on extracting data from revised designs and recalculating results. This standardised method for coordinating actors could potentially assist in achieving optimised SBD in a shorter time and with little effort.

Information exchange is made transparent through the formalisation of roles and responsibilities of the actors. Each level of the workflow process as detailed in the Use Case Scenario clearly shows the task to be performed, the actors involved, information to be released and the destination of the released output.

5.3 Technology

This study has inferred that technological enablers have reached a level of maturity that can facilitate LCA assessment in an efficient way if structured processes are followed. There is significant readiness for BIM-based LCA, but there is still lack of proper co-ordination between different perspectives (client, architect, sustainability expert). The proposed framework centres on process and information exchange and is not technology based. As such, Tally and GBS have been used to demonstrate the applicability of a BIM-based LCA and Energy analysis for SBD. It is acknowledged that there are other tools available for LCA such as ATHENA IE and OCL. Likewise, other energy analysis tools such as Ecotect, IES, EnergyPlus exist. Selection of the technology (software tools) would have to be critically done based on various criteria that would take into account the cost, user-friendliness, interoperability with BIM authoring tools, speed and accuracy of outputs; and various other 'use-case defined' requirements. The critical consideration for the software tools, would have to be concerning their ability to achieve SBD goals and accrue the said benefits.

Ultimately, these benefits rely on the availability of quality data. LCA relies on established life cycle databases to quantify impacts of materials and products. Tally, like other LCA tools are contextually not designed for Ghana and lack some context relevant data. This is because they rely on databases that have been developed over years for other geographies. For example, Tally relies on the GaBi database, which is suited to the North American context. Consequently, results obtained from the analysis are not fully reliable. To date, LCA data are not routinely collected from existing buildings. Existing databases are small-scale, fragmented, held in propriety formats and are not open source. Therefore, there is still the need for development of standardised procedures for the collection, structuring, and analysis of LCA data in order to comply with the granularity of BIM classification systems. This approach will allow benchmarking at varying levels of detail for both areas and components. Overall, there is a need for investment, training, and continuous education on computational tools for SBD. By this, the reliability of the proposed SBD framework for the purposes stated above could increase.

5.4 Policy

One of the findings of this study is that SBD is mostly driven by motivated individuals. Policy change through statutory regulations would enforce the implementation of SBD. With this framework, a defined set of impacts have been proposed to cover a section of the built environment (i.e. domestic building stock) that is largely ignored in the context of EIA in Ghana. However, permissible levels of impacts must be established to serve as benchmarks. The EIA process in Ghana has been noted to face challenges bordering on lack of sound scientific evidence to back EIA as found by [26]. Determining what constitutes significant environmental impact lies with the EPA [26]. This often leaves the scope for impact determination wide and ambiguous. With Ghana committed to action against climate change and sustainable cities and communities, it is important to have a holistic approach to meeting targets. Expanding the coverage of EIA to include carbon and greenhouse gas emissions will boost reporting of performance to elicit adequate action. The existing environmental monitoring activities of the EPA could be expanded and used as a tool to close the loop by comparing results from analysis done during design to in-use. By this effective impact characterisation over specific periods for materials and products can be developed and evaluated. Government could institute incentive schemes that reward clients who can show evidence of investing in materials with good energy and environmental impact ratings. Award schemes for design firms and subsidies on software could also enhance the adoption of similar technology. Most importantly, funding research on establishment of local databases and laws that require manufacturers to declare environmental impacts of their products are necessary.

In conclusion, it is evident that there are several benefits to be achieved from BIM-based LCA and Energy Analysis for sustainable building design in Ghana. For true benefits to be realised, field testing of the proposed framework to measure its effectiveness for change would be required. Cultural barriers associated with traditional practices could still prevail and hinder any initiatives targeted at introducing a change. So, effort would have to be put into adopting measures that identify potential barriers and devise measures to mitigate any associated risks on an ongoing basis. Furthermore, lack of databases which aggregate information about local materials, their properties, and their subsequent impact on the environment, could also hinder any change initiative. Thus, work on developing and maintaining such a local database that reflects the impact of Ghanaian construction materials and products on the environment, would be critical in equipping designers with the appropriate knowledge to make sustainable choices. It is recognised that for truly sustainable design choices to be made, inclusion of aspects such as daylighting and social sustainability, among other aspects, would be necessary and these would have to extend beyond the early design stage to include the 'cradle to grave' lifecycle stages. Only then can its full potential be realised. In this lies the challenge.

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Availability of data and material Processed and analysed survey results and models are available.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study received school level ethical approval with a risk assessment number FT_9271. Participants were kept anonymous. Analysis of survey results was group based and not individualised.

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