

Leveraging BIM for Sustainable Orphanage Design Using Locally Sourced Materials

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ABSTRACT

In Sub-Saharan Africa, and particularly Cameroon, the demand for socially inclusive and environmentally responsible architecture is growing due to rapid urbanisation, climate pressures, and the needs of vulnerable communities. Orphanages, as critical social infrastructure, are frequently delivered through cost-driven approaches that neglect sustainability and long-term performance. While Building Information Modelling (BIM) has globally advanced design precision, cost optimisation, and environmental performance analysis, its application in Africa especially for projects using eco-friendly materials such as compressed earth blocks (CEBs) remains limited. This study employs BIM, through Autodesk Revit, to design sustainable, child-centred orphanages in Cameroon using locally sourced materials. Two functionally equivalent prototypes, one with sandcrete blocks and another with CEBs, were developed and evaluated through comparative cost estimation, embodied carbon and energy analysis, and operational performance assessment, in line with life-cycle assessment (LCA) standards and thermal comfort benchmarks. Results show that CEBs delivered lower construction costs, reduced embodied impacts, and improved thermal comfort compared to sandcrete. BIM-enabled workflows enhanced quantity take-offs, integrated early LCA, and supported evidence-based material selection. This research provides one of the first regionally validated datasets on sandcrete and CEB performance in Cameroon, while proposing a replicable digital design framework for humanitarian architecture in resource-constrained Sub-Saharan contexts.

Keywords: BIM, Compressed Earth Blocks (CEBs), LCA, Orphanage, Sandcrete blocks, Sustainability

INTRODUCTION

Background of the Study

The design and construction of orphanages in Sub-Saharan Africa are increasingly influenced by the need to balance social responsibility, environmental sustainability, and economic constraints. In Cameroon, orphanages represent essential social infrastructure that supports vulnerable children; however, their development is often guided by cost-minimisation strategies that prioritise affordability and rapid delivery over long-term performance, environmental quality, and cultural responsiveness. Consequently, many orphanage facilities provide only basic shelter and fail to create healthy, adaptive, and contextually appropriate living environments [1] (UNEP, 2022).

A key contributor to this challenge is the widespread reliance on conventional construction materials such as sandcrete blocks. While these materials are widely available and familiar within the construction sector, they are associated with high embodied carbon, significant energy demand, and increasing lifecycle costs, which undermine sustainability objectives [2] (Awoussi et al., 2025). In contrast, locally sourced materials such as bamboo and compressed earth blocks (CEBs) offer considerable advantages, including lower environmental impact, improved thermal comfort, and alignment with local construction practices and cultural contexts ([3], [4]) (van den Heuvel, 2023; Sinha & Sudarsan, 2025). Despite these benefits, their adoption in institutional

buildings remains limited due to persistent perceptions of inferiority, insufficient performance validation, and lack of integration into formalised design and construction processes.

At the same time, Building Information Modelling (BIM) has emerged globally as a transformative tool within the architecture, engineering, and construction (AEC) industry, enabling integrated design, cost estimation, energy modelling, and life-cycle assessment ([5], [6]) (Cheng et al., 2024; Gladdys et al., 2025). International examples from countries such as Chile and New Zealand demonstrate how BIM can be effectively combined with locally sourced materials to enhance efficiency, resilience, and sustainability in social housing delivery [7], [8] (González et al., 2019; Smith & Thomas, 2021). These examples highlight a significant opportunity for similar innovation in Sub-Saharan Africa. However, in Sub-Saharan Africa, BIM adoption remains at an early stage, constrained by institutional, technical, and capacity-related barriers [9] (Abubakar et al., 2023).

Problem Statement

Despite the increasing demand for sustainable and socially responsive orphanage infrastructure in Cameroon, current design practices remain predominantly cost-driven and heavily dependent on conventional materials such as sandcrete blocks. This approach often results in buildings that are environmentally inefficient, culturally disconnected, and poorly adapted to local climatic conditions. Although alternative materials such as compressed earth blocks (CEBs) present viable and potentially superior solutions, their adoption is constrained by limited empirical validation, lack of context-specific performance data, and minimal integration into modern digital design workflows such as BIM.

As a result, architects, policymakers, and development organisations lack the necessary tools and evidence to make informed decisions regarding material selection and sustainable design strategies. This limitation contributes to the continued delivery of orphanage facilities that do not adequately address the environmental, social, and long-term functional needs of vulnerable children.

Research Gap

While existing studies have explored the benefits of sustainable materials and the capabilities of Building Information Modelling (BIM), there is a notable lack of research that integrates these two domains within the context of humanitarian infrastructure in Sub-Saharan Africa. In particular, few studies provide systematic, data-driven comparisons of conventional construction materials such as sandcrete blocks and locally sourced alternatives like compressed earth blocks (CEBs), especially in terms of cost, embodied carbon, energy performance, and thermal comfort.

Furthermore, the application of BIM as a decision-support tool for evaluating and validating the performance of local materials remains underexplored in the region. The absence of such integrated approaches limits the ability of stakeholders to adopt evidence-based design practices and hinders the transition toward more sustainable and contextually appropriate construction solutions. Addressing this gap is therefore essential for advancing both academic research and practical implementation in sustainable humanitarian architecture.

Aim and Objectives

The aim of this study is to apply Building Information Modelling (BIM) to comparatively design and evaluate orphanage buildings in Cameroon constructed using conventional sandcrete blocks and locally sourced materials such as compressed earth blocks (CEBs). The study focuses on assessing environmental performance, cost-effectiveness, and cultural responsiveness in order to generate evidence-based insights that can inform sustainable design practices.

To achieve this aim, the study pursues the following objectives:

- To establish the state-of-the-art on the use of local materials in building construction, with a focus on sandcrete blocks and compressed earth blocks (CEBs), assessing their properties and applicability in sustainable architectural design.

- To comparatively analyse the cost-effectiveness and environmental impact of sandcrete blocks and CEBs in the context of orphanage construction in Cameroon.
- To examine the role of BIM in supporting the comparative design process, particularly in relation to informed decision-making, energy modelling, and multidisciplinary coordination.
- To propose a BIM-enabled comparative design framework for orphanages in Cameroon that highlights material choices and can be adapted to similar contexts across Sub-Saharan Africa.

Significance of the Study

This study makes important contributions to both academic research and professional practice in sustainable construction and humanitarian architecture. First, it provides one of the first region-specific comparative datasets on the cost, embodied carbon, and energy performance of sandcrete blocks and compressed earth blocks (CEBs) in Cameroon. Second, it demonstrates the practical application of Building Information Modelling (BIM) as an integrated decision-support tool for evaluating material choices in resource-constrained environments.

Third, the study introduces a replicable BIM-enabled design framework that can guide architects, policymakers, and non-governmental organisations in the design and delivery of sustainable and culturally appropriate orphanage infrastructure. By bridging the gap between vernacular construction practices and advanced digital technologies, the research supports a transition toward more evidence-based, environmentally responsible, and socially responsive design approaches. Ultimately, the findings contribute to improving the quality, resilience, and long-term performance of orphanage facilities, ensuring that they better meet the needs of vulnerable children within their local contexts.

The remainder of the article is organised as follows. Section 2 reviews relevant literature on sustainable orphanage design, local materials, and BIM applications. Section 3 outlines the research methodology, including prototype development, evaluation criteria, and analytical frameworks. Section 4 presents the results and discussion, focusing on cost, embodied carbon, energy demand, and thermal comfort. Finally, Section 5 concludes with key findings, policy implications, and recommendations for future research.

LITERATURE REVIEW

Local Building Materials for Sustainable Construction

The use of locally sourced building materials is widely recognised as a cornerstone of sustainable construction due to its potential to reduce transportation emissions, minimise costs, and enhance climate responsiveness [4] (Sinha & Sudarsan, 2025). In Cameroon, often described as “Africa in miniature,” traditional construction has historically relied on clay, laterite, timber, bamboo, and stone [10] (Clark, 2020), reflecting broader African vernacular practices where materials such as earth blocks, bamboo, and stone are adapted to local climatic and cultural conditions [11] (Zoungrana et al., 2021). While recent scholarship highlights the environmental and thermal advantages of these materials [12], [4], [13] (Maina & Mwangi, 2022; Sinha & Sudarsan, 2025; Abanda et al., 2014a), the literature reveals a critical imbalance: extensive descriptive documentation but limited comparative and performance-based synthesis, particularly for institutional buildings.

A thematic analysis of the literature reveals five dominant material categories—bamboo, compressed earth blocks (CEBs), timber, adobe, and stone—each with distinct performance characteristics.

Bamboo is frequently highlighted for its exceptional strength-to-weight ratio and low carbon footprint, estimated at approximately 70% lower than conventional materials [14], [3] (Mefire, 2025; van den Heuvel, 2023). However, most studies emphasise its mechanical and environmental properties qualitatively, with fewer providing lifecycle-based comparisons against conventional systems. Similarly, timber offers carbon sequestration and thermal benefits [18] (WWF, 2021), yet concerns around deforestation and durability introduce trade-offs that are often discussed qualitatively rather than quantified across contexts.

By contrast, **compressed earth blocks (CEBs)** represent one of the most extensively studied low-carbon alternatives, with both qualitative and quantitative evidence available. Studies consistently report that CEBs reduce embodied energy and emissions by up to 80% compared to fired bricks [4] (Sinha & Sudarsan, 2025), while also offering high thermal mass and reduced reliance on cement. Empirical studies further demonstrate their suitability in tropical climates due to improved indoor thermal comfort and reduced operational energy demand [16] (Hogue, 2023). However, comparative analyses reveal important nuances: while CEB systems generally outperform conventional materials at the system level, individual stabilised units may exhibit higher embodied carbon per kilogram due to cement stabilisation [38] (Zoma et al., 2025). This highlights the importance of system-level rather than material-level evaluation, a distinction often underexplored in existing literature.

In contrast, **sandcrete blocks**, widely used across West and Central Africa, are associated with higher embodied energy and carbon due to their cement content [2] (Awoussi et al., 2025). Quantitative studies comparing sandcrete and earth-based systems consistently indicate that sandcrete is both more carbon-intensive and, in many cases, more expensive over the building lifecycle [13] (Abanda et al., 2014a). However, despite this evidence, sandcrete remains dominant due to its perceived durability, standardisation, and association with “modernity.” This reveals a critical divergence between quantitative performance evidence and qualitative socio-cultural acceptance, which continues to shape material selection in practice.

Across the literature, a clear gap emerges: while individual studies provide either quantitative metrics (e.g., embodied energy, cost comparisons) or qualitative insights (e.g., cultural perception, policy barriers), few integrate these dimensions into a unified comparative framework. For example, studies in Ghana and Nigeria quantify lifecycle carbon and cost advantages of earth-based materials [40], [41], [42] (Adu et al., 2025; Obaje et al., 2022; Saba et al., 2018), yet they often do not address the socio-cultural resistance highlighted in Central African contexts [22] (Fivez, 2024). Conversely, research on vernacular architecture emphasises cultural acceptance and climate adaptability but lacks robust performance benchmarking against conventional materials.

This fragmentation is particularly evident in Sub-Saharan Africa, where regional studies remain context-specific and lack cross-comparative synthesis, limiting their transferability. While global literature increasingly adopts lifecycle assessment (LCA) frameworks, African scholarship rarely applies these systematically to institutional buildings such as orphanages. As a result, decision-makers lack consolidated evidence comparing materials like sandcrete and CEB across key performance indicators, including cost, embodied carbon, thermal comfort, and cultural suitability.

Nevertheless, emerging case studies demonstrate the potential of integrating vernacular materials with modern construction practices. Projects such as the Noomdo Orphanage in Burkina Faso and the Nyumba Mpya Modular Bamboo Orphanage in Uganda illustrate that when traditional materials are combined with contemporary design and validated through performance analysis, they can meet or exceed modern standards. These examples reinforce that the primary barriers to adoption are not technical but rather institutional, perceptual, and data-related.

To address these gaps, the present study adopts a comparative, BIM-enabled evaluation framework, enabling simultaneous assessment of quantitative (cost, embodied energy, carbon) and qualitative (contextual suitability, cultural relevance) dimensions. By focusing specifically on sandcrete and CEB, two materials with contrasting performance profiles and widespread relevance in Cameroon. This study contributes to bridging the divide between descriptive knowledge and evidence-based decision-making.

While other materials such as rammed earth and hybrid timber systems also show potential, they were excluded due to limited regional datasets and practical constraints related to climate sensitivity and supply chains. Prioritising materials with both local availability and sufficient performance data ensures methodological robustness and relevance to real-world implementation.

BIM in Sustainable Design

Building Information Modelling (BIM) is widely recognised as a transformative digital methodology that integrates geometric, material, and performance data into a unified environment, enabling lifecycle-oriented decision-making in architecture, engineering, and construction [6] (Cheng et al., 2024). While the literature consistently highlights BIM's potential to improve sustainability outcomes, a closer examination reveals important distinctions between global versus regional applications, as well as between quantitative performance evidence and qualitative implementation narratives.

From a global perspective, BIM adoption is strongly associated with measurable sustainability benefits. Quantitative studies demonstrate its effectiveness in reducing material waste, improving energy efficiency, and enabling early-stage lifecycle assessment (LCA) integration [23], [24], [25], [26] (Bolognesi et al., 2025; Abanda et al., 2017a; Abanda et al., 2017b; Abanda & Byer, 2016). For instance, BIM-enabled workflows facilitate automated quantity take-offs, clash detection, and optimisation of material use, which directly translate into reductions in construction waste and cost overruns. Similarly, Green BIM applications embed environmental datasets within material libraries, allowing designers to evaluate embodied carbon and energy impacts during early design stages rather than post-construction [23] (Bolognesi et al., 2025). These capabilities position BIM as a quantitatively validated tool for performance optimisation, particularly in contexts where reliable datasets and digital infrastructure are available.

However, global case studies also reveal a concentration of BIM applications in high-resource and technologically advanced settings, raising questions about their transferability. For example, BIM-supported humanitarian housing projects in Chile and New Zealand demonstrate how digital workflows can integrate prefabrication, local materials, and disaster resilience strategies [7], [8] (González et al., 2019; Smith & Thomas, 2021). Similarly, post-disaster reconstruction projects in Indonesia and seismic retrofitting initiatives in Peru illustrate BIM's capacity to support rapid deployment and structural optimisation in vulnerable contexts [27], [28] (Rahmawati et al., 2020; Vargas-Neumann et al., 2018). While these studies provide robust quantitative evidence of BIM's effectiveness, they are largely situated in environments with established digital ecosystems, standardised data, and institutional support.

In contrast, the Sub-Saharan African context is characterised by limited BIM adoption and predominantly qualitative evidence. Existing studies focus primarily on identifying barriers such as high implementation costs, lack of technical expertise, limited policy support, and fragmented construction practices [9] (Abubakar et al., 2023). As a result, BIM is often discussed in terms of its *potential* rather than its empirically demonstrated performance within the region. This creates a significant gap: while global literature provides strong quantitative validation of BIM's benefits, African scholarship remains largely descriptive, with limited case studies demonstrating measurable outcomes such as cost savings, carbon reduction, or performance optimisation.

This disparity highlights a broader issue of contextual misalignment between global BIM capabilities and local realities. In many African contexts, construction practices are deeply embedded in informal systems, local material economies, and labour-intensive methods, which are not always easily compatible with standard BIM workflows. Consequently, the adoption of BIM cannot be understood solely as a technological transition but must also be considered a socio-technical transformation requiring adaptation to local conditions.

A critical synthesis of the literature further reveals that BIM's role in material evaluation—particularly for local and vernacular materials—remains underdeveloped. While global studies demonstrate BIM's ability to optimise industrial materials and prefabricated systems, there is limited research on integrating non-standardised materials such as compressed earth blocks (CEBs) into BIM environments. This gap is particularly significant in Sub-Saharan Africa, where such materials are central to sustainable construction but lack digital representation in standard BIM libraries. As a result, designers are often constrained to conventional materials not because of superior performance, but due to data availability and modelling limitations.

Moreover, the literature demonstrates an imbalance between quantitative BIM capabilities and qualitative implementation challenges. On one hand, BIM enables precise simulations of energy performance, embodied carbon, and lifecycle costs. On the other hand, qualitative factors such as user acceptance, training requirements, and institutional readiness often determine whether these capabilities can be effectively realised in practice. For example, while BIM can technically support the evaluation of CEB versus sandcrete systems, the absence of locally validated datasets and standardised modelling parameters limits its practical application in African contexts.

Despite these challenges, emerging research suggests that BIM can play a critical role in bridging the gap between traditional construction knowledge and modern performance-based design. By embedding local material properties into BIM libraries and aligning digital workflows with regional construction practices, BIM can support a more inclusive and context-sensitive approach to sustainability. This reframes BIM not as an imported technology, but as an adaptable platform capable of integrating vernacular materials into formal design processes.

In this context, the present study contributes to the literature by addressing three key gaps. First, it provides quantitative evidence of BIM-enabled performance evaluation within a Sub-Saharan African setting, moving beyond purely descriptive accounts of BIM adoption. Second, it integrates locally relevant materials (sandcrete and CEB) into BIM-based analysis, demonstrating how digital tools can support evidence-based material selection in contexts where such integration is currently limited. Third, it bridges global BIM methodologies with regional application, offering a replicable framework that aligns advanced digital workflows with local construction realities.

By positioning BIM as both a technical and contextual tool, this study advances the discourse from isolated case studies toward a comparative, performance-driven, and regionally grounded understanding of BIM in sustainable design.

Rethinking Sustainability in African Architecture

Sustainability in African architecture cannot be meaningfully advanced through the direct transfer of global design paradigms; rather, it requires a critical engagement with local material realities, socio-cultural values, and construction practices. While international discourse often emphasises high-tech solutions, industrialised materials, and standardised performance metrics, many African contexts demand approaches that are simultaneously climate-responsive, resource-efficient, and socially embedded [29] (Santos et al., 2024). This tension has produced a fragmented body of literature, where sustainability is variably defined and assessed across contexts.

A critical review of existing studies reveals a persistent divide between quantitative sustainability metrics and qualitative socio-cultural considerations. On one hand, quantitative approaches such as lifecycle assessment (LCA) and embodied carbon analysis prioritise measurable environmental performance indicators. These methods provide valuable insights into material efficiency and carbon reduction but often overlook contextual factors such as cultural acceptance, labour practices, and local knowledge systems. On the other hand, qualitative studies emphasise the socio-cultural and climatic appropriateness of vernacular materials, highlighting their role in enhancing thermal comfort, affordability, and community participation [2], [22] (Awoussi et al., 2025; Fizez, 2024). However, such studies frequently lack rigorous comparative data, limiting their influence on formal design decision-making and policy development.

This disconnect is particularly evident in the continued marginalisation of local materials. Despite strong evidence of their environmental and thermal advantages, materials such as adobe, bamboo, and compressed earth blocks (CEBs) are often perceived as inferior or temporary solutions. These perceptions are deeply rooted in colonial legacies and modernist biases that equate “development” with concrete and steel construction [2], [22] (Awoussi et al., 2025; Fizez, 2024). As a result, material selection in many African projects reflects symbolic and aspirational values rather than performance-based evidence, reinforcing the dominance of high-carbon materials such as sandcrete.

At the same time, the literature highlights important nuances that complicate simplistic narratives of “local equals sustainable.” For instance, the stabilisation of earth-based materials such as the addition of cement in CEBs improves durability and structural performance but can increase embodied carbon. This introduces a trade-off between environmental efficiency and material longevity, which is rarely examined through integrated frameworks. Similarly, while vernacular materials support community-based construction and local economies, their performance can vary significantly depending on soil composition, climate conditions, and construction quality. These variations underscore the need for context-sensitive sustainability assessments that move beyond generic assumptions.

Another key theme emerging from the literature is the hybridisation of traditional and modern construction systems. Increasingly, projects combine vernacular materials with contemporary techniques to achieve both performance and acceptability. However, this hybridisation introduces complexity in evaluation, as it challenges binary classifications of materials as either “traditional” or “modern.” Instead, sustainability must be understood as a spectrum, where different material systems offer varying trade-offs across environmental, economic, and social dimensions.

Despite these insights, the literature remains limited in its ability to support comparative and decision-oriented analysis. Few studies systematically evaluate how different materials perform across multiple criteria such as cost, embodied carbon, thermal comfort, and cultural acceptance within a single framework. This gap is particularly pronounced in institutional building contexts, such as orphanages, where design decisions must balance technical performance with social responsibility and long-term usability.

In this regard, the integration of digital tools such as BIM presents a significant opportunity. BIM enables the simultaneous assessment of multiple performance indicators, allowing designers to move beyond fragmented analyses toward holistic, evidence-based decision-making. By embedding environmental data, cost information, and material properties into a unified model, BIM facilitates the comparison of alternative design strategies in a way that is both quantitative and contextually informed. However, as highlighted in Section 2.2, this potential remains underutilised in African contexts due to limited datasets and the absence of locally adapted modelling frameworks.

The literature therefore points to a critical need for approaches that bridge three key divides:

- quantitative versus qualitative sustainability assessments,
- global design frameworks versus local construction realities, and
- traditional materials versus modern performance requirements.

Addressing these divides requires not only methodological innovation but also a reframing of sustainability itself from a purely technical objective to a multidimensional construct that integrates environmental performance, cultural relevance, and socio-economic viability.

In the context of orphanage design, this reframing is particularly urgent. Orphanages are not merely functional buildings; they are environments that shape the physical, emotional, and social well-being of vulnerable children. As such, sustainability must extend beyond energy and carbon metrics to include thermal comfort, psychological safety, cultural familiarity, and long-term adaptability. Conventional construction approaches based on sandcrete often fail to meet these broader criteria, while vernacular materials such as CEB offer potential advantages that remain insufficiently validated and underutilised.

To address these gaps, the present study adopts a BIM-enabled comparative framework that integrates both quantitative and qualitative dimensions of sustainability. By evaluating sandcrete and CEB within a unified analytical model, the study moves beyond isolated assessments toward a systematic, context-sensitive comparison. In doing so, it contributes to redefining sustainability in African architecture as a balance between performance, perception, and place.

Research Methods

This study adopts a mixed-method comparative prototype analysis, combining qualitative field data with quantitative BIM-based performance modelling. This approach was selected to bridge the gap between contextual understanding of orphanage needs and measurable environmental and cost performance of local materials.

Data Collection

To ensure a contextually appropriate and technically robust orphanage design, this study combined both **primary** and **secondary data sources**. Data were collected to guide material selection, cost estimation, and spatial planning, with each decision aligned to technical standards, cultural realities, and international sustainability norms.

Primary data were collected through on-site observations, complemented by discussions with orphanage caregivers, administrators, architectural educators, community planners, and representatives from humanitarian organisations such as the Charity Group Association. These discussions focused on common design challenges in orphanages, vernacular construction practices, local cost structures, and the spatial needs of children. Field visits were carried out at key orphanages in Yaoundé, the capital city of Cameroon, including *Saint Thérèse*, *Foyer École des Enfants Aveugles*, and *Centre d'Accueil de l'Espoir*. In addition, local construction companies such as MIPROMALO [30] (Owoyemi et al., 2021) were also consulted. These engagements provided valuable insights into functional layouts, sanitation placement, classroom adjacency, sleeping arrangements, infrastructure gaps that directly affect child well-being, as well as material conditions, maintenance practices, and cost estimation frameworks that informed the design of the orphanage.

Secondary data were obtained from published literature on orphanage design and child-centered environments. For example, [31] Khanbabaei (2016) investigated the factors that foster a sense of belonging among orphaned children, proposing supportive spaces that enhance social integration and reduce insecurity and alienation, thereby improving emotional, social, and psychological well-being. Similarly, [32] Helles (2021) examined how interior spatial design can mitigate post-parental loss psychological issues, highlighting specific architectural interventions. Relevant literature on environmental psychology was also reviewed, offering theoretical grounding for design strategies aimed at reducing children's psychological distress. Additional secondary sources included case studies, peer-reviewed articles, and books that provided insights into cost breakdowns, thermal comfort strategies, roof detailing, embodied carbon and energy data, and construction techniques associated with local materials.

Together, the primary and secondary data formed a comprehensive evidence base, guiding the development of design concepts and performance analyses for the proposed orphanage.

Project Design and Workflow Stages

Architectural Concept Development: The conceptualisation of the orphanage plan was guided by three key principles: cultural relevance, climatic responsiveness, and child-centred care. Drawing inspiration from traditional Cameroonian compound layouts, the design emphasised communal living, spatial dignity, and passive environmental comfort and other factors discuss in [31], [32] Khanbabaei (2016) and Helles (2021). Functional zones were positioned to support safety, emotional well-being, and social integration while ensuring flexibility for the application of local construction techniques. To enable material comparisons, 3D plans and models were developed for designs adapted to two construction systems: sandcrete and CEBs.

BIM Model Development: To test the influence of materials on performance, three orphanage prototypes were modelled in **Autodesk Revit** using identical spatial configurations:

- **Model A (973.4 m²):** Reinforced Concrete

- **Model B (973.4 m²):** CEBs (stabilised with ~8% cement)

The floor plan of the orphanage is presented in Figure 1 with the 3D models is presented in Figure 2. The different models were designed Autodesk Revit 2025.

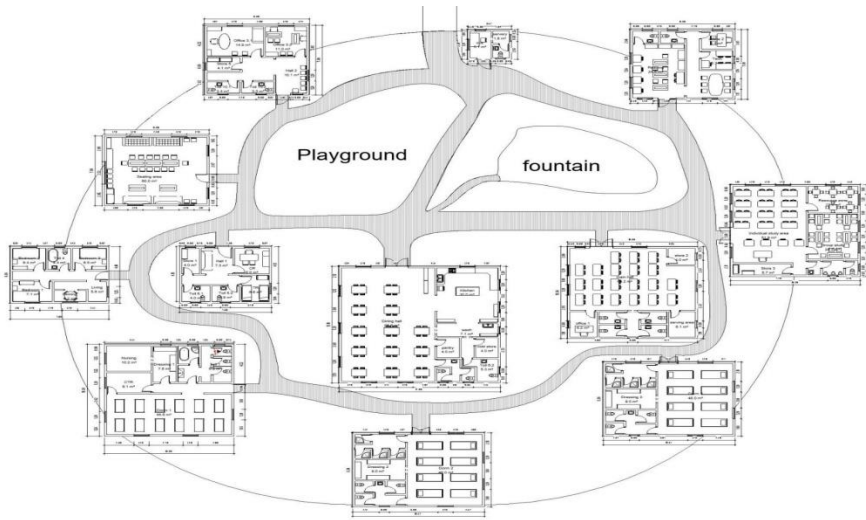
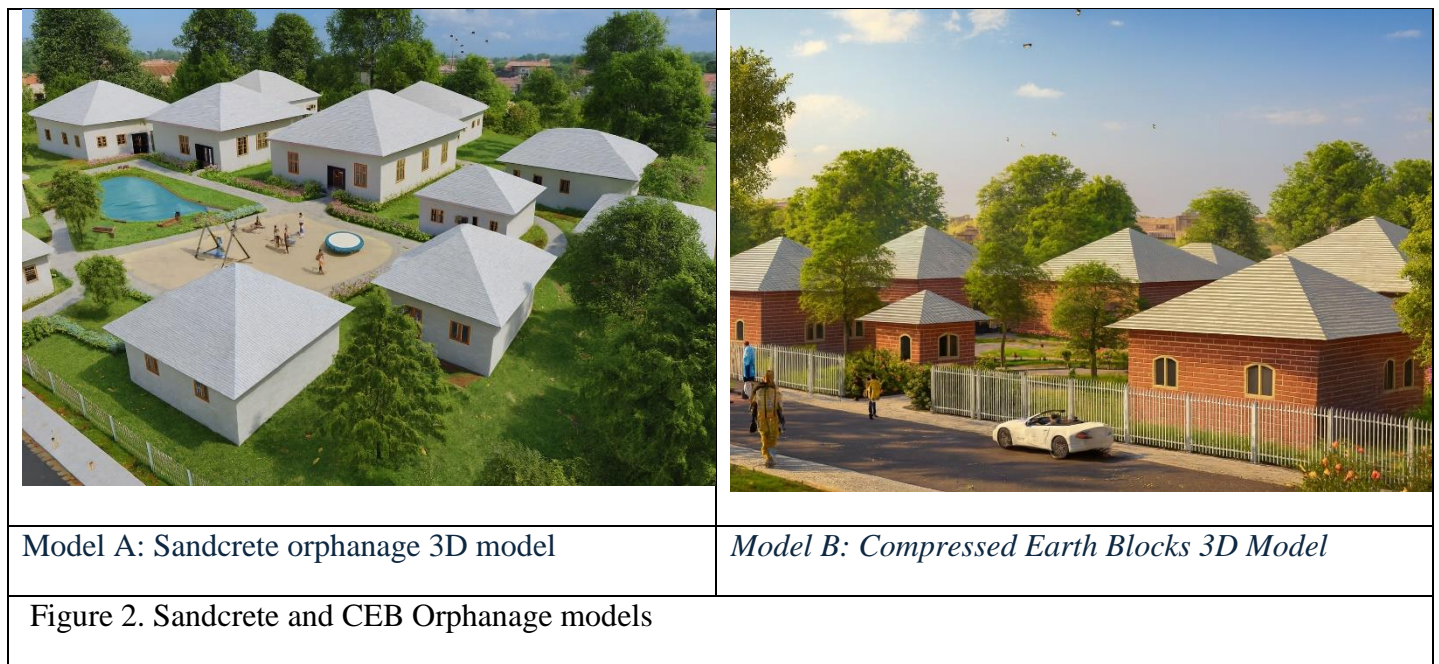


Figure 1. Floor plan of the orphanage



Each model was developed with standardised geometry, orientation, and consistent simulation parameters to allow fair comparison. Material-specific adaptive families (e.g., CEB wall systems) were incorporated, and environmental properties such as embodied carbon and thermal mass were assigned using validated values from the literature [33] (Adier et al., 2023).

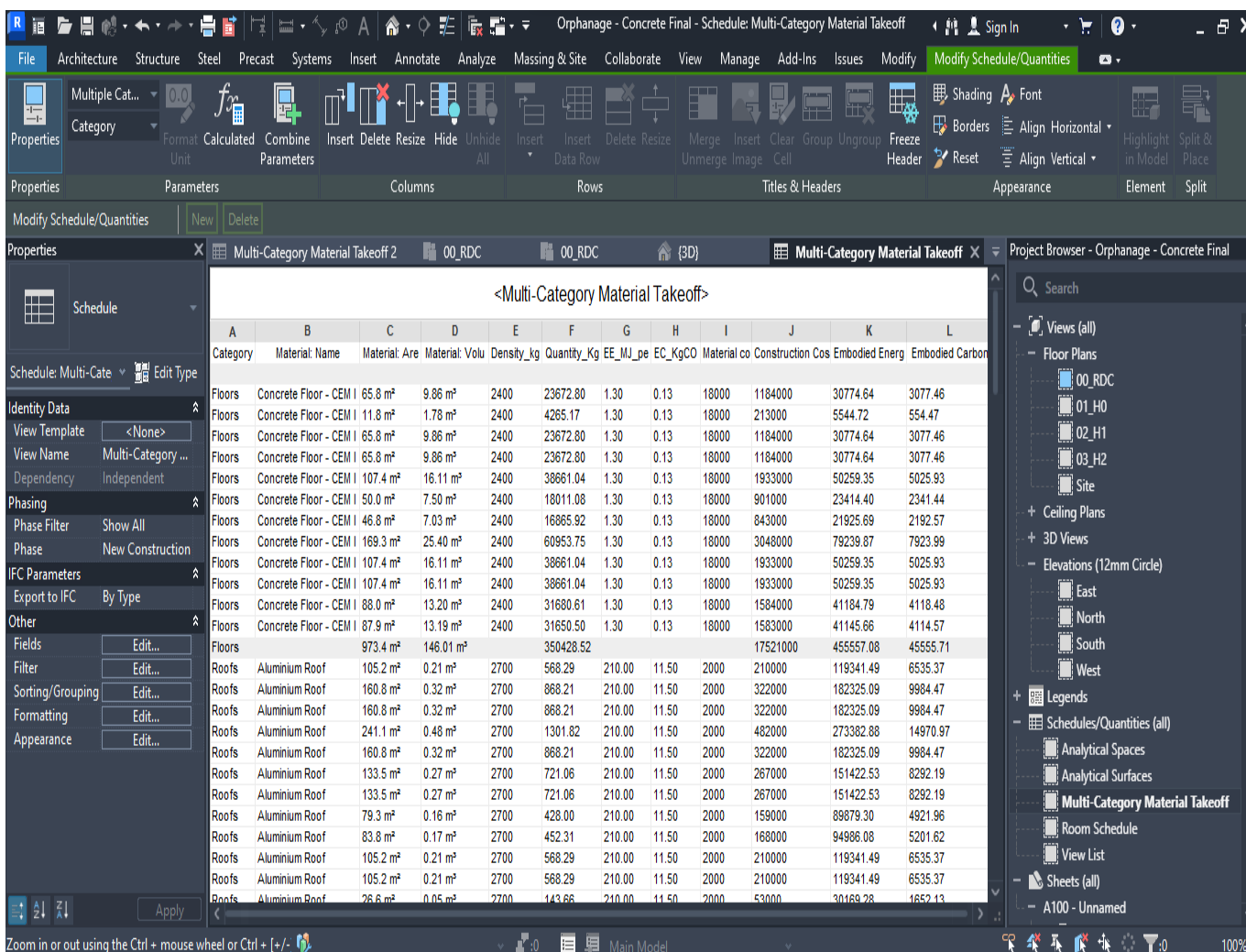
- **Material Properties:** Environmental datasets for sandcrete and CEB were sourced from peer-reviewed literature and cross-checked with local supplier specifications.
- **Standardisation:** All models were standardised for building orientation, occupancy schedules, and climate data to ensure comparability.
- **Level of Detail:** Models were developed to LOD 300, enabling accurate quantity take-offs and performance simulations.

Cost and Environmental Impact Computation

Cost Estimation

Material quantities for walls, roofs, and floors were extracted using Revit’s multicategory take-off tool and analysed in Microsoft Excel. Unit costs were assigned based on local market data and precedent studies, with adjustments made for labour and transport. Comparative cost tables were then generated to evaluate cost per square metre, total project costs, and the relative affordability of sandcrete blocks and CEB models.

In Revit 2025, a take-off was carried out and the unit costs of materials were updated. The unit cost data was sourced from various platforms, including the Mission for the Promotion of Local Materials (MIPROMALO). MIPROMALO is a Cameroonian public institution dedicated to the development and promotion of locally produced construction materials.



Category	Material Name	Material Area	Material Volume	Density_kg	Quantity_Kg	EE_MJ_pe	EC_KgCO	Material co	Construction Cos	Embodied Energy	Embodied Carbon
Floors	Concrete Floor - CEM I	65.8 m²	9.86 m³	2400	23672.80	1.30	0.13	18000	1184000	30774.64	3077.46
Floors	Concrete Floor - CEM I	11.8 m²	1.78 m³	2400	4265.17	1.30	0.13	18000	213000	5544.72	554.47
Floors	Concrete Floor - CEM I	65.8 m²	9.86 m³	2400	23672.80	1.30	0.13	18000	1184000	30774.64	3077.46
Floors	Concrete Floor - CEM I	65.8 m²	9.86 m³	2400	23672.80	1.30	0.13	18000	1184000	30774.64	3077.46
Floors	Concrete Floor - CEM I	107.4 m²	16.11 m³	2400	38661.04	1.30	0.13	18000	1933000	50259.35	5025.93
Floors	Concrete Floor - CEM I	50.0 m²	7.50 m³	2400	18011.08	1.30	0.13	18000	901000	23414.40	2341.44
Floors	Concrete Floor - CEM I	46.8 m²	7.03 m³	2400	16865.92	1.30	0.13	18000	843000	21925.69	2192.57
Floors	Concrete Floor - CEM I	169.3 m²	25.40 m³	2400	60953.75	1.30	0.13	18000	3048000	79239.87	7923.99
Floors	Concrete Floor - CEM I	107.4 m²	16.11 m³	2400	38661.04	1.30	0.13	18000	1933000	50259.35	5025.93
Floors	Concrete Floor - CEM I	107.4 m²	16.11 m³	2400	38661.04	1.30	0.13	18000	1933000	50259.35	5025.93
Floors	Concrete Floor - CEM I	88.0 m²	13.20 m³	2400	31680.61	1.30	0.13	18000	1584000	41184.79	4118.48
Floors	Concrete Floor - CEM I	87.9 m²	13.19 m³	2400	31650.50	1.30	0.13	18000	1583000	41145.66	4114.57
Floors		973.4 m²	146.01 m³		350428.52				17521000	455557.08	45555.71
Roofs	Aluminium Roof	105.2 m²	0.21 m³	2700	568.29	210.00	11.50	2000	210000	119341.49	6535.37
Roofs	Aluminium Roof	160.8 m²	0.32 m³	2700	868.21	210.00	11.50	2000	322000	182325.09	9984.47
Roofs	Aluminium Roof	160.8 m²	0.32 m³	2700	868.21	210.00	11.50	2000	322000	182325.09	9984.47
Roofs	Aluminium Roof	241.1 m²	0.48 m³	2700	1301.82	210.00	11.50	2000	482000	273382.88	14970.97
Roofs	Aluminium Roof	160.8 m²	0.32 m³	2700	868.21	210.00	11.50	2000	322000	182325.09	9984.47
Roofs	Aluminium Roof	133.5 m²	0.27 m³	2700	721.06	210.00	11.50	2000	267000	151422.53	8292.19
Roofs	Aluminium Roof	133.5 m²	0.27 m³	2700	721.06	210.00	11.50	2000	267000	151422.53	8292.19
Roofs	Aluminium Roof	79.3 m²	0.16 m³	2700	428.00	210.00	11.50	2000	159000	89879.30	4921.96
Roofs	Aluminium Roof	83.8 m²	0.17 m³	2700	452.31	210.00	11.50	2000	168000	94986.08	5201.62
Roofs	Aluminium Roof	105.2 m²	0.21 m³	2700	568.29	210.00	11.50	2000	210000	119341.49	6535.37
Roofs	Aluminium Roof	105.2 m²	0.21 m³	2700	568.29	210.00	11.50	2000	210000	119341.49	6535.37
Roofs	Aluminium Roof	28.6 m²	0.05 m³	2700	148.66	210.00	11.50	2000	58000	30189.28	1652.13

Figure 3. Multi Category Material Takeoff from Revit to Excel for Model A

Although the current focus is on cost estimation, the integrated nature of Revit has also allowed for the inclusion of embodied energy and carbon factors, which will later be used for environmental impact assessments. The data from Revit is exported to MS Excel by leveraging interoperability, where additional cost parameters such as labor costs and were incorporated to enable more flexible data manipulation.

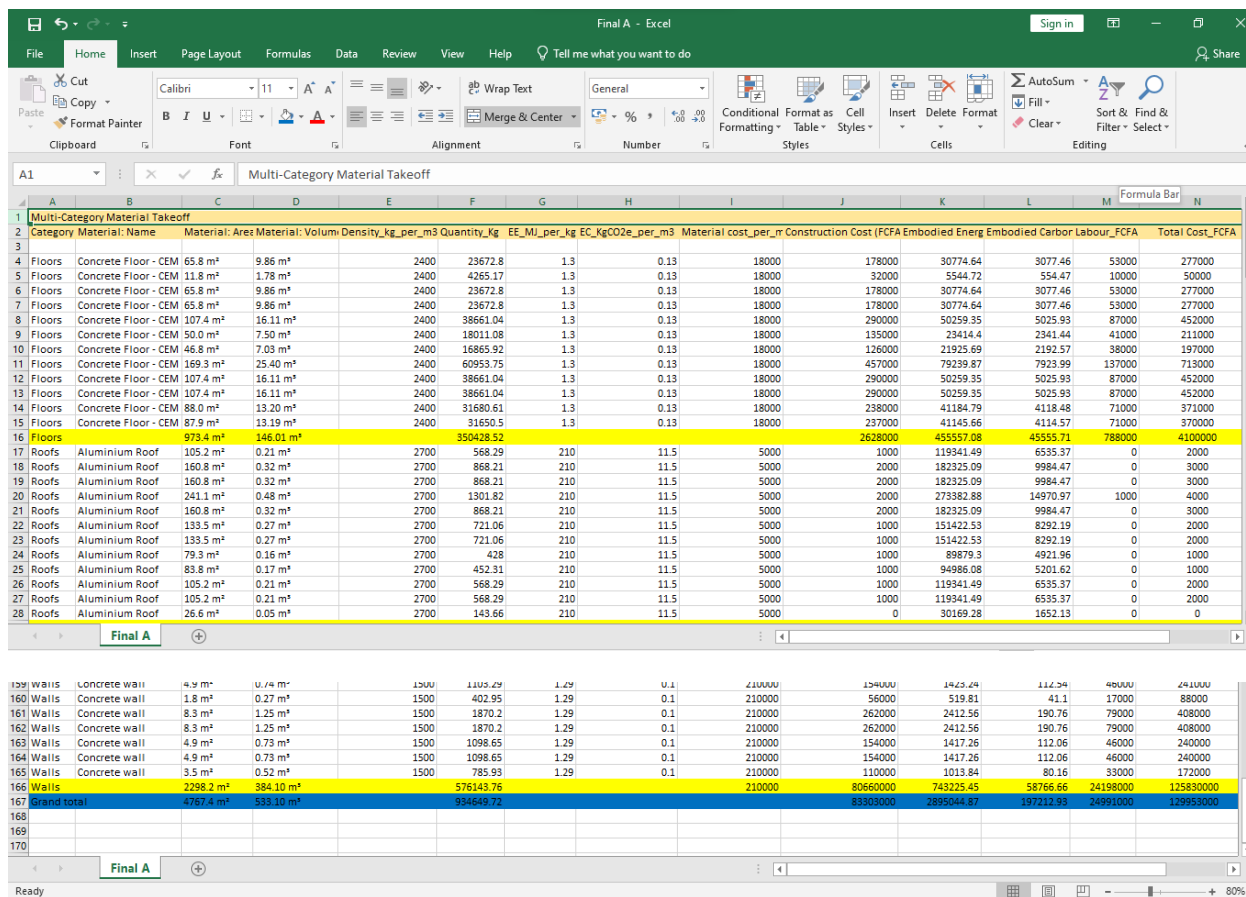


Figure 4. Grand Totals of the Different Parameters highlighted in blue

Similarly, the same approach was undertaken for Model B and the results are summarised as follows:

Table 1. Table showing Cost computations done in Excel for Models A and B

	Model A	Model B
Material cost	83,303,000	71,201,000
Labour cost	24,991,000	21,361,000
Contingency cost (20% of Labour + Material cost)	21,659,000	18,513,000
Grand total (FCFA)	129,953,000	111,079,000

NB: 1 USD is approximately 550 FCFA

Based on Table 1, the cost of sandcrete (Model A) is 17% higher than that of CEB (Model B). Although this analysis is specific to an orphanage project in Cameroon, the result is comparable to findings from a study in Nigeria, where sandcrete affordable housing was found to be approximately 20% more expensive than CEB housing [34] (Didel, 2014).

Environmental Performance Analysis

A reasonable share of the total global carbon emissions stems from building material production and construction and transportation processes, which consume significant energy and release carbon to the atmosphere [35] (Marzouk and Elshaboury, 2022). While strategies to compute and reduce the operation energy and carbon of buildings is well-established, substantial and effective reduction of carbon footprint is yet to be

achieved [35] (Marzouk and Elshaboury, 2022). Thus, embodied energy and carbon has gained interest in recent years amongst construction professionals. Consequently, only embodied energy and carbon will be computed in this study as part of the environmental impact assessment for the sandcrete and CEB orphanage. Thos will be computed with the help of Revit and EMS Excel.

For the computation of embodied energy and carbon, their factors or intensities were needed for the different materials. Given these values are not available for the different materials in Cameroon, global values and values for countries with similar tropical climates were adopted. For clarity purposes, the values for the different material used are presented in Table 2.

Table 2. Embodied energy and carbon factors

		Embodied energy factor (MJ/Kg)	Source/Comment	Embodied Carbon intensity (KgCO2/Kg)	Source/Comment
Model A (Sandcrete)	Concrete structural elements	1.12	[36] Taffese & Abegaz (2019), <i>Buildings</i> , 9(6), 13	0.095	[36] Taffese & Abegaz (2019), <i>Buildings</i> , 9(6), 13
	Hollow concrete blocks	1.29	[36] Taffese & Abegaz (2019), <i>Buildings</i> , 9(6), 13	0.102	[36] Taffese & Abegaz (2019), <i>Buildings</i> , 9(6), 13
	Aluzinc	210	[37] Bath ICE 2024	11.5	[37] Bath ICE 2024
	Concrete floor slab	1.3	[37] Bath ICE 2024	0.13	[37] Bath ICE 2024
Model B (CEB)	Aluzinc	210	[37] Bath ICE 2024	11.5	[37] Bath ICE 2024
	Concrete floor slab	1.3	[37] Bath ICE 2024	0.13	[37] Bath ICE 2024
	CEB walls	0.5	[38] Zoma et al. (2025)	0.05	[38] Zoma et al. (2025)

To ensure regional accuracy, embodied energy and carbon factors were sourced from peer-reviewed literature. For CEB, [38] Zoma et al. (2025) report 0.50 MJ/kg and 0.050 KgCO₂/Kg. Hollow concrete blocks were assigned 1.29 MJ/Kg and 0.102 KgCO₂/Kg from [36] Taffese et al. (2019). These values are summarised in Table 2. A key methodological limitation of this study relates to the use of non-local embodied energy and carbon datasets. Due to the absence of comprehensive and standardised databases for construction materials in Cameroon, values were sourced from international literature and studies conducted in regions with comparable tropical or developing-country contexts [36], [38] (Taffese et al., 2019; Zoma et al., 2025). While this approach enables preliminary performance evaluation, it introduces a degree of uncertainty, as embodied impacts can vary significantly depending on local production methods, energy sources, and transportation distances.

This limitation reflects a broader gap in Sub-Saharan African construction research, where region-specific environmental datasets remain underdeveloped. Consequently, the results should be interpreted as indicative rather than definitive, particularly in absolute terms. However, the comparative nature of the analysis remains valid, as both material scenarios were evaluated using consistent data sources and assumptions. Future work

should prioritise the development of locally calibrated embodied carbon databases, which would significantly enhance the accuracy and policy relevance of BIM-based sustainability assessments in the region.

Using the values in Table 2, Figures 3 and 4, and the mathematical model used in [39] Abanda et al (2014b), the embodied energy and carbon of the models have been computed and presented in Table 3.

$$EE_k = \sum_{k=1}^n (1 + \xi_k) \cdot Q_k \cdot I_k$$

$$EC_k = \sum_{k=1}^n (1 + \xi_k) \cdot Q_k \cdot I_k$$

Where:

EE_k and EC_k are embodied energy and embodied CO₂ of material type k with units MJ and KgCO₂ respectively;

ξ_k is the waste factor (dimensionless) of material type k ;

Q_k is the total functional quantity of material;

I_k is the embodied energy factor or embodied CO₂ factor with units MJ/functional unit and KgCO₂/functional unit of material respectively.

Due to lack of information about waste data in Cameroon, the waste factor was considered to be zero. The assumption of a zero waste factor was adopted as a controlled modelling simplification to ensure consistency and comparability between the two material scenarios. In BIM-based comparative studies, such assumptions are often used to isolate the influence of key variables, in this case, material choice without introducing additional uncertainty from poorly documented parameters. Given the absence of reliable and standardised waste data for construction practices in Cameroon, introducing estimated waste factors could have introduced bias or reduced the transparency of the analysis.

Table 3. Total embodied energy and carbon for the three models

Model	Embodied Energy (MJ)	MJ/m ²	Embodied Carbon (KgCO ₂)	KgCO ₂ /m ²
A	2 895 044.866	2974.16	197 212.9278	202.60
B	1 498 591.381	1539.54	111 491.299	114.54

GFA = 973.4 m²

Research Findings and Discussions

This section presents the findings from the BIM-based simulations and cost-benefit analyses of the two prototype orphanage designs: Sandcrete and CEB. Results are organised under three key performance indicators: environmental performance, economic performance, and BIM workflow outcomes. All values are derived from model-based simulations and verified quantity take-offs.

State-of-the-art on the use of local materials in building construction

Cost-effectiveness and Environmental impact of Sandcrete and CEB orphanage

This section synthesises the results of the BIM-based simulations through a comparative analysis of two orphanage prototypes: sandcrete (Model A) and compressed earth blocks (Model B). Rather than restating numerical outputs, the discussion focuses on interpreting performance differences across key indicators: cost, embodied energy, and carbon and situating these findings within existing literature. This approach enables a clearer understanding of how material selection influences sustainability outcomes in the specific context of Cameroon, while also contributing to broader discussions on low-carbon construction in Sub-Saharan Africa.

Cost-effectiveness of sandcrete and CEB orphanage

Based on Table 1, the cost of sandcrete (Model A) is 17% higher than that of CEB (Model B). This analysis, while specific to an orphanage project in Cameroon, is comparable to findings from a study in Nigeria, which found sandcrete affordable housing to be approximately 20% more expensive than CEB housing [34] (Didel, 2014). This cost differential can be attributed primarily to material composition and construction processes. Sandcrete blocks rely heavily on cement, which is both energy-intensive and subject to market price volatility, thereby increasing overall construction costs. In contrast, CEB utilises locally available soil with minimal cement stabilisation, significantly reducing material input costs and transportation requirements. This aligns with findings in [13] (Abanda et al., 2014a), which demonstrate that earth-based construction systems achieve cost efficiency through reduced dependence on industrial materials.

Furthermore, the observed cost advantage of CEB is not only a function of material pricing but also of construction efficiency. Interlocking or modular characteristics of earth blocks can reduce mortar usage and labour intensity, contributing to faster construction timelines. This supports evidence from [41] (Obaje et al., 2022), where CEB systems were shown to improve affordability through both material and process optimisation. Therefore, the results reinforce a broader pattern in the literature: cost savings from CEB are systemic rather than incidental, arising from integrated material and construction advantages.

The cost estimation for both models involved extracting material quantities using Revit’s multicategory take-off tool and analysing them in Microsoft Excel. Unit costs were assigned based on local market data and precedent studies, with adjustments made for labour and transport costs, sourced from platforms like the Mission for the Promotion of Local Materials (MIPROMALO). The gross floor area (GFA) for both models was 973.4 m².

It is imperative to consider embodied carbon and embodied energy to further compare the orphanages constructed with sandcrete or CEB.

Environmental Performance

Model	Embodied Energy (MJ)	MJ/m ²	Embodied Carbon (KgCO ₂)	KgCO ₂ /m ²
A	2 895 044.866	2974.16	197 212.9278	202.60
B	1 498 591.381	1539.54	111 491.299	114.54

The environmental performance assessment highlighted notable differences between Model A (Sandcrete) and Model B (Compressed Earth Blocks, CEB). Model A exhibited significantly higher embodied energy (2974.16 MJ/m²) and embodied carbon (202.60 KgCO₂/m²), whereas Model B demonstrated considerably lower embodied energy (1539.54 MJ/m²) and embodied carbon (114.54 KgCO₂/m²). It is important to note that these values does not include finishes and services.

These findings are broadly supported by literature, indicating that earth-based construction materials often yield lower overall environmental impacts compared to conventional sandcrete or hollow cement blocks [40], [41], [42], [Adu et al., 2025; Obaje et al., 2022; Saba et al., 2018; . This is frequently attributed to the reduced need

for plastering and painting in earth construction, which significantly lessens the high embodied carbon contribution from cement [40], [Adu et al., 2025]

However, the analysis presents nuances. For instance, individual stabilised laterite bricks can have a higher embodied carbon per kilogram than sandcrete blocks due to their cement content [40] [Adu et al., 2025]. Similarly, the embodied impacts of specific earth materials like vibration-compacted adobe bricks can vary, sometimes showing higher embodied carbon per kilogram than concrete blocks, emphasizing the influence of material composition and raw material transportation [38][Zoma et al., 2025].

Beyond direct carbon reductions, CEB construction systems offer enhanced thermal performance and energy efficiency, leading to improved indoor comfort [41], [Obaje et al., 2022] The use of interlocking blocks also significantly reduces material and labour costs due to minimal mortar requirements, accelerating construction speed compared to traditional sandcrete [41] Obaje et al., 2022].

Overall, despite variations in individual material impacts, CEB-based systems present a promising and sustainable alternative to sandcrete, offering both environmental and economic benefits for building construction [41], [42] [Obaje et al., 2022; Saba et al., 2018].

The magnitude of the differences observed between the two models highlights the structural impact of material selection on lifecycle environmental performance. The substantially higher embodied energy and carbon values associated with sandcrete can be directly linked to cement production, which is widely recognised as one of the most carbon-intensive processes in the construction sector [35] (Marzouk and Elshaboury, 2022). In contrast, the lower impacts of CEB are largely due to its reliance on minimally processed local materials, which reduces both energy consumption and emissions during production.

Importantly, these findings should be interpreted at the system level rather than at the individual material level. While some studies report higher embodied carbon per kilogram for stabilised earth materials due to cement content [40] (Adu et al., 2025), the overall building system often achieves lower total impacts due to reduced finishing requirements and improved thermal performance. This distinction is critical and aligns with observations in [38] (Zoma et al., 2025), where variations in material composition influence unit-level impacts but not necessarily whole-building performance outcomes.

Moreover, the improved thermal mass of CEB contributes to passive thermal regulation, which can reduce operational energy demand over the building lifecycle. Although operational energy was not quantified in this study, the findings are consistent with broader literature suggesting that earth-based materials enhance indoor thermal comfort and reduce cooling loads in tropical climates [41] (Obaje et al., 2022). This indicates that the environmental benefits of CEB may extend beyond embodied impacts, reinforcing its suitability for sustainable building design in Sub-Saharan Africa.

Benefits of BIM in the design process of sustainable Orphanage buildings

Building Information Modelling (BIM) has become a transformative innovation in the construction sector, enabling greater design precision, cost optimisation, and sustainability. These benefits are particularly important in Sub-Saharan Africa, where orphanage buildings must be designed to be child-centred, affordable, and environmentally responsive.

A key advantage of BIM is enhanced design precision. By centralising lifecycle data in a 3D digital environment, BIM integrates cost, performance, and sustainability assessments. Tools such as automated cost estimation, energy modelling, and life cycle assessment (LCA) provide accurate insights into the long-term performance of orphanages, ensuring that design solutions remain viable and resilient [43] (Zhang et al., 2025).

Sustainability is central to humanitarian architecture, and BIM plays a vital role through “Green BIM” applications. These embed environmental data directly into material libraries, enabling assessments of embodied carbon and recyclability during the early design stages [44] (Basart et al., 2023). For orphanages, this allows

designers to adopt eco-friendly solutions that minimise waste while ensuring healthy, child-friendly environments.

BIM also fosters collaboration among diverse stakeholders such as NGOs, architects, and local contractors. By consolidating architectural, structural, and systems data, BIM improves transparency, reduces errors, and enhances trust in decision-making [45] (Mbarga & Mpele, 2019). For orphanage projects that often depend on multiple funding and delivery partners, such collaborative tools are crucial to ensure alignment and efficiency.

Cost and resource efficiency further highlight BIM's relevance. Clash detection prevents costly rework on-site, while automated quantity take-offs reduce material waste by ensuring precise procurement [43] (Zhang et al., 2025). For orphanage prototypes, such features are particularly useful in maximising limited budgets while still meeting quality standards.

Finally, BIM enables the validation of local and affordable materials, such as CEBs. These are often overlooked due to misconceptions, yet BIM provides robust data to demonstrate their structural and environmental performance [45] (Mbarga & Mpele, 2019). In doing so, BIM supports culturally appropriate, sustainable, and cost-effective orphanage construction.

In sum, BIM provides significant benefits for orphanage design in Sub-Saharan Africa by improving design precision, sustainability, collaboration, and cost efficiency. Its ability to validate local materials and integrate environmental analysis ensures that orphanages are not only affordable and resilient but also culturally resonant and environmentally sound.

IM-enabled design framework for sustainable orphanages in Cameroon

This study applies Building Information Modelling (BIM), using Autodesk Revit, to design sustainable, child-centred orphanages in Cameroon with locally sourced materials. It introduces a BIM-enabled comparative design framework that highlights material choices and is adaptable across Sub-Saharan Africa. By combining qualitative field data with quantitative BIM-based modelling, the framework links contextual understanding with measurable outcomes in cost and environmental performance. The first stage involves systematic data collection to guide material selection, cost estimation, and spatial planning. Primary data came from on-site observations and consultations with caregivers, administrators, educators, planners, and humanitarian organisations, focusing on design challenges, vernacular practices, costs, and children's spatial needs. Field visits to orphanages in Yaoundé and collaboration with local firms such as MIPROMALO enriched the dataset. Secondary data, drawn from literature on orphanage design, child-centred environments, environmental psychology, and construction materials, provided insights into costs, thermal strategies, embodied carbon, and roof detailing. The second stage centres on project design and workflow. Guided by cultural relevance, climatic responsiveness, and child-centred care, the architectural concept drew inspiration from traditional Cameroonian compound layouts, emphasising communal living, safety, and spatial dignity. For material comparison, two prototypes were developed in Autodesk Revit: Model A (sandcrete) and Model B (Compressed Earth Blocks). Both shared identical spatial configurations, standardised geometry, and simulation parameters. Material-specific adaptive families were integrated, with environmental properties such as embodied carbon and thermal mass assigned from validated sources. Models were developed to Level of Detail (LOD) 300, enabling accurate take-offs and robust simulations.

The final stage focused on cost and environmental assessment. Material quantities were extracted from Revit and analysed in Excel, with local unit costs adjusted for labour and transport. Comparative cost tables were generated, while environmental performance was assessed through embodied energy and carbon indicators. In the absence of Cameroon-specific datasets, values were drawn from global databases and tropical-climate contexts. Revit's integrated tools facilitated the embedding of these environmental factors into material assessments.

Overall, the BIM-enabled framework provides a structured, replicable approach to designing sustainable humanitarian infrastructure in Cameroon. It supports evidence-based material selection, comprehensive

performance evaluation, and culturally grounded design. By integrating data-driven insights with advanced digital tools, the framework demonstrates strong potential for scalable, sustainable orphanage design across Sub-Saharan Africa.

CONCLUSIONS

This study effectively applied Building Information Modelling (BIM) through Autodesk Revit to design and evaluate sustainable, child-centred orphanages in Cameroon, integrating locally sourced materials. The research specifically compared two functionally identical prototypes: sandcrete blocks and Compressed Earth Blocks (CEB), assessing them against life-cycle assessment (LCA) standards for cost, embodied carbon, energy, and thermal comfort.

The findings unequivocally demonstrate CEB's superior performance across key sustainability indicators. CEB offered a significantly lower construction cost, being 17% cheaper than sandcrete blocks. Environmentally, CEB exhibited a substantially smaller overall carbon footprint and energy demand, with embodied energy of 1539.54 MJ/m² and embodied carbon of 114.54 KgCO₂/m², compared to sandcrete's 2974.16 MJ/m² and 202.60 KgCO₂/m² respectively. Furthermore, CEB outperformed sandcrete in thermal comfort and alignment with local traditions. BIM-enabled workflows were crucial, facilitating accurate quantity take-offs, early LCA integration, and evidence-based material selection. BIM's role in enhancing design precision, cost optimisation, and environmental performance analysis was central to this comparative evaluation. It supports comprehensive performance evaluation and culturally grounded design, providing a replicable digital design approach for humanitarian architecture in resource-constrained Sub-Saharan contexts. These results offer practical insights for architects, policymakers, and NGOs aiming to develop sustainable and culturally responsive infrastructure for vulnerable populations.

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