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Geomatics BIM Convergence: Interoperable Information Management and Modeling for Smart BuildingsCase Study: Ecological and Digital Building (EDB) Demonstrator at École Polytechnique Thiès (EPT)

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Abstract:

In the context of Senegal's energy transition, this study develops and applies a structured Geomatics-BIM methodology for the 3D digitization of sustainable buildings. The approach combines drone-based photogrammetry and terrestrial laser scanning to capture complementary datasets, processed through Agisoft Metashape, Trimble RealWorks, and Autodesk ReCap for cleaning and optimization. The resulting point clouds were integrated into Autodesk Revit to perform parametric modeling, ensuring interoperability through IFC standards. Applied to the Ecological and Digital Building (EDB) at École Polytechnique de Thiès, the workflow generated a photogrammetric model with 5.9 million points and a lasergrammetric dataset with 86.8 million points and millimetric precision. This hybrid integration produced a reliable digital twin, demonstrating the feasibility of low-cost, reproducible, and open-standard workflows for facility management, energy assessment, and future smart building applications in Sub-Saharan Africa

Keyword: Photogrammetry; laser scanning; Geomatics; BIM; Interoperability; Smart building

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1. Introduction: Geomatics–BIM Convergence for Smart and Sustainable Buildings

In a world facing accelerating climate change, depletion of natural resources, and rapid urbanization, the building sector must be regarded as a strategic lever for the energy and ecological transition. According to the International Energy Agency (IEA) [1], buildings and construction account for nearly 36% of final energy consumption and 39% of energy related CO_2 emissions worldwide. In developing countries, and particularly in Sub Saharan Africa, this situation is exacerbated by rapid urban growth, obsolete infrastructures, and a chronic shortage of housing adapted to climatic and social constraints [2].

In Senegal, demographic pressure and climate change call for a profound transformation of design, construction, and operation practices. This transformation relies on the adoption of digital technologies that enhance building quality, resilience, and energy efficiency. In this perspective, the digitization of the entire building value chain from design to deconstruction, including operation and maintenance emerges as an essential lever to increase productivity, rationalize resource use, and support the upskilling of local actors [3].

In this context, Compressed Earth Block (CEB) buildings represent a sustainable local solution, and their digitization illustrates how the convergence of geomatics and BIM can strategically support both heritage preservation and the modernization of construction practices.

Among the structuring tools of this digital transformation is Building Information Modeling (BIM), defined as a collaborative process for producing, structuring, and managing building data throughout its lifecycle [4]. By enabling geometric representation enriched with technical information, BIM supports simulation automation, early conflict detection, workflow optimization, and improvement of data quality. These contributions are especially crucial in contexts with limited human and material resources. Interoperability of data, ensured notably by the Industry Foundation Classes (IFC) standard defined by ISO 16739:2013, is a key component to guarantee digital continuity and exchange between heterogeneous platforms.

In parallel, geomatics contributes by spatially contextualizing projects using tools such as Geographic Information Systems (GIS), drone photogrammetry, or terrestrial laser scanning. These technologies facilitate the acquisition of high resolution three dimensional data, the modeling of topographic and environmental context, and multi scale analysis of urban dynamics. Integrating geospatial data into BIM processes, often referred to as GeoBIM, strengthens designers' ability to incorporate parameters such as solar exposure, network connectivity, natural hazards, and land use [4].

One promising path to study the complementarity of these domains is to explore the concept of smart buildings, introduced in the early 1980s [5]. This concept aims to transform conventional buildings into intelligent ones, enabling adaptive energy management based on data collected via intelligent system layers integrating IoT sensors. Despite its long standing recognition and growing international interest, the concept remains ambiguously defined and requires further formalization [6]. Current BIM software has matured in representing building components and exporting models in IFC format for visualization and analysis, but still faces limitations in incorporating intelligent elements such as IoT sensors. The absence of unified standards for functional descriptions of sensors, the difficulty of combining static and real time data flows, and the fragmentation between Building Management Systems (BMS) and BIM platforms [11] hinder the emergence of true digital twins in the building sector [10]. While the notion of smart buildings is increasingly present in global energy transition discussions, its operational deployment, particularly in Sub Saharan Africa, remains limited. Challenges persist, including the lack of reliable digital data, the absence of standardized structuring of connected objects in BIM environments, and weak interoperability between geospatial layers, digital models, and energy regulation systems.

Recent studies emphasize advanced SIG–BIM integration methods, such as the use of ontologies for semantic interoperability [7] or automated scan to BIM processes powered by artificial intelligence [9]. However, these approaches remain limited to high resource contexts, often requiring costly equipment and extensive computing power. This article complements the existing body of work by proposing a low cost, hybrid, and reproducible workflow that is both technically rigorous and adapted to West African realities, while remaining aligned with international open standards.

Against this backdrop, a central question arises: how can geospatial data be transformed and associated with BIM? The general objective of this article is to propose an integrated approach to digital building modeling in the context of the energy and digital transition, articulating BIM and geomatics tools, with an opening toward IoT. More specifically, the aims are: (i) to define a methodology for capturing and structuring spatial and construction data through drone based photogrammetry and terrestrial laser scanning adapted to West African conditions; (ii) to implement BIM modeling compliant with open standards (IFC) [12], integrating architectural, material, and technical characteristics of the building studied; and (iii) to apply and validate the approach on a real demonstrator, the Ecological and Digital Building (EDB) of École Polytechnique de Thiès, designed as a low carbon prototype building. While deliberately limiting the analysis to digital modeling of the building (without IoT sensor integration at this stage), this work explores the technical and methodological conditions that anticipate future extensions toward cyber physical systems, providing a robust basis for the development of interoperable smart buildings adapted to tropical environments.

The originality of this work lies in applying BIM–Geomatics convergence to a demonstrator building constructed with local eco materials such as compressed earth blocks and Typha insulation. Unlike most existing GeoBIM approaches developed in European or Asian contexts, this research introduces a pragmatic methodology adapted to Sub-Saharan African conditions characterized by limited resources. The hybrid integration of drone photogrammetry, terrestrial laser scanning, and open BIM standards (IFC4) provides an innovative framework for creating digital models of ecological buildings in tropical environments.

This research contributes to the literature in three ways. First, it applies a hybrid GeoBIM methodology to a demonstrator built with local eco-materials, an approach rarely documented in Sub-Saharan contexts. Second, it proposes a reproducible and low-cost workflow aligned with open standards such as IFC, making it adaptable to resource-constrained environments. Finally, it highlights the broader value of GeoBIM beyond technical accuracy, showing its potential for education, capacity building, and sustainable construction policies in Africa.

2. Proposed geomatics–BIM integration workflow

Figure 1 presents the methodological workflow implemented in this study, structured around three main stages: data acquisition, data analysis, and BIM & MN integration. In the acquisition phase, drone-based photogrammetry (DJI Phantom 4 RTK) and terrestrial laser scanning (Trimble X7) were combined to capture complementary datasets, ensuring both global coverage and millimetric precision. The data analysis phase involved photogrammetric reconstruction using Agisoft Metashape and laser scan registration in Trimble RealWorks, followed by cleaning and optimization in Autodesk ReCap Pro to standardize outputs. The final integration phase consisted of importing the point clouds into Autodesk Revit to perform parametric modeling of the building's main components, while ensuring interoperability through open IFC standards. This hybrid approach provides a reproducible workflow for GeoBIM integration, enhancing the accuracy and completeness of digital building models and supporting their use for facility management, energy performance assessment, and the development of smart building demonstrators in Sub-Saharan Africa.

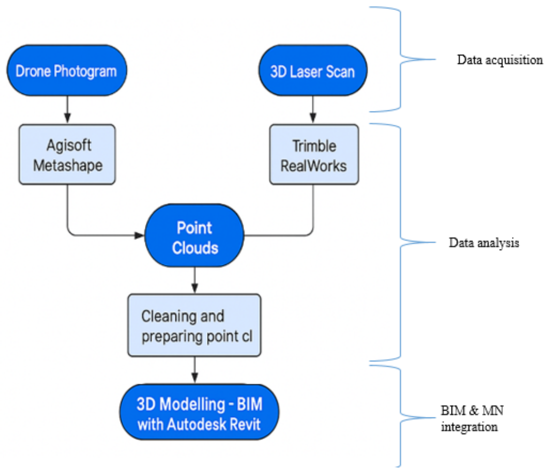

Figure 1 Methodology for GIS–BIM Integration

3. Case study: The Ecological and Digital Building (EDB) Demonstrator at EPT

The case study focuses on the Ecological and Digital Building (EDB), also referred to as the Compressed Earth Block (CEB) building, located on the educational campus of École Polytechnique de Thiès (EPT), Senegal. Initially constructed in the 1980s using geo concrete based on local laterite, the building was later enhanced with two experimental domes and rehabilitated between 2013 and 2017 under the PNEEB Typha program. This rehabilitation project explored the use of Typha based thermal insulation materials as part of a national initiative to promote energy efficient and sustainable construction. Today, the EDB serves as a demonstrator for low carbon building technologies and a platform for digital modeling experiments

Figure 2 : South façade - EDB EPT

3.1. Geospatial and 3D survey data acquisition

3.1.1. Drone based photogrammetry acquisition

A DJI Phantom 4 RTK drone equipped with a GNSS module was used to capture the building envelope. A total of 387 georeferenced images were acquired with a 70% frontal and 80% lateral overlap, under controlled lighting conditions to minimize shadows and distortions. The flight plan was set at an altitude of 26.7 meters with a 60° camera angle, ensuring sufficient redundancy for dense point cloud generation. This technique provided rapid and cost effective coverage of the building's exterior, with detailed and realistic texturing.

3.1.2. Terrestrial laser scanning acquisition

To complement photogrammetry, a Trimble X7 terrestrial laser scanner was deployed. The equipment offers a precision of ±2 mm and an effective range of 80 meters. Ten scan stations were positioned irregularly around the building to ensure complete coverage of façades and fine architectural details. Each scan lasted approximately three minutes, and registration was performed on site using a predefined reference station, ensuring spatial coherence without the need for external recalibration. This method produced highly detailed point clouds, with over 86.8 million points and an average registration error of 0.9 mm.

3.2. Data processing and analysis

3.2.1. Photogrammetry processing workflow

The images were processed using Agisoft Metashape following a standard pipeline: (i) image alignment, (ii) generation of a dense point cloud, (iii) mesh construction, and (iv) high resolution texturing. The resulting model was exported in .e57 format, cleaned in Autodesk ReCap Pro to remove artefacts such as vegetation and vehicles, and converted to .rcs format for integration into BIM software

Figure 3 : South façade processed in Agisoft Metashape

3.2.2. Lasergrammetry processing workflow

The point clouds acquired with the Trimble X7 were processed in Trimble RealWorks, including cleaning, spatial orientation, and segmentation. The data were exported in .laz format, then converted into .rcs using Autodesk ReCap Pro for BIM integration. This workflow highlighted both the quality of raw data and the importance of optimization steps to ensure compatibility with modeling tools.

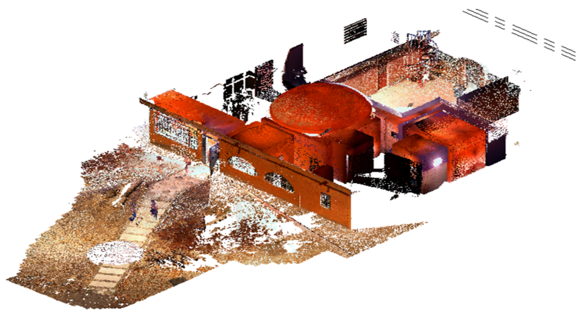

Figure 4 : South-East part from laser scanning in Autodesk Revit

3.3.Point cloud integration and building information modeling

The processed point clouds were imported into Autodesk Revit. The photogrammetric model was selected as the main reference due to its completeness and high quality textures, while the lasergrammetric data were used to refine structural details. Parametric modeling was performed to reconstruct key building components, including walls in compressed earth blocks, domes, roofs, openings (doors and windows), and architectural details such as grilles and ventilation systems. Alignment with reference elevations and adjustment of scale ensured geometric consistency.

A quality control process compared model dimensions with field measurements, validating accuracy. The final model was exported in IFC4 format to guarantee interoperability with third party tools and compliance with open standards. This process resulted in a robust digital model suitable for further applications in energy performance assessment, facility management, and education.

The methodological approach follows a Design Science Research (DSR) logic, where the iterative construction and validation of digital models under real world constraints is emphasized [13]. To further strengthen this approach, the inclusion of quantitative indicators would be beneficial, such as: (i) mean geometric error compared to field measurements, (ii) acquisition and processing cost per square meter digitized, (iii) total processing time for each workflow, and (iv) coverage rate of façades and interior spaces. These indicators would enable a more objective comparison with existing methodologies and facilitate replication in other contexts.

A total of 387 georeferenced images were captured with the DJI Phantom 4 RTK drone and processed in Agisoft Metashape under three different quality settings (low, medium, high) to evaluate trade-offs between processing time and accuracy. The Trimble X7 laser scanner was used to acquire dense point clouds, subsequently processed in Trimble RealWorks and Autodesk ReCap before integration in Revit. Both workflows enabled exports in IFC and E57 formats for cross-platform interoperability.

4. Visualization, Performance Assessment, and BIM

4.1. Visualization and characteristics of the 3D models

The photogrammetric model generated from 387 drone images contains approximately 5.9 million points and 1.18 million faces after removal of the surrounding environment. Processing times varied significantly depending on the quality settings in Agisoft Metashape, ranging from a few minutes (low quality) to over 11 hours (high quality). The resulting textured model exhibited high visual realism, with accurate reproduction of surface materials and colors. However, partial occlusion due to vegetation created gaps on the north eastern façade. Overall, photogrammetry proved highly suitable for capturing the global building envelope, with a strong balance between quality, cost, and processing time.

Table 1: Processing times according to quality settings

Step	Low Quality	Medium Quality	High Quality
Image alignment	9 mm 05s	14 mm 22s	13 mm 25s
Dense point Cloud	12 mm 53 s	55 mm 59s	11 mm 07s
Meshing	2 mm 41 s	11 mm 23 s	4 mm 43 s
Texturing	2 mm 19 s	8 mm 43 s	4 mm 08 s

Processing times in Metashape illustrate these trade-offs: image alignment required between 9 and 14 minutes depending on settings, dense cloud generation ranged from 13 minutes to more than 11 hours, while

meshing and texturing varied from 2 to 11 minutes (Table 1).
The lasergrammetric model, acquired with a Trimble X7 scanner across ten stations, yielded 86.8 million points and 17.4 million faces, demonstrating a much higher density than the photogrammetric dataset. Registration produced a spatial consistency of 97% with an average error of 0.9 mm. While geometric precision was excellent, textural rendering was limited, with artificial colors and noisy edges. The final dataset was also considerably heavier (416 MB after cleaning), requiring greater computational resources [14].

4.2. Comparative performance analysis of survey techniques

Table 2: Comparative performance of photogrammetry and laser scanning techniques

Criterion	Photogrammetry	Laser Scanning
Accuracy	± 50 mm	± 2 mm
Acquisition time	~ 20 min (automated)	~ 1h 30 min (manual)
Visual rendering	Excellent (realistic textures)	Limited (artificial colors)
Point cloud density	5.9 million points	86.8 million points
Processing workflow	Agisoft + ReCap (light)	RealWorks + ReCap (complex)
Interoperability	Good (.rcs, .rvt, .ifc)	Good but heavy
Estimated cost	Low (~4 million FCFA)	High (~20 million FCFA)

This comparison confirms that photogrammetry proved efficient, cost-effective, and visually realistic, while laser scanning provided superior accuracy and dense point clouds, but at the expense of longer processing times and higher hardware requirements (Table 2).

4.3. BIM 3D model

Both point clouds were imported into Autodesk Revit in .rcs format. The photogrammetric dataset was chosen as the main modeling base due to its completeness and visual quality, while the lasergrammetric data served to refine structural details. Parametric modeling reconstructed the key components of the building, including compressed earth block (CEB) walls, domes, roofs, windows, and secondary architectural details.

Geometric consistency was verified through comparison with on site measurements. The final BIM model was exported in IFC4 format, ensuring interoperability with third party software and compliance with open standards. The resulting digital model represents a static digital twin of the building, ready for further applications in energy performance assessment, facility management, and education.

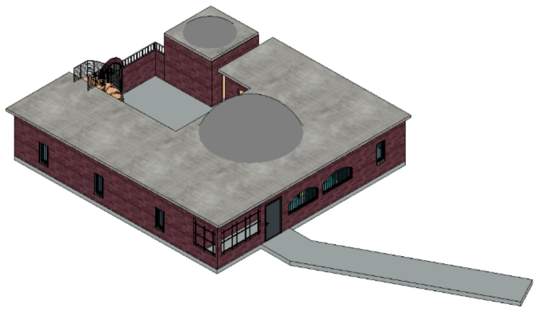

Figure 5 : South-East part from photogrametry in Autodesk Revit

5. Discussion: Complementarity of Photogrammetry and Laser Scanning for Geomatics-BIM

The findings confirm the technical feasibility of a hybrid modeling workflow combining photogrammetry and laser scanning, integrated into an interoperable BIM environment. Beyond accuracy and visual quality, this demonstrates the potential of digital models as decision support tools for maintenance planning and energy performance evaluation. A more detailed cost–benefit analysis—including equipment costs, software resources, acquisition time, and error reduction—would further strengthen the economic case for broader adoption of this methodology [14].

The comparative analysis of the two approaches highlights their complementary strengths and limitations. On the technical side, photogrammetry offers rapid acquisition, cost efficiency, and realistic textured rendering, making it highly effective for documenting the overall building envelope. Conversely, terrestrial laser scanning ensures millimetric precision and high density point clouds, which are critical for detailed structural analysis, diagnostics, and engineering applications. A hybrid approach, therefore, provides the most comprehensive solution, combining global coverage with fine grained accuracy.

Operationally, several constraints were identified. Photogrammetry requires relatively modest hardware and processing capacity, while lasergrammetry involves higher costs, longer acquisition times, and complex processing workflows. These limitations are particularly relevant in resource constrained contexts such as Sub Saharan Africa, where access to specialized equipment and advanced computing infrastructure remains limited.
Strategically, the study demonstrates that high quality digital building models can be generated using accessible tools and workflows, thus contributing to the democratization of BIM and geomatics in developing countries [15]. The resulting BIM model, compliant with IFC standards, provides a solid foundation for integrating future functionalities, such as semantic enrichment, ontologies, and eventually the coupling

with IoT systems to move toward dynamic digital twins.

This experiment confirms the importance of capacity building and knowledge transfer. For sustainable adoption, training local professionals in acquisition, processing, and BIM modeling is crucial. Moreover, the promotion of open standards and open source tools could mitigate the cost barrier while ensuring interoperability. While IFC and E57 formats provided a common ground for data exchange, several inconsistencies were observed when transferring models between photogrammetry, laser scanning, and BIM platforms. These interoperability issues underline the urgent need for simplified, context-adapted workflows and the development of local standards to ensure sustainable adoption in West African construction ecosystems.

In summary, the discussion emphasizes that the hybrid GeoBIM approach not only enhances technical accuracy but also has broader implications for digital transformation, sustainable construction, and the development of smart building practices in Sub-Saharan Africa.

A major transversal challenge revealed by this study concerns data governance. The absence of national standards for data storage, sharing, and long term preservation hinders the scaling up of such initiatives. Establishing national or regional interoperability frameworks could provide a stronger basis for institutional adoption. Furthermore, comparing this methodology with other building typologies, such as hospitals or schools, would reinforce its generalizability and help consolidate the demonstrator's role as a reference case for future GeoBIM integration in Sub Saharan Africa.

Beyond technical feasibility, the hybrid integration of photogrammetry and laser scanning opens perspectives for heritage documentation, sustainable urban planning, and the modernization of academic curricula in construction engineering. However, the long-term impact of such initiatives critically depends on data governance. In Sub-Saharan Africa, where the absence of national or regional frameworks for data storage and interoperability remains a challenge, digital sovereignty becomes a decisive issue. Ensuring that construction-related data are accessible, standardized, and reusable is essential for sustainable adoption. Establishing open interoperability frameworks would not only reduce dependency on proprietary platforms but also align African initiatives with global efforts on digital twins, while reinforcing the resilience of local digital ecosystems.

6.Conclusion and perspectives.

This study proposed and tested a structured methodology for the 3D digitization and BIM modeling of a sustainable building in Senegal, using complementary techniques of drone based photogrammetry and terrestrial laser scanning. Applied to the Ecological and Digital Building (EDB) demonstrator at École Polytechnique de Thiès, the approach contributes to the ongoing digital and energy transition by showcasing the feasibility of hybrid workflows in resource constrained contexts.

The results confirm the complementarity of the two acquisition methods. Photogrammetry proved to be rapid, lightweight, and capable of producing highly realistic textures, making it suitable for modeling exterior envelopes. In contrast, laser scanning provided highly precise geometric data and dense point clouds, essential for structural detail and diagnostics, albeit at higher financial and operational costs. The integration of point clouds into a BIM environment resulted in a static digital twin faithful to the building's geometry and structured according to open standards (IFC) [12], ensuring interoperability and reusability.

The resulting BIM model now constitutes a robust support for building management, operation, and maintenance (BOM). It enables accurate identification and localization of building components, progressive enrichment with technical metadata, and preparation of preventive and corrective maintenance scenarios [13]. Furthermore, it can be used for educational purposes, awareness raising in sustainable construction, and preliminary energy performance assessments.

Beyond static representation, the digital model provides a foundation for progressive development toward dynamic digital twins. Future perspectives include:

- Methodological improvements: enhance acquisition protocols, combine point clouds for optimal hybridization, and automating scan to BIM workflows.
- Technological integration: developing middleware for IoT data collection and deploying interoperable BIM–BMS supervision platforms.
- Facility management (FM) [11]: defining performance indicators tailored to bioclimatic buildings in tropical contexts.
- Socio technical adoption: fostering the appropriation of these tools by asset managers, decision makers, and building occupants in order to democratize BIM in Africa [15].

The implications of this research extend beyond the academic domain. For education, it provides a reproducible protocol to train students and professionals in digital construction practices. For industry, it demonstrates that reliable digital twins can be produced at relatively low cost, thus encouraging democratization of BIM and geomatics tools in African construction markets. For society, it highlights how 3D digitization and BIM integration can enhance the resilience of the built environment, improve lifecycle management, and support sustainable energy transition policies.

The proposed demonstrator also has a transferable dimension, as the methodology developed here could be applied to schools, hospitals, and other public infrastructures, thus supporting the digital modernization of essential facilities. Furthermore, the static BIM model provides a robust foundation for a progressive transition toward dynamic digital twins, integrating IoT sensors, real-time monitoring, and facility management platforms for predictive maintenance and performance optimization. Overall, this study confirms the feasibility and added value of GeoBIM convergence for sustainable construction in Sub-Saharan Africa. It paves the way for the implementation of interoperable smart buildings that combine local eco-materials, digital technologies, and open standards, contributing to an inclusive and resilient digital transition of the construction sector.

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