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Contribution of 3D and 7D BIM to the Diagnostic Assessment of the Former National Council of Shippers of Benin Building (G + 4) in Cotonou

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Abstract

In Benin, the diagnostic assessment of public buildings is hindered by the rapid aging of the building stock and the near-total absence of as-built drawings, limiting the scope of traditional diagnostic methods, based on visual inspection, site surveys and isolated tests, but poorly structured and difficult to use over time. This study aims to integrate BIM into this process, using the former National Council of Shippers of Benin building, a structure of type R + 4 with basement, in Cotonou, as a case study. The approach combines visual inspection with a Scan-to-BIM workflow. A 3D laser scan survey enabled the reconstruction of the building's geometry in Autodesk Revit, representing the 3D dimension of BIM. Semantic enrichment through a custom property set integrated diagnostic data into the model prior to IFC 4 × 3 export and visualization in BIMcollab Zoom, representing the 7D dimension dedicated to operation and maintenance. Structural verification of load-bearing elements followed the BAEL 91 (amended 1999) regulations, with cross-validation through Revit-Robot Structural Analysis interoperability. Nine non-structural defects were identified and located on the digital model. Significant structural deterioration was observed in the beam supporting the skylight at level R + 4, whose actual depth of 33 cm does not meet the 40 cm minimum required by the manual calculation, both methods nonetheless converging on the same steel cross-section of 1.57 cm^2. The associated column was found compliant, with 4HA12 reinforcement. These results propose a reproducible protocol combining traditional diagnosis with the 3D and 7D dimensions of BIM, supporting sustainable digital management of Benin's public building heritage.

Keywords

Diagnostic, 3D, 7D, Scan-to-BIM, R + 4, Autodesk Revit, Cotonou

1. Introduction

The durability of a structure depends on its ability to maintain, over time, the mechanical and functional performance for which it was designed. However, under the influence of mechanical loads, climatic conditions, and usage, this performance tends to degrade gradually. Consequently, a technical assessment is essential to evaluate the structure's actual condition, identify defects such as cracks, water infiltration, or structural deterioration and propose appropriate interventions.

However, a rigorous assessment requires significant technical and financial resources, including measurement equipment, specialized testing, and long-term monitoring. In Benin, traditional methods based on visual inspection, site surveys, and in-situ testing often yield fragmented data that is difficult to utilize over the long term and not easily accessible to all stakeholders involved in managing the structure.

In this regard, Building Information Modeling (BIM) offers added value by enabling building data to be structured, centralized, and stored within a single digital model, thereby facilitating condition monitoring and decision-making regarding maintenance and rehabilitation. Using a standardized format such as IFC (Industry Foundation Classes) an internationally recognized open standard is essential to ensure interoperability and reliable data exchange between software applications and project stakeholders. Despite this potential, the integration of BIM into assessment practices for existing buildings remains limited; experts predominantly rely on traditional methods, creating a risk of data loss and complicating long-term monitoring. This is compounded by the fact that data sharing among engineers, architects, technicians, and project owners is often complex due to the use of diverse software and non-standardized formats. The central question guiding this study is, therefore, how BIM can contribute to improving the quality and efficiency of the traditional assessment process for existing buildings. Combining the assessment with a BIM-based approach will therefore make it possible to identify the defects affecting the building under study with greater precision and to highlight concrete avenues for improving the assessment process. The overall objective of this study is to integrate BIM into the traditional assessment process for existing buildings, using the former CNCB building in Cotonou as a case study. Three specific objectives stem from this:

- Conduct a traditional assessment of the building by identifying defects according to their nature and severity;
- Create a BIM digital model based on 3D laser scanning data, incorporating the identified defects;

- Implement a system for visualizing and accessing information on the defects via the digital model.

2. State of the Art and Context of the Study Area

2.1. Building Pathology

In the building sector, a defect refers to a visible anomaly affecting a component of the structure, whereas pathology refers to the study of these defects, their origin, mechanism, and evolution over the structure's lifespan. Such defects most often result from a combination of design flaws, construction errors, environmental factors, and aging due to a lack of maintenance [1]. Pathologies fall into three categories, structural, functional, and aesthetic, depending on whether they affect the structure's stability, usability, or merely its visual appearance.

2.2. Building Information Modeling (BIM)

Several definitions of BIM coexist in the literature, each highlighting a specific aspect of the approach. BIM entails the use of a shared digital representation of a structure, facilitating design, construction, operation, and decision-making [2]. It is also defined as a modeling technology linked to processes for model production, communication, and analysis [3]. This approach incorporates additional dimensions, ranging from geometric 3D to industrial 10D; 7D is utilized for operation and maintenance, which is the focus of the present assessment. Its precision is characterized by Levels of Development (LOD) [4], and its collaborative maturity by a dedicated maturity model [5], as illustrated in **Figure 1**.

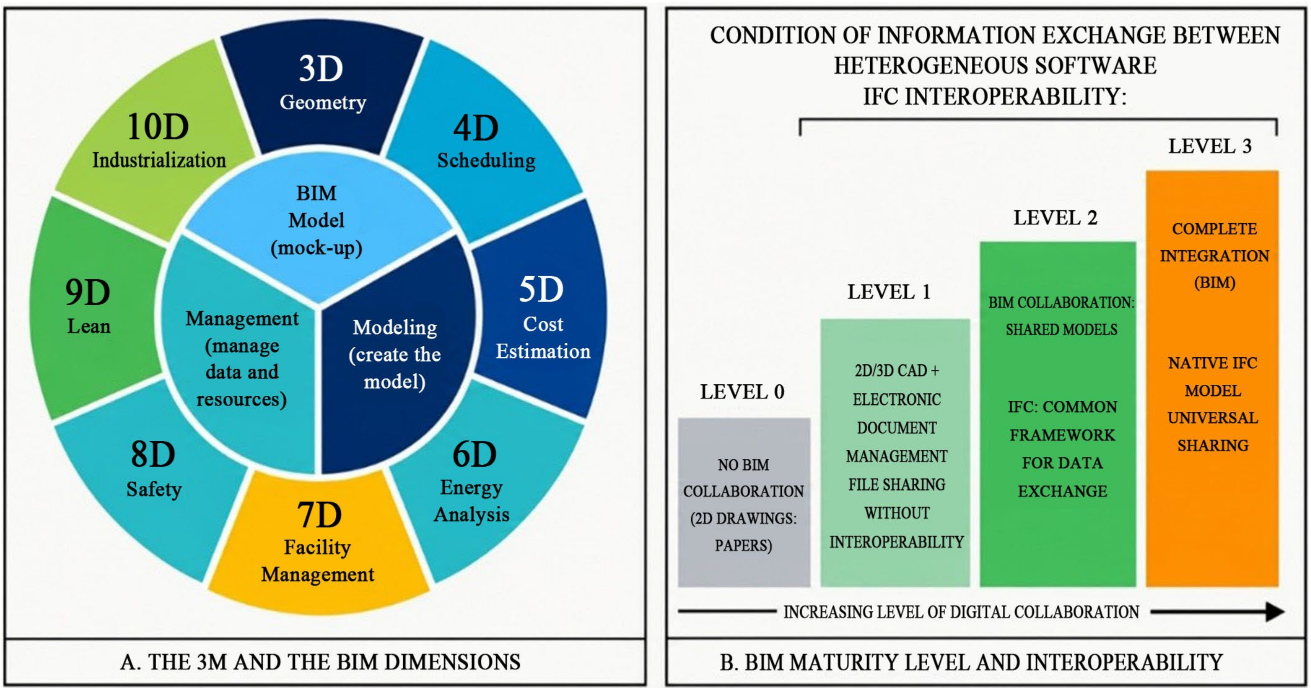


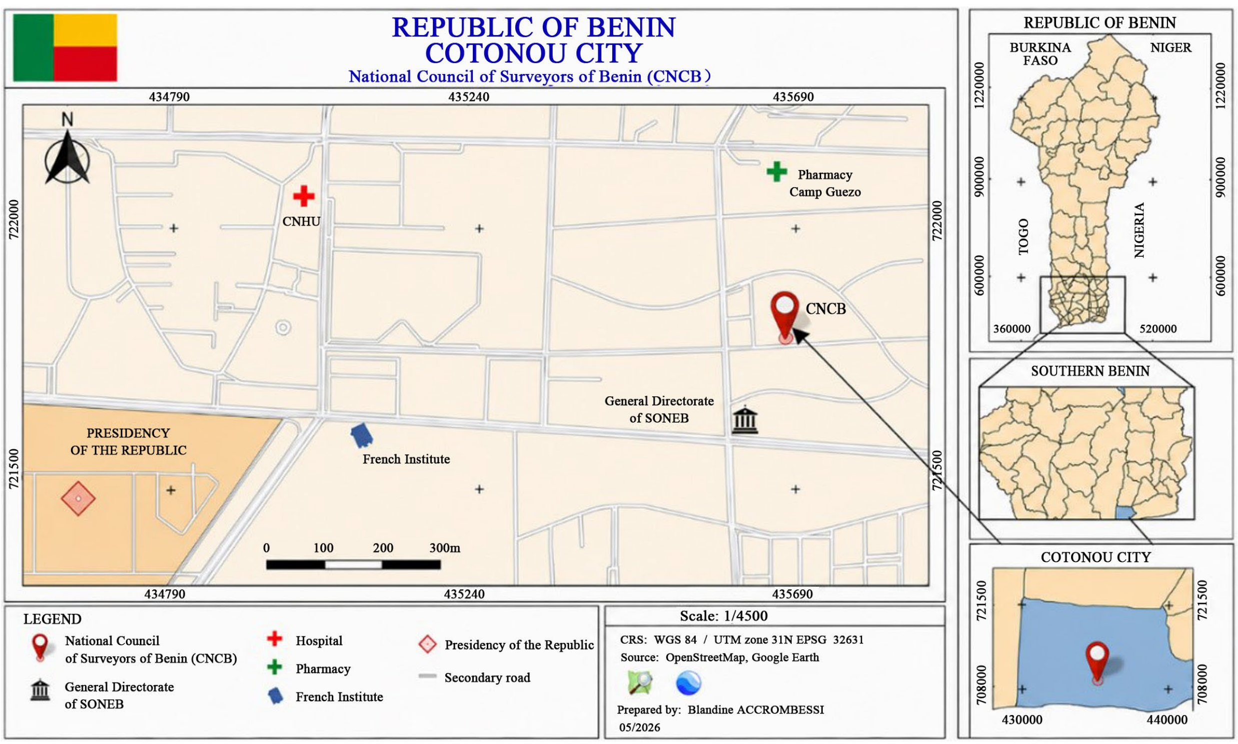
Figure 1. BIM dimensions and maturity levels.

2.3. BIM Interoperability

BIM interoperability refers to the ability to exchange and utilize digital model data between software applications without loss of information. It relies on the open IFC (Industry Foundation Classes) format, developed by buildingSMART International [6] and standardized via a dedicated ISO standard since 2013 [7]; this format supports exchange via STEP (.ifc) text files, XML (ifcXML), or compressed (ifcZIP) versions. The format has undergone several generations since its inception in 1996; IFC 2x3 and IFC 4 remain the most widely used versions, while the latest version, IFC 4x3, now extends the format to linear infrastructure.

2.4. Location of the Study Area

The building subject to the study is located in the Zongo neighborhood (Lot 557, Plot B) within the UNDP residential zone in Cotonou's 12th arrondissement, behind the headquarters of the National Water Company of Benin (SONEB), as shown in Figure 2. It is a reinforced concrete structure featuring a column-beam-slab framework; the building comprises a basement, a ground floor, and four upper stories (R + 4), topped by a concrete roof terrace. It was constructed approximately twenty years ago and has undergone no major renovations since. The basement houses offices, the ground floor contains reception and circulation areas, and the upper levels consist of individual offices created through the progressive partitioning of originally open-plan spaces.



Source: Open Street Map.

Figure 2. Location of the former CNCB study building.

3. Materials and Methods

3.1. Materials

The digital workflow implemented in this study relies on four complementary tools: the FARO Focus S350 3D laser scanner shown in Figure 3, Autodesk Revit 2025 software shown in Figure 4, BIMcollab Zoom software and Autodesk Robot Structural Analysis software shown in Figure 5.

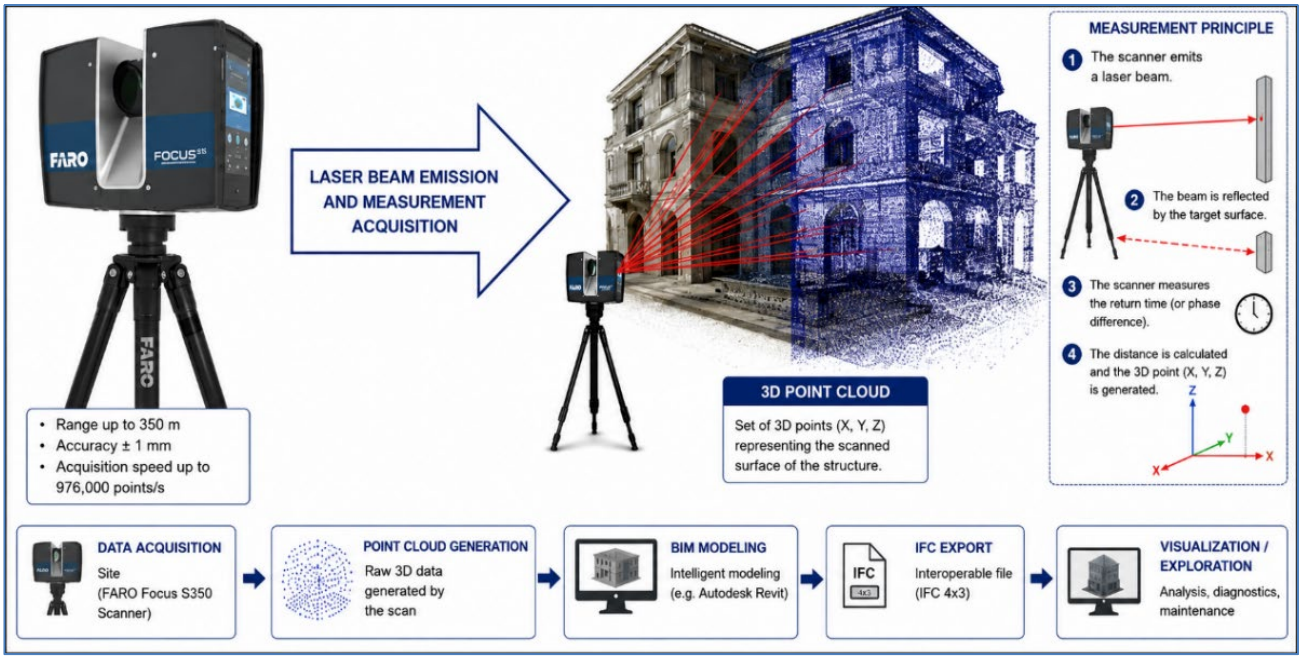


Figure 3. FARO Focus S350 3D laser scanner and its operating principle.

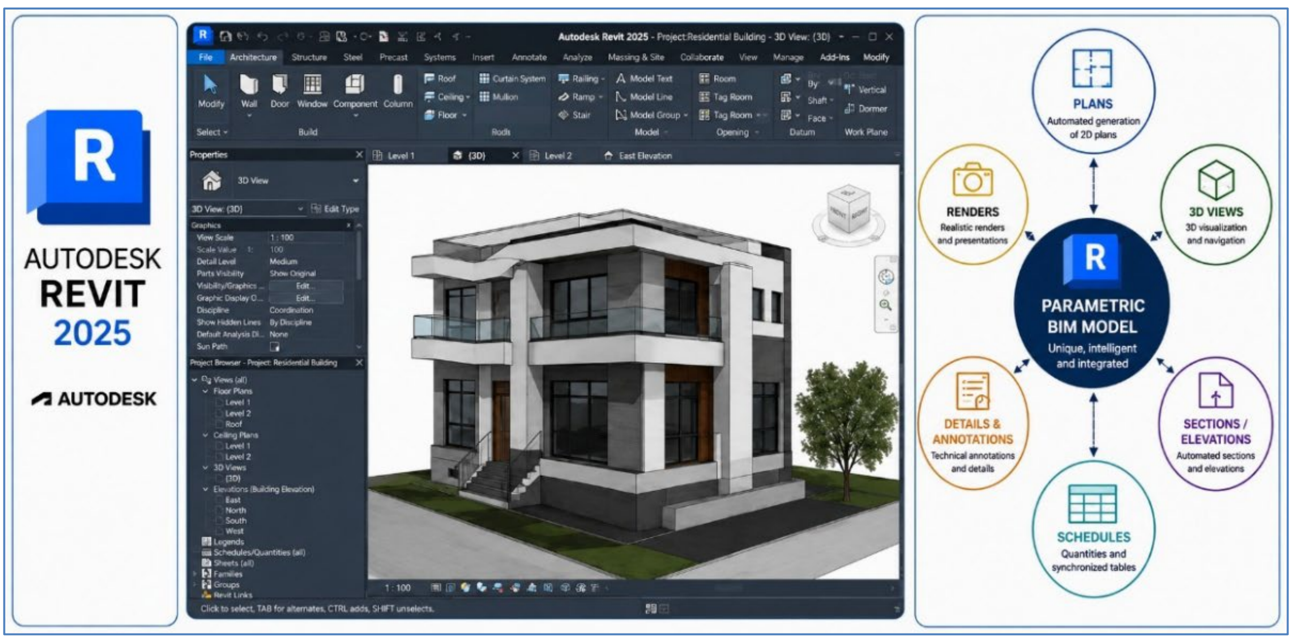


Figure 4. Autodesk Revit 2025 software interface and its operation.

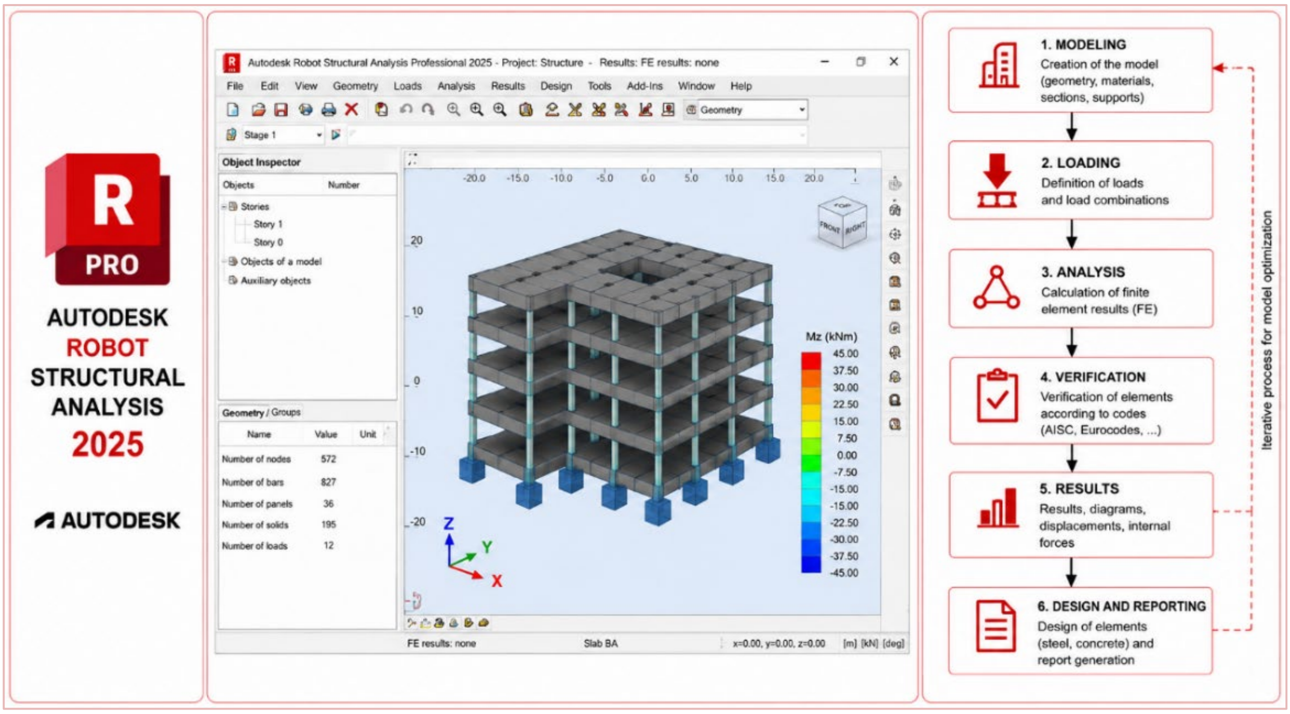


Figure 5. Autodesk Robot Structural Analysis 2025 software interface and its operation.

3.2. Methods

3.2.1. Traditional Assessment

1) Visual inspection

The equipment used for visual inspection is shown in/see Plate 1.

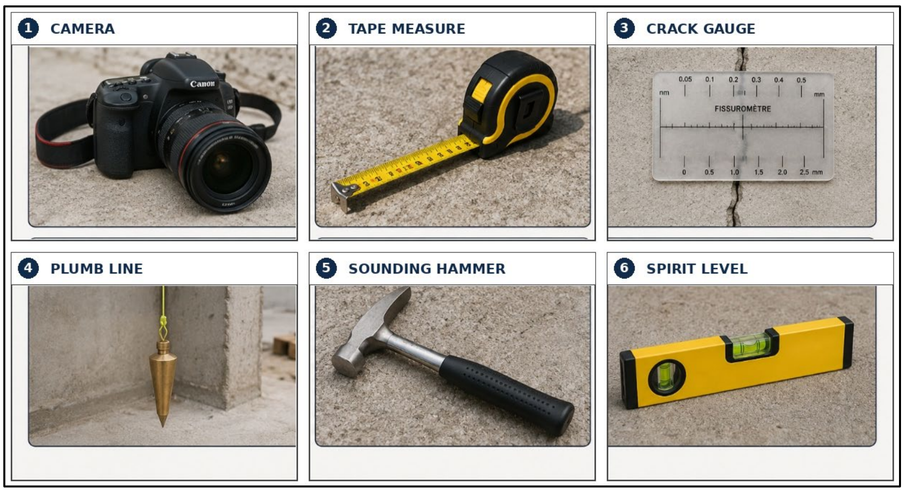


Plate 1. Main visual inspection instruments.

The various phases of the intervention are summarized in **Table 1**. A visual inspection of the building was carried out on site together with the AVESIG Bénin team, complementing and validating the technical expertise report produced by AVESIG in 2022 on behalf of the Ministry of Justice, the building having undergone no rehabilitation since then. This inspection covered all levels of the building, basement, ground floor and four upper floors, organized by work package, masonry and structural works, finishes, secondary works, plumbing, electrical and HVAC networks, in order to confirm on site the defects affecting the building fabric and to produce an updated condition survey. Each identified defect was photographed and located, by level, room and position on the element concerned, before being classified according to its nature, structural, functional or aesthetic, and according to four severity levels of the Table 2, assigned on the basis of a combined appraisal of the nature of the defect, its extent and its potential impact on the safety, functionality or appearance of the structure.

Table 1. Phases and methodology of the building's visual inspection.

Phase	Designation	Tools	Method, scope and results
1	Documentary analysis and preparation	AVESIG expertise report (2022), site visit sheets	Analysis of the expertise report produced in 2022 on behalf of the Ministry of Justice. Definition of the inspection methodology and areas to be examined.
2	On-site visual inspection	Camera, tape measure, crack gauge, plumb line, sounding hammer, spirit level, survey sheets…	Inspection of all levels of the building (basement, ground floor and four upper floors). Verification of the defects reported in the 2022 report and identification of current deterioration.
3	Mapping and recording of defects	Camera, location plans, survey sheets	Location and recording of defects by level, room and element concerned. Survey of cracks, finish deterioration, secondary works defects and network anomalies.
4	Classification and severity assessment	Assessment matrix, office tools	Classification of defects by nature (structural, functional or aesthetic) and assignment of a severity level.
5	Updated condition survey and recommendations	Office and layout software	Preparation of an updated condition survey of the building, validation of the findings of the 2022 report, and formulation of rehabilitation recommendations.

Table 2. Classification matrix for defects based on severity level.

Severity level	Assessment criteria	Color code
Low	Normal aging of the structure, no functional	(green)
Moderate	Stabilized; impact on comfort or aesthetics	(yellow)
High	Progressive; risk of worsening over time	(orange)
Critical	Immediate risk to the safety of occupants	(red)

2) Sizing of a beam-column system

The beam-column system identified as the most critical during the visual inspection was sized in accordance with the BAEL 91 (amended 1999) regulations, based on material assumptions in the absence of in-situ testing, concrete class C25/30 and Fe400 steel put on Table 3. The loads applied to the beam, self-weight,

weight of the skylight glazing and weight of the aluminium profiles, were evaluated on the basis of standard dimension and density assumptions. The beam was modeled as statically determinate on two simple supports, subjected to a uniformly distributed load, while the associated column was considered fixed at its base in the lower floor slab of level R + 4 and pinned at its head at the connection with the beam.

Table 3. Input data for beam sizing.

Parameter	Retained value
Beam span L	3.97 m
Permanent load G	2.85 kN/m
Live load Q	1.60 kN/m
Concrete strength (C25/30)	fc28 = 25 MPa
Steel yield strength (Fe400)	fe = 400 MPa
Effective depth d	d = 0.9h
Support conditions	Statically determinate, simple supports

- Design load combination

$$ELU : qu = 1.35G + 1.5Q \quad (1)$$

$$ELS : qser = G + Q \quad (2)$$

- Maximum bending moment

$$M\max = \frac{qul2}{8} \quad (3)$$

- Required reinforcement area

$$Au = \frac{Mu}{Zb \times f_{ed}} \quad (4)$$

- Non-brittleness condition

$$Au \geq A\min \quad (5)$$

$$A\min = 0.23 \times b \times d \times \left(\frac{ft28}{fe}\right) \quad (6)$$

For the column subjected to simple compression, the ultimate axial load (Nu) was determined using the same load combination; the buckling length (lf) was used to calculate the slenderness ratio which was compared against the regulatory limit of 50 before verifying the reinforcement area against the minimum required by the regulations.

- Loading at the Ultimate Limit State (ULS)

$$Nu = 1.35Gp + 1.5Qp \quad (7)$$

- Slenderness condition

$$\lambda \leq 50 \text{ with } \lambda = \frac{lf}{i} \quad (8)$$

- Theoretical reinforcement area

$$Ath = \left[\frac{Nu}{\alpha} - \frac{Brfc28}{0.9\gamma b}\right]\frac{\gamma}{fe} \tag{9}$$

- Minimum reinforcement area

$$A\min = \max\left(4u; \frac{0.2B}{100}\right) \tag{10}$$

3.2.2. Implementation of the BIM Process

1) Scan-to-BIM Process and Quality Control

I) Scan-to-BIM Process

a) 3D Laser Scanning

The building survey was carried out by the AVESIG Bénin technical team using a FARO Focus S350 3D laser scanner, in accordance with its standard acquisition protocol. The parameters were adapted to site conditions, with an indoor profile for distances under 10 m and an outdoor profile for distances under 20 m. An appropriate resolution was selected to ensure the required level of detail, while color acquisition enabled point cloud colorization. Several scan stations were set up to ensure sufficient overlap between acquisitions. Data registration relied on the overlapping areas between scans, without the use of artificial targets. After cleaning extraneous elements and assembling the scans in FARO Scene, a single, coherent point cloud was obtained to serve as the basis for the digital reconstruction of the building.

b) Modeling in Autodesk Revit

The assembled point cloud was imported into Autodesk Revit 2025 and aligned with the project's coordinate system. Parametric modeling was then carried out progressively, drawing directly on the survey data. The building's main elements, including walls, columns, beams, slabs, stairs, joinery and suspended ceilings, were reconstructed to form a digital model representative of the existing condition shown in Figure 6. Throughout the process, the model's geometric consistency was checked against the source point cloud, with occasional adjustments made to improve the accuracy of the model.

II) Quality Control

Given the scope of the survey, quality control focused primarily on the geometry of the existing building, as summarized in Table 4. Technical networks were not included in the scanning campaign and are therefore not covered by the compliance checks described below.

Table 4. Quality control.

Phase	Quality control performed	Verification method
Survey acquisition	Building coverage	Multiplication of scan stations to limit shadow areas and ensure overlap between acquisitions
Survey acquisition	Quality of acquired data	Resolution settings and color acquisition

Continued

Scan assembly	Registration consistency	Verification of station alignment in FARO Scene
Point cloud processing	Data cleaning	Removal of extraneous elements before export
BIM modeling	Geometric correspondence	Continuous comparison between Revit objects and the point cloud
Final validation	Model compliance	Overall verification of the model's geometric consistency

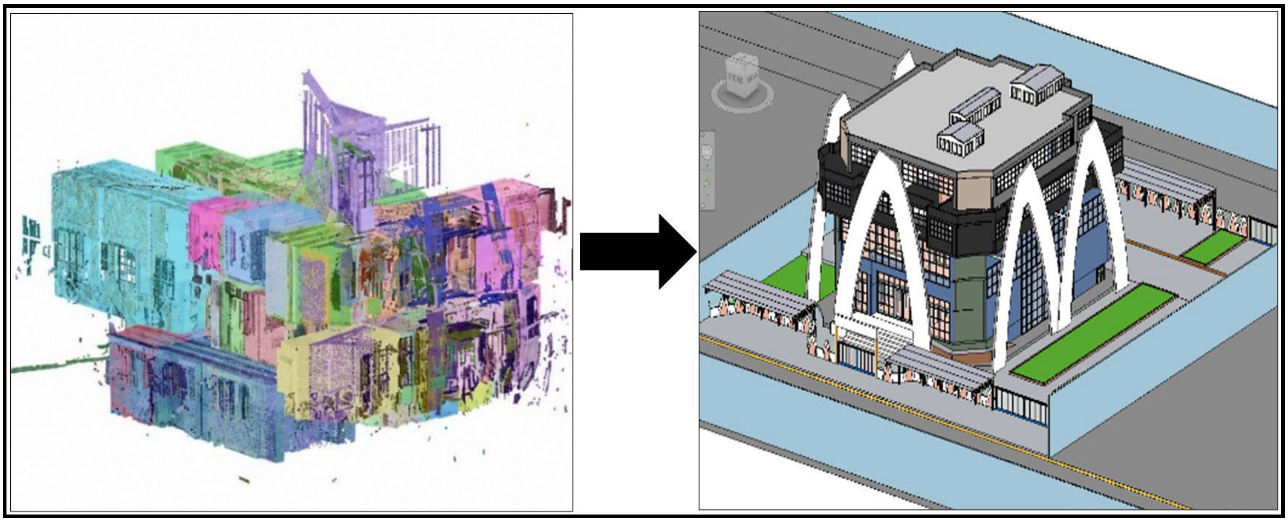


Figure 6. Raw point cloud (from basement to second floor) on the left and reconstructed digital model on the right.

III) Integration of defects

Each defect identified during the traditional diagnosis was linked to the corresponding element in the model via a custom property set, Pset_DiagnosticCNCB. This set populates three attributes: the nature of the defect, the severity level (based on the adopted classification matrix), and the reference of the associated diagnostic report.

IV) Creation of Smart Views

The enriched model was exported in IFC 4x3 format and then checked in BIMcollab Zoom, where "Smart Views" were created to enable automatic color-coded visualization of defects based on their severity level.

V) Sizing in Robot Structural Analysis

The beam-column system underwent a second verification in Autodesk Robot Structural Analysis Professional. This was achieved by directly transferring the analytical model from Revit, leveraging the native interoperability between the two software applications. Loads and load combinations were defined in accordance with the BAEL 91 (amended 1999) regulations covering both ultimate limit states and serviceability limit states prior to calculating reinforcement and verifying the design within Robot.

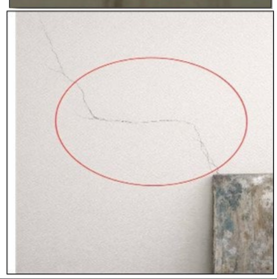
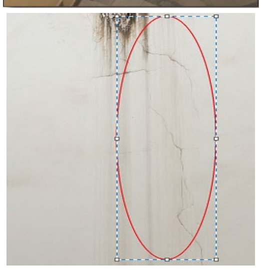
4. Results and Discussion

4.1. Results

4.1.1. Identified Defects

Nine non-structural defects were identified on the building as Table 5 shows, primarily affecting the structural shell and secondary elements without compromising the structure's overall stability. These fall into two main categories: moisture-related issues (such as water ingress, mold, and façade cracks) and deterioration of finishes and secondary elements due to a lack of maintenance. Additionally, localized structural degradation was observed on the beam supporting the glass roof at the fourth-floor level (R + 4), characterized by spalling of the concrete cover and exposed reinforcement.

Table 5. Illustration of some defects identified on the building.

Pathologies	Images	Pathologies	Images
Tile detachment—Interior walls of restrooms—Moderate severity		Water infiltration and mold—Interior walls, 3rd and 4th floors—Critical severity	
Paint flaking—Secondary works, widespread across several façades of the building—Moderate severity		Crazing, fine surface cracks with a width of ≤ 0.2 mm—Exterior façade walls and window frames—High severity	
Cracks, wide fissures with a width of ≥ 2 mm—Exterior façade walls—High severity		Reinforcement corrosion Spalling of the concrete cover Beam supporting the skylight, level R + 4—Critical severity	

4.1.2. Digital Model and Diagnostic Model

Applying the Scan-to-BIM process resulted in a comprehensive 3D digital model covering all six levels of the building from the basement to the fourth floor that faithfully reproduces the structure's actual geometry. Enriching the model with semantic data via the Pset_Diagnostic CNCB property set made it possible to associate three attributes with each affected component: the type of defect, the severity level, and the diagnostic report reference. Configuring "Smart Views" in BIMcollab Zoom based on the severity parameter generated a color-coded visualization of the defects across four criticality levels shown in Figure 7, providing an immediate spatial overview of the structure's condition.

Figure 7. 3D rendering of the digital model (left) and the diagnostic model (right).

4.1.3. Results of Manual Sizing and Sizing Using Robot Structural Analysis

Manual sizing of the beam yields a required minimum depth of 40 cm for a width of 20 cm, against an actual depth measured on site of 33 cm for a width of 25 cm, the beam thus being deemed non-compliant according to the manual calculation of Table 6. The required steel cross-section is 1.57 cm^2; this value, like that given for the column, corresponds to the theoretically required reinforcement according to the calculation, and not to a survey of the reinforcement actually in place. The associated column, with a 20 × 20 cm section, is confirmed compliant with a minimum reinforcement area of 3.2 cm^2 satisfied by 4HA12 mentioned in Table 7. Under Robot Structural Analysis, the section from the manual calculation, 20 × 40 cm, is first confirmed compliant, as is the actual section measured on site, 25 × 33 cm, validated despite the degradation observed. An optimization then yields a minimum section of 20 × 30 cm for 1.57 cm^2 of steel. For the column, Robot confirms compliance with 4.52 cm^2 of steel and the same 4HA12 reinforcement.

Table 6. Comparison of beam sizing results.

Parameter	Manual calculation	Actual section	Robot Structural Analysis
Concrete section	20 × 40 cm^2	25 × 33 cm^2	20 × 30 cm^2
Steel area (Au)	1.57 cm^2	Not quantified	1.57 cm^2
Selected reinforcement	2HA10	—	2HA10 (+2HA10 assembly bars)
Compliance	Non-compliant (h = 33 cm)	Compliant	—

The manual calculation, more conservative, judges the actual section non-compliant as it does not reach the required 40 cm, whereas Robot Structural Analysis, applied to this same 25 × 33 cm section, confirms it compliant, qualifying the severity of the manual diagnosis without invalidating it. The optimization to 20 × 30 cm further confirms a substantial margin between the regulatory minimum and the section actually in place.

Table 7. Comparison of column sizing results.

Parameter	Manual calculation	Robot Structural Analysis
Concrete section	20 × 20 cm^2	20 × 20 cm^2
Steel area (Au)	3.2 cm^2 (code minimum)	4.52 cm^2
Selected reinforcement	4HA12	4HA12
Compliance	Compliant	Compliant

Both methods converge regarding the column's compliance, with the same 4HA12 reinforcement selected in both cases. Only the calculated steel cross-section differs slightly governed by the regulatory minimum in the manual calculation versus a slightly higher value in Robot reflecting a load-bearing capacity reserve without calling into question the compliance confirmed by both approaches.

4.1.4. Structural Model and Internal Force Diagrams in Robot Structural Analysis

The building's analytical model of Figure 8, obtained via transfer from the Revit model, represents the geometry of all load-bearing elements columns, beams, and floor slabs across the structure's six levels. Only the beam supporting the glass canopy at level R + 4 and its associated column underwent a full structural analysis; the resulting internal force diagrams showing bending moments and shear forces of Figure 9 were extracted for the ultimate limit state.

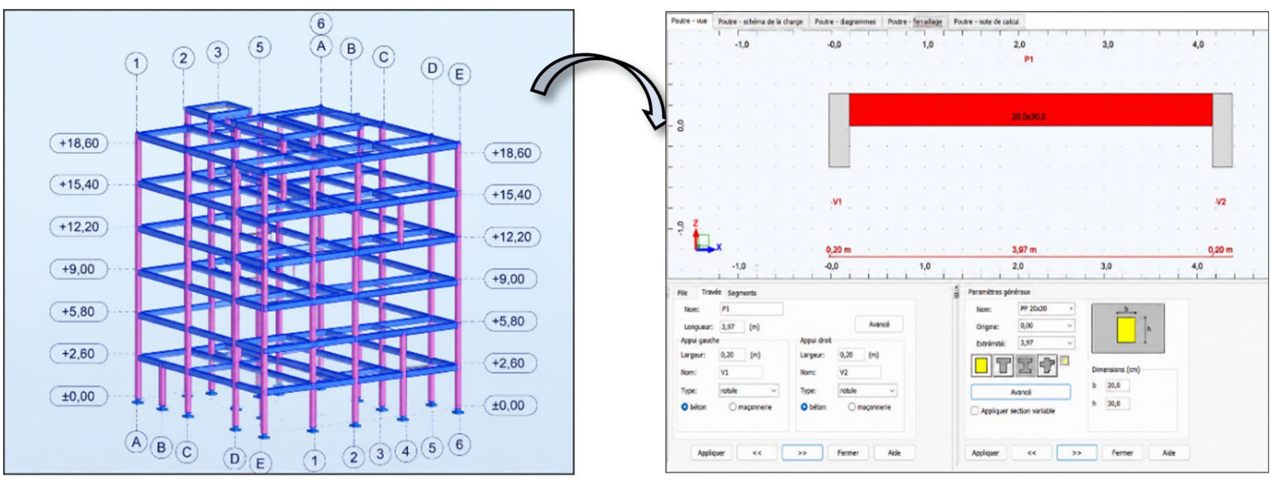


Figure 8. Analytical model of the building and the beam under study in Autodesk Robot Structural Analysis.

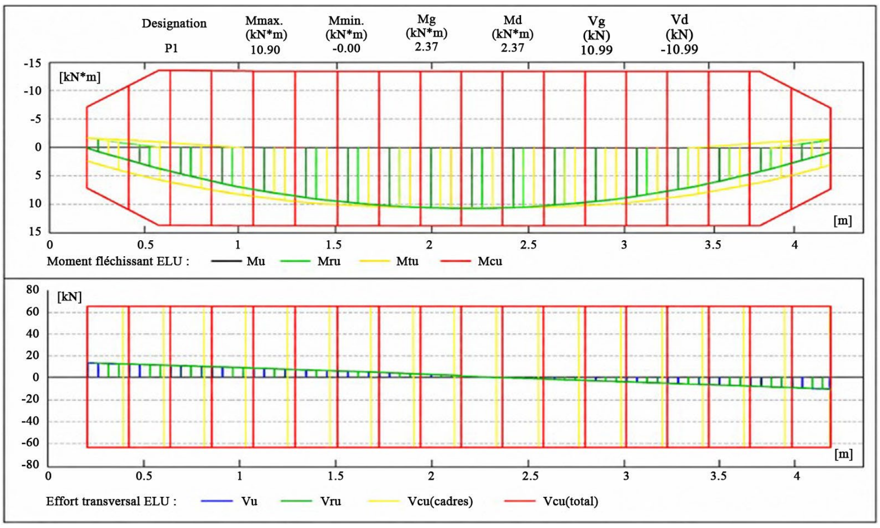


Figure 9. Moment and force diagrams at the Ultimate Limit State (ULS) for the beam under study.

The bending moment diagram confirms a maximum moment at mid-span, consistent with the expected behavior of a statically determinate beam subjected to a uniformly distributed load, while the shear force diagram shows a symmetrical linear distribution with maximum values at the supports.

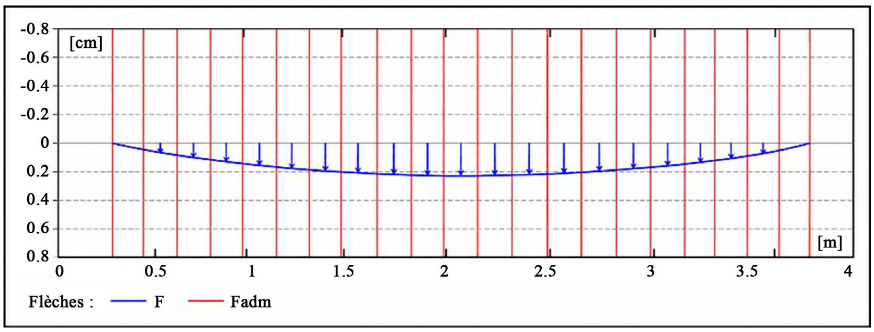


Figure 10. Total deflection and permissible deflection.

Furthermore, the deflection check confirms that the calculated total deflection remains within the permissible limit across the entire span as it is shown on **Figure 10**.

This compliance with serviceability limit states suggests that the deterioration observed on site stems more from reinforcement corrosion caused by chronic water ingress than from excessive deformation of the element.

4.2. Discussion

Analysis of the results reveals that Building Information Modeling serves as a methodological complement to traditional assessment rather than a substitute for it. Geometric reconstruction via Scan-to-BIM overcame the lack of original plans a major constraint identified in BIM applications for existing structures [8]. Semantic enrichment using the CNCB Pset_Diagnostic transforms the model into an active management tool, aligning with the vision of BIM as a shared information repository [3], while color-coded visualization of defects facilitates the prioritization of interventions, echoing findings on BIM's contribution to decision-making [9]. Furthermore, exporting data in IFC 4x3 format ensures collaborative utility in accordance with principles established by buildingSMART International [6], and native interoperability between Revit and Robot Structural Analysis eliminates the risk of manual data re-entry by ensuring consistency between the architectural and structural analysis models.

However, this approach has limitations. The precision reports transmitted for point cloud processing remain partial, not allowing exact documentation of the geometric registration tolerance between scan stations, only a qualitative verification of the model consistency having been carried out. The absence of more advanced non-destructive testing, in particular pachometry for detecting the existing reinforcement, leaves the assessment of load-bearing elements incomplete, visual inspection needing to be supplemented by further investigations whenever structural defects are suspected [10]. Similarly, the structural characterization relies on loads evaluated using standard dimension and density assumptions, rather than on measured or documented loads, as well as on material properties derived from standard regulatory classes rather than confirmed by in-situ testing. Moreover, the reproducibility of this approach is constrained by the lack of a national BIM regulatory framework and the cost of equipment, two significant barriers in the Beninese context. Overcoming these obstacles would be a natural next step for this work, involving the performance of the recommended tests and the gradual extension of the approach to other existing public buildings, contingent upon the establishment of national BIM regulations and enhanced training for sector stakeholders.

5. Conclusions

This study integrated BIM into the traditional diagnostic process for the former CNCB building, a reinforced concrete structure of type R + 4 with basement, lacking original construction drawings. Ten defects were identified, classified and mapped onto the digital model, including a critical structural defect in the beam supporting the skylight at level R + 4, deemed non-compliant according to the manual calculation since its actual depth of 33 cm falls short of the required minimum of 40 cm, although Robot Structural Analysis confirms this same section as compliant. Both methods nonetheless converge on a required steel cross-section of 1.57 cm^2, while the associated column, with 4HA12 reinforcement, meets regulatory requirements.

These results demonstrate that BIM significantly enhances traditional assessment by equipping the model with capabilities for analyzing, centralizing, and sharing data on building defects capabilities that conventional methods alone cannot achieve. The developed approach is thus intended to serve as a replicable protocol for the digital management of public building assets in Benin, subject to the aforementioned additional testing and regulatory framework.

Authors Contributions

Conceptualization, Kassa Issifou Mounou Sambieni, Blandine G.F. Accrombessi and de Paule Codo; Methodology, Kassa Issifou Mounou Sambieni; software, Kassa Issifou Mounou Sambieni; validation, Kassa Issifou Mounou Sambieni, Blandine G.F. Accrombessi and de Paule Codo; formal analysis, Kassa Issifou Mounou Sambieni; investigation, Kassa Issifou Mounou Sambieni; Re-sources, Kassa Issifou Mounou Sambieni; data curation, Kassa Issifou Mounou Sambieni and Blandine G.F. Accrombessi; writing original draft prepara-tion, Kassa Issifou Mounou Sambieni; writing review and editing, Kassa Issifou Mounou Sambieni; visualization, Kassa Issifou Mounou Sambieni; supervision, Kassa Issifou Mounou Sambieni and de Paule CODO; project administration, Kassa Issifou Mounou Sambieni; Funding acquisition, Kassa Issifou Mounou Sambieni.

All authors have read and agreed to the published version of the manuscript.

Declaration

The use of AI into our BIM-based study was primarily driven by the need to manage and process the massive, complex datasets associated with the existing infrastructure. BIM models generate gigabytes of administrative, environmental, geometric, and technical data; AI enables the correlation of thousands of variables through algorithms that structure this information instantly. Furthermore, AI has facilitated the automated creation of design variants, object recognition, the enrichment of project models, and the optimization of outcomes. Its use has also enabled error anticipation and predictive analysis by linking BIM with the Internet of Things across the building studied and its environment. In conclusion, we can say that the incorporating AI into our BIM study helped to optimize the collaborative management process, which relies on a 3D digital model consolidating all the building's technical data.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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