

BUILDING INFORMATION MODELING (BIM) FOR SUSTAINABLE BUILDING DESIGN IN NEPAL: A SYSTEMATIC REVIEW OF BIM-ENABLED ASSESSMENT APPROACHES

Sujata Dhakal^{1*}

^{1*}*Alumna, Department of Architecture, Cosmos College of Management and Technology, Lalitpur, Nepal*

**Correspondence to: sujatadhakal32@gmail.com (S. Dhakal)*

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ABSTRACT

Nepal's construction sector is rapidly transforming due to postearthquake reconstruction, urbanization, and environmental pressures, highlighting need for sustainable building design practices. Building Information Modeling (BIM) has emerged as an effective digital approach for improving sustainable building design by integrating design, construction, and lifecycle information within a collaborative environment. Despite Building Information Modeling (BIM)'s potential for lifecycle-integrated, energy-efficient, and sustainable design, its application for sustainability assessment within Nepal's Architecture, Engineering, and Construction (AEC) sector remains limited. This study presents structured review of Global and South Asian literature to evaluate how BIM can support sustainable building design in Nepal. It focuses on three sustainability assessment approaches: Green Building Rating Systems, Life Cycle Assessment (LCA), and BIM-based energy simulation workflows, mapping their applicability to Nepal's technical, institutional, and policy context. The review is grounded in frameworks integrating BIM Maturity Model (Bew-Richards), Triple Bottom Line (TBL), and BIM-LCA workflows. Findings indicate that although awareness of BIM is increasing within Nepal's AEC industry, its application for sustainability assessment remains limited. Key barriers include the absence of national BIM policy, limited BIM-LCA interoperability, lack of Nepal-specific green building rating system, and limited academic integration. The study identifies gaps and recommends localized BIM-integrated sustainability assessment framework aligned with Nepal's National Building Code and climate commitments.

Key Words: Building Information Modeling (BIM), Sustainable Building Design, Sustainability Assessment Framework, Nepal AEC Industry

1. Introduction

The global construction sector accounts for approximately 30-37% of total energy consumption and is responsible for nearly 37% of global CO₂ emissions, making it one of the most environmentally

significant industries worldwide (Buildings- Energy Efficiency Analysis, IEA, 2025). As nations accelerate efforts to meet the Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action), the building sector has become a critical focus of both technological innovation and policy reform. Building Information Modeling (BIM), a digital, object-based representation of a building's physical and functional characteristics across its full life cycle, has emerged as one of the most transformative tools for enabling evidence-based, sustainability-driven design decisions (Sacks et al., 2018). When integrated with sustainability assessment methods and tools, BIM can support optimization of energy use, operational carbon, water consumption, and material impacts during early design, where the potential for improvement is greatest, operationalized internationally through rating systems such as LEED, BREEAM, and Green Star combined with BIM-enabled energy and environmental analysis tools.

In low and middle income countries such as Nepal, rapid urbanization, seismic vulnerability, resource constraints and limited regulatory enforcement make the delivery of safe, energy efficient, and climate responsive buildings particularly challenging. The 2015 Nepal earthquakes (7.8-magnitude, followed by a severe 7.3-magnitude aftershock) destroyed or damaged over 600,000 structures, exposing critical deficiencies in building design, documentation, and lifecycle management (National Reconstruction Authority [NRA], 2016). The subsequent NRA-led reconstruction initiated over one million housing unit rebuilds under an owner-driven model, yet the deployment of digital tools such as BIM for sustainability assessment remained largely absent from reconstruction workflows. Concurrently, Kathmandu Valley and other rapidly urbanizing centers are experiencing a shift from “green to grey”, unplanned, energy-intensive concrete construction driven by economic growth and land fragmentation without adequate environmental planning. Electricity consumption has grown at approximately 10% per year, placing immense pressure on already-strained energy infrastructure (Sharma et al., 2023).

Although Nepal has introduced regulatory frameworks including the National Building Code (NBC 205 and NBC 206), the Building Energy Efficiency in Nepal (BEEN) project (2022–2026) supported by the EU under the SWITCH-Asia Programme, the National Urban Development Strategy (NUDS, 2017), and the Green Building Guidelines (2016), promoting energy-efficient design, and sustainable urbanization with green infrastructure and eco-friendly building materials, their enforcement remains uneven and the absence of digital compliance systems continues to limit effective implementation. BIM adoption in Nepal's AEC industry remains nascent. (Paneru et al., 2023) demonstrated through logistic regression analysis that, while stakeholders show strong intent to adopt BIM, structural barriers including the absence of national BIM standards, lack of skilled professionals, and insufficient training programs significantly impede implementation. Similarly, (Shrestha et al., 2024) found that 55% of AEC professionals in Nepal reported familiarity with BIM, yet sustainability-specific applications such as energy simulation or LCA-linked workflows are rarely documented in practice.

This research addresses a critical gap in the current body of knowledge: the absence of a comprehensive, Nepal-focused synthesis of how BIM-enabled sustainability assessment approaches can be systematically integrated into building design within the country's specific technical, institutional, and climatic context. Accordingly, this study aims to

- Review global and South Asian literature on BIM and sustainability assessment methodologies.

- Identify and compare conceptual frameworks applicable to the Nepali context.
- Analyze the current state of BIM adoption and green building practices in Nepal.
- Examine relevant South Asian case evidence.
- Propose targeted recommendations for bridging identified gaps.

The central research question is: how are BIM-enabled sustainability assessment approaches used globally, and what lessons and gaps can inform their application for sustainable building design in Nepal? Through systematic literature review and contextual analysis, the paper highlights that key gaps exist in understanding BIM's role in early-stage sustainability decision-making in Nepal, the suitability of existing sustainability frameworks for local AEC practices, and the institutional, technical, and educational barriers that hinder BIM-sustainability integration in emerging economies.

2. Literature Review

2.1 BIM and Sustainability

Building Information Modelling (BIM) is a digital methodology that integrates 3D with comprehensive project information to support the management of building data throughout the entire lifecycle, including design, construction, operation, and maintenance. It also facilitates collaboration and information exchange among architects, engineers, contractors, and other project stakeholders. When aligned with sustainability goals, BIM reduces environmental impacts and improves building efficiency through multiple functions: (i) energy efficiency and optimization via simulations of energy use, sunlight exposure, and building orientation, (ii) material optimization through accurate quantity estimation and selection of low-carbon materials (iii) waste reduction through early clash detection and prefabrication, (iv) lifecycle analysis using sensor and IoT data for energy, water, and occupancy tracking, (v) water conservation through efficient plumbing design and rainwater harvesting systems, and (vi) circular economy support through digital material records enabling reuse, recycling, and sustainable deconstruction.

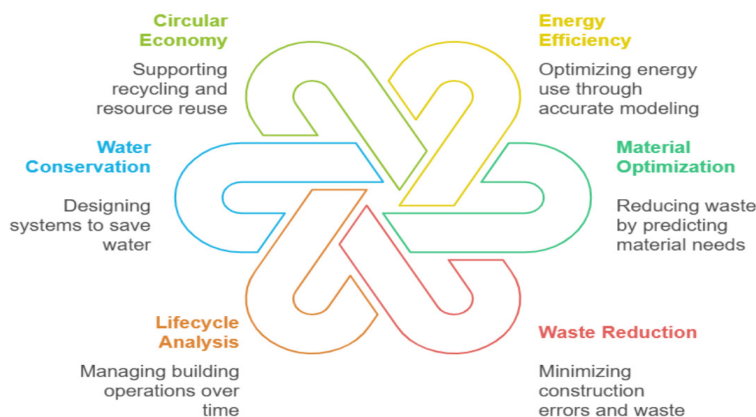


Figure 1. BIM and its relevance to Sustainability (BIM Associates, 2026)

BIM platforms provide material databases containing embodied carbon, recyclability, and durability information, with environmental assessment tools such as OneClick LCA supporting compliance with certification systems like LEED and BREEAM, enabling informed and low-carbon design decisions.

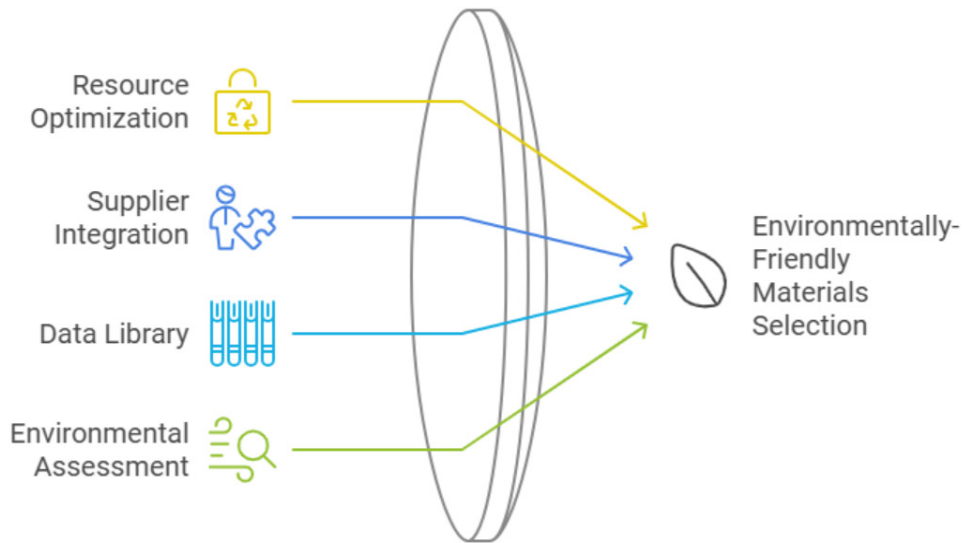


Figure 2. Environment friendly materials selection through BIM (BIM Associates, 2026)

Additionally, collaborative platforms like Autodesk BIM 360 and Trimble Connect enhance transparency and coordination through real-time collaboration in a centralized data environment. BIM-supported prefabrication enables precise off-site manufacturing of components such as walls, beams, columns, and façade systems, improving efficiency and reducing waste through accurate 3D modelling and optimized production. BIM also supports robotics and automation in tasks like bricklaying, painting, and installation, improving accuracy, reducing rework, and enhancing worker safety by minimizing exposure to hazardous and repetitive tasks.

2.2 BIM and Sustainable Building Design: Global Perspectives

Research on the integration of BIM with Green Building Rating Systems (GBRS) has significantly expanded since 2018. (Cascone, 2023) demonstrated that LEED certification workflows can be partially automated through BIM-API integration, particularly for energy compliance documentation, materials credits, and daylight analysis. Similarly, (Idrissi Gartoumi et al., 2025) confirm that LEED and BREEAM remain the dominant GBRS frameworks in BIM-linked sustainability discourse, with strong emphasis on early-stage design decision support. A study by (Salem & Elwakil, 2025), conducting simulations on office buildings in contrasting climates- Egypt (hot climate) and Indiana, USA (cold climate), found integrating BIM with sustainability metrics using Autodesk Revit and Insight 360 significantly improves energy reductions of 46% in hot and 50% in cold climate, with key influencing factors including HVAC systems, building envelope design, and operational schedules, alongside climate-specific strategies such as solar optimization and infiltration control.

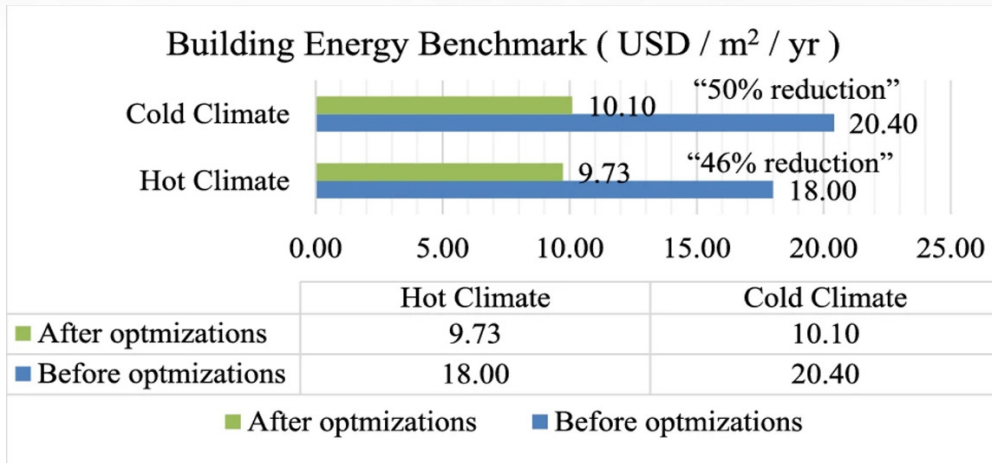


Figure 3. BIM-based energy optimization in contrasting climate (Salem & Elwakil, 2025)

Current BIM-based sustainability practice typically relies on the integration of BIM authoring tools (e.g., Autodesk Revit, ArchiCAD), energy simulation platforms (e.g., EnergyPlus, DOE-2), and environmental assessment tools (e.g., Tally, SimaPro, OpenLCA); however, software interoperability remains a major barrier to BIM-LCA integration, requiring improved data exchange between BIM authoring tools and LCA platforms (Ruchit Parekh & Dario Trabucco, 2024).

In parallel, Life Cycle Assessment (LCA) integration with BIM has gained prominence for evaluating embodied carbon and operational impacts.

A study by (Asare et al., 2020) demonstrates the feasibility of BIM-LCA workflows in developing country contexts using tools such as Revit, Green Building Studio, and Tally, providing a relevant precedent for resource-constrained settings like Nepal. Supporting these findings, a 2025 industry analysis by (Planning, Building & Construction Today, 2025) reports that BIM-LCA integration in a high-rise project achieved up to a 45% reduction in carbon emissions through material optimization and improved energy modeling, although manual data transfer between BIM and LCA platforms remains a key implementation barrier.

Researchers have developed interoperable simulation environments linking BIM tools such as Revit with platforms like IES VE and Modelica to enable coupled energy–exergy analysis. These BIM-integrated simulation workflows enable comprehensive thermal performance analysis, including heating/cooling loads, airflow, exergy loss, and indoor comfort, while improving design efficiency through accurate energy modeling that optimizes HVAC sizing and reduces equipment costs by up to 7.2% (Numan et al., 2024).

Similarly, a study on the integrated Green Building Assessment Tool (GBAT+) demonstrates the effectiveness of coupling architectural, mechanical, and electrical system models for holistic sustainability evaluation. The framework enables simultaneous assessment of multiple performance indicators, showing measurable improvements in key environmental parameters, including an 11% reduction in operational energy use intensity (420 to 375 MJ/m²·yr), an 8% reduction in embodied carbon emissions (3543 to 3272 kgCO₂e/m²), a 29% decrease in stormwater runoff (227 to 162 m³), and a 28% increase in daylight factor (3.2% to 4.1%). These results highlight the importance of integrated modeling approaches in capturing interdependencies across building systems and

improving overall sustainability performance (Sangi & Müller, 2016).

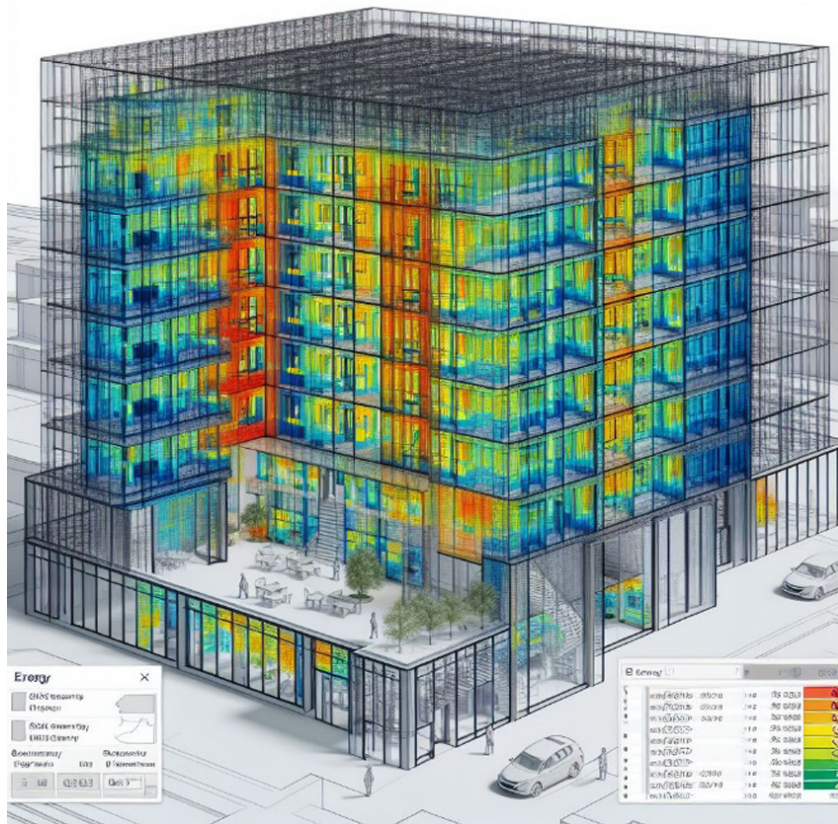


Figure 4. Energy analysis visualization in Autodesk Revit BIM (Numan et al., 2024)

Table 1. Performance Improvements through Integrated Sustainability Assessment (GBAT+) (Sangi & Müller, 2016)

Parameter	Baseline	Improved Case	% change
Energy Use Intensity	420 MJ/ m ² -yr	375 MJ/ m ² -yr	-11%
Embodied Emissions	3543 kgCO ₂ e/m ²	3272 kgCO ₂ e/m ²	-8%
Stormwater runoff	227 m ³	162 m ³	-29%
Daylight factor	3.2%	4.1%	+28%

2.3 Sustainability Assessment Frameworks: GBRS, LCA, and BIM-LCA

Three primary sustainability assessment methodologies are relevant to the BIM-Nepal nexus. First, Green Building Rating Systems (GBRS) provide standardized, holistic frameworks for evaluating building performance across energy, water, materials, site ecology, and indoor environmental quality. The most prominent international systems are BREEAM (UK, 1990), LEED (US, 2000), and CASBEE (Japan, 2001). A comparative case study when applied to an identical residential building by (Hussain and Sheikh, 2023) demonstrated buildings achieved different ratings under each system: LEED (42.72%, GOLD), BREEAM (40.03%, GOOD), and CASBEE (33%, GOOD),

illustrating that rating system selection significantly affects sustainability outcomes and that local context matters for appropriate benchmarking.

Research by (Nasir et al., 2026a) on a BIM-based integrated framework for Building Sustainability Assessment (BSA) in India, Nepal's closest geographic and climatic analog, articulated that both GBRS and LCA are the most widely adopted BSA methodologies globally. The Indian GRIHA (Green Rating for Integrated Habitat Assessment) system, developed by TERI, MNRE and the Government of India, is more relevant to Nepal given shared climatic conditions across South Asian climate zones. GRIHA has been formally promoted by the Nepal Green Building Council (NGBC) as an applicable certification framework for Nepalese buildings, alongside LEED (Nepal Green Building Council, 2022). However, systematic adoption of GRIHA or LEED through BIM workflows in Nepal has not been documented in peer-reviewed literature.

Second, Life Cycle Assessment (LCA) provides a science-based cradle-to-grave quantification of environmental impacts. LCA standards (ISO 14040 and 14044) define four phases: goal and scope definition, inventory analysis, impact assessment, and interpretation. In the building context, LCA covers the product stage (A1–A3: material extraction and manufacturing), construction process stage (A4–A5), use stage (B1–B7: operational energy, maintenance, replacement), and end-of-life stage (C1–C4). The operational carbon of buildings globally reached an all-time high of 10 gigatonnes (GtCO₂) in 2022, underscoring the urgency of LCA-informed design decisions (Xie et al., 2023).



Figure 5. Modules in Life Cycle Assessment (Circular Ecology, n.d.)

Third, BIM-LCA integration workflows represent the synthesis of both approaches. The current state of practice involves combined use of tools for 3D modeling, energy simulation, and material-based LCA, connected through the IFC (Industry Foundation Classes) open data format. Research on BIM-based LCA for seismic and energy retrofit (Caruso et al., 2021) demonstrated a cradle-to-grave framework covering product, construction, operational, and end-of-life carbon stages, with Autodesk Revit as the authoring platform, providing a scalable model applicable to Nepal's building typologies.

2.4 BIM Adoption in South Asia and Nepal

BIM adoption in South Asia lags significantly behind developed economies but is accelerating. In India, BIM is increasingly applied in major public infrastructure projects, supported by the Bureau of Indian Standards (BIS) and GRIHA-linked sustainability programs. In the South Asian context,

recent research from India demonstrates the growing integration of BIM with sustainability assessment frameworks. By linking BIM models with Life Cycle Assessment (LCA), Life Cycle Cost Analysis (LCCA), and national green building rating systems such as GRIHA and IGBC, the study developed a comprehensive decision-support framework for evaluating sustainable building performance throughout the building lifecycle. The framework also establishes a systematic mapping of GRIHA-2019 and IGBC appraisal/credit points across life cycle phases and sustainability criteria (procedural, environmental, economic, social, and innovation) and was validated with an office building in northwestern India, including uncertainty analysis of BSA parameters (Nasir et al., 2026b). The BIM-based integrated sustainability assessment framework for India demonstrating localized approach combining GBRS and LCA within BIM workflows being both technically feasible and institutionally viable in the South Asian context, provides a direct roadmap applicable to Nepal. In Nepal specifically, a 2023 study (Paneru et al., 2023) provided the first systematic empirical analysis of BIM maturity in Nepal's AEC industry, finding that standards and guidelines remain the primary unifying barrier. The Nepal BIM Forum (NBIMF), established as a professional body, has been active in awareness campaigns and signed MOUs with engineering colleges to integrate BIM into academic curricula. A 2017 study found that only 23.52% of surveyed construction firms reported any level of BIM application, with Autodesk Revit dominating at 81.25% usage among adopters, followed by Graphisoft ArchiCAD at 18.75% (Phuyal, 2017). More recently, 62% of BIM users apply it from the initial design stage, while 38% use BIM mainly for model creation from existing CAD drawings (Shrestha et al., 2024).

■ Creating BIM from initial phase of design ■ Modeling from CAD documents

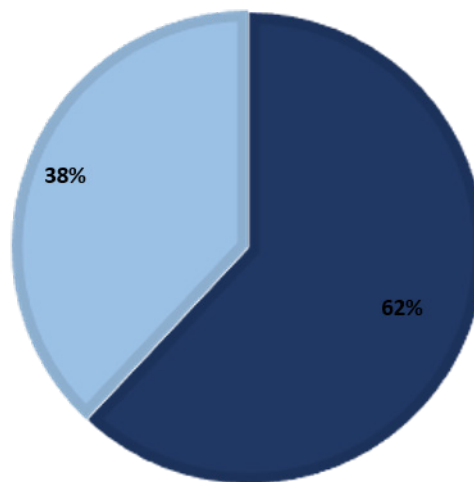


Figure 6. BIM adoption levels in Nepal (Shrestha et al., 2024)

The findings further indicate that Nepal's AEC sector still largely depends on conventional 2D drafting and fragmented BIM use, mainly limited to basic design visualization. While partial adoption exists in some firms, BIM is rarely utilized for coordination, simulation, or lifecycle-based sustainability analysis. This reflects a clear gap between global BIM practices and Nepal's emerging but immature BIM implementation, underscoring the need for stronger capacity building, institutional support, and policy-level integration.

Similarly, Nepal's heritage buildings, especially in Kathmandu Valley Durbar Squares and temples, are increasingly threatened by neglect, urbanization, and loss of traditional construction knowledge. Literature shows that Heritage BIM (H-BIM) enables detailed digital documentation of historic structures by capturing geometry, materials, textures, and spatial relationships, supporting conservation, restoration, structural analysis, and visualization (Stober et al., 2018).

Critically, the literature indicates a complete absence of documented evidence on the use of BIM for sustainability-specific applications in Nepal, including energy performance simulation, green building rating system (GBRS) integration, or life cycle assessment (LCA), highlighting a significant gap between global BIM capabilities and current Nepalese practice, representing a key research and implementation gap in the field.

2.5 Green Building Practice and Policy in Nepal

Nepal's national building regulatory environment is governed by the Nepal National Building Code (NBC), administered by DUDBC under the Ministry of Urban Development. The updated NBC 2024, including NBC 105-2025, NBC 205-2024 and NBC 206-2024, incorporates few provisions for energy-efficient design, eco-friendly materials, seismic resistance, and sustainable infrastructure (DUDBC, 2024). However, the code does not yet include explicit BIM compliance pathways or mandatory sustainability performance thresholds tied to GBRS.

Renewable energy subsidy policies and programs such as the EU-supported Building Energy Efficiency in Nepal (BEEN) project (2022–2026) under the SWITCH-Asia initiative project, key regulatory policies including the National Urban Development Strategy (NUDS, 2017), which promotes sustainable urbanization, Green Building Guidelines (2016), which provide principles for energy efficiency, water conservation, and environmentally responsible design, the Building Construction Guidelines (2009) to improve energy-efficient building practices. Nepal is also a signatory to the Paris Agreement and has submitted Nationally Determined Contributions (NDCs) that include mitigation targets for the energy and buildings sectors.

Institutions such as the Nepal Green Building Council have played a key role in promoting certification systems like LEED and GRIHA, encouraging adoption in selecting commercial and institutional projects. However, despite these developments, the overall adoption rate of green buildings remains low, primarily due to limited technical expertise, financial barriers, and insufficient integration of supportive policies into mainstream construction practice.

3. Conceptual Frameworks

This review employs three complementary conceptual frameworks to structure the analysis of BIM for sustainable building design in Nepal, collectively, providing a theoretical basis for assessing current state of BIM adoption, defining the characteristics of mature BIM–sustainability integration, and guiding the practical transition pathway toward implementation in the Nepalese AEC context.

3.1 The Bew-Richards BIM Maturity Model

The (Bew-Richards BIM Maturity Model, 2008), is the global standard framework for assessing the level of digital integration, information management, and collaborative working practices within construction and infrastructure projects. Widely adopted in international BIM policy (including the UK BIM Framework and PAS 1192 series), defines four maturity levels of BIM adoption:

(i) Level 0 (unmanaged CAD, paper-based),

- (ii) Level 1 (managed 2D/3D CAD with some metadata),
- (iii) Level 2 (managed 3D BIM with discipline-specific federated models and collaborative data environments), and
- (iv) Level 3 (fully integrated, interoperable, cloud-based open BIM across the building lifecycle).

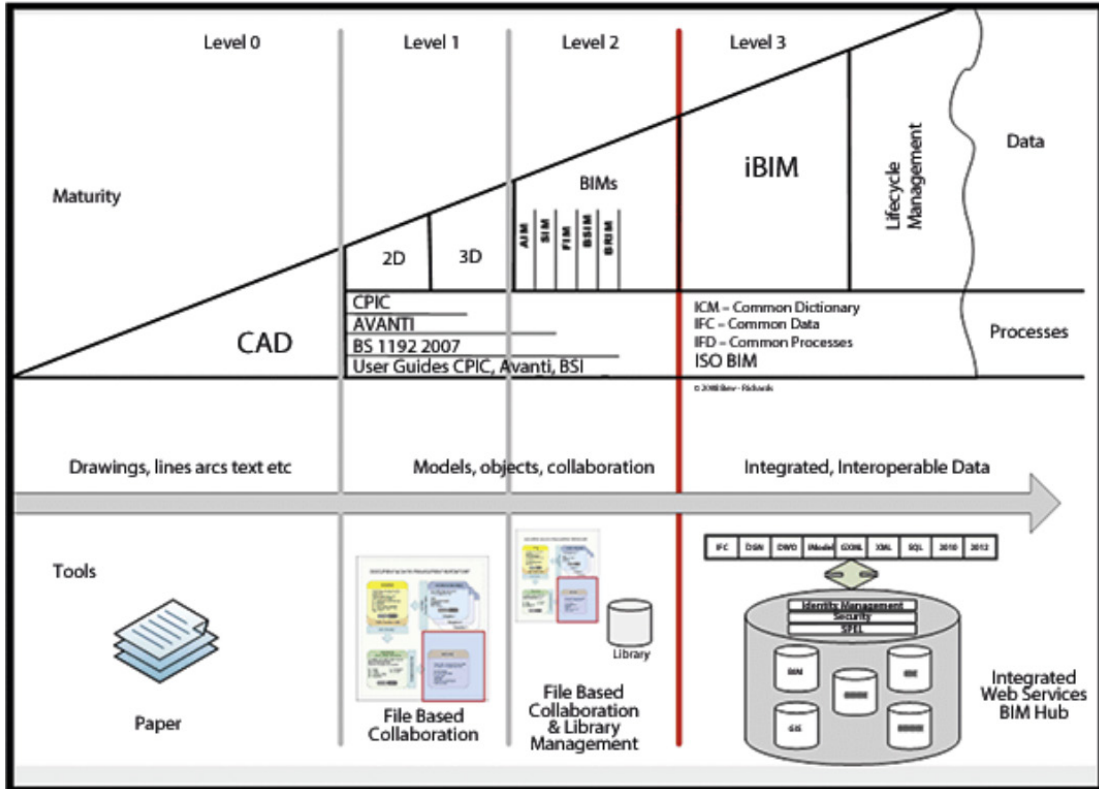


Figure 7. BIM Maturity Model (Bew & Richards, 2008)

3.2 The Triple Bottom Line (TBL) Sustainability Framework

The Triple Bottom Line (TBL), introduced by John Elkington in 1994 broadens traditional measures of success to include three interrelated dimensions: environmental (ecological footprint, energy, carbon, water), social (occupant health, community impact, disaster resilience), and economic (lifecycle costs, affordability, return on investment).

In the context of Nepal, all three dimensions carry acute significance: the environmental dimension is framed by climate change vulnerability and energy scarcity, the social dimension is shaped by seismic risk and post-disaster reconstruction imperatives and the economic dimension is constrained by a developing economy with limited capital for premium sustainable technologies. BIM tools, when deployed appropriately, provide quantitative data streams that can inform decision-making across all three TBL dimensions simultaneously, through energy simulation (environmental), occupant comfort analysis (social), and lifecycle cost estimation (economic).



Figure 8. Elements of Triple Bottom Line concept (Elkington, 1994)

3.3 BIM-LCA Integration Workflow Framework

Table 2. BIM-Sustainability Assessment Frameworks- Comparative Overview

Framework	Origin/Source	Core Concept	Nepal Applicability
Bew- Richards BIM Maturity	Bew & Richards (2008), UK	Progressive BIM levels 0–3, defines readiness for collaborative, data-rich design	Nepal at Level 0-1, Level 2 required for sustainability integration
Triple Bottom Line (TBL)	Elkington (1994)	Environmental, social, and economic sustainability dimensions assessed simultaneously	Aligns with Nepal’s seismic, energy, and development priorities
BIM-LCA Integration Workflow	Multiple Sources (2020-2025)	Five-stage process: BIM model → energy sim → material LCA → GBRS mapping → optimization	Technically feasible at Level 2 BIM, requires IFC interoperability and LCA data localization

The BIM-LCA integration workflow framework, synthesized from multiple peer-reviewed sources (Asare et al., 2020, Numan et al., 2024), complemented by selected recent industry reports defines a five-stage process for sustainability assessment: (Stage 1) BIM Model Creation: using equivalent IFC-compliant authoring tool to produce a parametric 3D building model with full material

and geometry metadata, (Stage 2) Energy Simulation: using relevant energy analysis tools (e.g. EnergyPlus, Autodesk Insight 360, or Green Building Studio) for operational energy analysis and carbon quantification, (Stage 3) Material LCA: using plugins such as Tally or external tools (e.g. SimaPro, OpenLCA) to quantify embodied carbon across A1–A5 lifecycle stages, (Stage 4) GBRs Compliance Mapping: comparing simulation outputs against LEED, BREEAM, GRIHA, or a local equivalent rating system to identify compliance gaps, and (Stage 5) Iterative Optimization: using the integrated data to refine design decisions and re-simulate until sustainability targets are achieved. This framework serves as the normative model against which Nepal’s current practice is evaluated in Section 5 of this paper.

4. Methodology

4.1 Research Design

This study adopts a systematic literature review (SLR) methodology in line with established protocols in engineering and built environment research (Tranfield et al., 2003) (Moher et al., 2009): PRISMA guidelines. The SLR is supplemented by a comparative framework analysis to critically evaluate sustainability assessment approaches in relation to Nepal’s specific institutional, climatic, and technical conditions, enabling a context-sensitive interpretation of BIM-enabled sustainability practices.

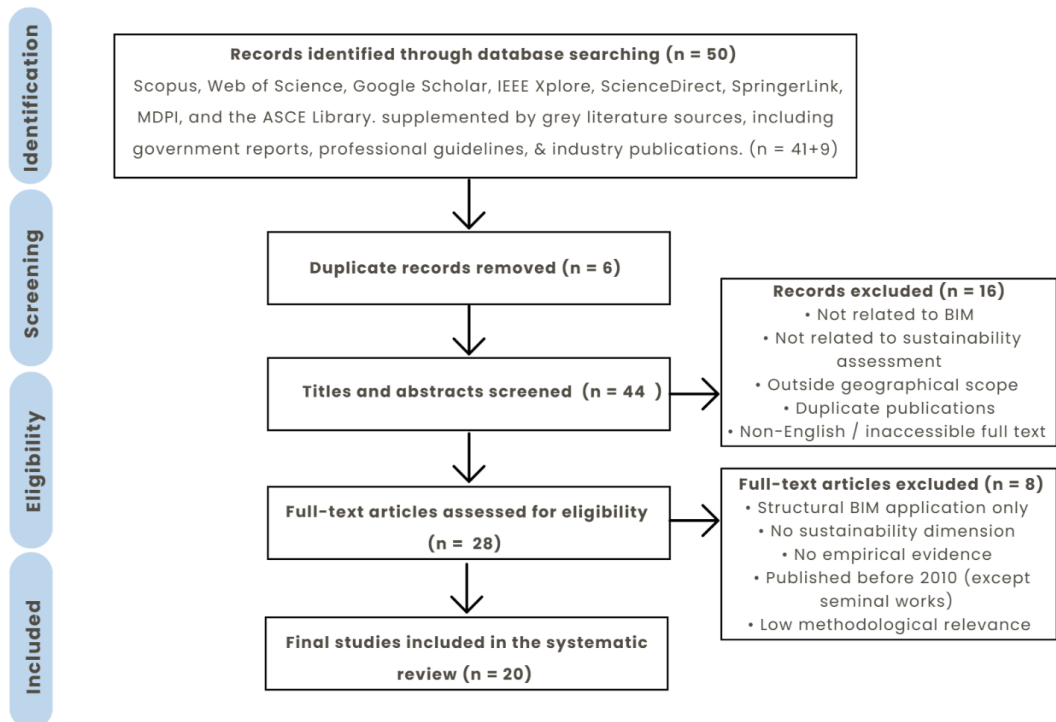


Figure 9. PRISMA 2020 flow diagram illustrating the literature search and study selection process for the systematic literature review.

4.2 Literature Search Protocol

A structured literature search was conducted across major academic databases, including Scopus, Web of Science, Google Scholar, IEEE Xplore, MDPI, Springer Nature, ScienceDirect, and ASCE library, supplemented by grey literature from government reports, professional guidelines and industry publications (e.g. DUDBC, IEA, UNEP, Nepal BIM Forum, Academia, ResearchGate, blogs, etc).

Search queries used Boolean combinations of key terms: (“BIM” or “Building Information Modelling”), (“sustainability” or “green building” or “sustainable design”), (“Nepal” or “South Asia” or “developing countries”), along with focused strings on BIM with LEED/BREEAM/GRIHA, BIM–LCA integration, and BIM adoption in Nepal. Publication date filters were set to 2015–2026, with exceptions for foundational texts (e.g., Elkington, 1994; Bew & Richards, 2008).

4.3 Inclusion and Exclusion Criteria

Inclusion criteria were: (a) peer-reviewed journal articles, conference papers, funded research reports or credible institutional reports, (b) studies directly addressing BIM, sustainability assessment, or green building in either a global, South Asian, or Nepal context, (c) studies providing empirical data, case studies, or systematic reviews, (d) grey literature including publications from recognized governmental agencies, international organizations, and professional institutions (e.g. DUDBC, IEA, UNEP, Nepal BIM Forum, Academia, ResearchGate, blogs, etc) were included where peer-reviewed evidence was unavailable, particularly for recent policy developments and emerging industry practices. Exclusion criteria were: (a) non-peer-reviewed web content without institutional or professional credibility, such as personal blogs and unsupported online articles. However, a limited number of grey literature sources, including government reports, professional guidelines, and industry publications, were included where peer-reviewed evidence was unavailable, particularly for recent policy developments and practical BIM implementation. (b) studies focused exclusively on structural BIM applications without sustainability dimensions, (d) studies published before 2010, unless foundational theoretical works.

4.4 Comparative Framework Analysis

Following the SLR, a structured comparison was developed across four analytical dimensions: (i) Global BIM-Sustainability Practice: benchmarking international best practices in BIM-integrated sustainability assessment, (ii) South Asia Context: reviewing India-specific and regional applications of GBRS and BIM-LCA, (iii) Nepal Current State: mapping BIM maturity, green building practice, and policy environment based on empirical Nepal-specific studies, and (iv) Gap Analysis: identifying explicit gaps between global best practice and Nepal’s current state across technical, institutional, and educational dimensions. The comparison is structured using the Bew-Richards maturity levels and the TBL sustainability dimensions as organizing lenses.

5. Analysis and Discussion

5.1 Global BIM-Sustainability Integration: State of Practice

Table 3 provides a comparative summary of the current state of BIM-enabled sustainability assessment in leading countries and Nepal. The discussion begins by examining global best practices, which serve as the benchmark for evaluating Nepal’s current level of implementation across the technical, institutional, educational, and regulatory dimensions.

Globally, BIM-integrated sustainability assessment has matured significantly over the past decade.

As summarized in Table 3, leading countries have BIM Maturity Levels 2-3, where the dominant workflow involves Autodesk Revit, integrated with energy simulation tools (EnergyPlus, Autodesk Insight 360) and LCA software (Tally, SimaPro) through IFC data exchange protocols. Optimization research has demonstrated, integrated BIM platforms such as Revit-Insight 360 demonstrate significant sustainability and efficiency gains, including up to 21% reduction in energy use intensity (EUI) and 8.5% lower lifecycle costs through multi-objective optimization of building orientation, envelope, and HVAC systems. Advanced thermal analysis enables more accurate zoning and solar gain modelling, leading to up to 7.2% reduction in heating equipment sizing compared to conventional methods. BIM automation also reduces 50-80% of manual effort in green certification documentation (e.g., LEED, BEAM Plus), while construction applications show 50-80% reduction in material waste and 13-23% reduction in operational energy consumption. Overall, BIM adoption improves certification compliance, reduces project timelines, and delivers long-term cost savings. However, interoperability between authoring tools and LCA databases remains the primary technical limitation, with manual data entry still required in most documented workflows (Asare et al., 2020).

For GBRS-BIM integration, research confirms that LEED remains the most widely studied system for BIM-enabled compliance documentation, with approaches ranging from API-based automation to cloud-BIM integration (Hussain and Sheikh, 2023). BREEAM integration has been demonstrated through parametric BIM models analyzing geometric and spatial indicators (Idrissi Gartoumi et al., 2025). The Frontiers review also confirmed that as of the end of 2024, LEED and BREEAM are the predominant frameworks in BIM-sustainability research globally. Importantly, CASBEE and regional systems (GRIHA, GreenRE) are gaining research attention for their context-sensitive alignment with local construction practices and material availability.

5.2 Nepal BIM and Sustainability Landscape: Critical Analysis

Against the global benchmark, Nepal's current BIM-sustainability landscape presents a stark gap. Based on the reviewed literature, the following critical assessment is offered across three analytical dimensions:

5.2.1 Technical Dimension

Nepal's AEC industry is primarily operating at BIM Maturity Level 0 to Level 1. The dominant design workflow remains 2D drafting software's (most commonly AutoCAD in Nepal) with limited transition to 3D modeling. BIM applications documented in Nepal (Shah & Shrestha, 2023, Mishra, et al, 2026) are confined to architectural visualization and project scheduling (4D BIM) in commercial projects, with no documented instances of BIM-integrated energy simulation, material LCA, or GBRS compliance documentation in peer-reviewed literature. This represents a direct contrast to developing country peers such as Ghana (Springer Nature, 2020) and India where BIM-LCA integration frameworks have been practically tested. The technical gap is compounded by software cost barriers, limited local BIM data libraries (BIM object families), and lack of building energy simulation program's climate data calibrated for Nepal's diverse climatic zones.

5.2.2 Institutional and Policy Dimension

Nepal lacks a national BIM mandate or standard, in contrast to the UK (BIM Level 2 mandate since 2016), Singapore (BCA's BIM adoption roadmap), and India (BIM roadmap under the National Infrastructure Pipeline, standardized BIM protocols under BIS). The DUDBC-administered NBC

2024 does not include explicit BIM implementation requirements or sustainability performance metrics linked to Green Building Rating Systems (GRBS). Nepal's Paris Agreement NDCs do not yet include building sector digital transformation targets, representing a missed policy alignment opportunity. This institutional gap is the single most impactful barrier identified in the literature: absent government mandates, BIM adoption, particularly for sustainability purposes, is market-driven and inconsistent.

5.2.3 Educational and Human Capital Dimension

A 2023 study on BIM implementation in Nepal by (Lama & Karki, 2023) found that BIM awareness and application within the AEC sector remain limited despite growing interest in digital construction practices. Survey results indicate that BIM usage is largely concentrated in the design phase, with minimal integration across construction, operation, and maintenance stages. Complementary studies further reveal that only a portion of AEC professionals are familiar with BIM concepts, while a significant proportion 41%, either lack awareness or possess only basic-level understanding of the technology (Shrestha et al., 2024). In terms of education and institutional support, BIM-related training in Nepal is currently offered by a limited number of private institutions and professional bodies such as the Nepal BIM Forum (NBIMF), and integration into formal engineering curricula, while progressing, most notably through the incorporation of BIM courses into Tribhuvan University's master's curriculum and planned integration within Pokhara University, yet to reach the breadth and consistency required for sector-wide capability development, requires more such efforts. Evidences show despite moderate awareness levels, BIM adoption is largely restricted to basic modelling activities rather than lifecycle-based applications, indicating a clear gap between knowledge and practical implementation in the Nepalese AEC industry (Shah & Shrestha, 2023). Critically, sustainability-focused BIM education, covering energy simulation, LCA methodology, and GBRS compliance has not been identified in any documented Nepalese academic program, creating a significant skills gap for the next generation of practitioners.

5.2.4 Comparison Table: Global vs. Nepal Context

Table 3. BIM-Sustainability Assessment (Global Practice vs. Nepal Context)

Dimension	Global Best Practice	Nepal Current State
BIM Maturity	Level 2–3 in leading nations, federated models, open BIM (IFC)	Level 0–1, primarily 2D CAD, limited 3D/4D BIM in select commercial and governmental projects
National BIM Policy	Mandatory in UK, Singapore, roadmaps in India, Australia	No national BIM mandate, no published BIM standard
GBRS Adoption	LEED, BREEAM, CASBEE widely used, BIM-linked compliance workflows documented	LEED and GRIHA promoted by NGBC, no Nepal-specific rating system, limited certified buildings

Dimension	Global Best Practice	Nepal Current State
LCA Integration	BIM-LCA workflows with Tally, SimaPro, 45% carbon reduction demonstrated	No documented BIM-LCA projects; local LCA material databases absent
Energy Simulation	EnergyPlus, Insight 360 routinely used, 46–50% energy reduction achieved	Energy simulation tools available but rarely deployed; climate data calibration needed
BIM Education	Integrated into engineering/architecture curricula in USA, UK, Australia, Singapore	Emerging through NBIMF and selected institutions (e.g., TU, PU, etc.), yet sustainability-BIM education absent
Building Codes (Sustainability)	Energy performance codes with digital compliance (e.g., ASHRAE 90.1, Part L UK)	NBC 2024 includes eco-friendly material provisions but no digital compliance pathway

Table 3 summarizes the key findings of this review and highlights the gap between global best practices and Nepal's current BIM implementation. The comparison identifies major deficiencies in BIM policy, BIM–LCA integration, sustainability-focused education, and digital regulatory support, which should be prioritized to advance sustainable building design in Nepal.

6. Lessons For Nepal: From South Asian Case Studies

6.1 BIM-Integrated Sustainability Assessment in India (Reference Framework)

The most directly applicable case study to Nepal's context is the BIM-based integrated framework for Building Sustainability Assessment (BSA), developed and tested in India by researchers (Nasir et al., 2026b). This study is most significant because India shares Nepal's South Asian climate zones, construction material supply chains, regulatory traditions, and development constraints in some extent. The framework combined GRIHA with LCA methodologies within a BIM authoring environment, addressing both the operational and embodied carbon dimensions of building performance.

The framework was implemented as a five-stage workflow: (i) parametric BIM model creation with full material metadata, (ii) climate zone-specific energy simulation, (iii) automated GRIHA compliance scoring from the BIM model, (iv) LCA computation for material embodied carbon, and (v) climate sensitivity analysis across India's diverse climate zones. The study demonstrated that BIM integration reduced GRIHA documentation time by an estimated 30–40% compared to manual assessment methods, and that early-stage design modifications guided by BIM simulation data achieved significant improvements in GRIHA scores without cost penalties. Critically, the researchers identified the need for localized LCA material databases as the primary technical prerequisite for scaling this approach, a finding directly transferable to Nepal's context, where such databases do not yet exist.

6.2 BIM Opportunities in Nepal (Housing, Government, Heritage and Earthquake Resistance)

Nepal's post-2015 earthquake reconstruction program represents the largest coordinated housing recovery initiative in recent history, providing an important contextual foundation for understanding

BIM's potential role in sustainable and resilient construction. The National Reconstruction Authority (NRA) oversaw the reconstruction of more than 600,000 housing units under an owner-driven reconstruction model, supported by approximately 3,000 field engineers, aligned with the "Build Back Better" (BBB) principle and the Sendai Framework for Disaster Risk Reduction (2015–2030). While this program achieved significant progress in structural safety and NBC compliance, its implementation remained largely dependent on conventional inspection-based and 2D documentation workflows, with no systematic use of digital tools for lifecycle documentation, sustainability assessment, or performance monitoring.

Existing literature on BIM in Nepal further emphasizes that the AEC sector remains in an early stage of digital adoption, where BIM is primarily limited to visualization and basic design support rather than integrated project delivery systems (Phuya, 2017). Although global applications demonstrate BIM's effectiveness across multiple domains, its use in Nepal has not yet extended to lifecycle-based sustainability integration. For example, international case studies show BIM-enabled affordable housing projects in Austin, Texas and Ahmadabad, India, achieving 16% and 23% energy cost reductions, 6% and 8% reduction in material cost respectively and notable savings in construction time and material use, while also improving design transparency and user participation (Moore, Adapting Building Information Modeling (BIM) for Affordable & Sustainable Housing, 2015) (Dowhower, 2010)

Beyond housing, BIM in Nepal's government projects can significantly improve project delivery by reducing delays, cost overruns, and inefficiencies through 3D-based quantity estimation, improved scheduling and coordination, enhanced transparency, and better accountability across design, tendering, and construction stages. Similarly, in heritage conservation, BIM and Heritage BIM (HBIM) have been widely applied for documentation, restoration, and virtual preservation of cultural assets using photogrammetry, LiDAR, and UAV-based scanning technologies, enabling both physical reconstruction and digital preservation of heritage sites (Stober et al., 2018), (Arayici, 2018). This is particularly relevant for Nepal, where post-earthquake reconstruction of heritage sites such as Kathmandu Valley's Durbar Squares revealed the limitations of traditional reconstruction approaches in the absence of accurate digital documentation.

The September 2025 Gen Z movement has further intensified the urgency of digital transformation in Nepal's AEC sector, with a government assessment committee confirming total physical losses of approximately Rs 84.45 billion across 2,671 buildings in 2,168 public institutions, including landmark structures such as Singha Durbar, the Federal Parliament, and the Supreme Court, as well as provincial offices, police stations, and municipal buildings across multiple cities (Kathmandu Post, 2025). Many affected structures are confirmed as beyond conventional retrofitting and require complete rebuilding, a process critically complicated by the absence of accurate pre-existing digital records of their as-built conditions (Caliber.Az, 2025). This situation closely parallels, and arguably exceeds, the documentation challenges of the 2015 earthquake reconstruction, with the added complexity that many destroyed buildings carried both administrative and heritage significance. In this context, BIM integrated with LiDAR, UAV photogrammetry, GIS, and digital twin technologies could support rapid damage assessment, structural evaluation, cost estimation, and evidence-based reconstruction planning by generating accurate 3D as-built models from surviving archival drawings, historical photographs, and structural remains. Beyond individual buildings, the scale of simultaneous reconstruction across thousands of public sites presents an opportunity to establish

BIM-based asset registries enabling centralized digital records of structural condition, cost, and schedule, an institutional capability absent during post-2015 recovery, while building long-term digital infrastructure management capacity ahead of future seismic or political disruptions.

7. Research Gaps

Based on the systematic literature review and comparative analysis, the following research gaps are identified, defining the frontier for future research in BIM-enabled sustainable building design in Nepal:

Gap 1- Absence of a Nepal-Specific Green Building Rating System: No peer-reviewed study has developed, tested, or validated a green building rating system specifically calibrated for Nepal's climate zones, building typologies, and socioeconomic conditions. While GRIHA and LEED have been referenced by the NGBC, their applicability to Nepali vernacular construction and informal building stock has not been empirically studied.

Gap 2- No Documented BIM-LCA Integration in Nepal: The reviewed literature contains no case study or pilot project demonstrating the full BIM-LCA workflow for a Nepalese building. This gap precludes evidence-based quantification of embodied and operational carbon reduction potential in the Nepali building stock.

Gap 3- Lack of Localized BIM Material Databases: Nepal-specific BIM object families for locally sourced building materials, including stone masonry, stabilized soil blocks, bamboo composites, and locally produced concrete, do not exist in any documented open-access repository, creating a fundamental data gap for BIM-LCA implementation.

Gap 4- Absence of Energy Performance Benchmarks: No nationally validated energy performance benchmarks for Nepal's diverse building typologies (residential, commercial, government, educational) across its multiple agro-climatic zones (tropical Terai, temperate mid-hills, alpine mountain) have been published, making energy simulation result validation difficult.

Gap 5- No Policy-Technology Integration Research: No study has analyzed the specific regulatory and policy interventions required to align Nepal's NBC with BIM-based digital compliance mechanisms, or establish mandatory green building performance thresholds for government-funded construction.

8. Conclusion and Recommendations

8.1 Conclusion

This paper has presented a systematic review of Building Information Modeling (BIM) as an enabler of sustainable building design in Nepal, evaluating three primary sustainability assessment approaches: Green Building Rating Systems (GBRS), Life Cycle Assessment (LCA), and BIM-LCA integration workflows, against the country's current technical, institutional, and policy landscape, grounded in the Bew-Richards BIM Maturity Model, the Triple Bottom Line (TBL) framework, and the BIM-LCA integration workflow. This together provided a structured lens through which Nepal's current state of practice was critically assessed and benchmarked against global and South Asian precedents. The review demonstrates that while BIM adoption in Nepal is growing, sustainability-specific BIM applications remain almost entirely absent from documented practice. The gap between Nepal's current BIM maturity (Level 0–1) and the Level 2 threshold required for meaningful sustainability assessment integration is large but bridgeable through targeted

interventions. The gap between Nepal's current practice and meaningful sustainability integration therefore reflects a systemic deficit spanning policy, institutional capacity, professional education, and industry incentive structures simultaneously.

The consequences of this gap are tangible and compounding. Nepal's CO₂ emissions are rising, electricity demand is growing annually, and rapid urbanization is producing unplanned, energy-intensive construction without adequate environmental oversight. The 2015 earthquakes damaged over 600,000 structures, yet BIM-based documentation or sustainability monitoring was a missed opportunity whose cost is now well understood. The September 2025 Gen Z movement has further deepened this challenge recently, damaging 2,671 buildings across 2,168 public institutions and destroying irreplaceable archival and as-built records at landmark sites including Singha Durbar, the Federal Parliament, and the Supreme Court, with total losses assessed at Rs 84.45 billion (Kathmandu Post, 2025). With many structures confirmed as beyond retrofitting and requiring complete rebuilding (Caliber.Az, 2025), the ongoing reconstruction program represents a rare, if painful, opportunity to embed BIM, LiDAR and other technology-assisted documentation, and lifecycle sustainability workflows into Nepal's institutional construction practice at scale.

The five research gaps are identified in this review and global evidence base is sufficient and compelling and Nepal stands at a pivotal moment in its built environment history. Two episodes of large-scale destruction, have each exposed the same fundamental vulnerability: a construction sector that rebuilds without the digital documentation, lifecycle intelligence, or sustainability governance needed to do so resiliently or equitably. If Nepal's government, academic institutions, industry and private sector act with coordinated urgency, BIM-enabled sustainable building design can become not a future aspiration but the documented, evidence-based foundation of how Nepal builds its next century.

8.2 Recommendations

Based on the findings of this review, the following recommendations are advanced for government bodies, academic institutions, and industry stakeholders:

For Government Bodies: Develop and publish a National BIM Roadmap for Nepal, aligned with the NBC, establishing phased BIM Level 2 requirements for government-funded construction above a defined threshold. Commission a pilot BIM-sustainability assessment program for new government-governed public buildings, using GRIHA or an adapted Nepali equivalent as rating framework. Establish a dedicated Nepal BIM Library with BIM object families for locally sourced building materials, co-developed with institutions or relevant organizations.

For Academic Institutions: Integrate BIM and sustainability assessment modules, including energy simulation, material LCA, and GBRS familiarization, into undergraduate civil engineering, architecture, and construction management curricula. Establish joint research programs with Indian institutions (such as TERI) to develop Nepal-specific local GBRS framework and LCA material databases and localized climate data sets for building energy simulation program.

For Industry (AEC Firms): Industry leaders should pilot BIM-LCA workflows on demonstration projects and publish findings in peer-reviewed venues to build the evidence base for scaled adoption. At the organizational level, firms should establish BIM competency as a formal hiring criterion, invest in structured in-house training, and engage with relevant professional bodies to contribute toward a localized BIM material library and national BIM standards.

For Private Project Developers: Private developers should begin by integrating BIM from design phase, leveraging clash detection, 3D quantity take-off, and construction scheduling tools to reduce material waste, rework, and cost overruns. BIM adoption should further extend into lifecycle asset management for commercial, hospitality, and residential developments. At the organizational level, firms should invest in structured BIM training for in-house technical teams and incentivize BIM competency as a hiring criterion, reducing consultant dependence and building the internal capacity needed to drive Nepal's broader digital construction transition.

Conflict of interest

The author declares no conflict of interest.

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