BARRIERS AND ENABLERS TO BIM-ENABLED ENERGY EFFICIENCY OPTIMISATION IN THE SRI LANKAN BUILDING SECTOR

A Conceptual Analysis of Stakeholder Readiness, Information Flow, and Digital Adoption

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Abstract. This paper examines the barriers and enablers shaping Building Information Modelling (BIM) enabled energy-efficiency optimisation in Sri Lanka's building sector. Although BIM is widely associated with digital modelling, coordination, and visualisation, its value for energy performance depends on whether project teams can generate, exchange, interpret, and act on reliable information across the building lifecycle. The study adopts a conceptual research design that synthesises the literature on BIM-based energy analysis, Levels of Development (LOD), interoperability, stakeholder readiness, and implementation conditions in developing countries. The analytical procedure organises the evidence around lifecycle decision points, phase-specific capacity demands, information-handover requirements, and the quality conditions required for dependable simulation outputs. The results identify BIM information maturity, information quality, interoperability, stakeholder capacity, and governance as the principal determinants of decision readiness for energy optimisation. They also show that barriers and enablers vary by project phase, requiring differentiated interventions rather than generic BIM training. Based on this synthesis, the paper presents the conceptual framework developed for the study and operationalises its constructs for later empirical application. The paper contributes an energy-first, lifecycle-oriented explanation of how digital adoption can enable more dependable energy-related decision-making and building performance improvement in Sri Lanka and comparable developing-country contexts.

Keywords. *Building Information Modelling (BIM); Energy Efficiency; Barriers And Enablers; Stakeholder Readiness; Information Flow; Sri Lanka.*

1. Introduction

The architecture, engineering, construction, and facilities management sector is under growing pressure to deliver buildings that are not only better coordinated but also measurably more efficient, climate responsive, and operationally robust (Al-Raqeb & Ghaffar, 2025). In that setting, Building Information Modelling has become more than a three-dimensional representation tool. It is increasingly understood as an information environment through which design intent, engineering logic, construction knowledge, and operational data can be coordinated over time. When BIM is meaningfully integrated with building energy modelling, it can support earlier and more transparent decisions regarding form, envelope performance, system selection, commissioning, and post-occupancy optimisation (Biswas et al., 2024). However, the energy value of BIM does not arise automatically from software adoption or the presence of a model. Energy-related decisions depend on the timing, quality, and usability of information. A conceptual model may be sufficient for comparing massing, orientation, and broad passive options. However, it cannot support the same level of inference as a coordinated model with validated spaces,

https://doi.org/10.31705/ICFMF2026.29

detailed envelope properties, schedules, system assumptions, and operational parameters. BIM-enabled energy optimisation is therefore inseparable from information maturity throughout the project lifecycle and from stakeholders' capacity to create, interpret, exchange, and act on that information (Al-Raqeb & Ghaffar, 2025; Ikediashi et al., 2025).

These issues are particularly significant in developing-country contexts. In Sri Lanka, BIM adoption remains uneven, open data standards are still maturing, and project organisations often face fragmented responsibilities, inconsistent documentation, constrained software access, and weak continuity between design, construction, and operations. (Perera et al., 2024; Siriwardhana & Moehler, 2024). Such conditions affect digital adoption in general, but they are especially damaging to BIM-based energy workflows because those workflows are highly sensitive to missing inputs, interoperability failures, and a lack of clear ownership of model development and information handover. A further limitation is that capacity-building efforts are often framed too generically. Training may focus on modelling, clash detection, or visual coordination without sufficiently addressing energy-specific competencies such as analytical zoning, schedule and internal gain modelling, model quality checks for simulation, calibration logic, commissioning data capture, or BIM-to-facility-management handover. The result is a recurring implementation gap: organisations may produce models without producing dependable energy evidence, or they may generate simulation outputs that are too uncertain, too late, or too poorly aligned with stakeholder needs to shape decisions in practice(Ilbeigi & Farahani, 2025; Merino et al., 2025).

This paper addresses that gap by examining BIM-enabled energy-efficiency optimisation in Sri Lanka through the combined lenses of information maturity, information quality, interoperability, and stakeholder capacity across the building lifecycle. Rather than treating BIM adoption as a purely technical issue, the paper argues that energy value emerges only when project information becomes sufficiently mature, analytically usable, and organisationally actionable at the point of decision-making. The paper makes three contributions. First, it develops a lifecycle-oriented conceptual explanation of how BIM information maturity influences energy decision-making through information quality and simulation usefulness. Second, it introduces the concept of decision readiness to distinguish the mere production of simulation outputs from their practical credibility for design, construction, and operational decisions. Third, it identifies phase-specific capacity priorities for stakeholders in Sri Lanka's building sector and translates them into a framework to guide future empirical assessments and implementation strategies.

2. Literature Review

2.1. BIM BEYOND THREE-DIMENSIONAL COORDINATION

The literature consistently shows that BIM should not be reduced to software or geometry. It is better understood as an information-rich socio-technical process through which project participants define, exchange, refine, and govern knowledge about the building over time. Chen et al. (2024) argued that BIM provides a framework for industry transformation by aligning people, processes, and technologies around shared digital objects rather than isolated drawings and document sets. For energy-related decision-making, this distinction is crucial. What matters is not simply whether a model exists, but whether the model contains structured and trustworthy information about spaces, materials, systems, schedules, and operational intent that can support performance reasoning.

From an energy perspective, BIM offers value because it can connect geometric representation with analytical use. Studies on BIM-enabled sustainable design and building energy analysis show that model-based workflows can support early-stage option comparison, structured sustainability assessment, more coordinated design iteration, and the communication of performance implications to non-specialist stakeholders (Ghalenoei et al., 2024; Pacheco et al., 2024). Pereira et al. (2021) similarly found that the BIM-energy literature increasingly treats BIM as a bridge between architectural decision-making and building energy modelling, particularly when projects seek to compare alternatives before they become costly to reverse.

2.2. LEVELS OF DEVELOPMENT AND STAGE-APPROPRIATE ANALYSIS

Levels of Development provide a useful way to conceptualise BIM information maturity. LOD does not merely refer to visual detail; it indicates the extent to which building elements are defined, coordinated, and usable for downstream decision-making. showed that multi-LOD thinking matters because different project stages tolerate different levels of uncertainty. Early-stage design benefits from flexibility and broad comparisons, while later stages require greater precision, richer attributes, and stronger internal consistency.

For energy analysis, LOD progression changes the type of performance questions that can be addressed. At LOD 100 to 200, concept and schematic design models typically support high-level questions about orientation, massing, window-to-wall ratios, shading concepts, and broad solar exposure. At this stage, rough-order simulations can still be highly valuable because they guide major passive design decisions before costly commitments are made. Gonzalo et al. (2023) note that early-stage simulation tools are most useful when they help designers narrow the solution space rather than falsely promise precision.

As projects move toward LOD 300, the analytical focus shifts. More detailed envelope definitions, space zoning, schedules, gains, and system assumptions allow teams to examine loads, comfort conditions, and system alternatives with greater confidence. Utkucu and Sözer (2023) emphasise that building performance optimisation improves when design decision processes are linked to a staged, holistic information structure rather than to isolated specialist models. Beyond that, LOD 350 to 400 introduces a different set of energy tasks: quality assurance of energy-critical details, commissioning preparation, asset data structuring, and the translation of design intent into evidence of as-installed performance. At LOD 500, the issue becomes operational continuity, where the as-built model can support monitoring, tuning, and performance verification if the right data structures and responsibilities are in place.

This staged view is important because the value of simulation outputs is inseparable from uncertainty. A model sufficient for comparing two massing options should not be mistaken for one that can justify detailed HVAC sizing or operational performance guarantees. The notion of decision readiness used in this paper, therefore, extends beyond raw simulation output. It captures the degree to which those outputs are stable, interpretable, and actionable for the stakeholder who must decide at a given phase.

2.3. INTEROPERABILITY, INFORMATION QUALITY, AND SIMULATION RELIABILITY

Even when BIM models become more detailed, reliability is not guaranteed. One of the most persistent findings in BIM-based energy research is that interoperability and data quality can limit analytical usefulness. showed that BIM-based building energy modelling often suffers from mismatches between design-oriented models and analysis-oriented data requirements. Utkucu and Sözer (2020) similarly demonstrated that information exchange issues within BIM platforms can distort building performance evaluation when naming conventions, parameter structures, analytical boundaries, or export conditions are inconsistent.

These issues are not merely technical nuisances. They shape whether a project team can trust its outputs. Missing space boundaries, incomplete envelope parameters, poorly structured schedules, inconsistent system definitions, or weak coordination between architectural and MEP models can make simulation results highly sensitive to assumptions. In practice, this means that simulation can appear rigorous yet remain weakly grounded. If a project lacks a disciplined approach to checking analytical spaces, validating inputs, controlling parameter schemas, and documenting assumptions, the credibility of model-based energy decisions becomes fragile.

2.4. DIGITAL EXTENSIONS: AI, IOT, AND DIGITAL TWINS

Recent developments in AI, sensor integration, and digital twins are expanding the horizon of BIM-enabled energy optimisation. AI-assisted optioneering can evaluate larger design spaces; rule-based or machine-learning workflows can support optimisation or anomaly detection; and digital-twin environments can connect the model to live or near-live operational data. Abd-Elnaby and Reffat (2024) describe the broader transition from BIM toward extended digital environments in which model data support richer visualisation, interaction, and lifecycle integration. Schery et al. (2025) further show how BIM-driven energy simulation can be positioned within broader net-zero and optimisation agendas. However, these digital extensions should not be romanticised. Advanced tools raise the quality threshold for underlying data and increase the coordination burden placed on teams. AI can explore more alternatives, but it still depends on valid inputs, coherent objectives, and human interpretation. Digital twins can support post-occupancy optimisation, but only if the project has already secured reliable asset data, integration with monitoring systems, and the organisational capacity to act on feedback. In low-capacity settings, layering advanced tools on top of weak BIM practices may amplify confusion rather than deliver performance benefits.

2.5. SYNTHESIS OF THE LITERATURE AND RESEARCH GAP

Taken together, the literature points to an unresolved issue. Research has shown the promise of BIM for sustainable design, the importance of information maturity, the persistence of interoperability problems, and the emerging role of advanced digital technologies. What remains less developed is an integrative explanation of how these factors interact with stakeholder capability across project stages, particularly in a developing-country context. Technical studies often assume that if the model is refined, performance decisions will improve. Capacity-building discussions, by contrast, may focus on BIM adoption in general without clarifying which energy tasks, at which stages, require which competencies. This paper addresses fragmentation by linking information maturity, information quality, decision readiness, and stakeholder capacity within a single lifecycle-oriented conceptual structure. The novelty of this paper lies not simply in identifying barriers to BIM adoption, but in explaining how information maturity, information quality, and stakeholder capacity interact across lifecycle stages to determine whether BIM-generated energy evidence becomes decision-ready in practice.

3. Research Methodology

3.1. RESEARCH DESIGN

This study adopts a conceptual research design to explain the barriers and enablers affecting BIM-enabled energy-efficiency optimisation in the Sri Lankan building sector. Rather than testing hypotheses through a single case study or survey dataset, the paper develops a theory-informed explanatory framework grounded in a structured synthesis of prior literature and lifecycle logic. This design is appropriate because the problem addressed is not only whether BIM supports energy analysis, but how information maturity, interoperability, and stakeholder capacity interact across project stages to shape the credibility and usefulness of energy-related decisions.

The evidence base for the synthesis combines three strands. First, the study draws on the literature on BIM, building energy modelling, LOD progression, interoperability, lifecycle information exchange, and socio-technical adoption. Second, it uses lifecycle and stakeholder matrices developed for the Sri Lankan context to identify phase-specific decision points and capability demands. Third, it integrates the study's conceptual framework and construct operationalisation to produce a researchable model for later empirical application.

3.2. ANALYTICAL PROCEDURE

The analytical procedure was undertaken in four steps. First, the literature was reviewed to identify the variables that recur most consistently in BIM-enabled energy studies, including information maturity, model quality, interoperability, simulation usefulness, stakeholder capability, and governance conditions. These variables were treated as candidate determinants of energy decision readiness.

Second, the variables were reorganised by project phase and LOD to determine when they matter most. This step allowed the analysis to distinguish early-stage optioneering needs from later-stage documentation, commissioning, and operational continuity needs, which is critical for understanding why barriers differ across the lifecycle.

Third, the barriers and enablers were coded through four interacting dimensions: people, process, technology, and governance. Barriers were interpreted as conditions that weaken information quality, break handover, reduce simulation credibility, or limit stakeholder action. Enablers were interpreted as conditions that strengthen decision readiness, improve model reliability, and align responsibilities with energy objectives.

Finally, the conceptual framework was assembled as a causal pathway linking project energy intent, BIM information maturity, information quality, simulation outputs, decision readiness, stakeholder capacity, and resulting capacity gaps or intervention priorities. This step moved the analysis beyond descriptive synthesis by specifying the mechanism through which digital maturity is expected to translate into energy-related decision value and by clarifying where that mechanism is likely to break down in practice.

3.3. ANALYTICAL OUTPUT AND EVALUATION LOGIC

The outcome of this methodology is not a statistical model but a conceptual explanation. Its value at this stage lies in its internal coherence, alignment with prior literature, lifecycle completeness, and the explicit linkage it establishes between theoretical constructs and observable indicators such as model content, interoperability checks, simulation outputs, workflow evidence, and stakeholder capability requirements. In this sense, the framework is intended not merely as a descriptive diagram, but as a structured basis for later empirical testing and implementation diagnosis.

Accordingly, the results section presents three integrated outputs: the phase-targeted capacity priorities that emerge from the lifecycle analysis, the conceptual framework that organises the barrier-and-enabler logic, and the framework operationalisation that can support subsequent empirical application in Sri Lanka.

4. Conceptual Findings and Framework Development

4.1. PHASE-SPECIFIC DECISION LOGIC

A central premise of this paper is that energy-related decisions are not distributed evenly across the project lifecycle. The highest leverage on passive performance typically lies in concept and schematic design, when orientation, massing, window-to-wall ratio, and shading strategies remain adjustable. At that stage, the most important capacity is not detailed model production but performance-based design literacy: the ability to structure early options, interpret quick simulations, and use energy evidence to guide form-making rather than merely justify it after the fact.

As design development progresses, the problem becomes more detailed and multidisciplinary. Envelope assemblies, zoning logic, internal gains, comfort conditions, and system alternatives must be coordinated more carefully. This phase demands stronger data discipline because the relationship between design assumptions and simulation outputs becomes more direct. Later still, documentation and pre-construction stages require energy-critical quality assurance. It is no longer enough to know the intended performance concept; the project team must check whether specifications, details, coordination decisions, and commissioning preparations preserve that intent.

Fabrication, commissioning, and operations introduce yet another shift. At these stages, the issue is not primarily whether the design was conceptually sound, but whether the installed asset, recorded test evidence, and operational interfaces enable ongoing performance management. That requires competencies in field-to-model data capture, asset parameterisation, commissioning logging, and FM system linkage. Capacity development should therefore follow the energy task across the lifecycle rather than remain attached to generic BIM functions.

4.2. PHASE-TARGETED CAPACITY PRIORITIES

This lifecycle view leads to a simple but important conclusion: stakeholder capacity is both cumulative and phase specific. Some capabilities, such as BIM literacy, naming discipline, and a culture of collaboration, are foundational across all stages. Others are highly phase dependent. Early stages need optioneering and quick performance reasoning. Middle stages require analytical discipline and system-level coordination. Later stages need quality assurance, commissioning, and operational data practices. Table 1 summarises the phase-targeted capacity priorities synthesised from the thesis.

Phase / LOD	Core decision focus	Priority capacities	Indicative interventions
Concept & schematic (LOD 100-200)	Massing, orientation, envelope concepts, early targets	Performance-based design; Insight workflows; schedule and gain modelling	Studios and CPD on Revit Energy Settings and Insight; optioneering playbooks
Design development (LOD 300)	Detailed envelope and systems integration	Detailed loads; envelope data discipline; comfort analysis; life-cycle cost reasoning	Hands-on clinics; energy-related BEP templates; QA dashboards
Documentation / pre-construction (LOD 350)	Buildability and QA of energy-critical details	Detail QA; clash routines for performance zones; commissioning preparation	Envelope checklists; commissioning datafield standards; coordinated reviews
Fabrication/commissioning (LOD 400)	As-installed performance verification	Field-to-model data capture; asset parameterization; structured test logging	Mobile forms; COBie training; reality-capture supported workflows
Operations/maintenance (LOD 500)	Monitoring, tuning, and continuous improvement	CMMS/BMS linkage; KPI design; tuning; measurement and verification	FM upskilling; data integration guides; periodic optimization clinics

Table 1: Phase-targeted capacity priorities for BIM-enabled energy optimization.

Sources: (Abualdenien & Borrmann, 2018; Geyer et al., 2018; Xiao et al., 2025)

4.3. INFORMATION FLOW, HANDOVER, AND OPERATIONAL CONTINUITY

A lifecycle perspective also reveals the importance of information handover. Energy optimisation cannot be sustained if data structures collapse when one phase ends and another begins. Perera et al. (2022) emphasise that BIM-enabled projects depend on robust information flows, a point that is especially relevant to energy-related decisions. If the owner, facility manager, or operator receives incomplete asset information, undocumented assumptions, or a model with poor parameter logic, the ability to tune performance in operation is weakened. Conversely, when information handover is deliberate, the operational phase becomes a continuation of the energy strategy rather than a disconnect from it

4.4. CONCEPTUAL FRAMEWORK FOR BIM-ENABLED ENERGY EFFICIENCY OPTIMISATION

4.4.1 Overview of the Framework

The conceptual framework was designed to explain why BIM-enabled energy optimisation succeeds in some contexts and stalls in others, even when digital tools are nominally available. Figure 1 presents the framework exactly as used in the study. It does not treat BIM maturity as a self-contained technical ladder. Instead, it presents a connected pathway in which project energy intent and contextual constraints shape the modelling route; BIM information maturity influences information quality; information quality affects the usefulness of energy simulation outputs; stakeholder capacity mediates and moderates these relationships; and the resulting analysis reveals capacity gaps and strategy priorities. This framing moves the discussion beyond the common assumption that more detailed BIM models automatically produce better energy outcomes. The framework argues instead that BIM information maturity creates only the potential for energy value. That potential is realised only when information is sufficiently accurate, interoperable, and interpretable for a specific decision at a specific project stage, and when stakeholders possess the capacity to act on it. In this sense, the framework repositions BIM-enabled energy optimisation as a socio-technical decision system rather than a software-led modelling process. In contexts such as Sri Lanka, where technical constraints and organisational fragmentation often coexist, this explanation is more realistic and actionable than models that focus solely on digital capability.

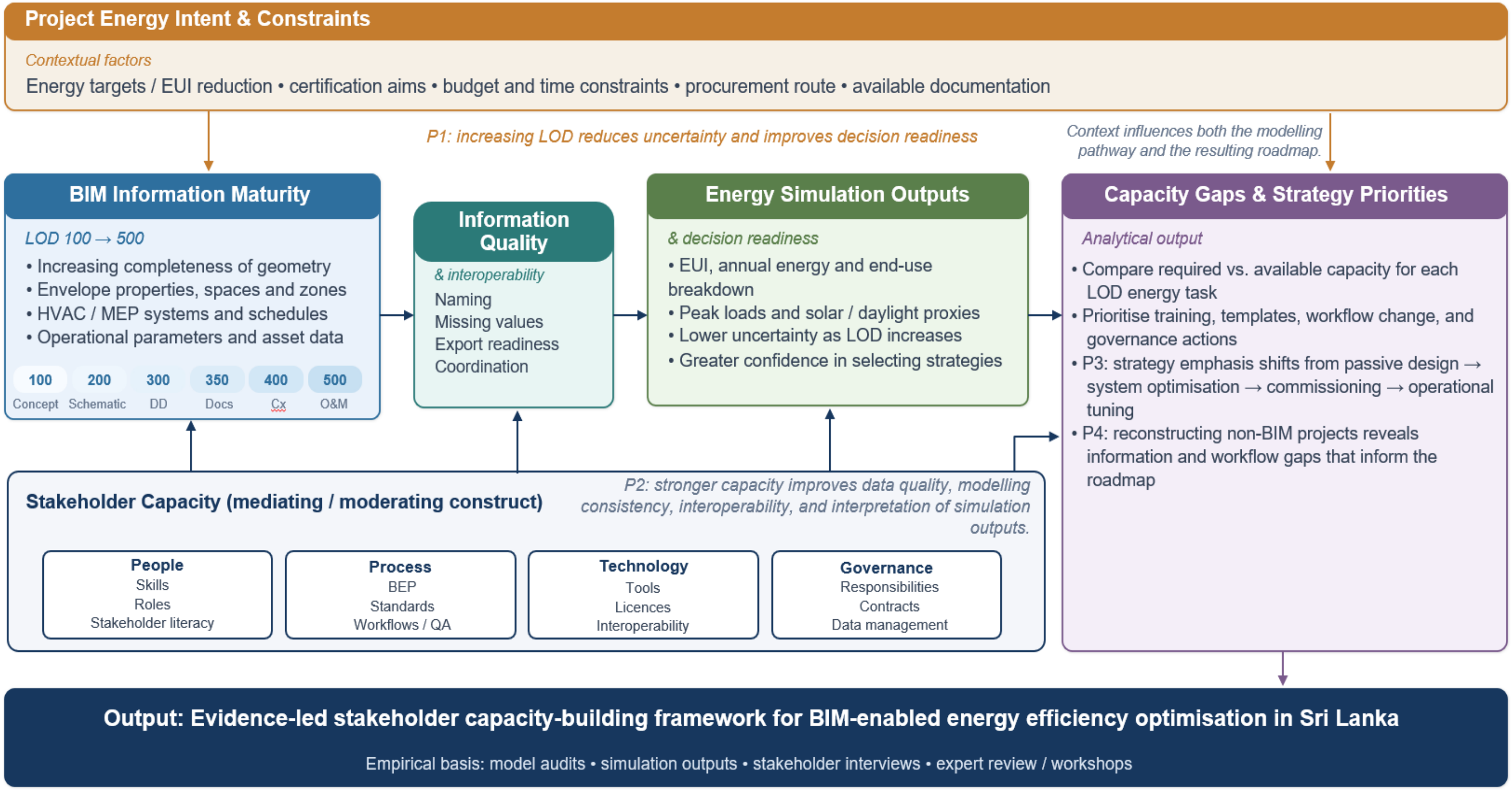

Figure 1: Conceptual framework for BIM-enabled energy efficiency optimisation in Sri Lanka.

4.4.2 Project energy intent and BIM information maturity

At the top of the framework sits the project energy intent and constraints. This construct captures the contextual conditions that shape everything downstream. Energy reduction targets, certification ambitions, budget limits, procurement routes, available documentation, and time pressures influence how far BIM reconstruction can realistically proceed and which energy strategies are worth exploring. A project with weak baseline documentation and tight delivery pressures may not support the same modelling ambition as a project with strong records, a committed client, and explicit performance goals.
The next construct is BIM information maturity, represented through the LOD progression from 100 to 500. In the framework, LOD serves as the principal independent construct because it reflects the extent to which project information becomes progressively available for energy reasoning. The focus is not only on geometry, but also on envelope properties, spaces and zones, HVAC or MEP systems, schedules, operational parameters, and asset data. Each increase in LOD potentially enables a different class of energy task and improves the scope for more dependable decision support. When a project that did not originally adopt BIM is reconstructed at successive LOD levels, the exercise reveals what information is required, what is missing, and where workflow discontinuities occur.

4.4.3 Information quality, interoperability, and simulation outputs

Between BIM maturity and simulation output lies information quality and interoperability. This construct highlights that richer models are not automatically better models for energy purposes. The framework identifies naming consistency, missing values, export readiness, and coordination as core sub-components because these issues determine whether energy-relevant data can move across tools and stakeholders without distortion. In practice, this construct captures the quality assurance layer that often separates an impressive-looking BIM environment from a genuinely trustworthy analytical workflow.
The framework then links information quality to energy simulation outputs and decision readiness. The outputs themselves include measures such as annual energy use, Energy Use Intensity, end-use breakdowns, peak loads, and solar or daylight proxies, depending on the stage and available tools. A central contribution of the framework is the concept of decision readiness. Decision readiness refers to the degree to which simulation outputs are sufficiently stable, interpretable, and credible to support a real decision at a specific stage of the project lifecycle. This distinction is important because the existence of a simulation output does not, by itself, justify action. Outputs may remain too assumption-sensitive, too weakly validated, too poorly timed, or too disconnected from the stakeholder's immediate decision context to influence practice. By introducing decision readiness, the paper shifts attention from output generation alone to the practical conditions under which simulation evidence becomes actionable.

4.4.4 Stakeholder capacity and strategy priorities

Stakeholder capacity forms the central enabling construct in the framework because it explains why similar levels of digital maturity can produce very different energy outcomes across projects. It is explicitly modelled as both a mediating and moderating variable. It mediates the process by enabling stakeholders to generate, structure, exchange, interpret, and apply the information that flows through BIM-enabled energy workflows. It moderates the process because stronger capacity improves the quality and usefulness of the relationships among LOD progression, information quality, simulation outputs, and decision readiness. In practical terms, this means that a project with stronger stakeholder capacity can derive more reliable and more actionable energy insight from the same nominal level of BIM maturity than a project with weaker capacity.

The framework structures capacity into four dimensions. The people dimension covers skills, roles, and stakeholder literacy. The process dimension covers standards, workflows, and quality assurance. The technology dimension covers tools, licences, and interoperability routes. The governance dimension covers responsibilities, contracts, and data management. This structure recognises that capacity building is more than training. It is also about workflows, affordable toolchains, clear ownership, and minimum information obligations across project phases.

The final construct is capacity gaps and strategy priorities. Once the required capabilities at each LOD energy task are compared with the capabilities currently available, the framework reveals where intervention is most needed. Training needs can be prioritised, templates developed, workflow changes designed, and governance actions specified. Earlier stages emphasise passive design reasoning, middle stages emphasise system optimisation and data discipline, and later stages emphasise commissioning and operational tuning. This is what converts the framework from a descriptive map into a roadmap.

4.4.5 Propositions and evidence logic

To make the framework analytically explicit and empirically researchable, four propositions are proposed. P1 states that increasing LOD is expected to reduce the uncertainty of energy simulation outputs and improve decision readiness. P2 states that higher stakeholder capacity is expected to strengthen the relationship between LOD progression and simulation reliability by improving data quality, modelling consistency, interoperability, and interpretation. P3 states that the energy-saving strategies that appear feasible and high impact are expected to change by the LOD stage, shifting from passive design options toward systems optimisation, commissioning, and operational tuning. P4 states that when BIM was not initially adopted, reconstructing a project at successive LOD levels will reveal information and workflow gaps that can be translated into a phased capacity-building roadmap.

The framework is also designed to be researchable. It links each construct to observable indicators and data sources so that later empirical work can evaluate the proposed relationships rather than treat them as abstract assumptions. Project intent and constraints can be identified from briefs, design documents, and stakeholder interviews. BIM information maturity can be examined through model audits and drawing or specification review. Information quality and interoperability can be assessed through parameter checks and export tests. Energy simulation outputs can be compared across LOD stages, while decision readiness can be inferred from output stability, sensitivity, and expert judgement. Stakeholder capacity and resulting strategy priorities require socio-organisational evidence in addition to technical data, including interviews, document reviews, workflow observations, and expert review.

Table 2: Operationalization derived from the study framework's construct logic, re-styled for conference presentation.

Construct	**Variables/indicators**	**Data source/measurement**	**Where applied (LOD / phase)**
Project energy intent & constraints	Energy targets (EUI / consumption reduction), certification aims, budget/time constraints, procurement route, and available documentation	Project brief, design documents, stakeholder interviews	All stages; used as contextual controls
BIM information maturity (LOD)	LOD level; completeness of geometry, envelope properties, spaces/zones, HVAC / MEP systems, schedules, operational parameters	BIM model audit/checklist per LOD; review of drawings and specifications	LOD 100-500 (concept to operation)
Information quality & interoperability	Consistency of naming/parameters; missing values; IFC or export readiness; model coordination issues	Model checking logs; export tests; interview evidence of data exchange issues	Primarily LOD 200-500
Energy simulation outputs	Annual energy use and EUI; end-use breakdown (HVAC, lighting, equipment); peak loads; solar / daylight proxies where feasible	Simulation reports from Revit, Insight, EnergyPlus, or selected toolchain	Each LOD simulation run
Decision readiness/uncertainty	Stability of results across iterations; sensitivity to assumptions; confidence level for selecting strategies	Comparison of outputs across LODs; expert judgement from interviews	Synthesized at each LOD / stage
Stakeholder capacity	People: skills/roles; Process: standards / BEP, workflows; Technology: tools, licenses, interoperability; Governance: responsibilities, contracts, data management	Semi-structured interviews; document review; observed workflow evidence	Mapped per phase / LOD and stakeholder group
Capacity gaps & strategies	Gap between required and available capacity for each LOD energy task; prioritized actions such as training, templates, process changes, and governance	Derived from cross-analysis of interviews and simulation requirements; refined by expert review or workshop	The output of the analysis informs the final framework.

4.5. DISCUSSION AND IMPLICATIONS

4.5.1 Theoretical contribution

The principal theoretical contribution of the paper is to reposition BIM-enabled energy optimisation as a socio-technical decision-maturity problem rather than as a narrowly technical modelling problem. Existing studies often discuss BIM maturity, simulation workflows, stakeholder adoption, or sustainability outcomes in relative isolation. The framework developed here integrates these strands by explaining how project energy intent, BIM information maturity, information quality, stakeholder capacity, and decision readiness interact across the project lifecycle to shape whether energy evidence becomes actionable in practice. A second contribution is the introduction of decision readiness as a distinct analytical concept. Much of the BIM-energy literature focuses on the production of outputs, but project actors do not act on outputs in the abstract. They act on outputs that are credible, timely, and relevant enough for a particular decision. By distinguishing output generation from decision readiness, the paper introduces a more practice-sensitive explanation of how simulation evidence enters decision processes. A third contribution lies in structuring the capacity lifecycle. Rather than treating stakeholder readiness as a general condition of BIM adoption, the framework shows that different project stages require different configurations of capability, information discipline, and governance support. This helps explain why generic BIM training programmes often fail to produce meaningful energy outcomes, particularly in settings where digital adoption is emerging but uneven.

4.5.2 Practical implications for Sri Lankan stakeholders

The framework has immediate practical relevance for Sri Lanka's AEC/FM sector. For designers, it suggests that BIM training for energy outcomes should begin with performance-based design literacy rather than generic modelling alone. Teams need confidence in setting up concept-stage energy studies, interpreting solar and daylight proxies, managing schedules and internal gains, and communicating uncertainty honestly. For MEP and energy specialists, the priority shifts toward detailed loads, envelope data discipline, controls intent, and translating model assumptions into robust simulation practice. For contractors, commissioning agents, and site-based teams, the implications are different. Capacity development should focus on preserving energy-critical intent during coordination, recording commissioning evidence, structuring asset data, and linking field information back to the model. For facility managers and operators, the framework points to an underdeveloped but high-value frontier: CMMS or BMS linkage; KPI definition, tuning, measurement, and verification; and the use of BIM as an operational information environment rather than a design archive. These are not secondary issues. They determine whether lifecycle value is realised. Owners, clients, and policymakers also have a central role. Without explicit performance goals, realistic procurement routes, and minimum information expectations, project teams have little incentive to develop energy-oriented BIM capabilities. The framework, therefore, implies a broader enabling agenda for Sri Lanka: pilot projects, shared templates for energy-related BIM execution plans, clearer handover requirements, institutional support for training, and mechanisms to improve access to software and interoperable practices. Because the framework is staged, it does not require an instant full-scale transformation. It supports a gradual but purposeful progression.

4.5.3 TRANSFERABILITY AND FUTURE EMPIRICAL APPLICATION

Although the framework is grounded in Sri Lanka, its underlying logic is relevant to other developing-country settings where BIM adoption remains uneven and energy-oriented digital workflows are still emerging. Many such contexts share similar structural conditions, including fragmented information flows, constrained digital infrastructure, cost sensitivity, scarce specialist expertise, and weak continuity between project delivery and operations. In such environments, the most effective implementation strategy is unlikely to be the wholesale transfer of high-resource BIM roadmaps developed elsewhere. A more realistic approach is to identify which level of information maturity is feasible, which energy decisions matter most at each stage, and which targeted capacity interventions are needed to unlock the next stage of value. As a conceptual study, the paper does not yet empirically test all proposed relationships. Its next value, therefore, lies in guiding empirical work through model audits, stakeholder interviews, workflow mapping, and the phased evaluation of simulation outputs across LOD levels. In this way, the framework serves not only as a conceptual explanation, but also as a practical research scaffold for identifying where BIM-enabled energy initiatives are likely to stall and what forms of intervention are most likely to improve implementation.

5. Conclusion

This paper has presented a conceptual analysis of the barriers and enablers affecting BIM-enabled energy-efficiency optimisation in Sri Lanka's building sector. Its central argument is that stronger energy outcomes depend not only on the presence of digital models or simulation tools, but on the interaction among BIM information maturity, information quality, interoperability, stakeholder capacity, and lifecycle continuity. The paper's main contribution is the development of a lifecycle-oriented conceptual framework that explains how these factors combine to shape decision readiness for energy optimisation. By linking LOD progression, information quality, simulation usefulness, and capacity gaps, the framework shows why different project stages require different interventions and why generic BIM adoption efforts often fail to deliver dependable energy value. The study therefore provides a theoretically grounded and practice-oriented basis for future empirical testing as well as for implementation strategy in Sri Lanka and other comparable developing country contexts.

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