Integrated Sustainable Building Maintenance: Frameworks, Technologies, and Life-Cycle Optimization

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ABSTRACT

Integrated sustainable building maintenance balances environmental, financial, and social demands across the building life-cycle by connecting organizational workflows, asset decision-making, and digital tools. This paper evaluates conceptual models across organizational planning, asset optimization, rule-based process controls, and BIM-driven information systems. It assesses maintenance strategies ranging from reactive repairs to predictive approaches, reliability-centered maintenance (RCM), and Lean Six Sigma frameworks. Empirical findings show that while reactive maintenance remains common despite high long-term costs and occupant disruption, predictive IoT and AI systems can deliver major life-cycle carbon and cost reductions. However, adoption is often limited by capital costs, poor data quality, and system interoperability. Inspection-driven case-based reasoning (CBR) and hybrid knowledge systems offer viable, lower-cost predictive alternatives. Multi-criteria optimization models such as AHP-TOPSIS combined with bi-objective resource allocation demonstrate effective trade-off management among carbon emissions, expenses, and labor constraints. Sectoral analysis highlights distinct operational needs across heritage, public, and educational facilities, while governance research shows that procurement rules, inspection mandates, and technical support govern implementation success. Finally, the paper outlines a four-stage modular framework that links diagnostics, analytics, and optimization with ISO-aligned performance indicators to guide future longitudinal studies, open defect datasets, and interoperability standards.

Keywords: Sustainable building maintenance, Predictive maintenance, Building information modelling (BIM), Life-cycle carbon, multi-objective optimization, Case-based reasoning (CBR)

INTRODUCTION AND OPERATIONAL FRAMING

Definition and Systemic Scope

Integrated sustainable building maintenance provides operational governance that aligns environmental, economic, and social goals throughout an asset's lifespan. Rather than treating maintenance as isolated, failure-driven repairs, this approach merges organizational strategy, physical asset management, and digital monitoring into a single operational system. Connecting maintenance directly to global climate targets supports United Nations Sustainable Development Goals (SDGs)—specifically SDG 9 (Industry, Innovation, and Infrastructure), SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action)—as well as broader urban resilience planning (Hauashdh et al., 2024). Structured maintenance roadmaps assist facility managers in allocating capital efficiently while mitigating the environmental and social impacts of physical deterioration (Hauashdh et al., 2022). Adopting ISO 55000 asset management standards further establishes an institutional structure for connecting physical maintenance with long-term risk management and organizational value preservation.

Research Aims, Questions, and Novelty

This paper evaluates the current landscape of sustainable building maintenance to bridge conceptual frameworks,

digital diagnostic technologies, and portfolio-level optimization tools. To provide a rigorous operational investigation, three core Research Questions (RQs) guide this study: 1) RQ1 (Frameworks & Contexts): How do conceptual and operational maintenance frameworks integrate environmental, economic, and social dimensions across diverse building sectors and geographic regions? 2) RQ2 (Predictive Trade-offs): What are the empirical trade-offs, implementation barriers, and quantifiable outcomes associated with predictive technologies—ranging from high-cost Internet of Things (IoT) sensor networks to low-cost Case-Based Reasoning (CBR) inspection systems? 3) RQ3 (Policy & Governance): How can governance mechanisms, procurement reforms, and lifecycle parameters (including embodied carbon, circularity, occupant health equity, and climate adaptation) be unified into a modular, actionable maintenance framework?

In positioning this work against existing literature, prior reviews have primarily focused on narrow technological subsets, such as standalone Building Information Modelling (BIM) applications (Mittal et al., 2025) or high-level bibliometric mappings (Purnomo Retno et al., 2021). While Hauashdh et al. (2024) established valuable strategic SDG linkages, existing frameworks often omit upstream embodied carbon in repair materials, circular economy principles, occupant equity, and extreme weather adaptation. Furthermore, empirical coverage in prior reviews leans heavily toward commercial estates in Western economies. This paper delivers a novel contribution by synthesizing multi-objective portfolio optimization, CBR diagnostic alternatives, and a four-stage modular framework while explicitly extending analysis to multi-family residential housing and Global South operational environments (including Malaysia, South Africa, the United Arab Emirates, Nigeria, and Indonesia).

Boundary Conditions and Sectoral Scope

Managing building performance across the lifecycle requires aligning early design and procurement decisions with long-term operation, scheduled maintenance, and eventual retrofitting. Empirical lifecycle studies demonstrate that initial material selection and procurement contracts heavily influence subsequent maintenance requirements, operational expenditures, and embodied carbon footprints (Chiang et al., 2014; Chiang et al., 2016). Mathematical optimization models allow decision-makers to evaluate competing trade-offs between carbon reduction, budget constraints, and workforce availability. Furthermore, incorporating sustainable materials, energy management tools, and predictive maintenance protocols into daily operations reduces energy demand and material waste when supported by clear governance (Yu, 2024). This review focuses on four primary building sectors facing distinct operational challenges: (1) multi-family residential housing, (2) public and government office buildings, (3) university and educational estates, and (4) historic or heritage structures. Deferred maintenance in these sectors directly undermines occupant safety, increases operational costs, and degrades cultural assets (Dziadosz et al., 2024; Dithebe et al., 2025; Norazman et al., 2025; Shamsuddin et al., 2025).

RESEARCH METHODOLOGY

Database Selection and Search Strategy

To ensure a rigorous and repeatable evidence base, a systematic literature review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Literature identification was performed across four major academic databases: Web of Science (WoS), Scopus, IEEE Xplore, and Google Scholar. The search covered studies published between January 2014 and January 2026. Targeted Boolean search strings were formulated to capture the intersection of maintenance strategy, digital tools, and sustainability parameters.

The primary search query was constructed as follows: ("sustainable building maintenance" OR "green building operation and maintenance" OR "sustainable facility management") AND ("predictive maintenance" OR "building information modeling" OR "BIM" OR "life-cycle carbon" OR "multi-objective optimization" OR "case-based reasoning" OR "reliability-centered maintenance").

Inclusion and Exclusion Criteria

Studies retrieved through database searches were subjected to pre-defined inclusion and exclusion screening criteria; 1) Inclusion Criteria 1 (Publication Type): Peer-reviewed journal articles, books, and full conference papers published in English between 2014 and 2026. 2) Inclusion Criteria 2 (Focus Domain): Studies addressing operational, physical, or digital maintenance of built environment assets with explicit environmental, financial, or social sustainability metrics. 3) Inclusion Criteria 3 (Methodological Rigor): Research presenting empirical field data, mathematical optimization models, validated machine learning algorithms, or structured expert consensus (e.g., Delphi method). 4) Exclusion Criteria 1: Non-peer-reviewed editorials, opinion pieces, commercial whitepapers, and unvalidated conceptual posters. 5) Exclusion Criteria 2: Studies focused solely on initial construction or deconstruction without operational maintenance coverage. 6) Exclusion Criteria 3: Single-family residential DIY maintenance lacking institutional asset management scope.

Screening Protocol and PRISMA Flow

The selection process followed a structured four-stage screening protocol; Stage 1 (Identification): A total of 342 records were identified across the selected databases (WoS: 112, Scopus: 145, IEEE Xplore: 48, Google Scholar / Other: 37). Stage 2 (Screening): After removing 157 duplicate entries, 185 unique titles and abstracts were screened against inclusion criteria, resulting in the exclusion of 117 irrelevant articles. Stage 3 (Eligibility): The remaining 68 full-text articles were thoroughly assessed for empirical quality, domain alignment, and reporting completeness. 46 studies were excluded due to insufficient quantitative rigor or lack of sustainability metrics. Stage 4 (Inclusion & Synthesis): A core synthesis cohort of 22 empirical and review studies was retained, with 10 primary empirical landmark papers selected for detailed comparative matrix mapping.

Critical Appraisal Approach

Included studies underwent quality assessment using a critical appraisal framework adapted for built environment research. Each paper was evaluated across four criteria: (1) clarity of research design, (2) sampling adequacy and dataset transparency, (3) rigor of analytical or optimization methods, and (4) practical alignment with ISO 55000 or SDG performance indicators. Studies scoring high across all criteria were prioritized for quantitative trade-off synthesis.

CONCEPTUAL FRAMEWORKS AND MAINTENANCE STRATEGY SPECTRUM

Comparative Analysis of Conceptual Model

Conceptual frameworks for sustainable building maintenance operate at four administrative levels: organizational roadmaps, asset optimization tools, process knowledge systems, and digital twin architectures. Organizational roadmaps link day-to-day maintenance tasks with institutional strategy, environmental assessments, and SDG targets (Hauashdh et al., 2024). Strategic models focus on managerial elements such as stakeholder communication, procedural improvements, resource management, and long-term financial planning (Hauashdh et al., 2022). In Industry 4.0 applications, reliability-centered maintenance models target six core capabilities: financial control, workforce development, stakeholder relations, digital technology adoption, asset reliability engineering, and risk management (Ngcobo et al., 2025). This structure frames sustainable maintenance as an enterprise-wide strategy rather than a purely technical function.

At the operational level, Building Information Modelling for Sustainable Maintenance (BIM4SM) acts as a central data repository, linking static as-built models with real-time operational records to track components and manage sustainable materials (Ismail, 2020; Mittal et al., 2025). Knowledge-based models combine rule-based logic with Lean Six Sigma methods to remove process bottlenecks, standardize quality checks, and create feedback loops for continuous improvement (Aldairi et al., 2017). When high installation costs prevent dense sensor deployment, CBR tools use standardized physical inspection data to build case libraries. These libraries provide automated decision support and predictive insights at significantly reduced software and infrastructure investment compared to full IoT networks (Dziadosz et al., 2024).

Evaluation of the Maintenance Strategy Spectrum

Building maintenance strategies follow a continuum from reactive repairs to predictive routines, with distinct operational and financial trade-offs; 1. Corrective (Reactive) Maintenance: Interventions occur only after component failure. While this avoids upfront planning and sensor costs, literature reports that it leads to high lifecycle expenses, costly emergency repairs, faster asset degradation, and frequent service disruptions (Dziadosz et al., 2024). 2. Planned (Preventive) Maintenance: Scheduled interventions rely on fixed time intervals or usage thresholds. This approach prevents sudden equipment failures and stabilizes operational budgeting, but can result in unnecessary repairs when inspections lack granular condition data (Chiang et al., 2016). 3. Predictive (Proactive) Maintenance: Continuous condition monitoring using IoT sensors and machine learning algorithms predicts failure points. This optimizes repair timing, extends component service life, and lowers operational carbon emissions. High sensor installation costs and data integration hurdles remain key adoption barriers in public and residential portfolios (Dziadosz et al., 2024; Yu, 2024). 4. Reliability-Centered Maintenance (RCM): Systemic failure-mode analysis directs maintenance resources toward high-risk critical components. Successful implementation requires strong internal engineering capacity and structured asset data (Ngcobo et al., 2025). 5. Lean Six Sigma Maintenance: Quality-driven workflows focus on reducing process variation and material waste while establishing standardized metrics for ongoing performance evaluation (Aldairi et al., 2017).

Digital Technologies, Ai, And Decision-Support Tools

Multi-Layer Digital Technology Architecture

Digital transformation in facility management relies on a four-layer technology architecture; Layer 1 (Sensing & IoT Layer): Environmental, acoustic, temperature, humidity, and vibration sensors collect real-time condition data to support fault detection, trend analysis, and degradation modeling (Yu, 2024; Shamsuddin et al., 2025). Layer 2 (Analytics & AI/ML Layer): Machine learning algorithms, computer vision, and pattern recognition process sensor data and inspection photos to classify building defects, project remaining service life, and prioritize repair work (Mohamed et al., 2024; Olanrewaju, 2025). Layer 3 (BIM & Data Integration Layer): BIM4SM acts as an object-oriented database that connects 3D geometric models with maintenance logs, warranty data, and material specifications (Ismail, 2020; Mittal et al., 2025). Layer 4 (BMS & Digital Twin Operations Layer): Building Management Systems (BMS) and dynamic digital twins aggregate operational metrics to automate energy controls, optimize HVAC performance, and improve building climate resilience (Shamsuddin et al., 2025).

Multi-Criteria Optimization and Portfolio Decision Models

Optimization tools convert qualitative sustainability targets into mathematical decision models. Masmoudi et al. (2026) introduced an approach combining the Analytic Hierarchy Process (AHP) for weighting sustainability criteria with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to rank maintenance contractors. These scores feed into a bi-objective integer linear programming model. Tested across 146 government buildings in the UAE, this model reported a 23.01% reduction in direct maintenance costs, a 50.02% increase in composite sustainability performance scores, and consolidated contractor networks down to three specialized firms (Masmoudi et al., 2026).

For repair material selection, multi-objective portfolio optimization generates Pareto-optimal frontiers that balance lifecycle carbon emissions, capital budgets, and local employment generation (Chiang et al., 2014; Chiang et al., 2016). These mathematical models allow facility managers to optimize primary sustainability targets while treating secondary financial and social goals as bounded constraints.

Broadened Sustainability Lens And Comparative Synthesis

Broadened Sustainability Parameters

To address contemporary environmental and societal challenges, the evaluation of sustainable building

maintenance must expand beyond operational energy efficiency to incorporate four emerging parameters; 1) Embodied Carbon of Repair Materials: While energy efficiency reduces operational carbon, routine maintenance and refurbishment consume carbon-intensive materials (such as concrete, steel, insulation, and synthetic coatings). Evaluating the embodied carbon of repair materials through localized Life Cycle Assessments (LCA) ensures that maintenance interventions do not inadvertently increase net lifecycle carbon footprint (Chiang et al., 2014). 2) Circularity and Material Stewardship: Incorporating circular economy principles into maintenance workflows requires designing for disassembly, prioritizing component remanufacturing, and enforcing site waste diversion protocols. Modular replacement strategies extend product lifespan and minimize landfill disposal during building operations. 3) Occupant Health, Well-being, and Social Equity: Maintenance quality directly impacts Indoor Environmental Quality (IEQ), acoustic comfort, thermal regulation, and indoor air safety. In public and multi-family social housing, equitable maintenance distribution prevents environmental injustice and supports tenant physical and mental health (Chan, 2019; Dziadosz et al., 2024). 4) Climate Adaptation and Physical Resilience: Accelerating climate change introduces extreme weather events, thermal stress, and flood risks. Sustainable maintenance protocols must incorporate adaptive measures—such as high-durability sealants, storm-water drainage clearing, and thermal envelope reinforcement—to maintain structural resilience against climate hazards. 5) Expanded Geographic and Sectoral Coverage: Maintenance research must bridge the gap between commercial high-rises in developed nations and resource-constrained environments. Extending empirical study to multi-family residential housing and Global South contexts (e.g., Malaysia, South Africa, UAE, Nigeria, Indonesia) highlights how procurement rules, informal building modifications, and financial constraints shape operational maintenance realities (Dithebe et al., 2025; Norazman et al., 2025; Zainal Abidin et al., 2025).

Comparative Literature Matrix

Table 1 provides a systematic comparative synthesis of key landmark studies across conceptual focus, empirical methodology, sustainability metrics, and recalibrated quantitative outcomes.

Table 1: Comparative Synthesis of Key Literature on Sustainable Building Maintenance

Author(s) & Year	Framework / Focus Domain	Primary Methodology	Key Sustainability Metrics	Reported Outcome & Context
Hauashdh et al. (2024)	Integrated SBM Roadmap	Systematic Review & Conceptual Synthesis	SDG Alignment, Life-Cycle Carbon, Climate Resilience	Proposed multi-tier governance roadmap linking maintenance operations directly to UN SDGs and 4IR technologies.
Hauashdh et al. (2022)	Seven Strategic SBM Pillars	Expert Interviews & Literature Review	Resource Efficiency, Economic Viability, Social Well-being	Identified 7 strategic pillars emphasizing stakeholder engagement, procurement reform, and workforce capability building.
Dziadosz et al. (2024)	Inspection-Driven CBR Model	Property Surveys & CBR Machine Learning	Lifecycle Cost, Repair Risk, Operational Disruption	Delivered predictive decision-support alternative using mandatory inspection protocols in residential housing portfolios.
Masmoudi et al. (2026)	Public Estate Contractor Allocation	AHP-TOPSIS & Bi-objective Optimization	Direct Maintenance Cost, SDG Score, Contractor Count	Reported 23.01% maintenance cost reduction and 50.02% sustainability score increase across 146 UAE public assets.

Author(s) & Year	Framework / Focus Domain	Primary Methodology	Key Sustainability Metrics	Reported Outcome & Context
Chiang et al. (2014, 2016)	Life-Cycle Portfolio Optimization	Multi-objective Mathematical Programming	Life-Cycle Carbon, Total Cost, Local Labor Employment	Quantified trade-off frontiers between carbon reduction, capital expenditure, and social labor deployment in Hong Kong.
Ngcobo et al. (2025)	4IR Reliability-Centred Maintenance	Delphi Expert Panel & 6-Construct Model	Asset Reliability, Financial Viability, HR Capacity	Validated enterprise capability framework integrating financial, human, and technical dimensions for 4IR adoption in South Africa.
Olanrewaju (2025)	Sustainable Building Pathology	ML Defect Classification & Diagnostic Triage	Defect Risk Score, Repair Durability, Quality Index	Developed automated ML defect triage classifier to mitigate design/construction flaws in sustainable building fabric.
Chan (2019)	Mandatory Building Inspection (MBIS)	Empirical Stakeholder Survey & Evaluation	Public Safety, Compliance Rate, Remedial Quality	Demonstrated that technical guidelines, financial subsidies, and public campaigns increase inspection compliance in Hong Kong.
Sodangi et al. (2014)	Heritage Maintenance Management	Empirical Ranking & Best Practice Survey	Conservation Integrity, Staff Competence, Craft Skill	Identified workforce training and specialist expertise as highly ranked criteria for sustainable heritage care in Malaysia.
Aldairi et al. (2017)	Knowledge-Based Lean Six Sigma	Rule-Based System & Quality Engineering	Process Waste, Service Quality, Operational Variance	Structured operational pre-assessment rules reducing material waste and maintenance execution variance in commercial stock.

Integrated Four-Stage Modular Framework And Kpi Architecture

Standardized KPI Architecture and ISO Alignment

An effective sustainable maintenance program tracks metrics across four balanced core performance areas; 1) Environmental & Carbon Metrics: Operational and embodied carbon emissions (kgCO2e/m2/yr), energy use intensity (EUI, kWh/m2/yr), water consumption efficiency, and material waste diversion rates from landfill (Chiang et al., 2014). 2) Financial & Lifecycle Cost Metrics: Total cost of ownership (TCO), net present value (NPV) of maintenance interventions, capital replacement reserve ratios, and maintenance cost as a percentage of asset replacement value (Obradovic et al., 2025). 3) Operational Reliability Metrics: Mean Time Between Failures (MTBF), system availability rates, mean time to repair (MTTR), and planned-versus-unplanned work ratios aligned with ISO 55000 asset management standards (Hauashdh et al., 2024; Ngcobo et al., 2025). 4) Social & Occupant Well-being Metrics: Indoor environmental quality (IEQ) compliance, tenant health and safety incident rates, labor standard compliance, and occupant thermal/acoustic satisfaction scores (Chan, 2019).

The Four-Stage Modular Decision Framework

To bridge theoretical principles and practical facility management workflows, a four-stage modular decision

framework is established; Stage 1: Diagnostic Entry Layer: Captures physical building condition data using low-cost inspection protocols (CBR) or targeted IoT sensor deployments depending on available capital budget and technical capacity. Stage 2: Analytics & Pathology Layer: Applies machine learning classification algorithms and building pathology rules to identify defect mechanisms, assess structural risk, and estimate remaining service life. Stage 3: Multi-Objective Optimization Layer: Executes resource allocation and repair material selection algorithms (e.g., AHP-TOPSIS and bi-objective integer linear programming) to optimize trade-offs between carbon emissions, operating budgets, and workforce constraints. Stage 4: Governance & Operational Feedback Layer: Implements Lean Six Sigma feedback controls, tracks ISO 55000-aligned KPIs, enforces green procurement rules, and updates diagnostic case libraries with ongoing field performance data.

DISCUSSION AND LIMITATIONS

Discussion of Integrated Findings

The synthesis of literature reveals a clear technological and strategic evolution in sustainable building maintenance. While traditional maintenance treated repairs as localized reactive tasks, contemporary practice frames asset care as an enterprise-wide risk management strategy aligned with UN SDGs and ISO 55000. Digital innovations—particularly BIM integration, IoT sensing, and machine learning defect triage—demonstrate significant potential for optimizing asset performance and extending service lifespans. However, adoption barriers persist, particularly capital intensity, data fragmentation, and workforce skill gaps in emerging markets.

A central finding of this review is that high-cost IoT networks are not the sole pathway to predictive maintenance. Low-cost CBR models and structured physical inspection frameworks (such as Hong Kong's MBIS) offer accessible, scalable decision support for multi-family residential housing and public sector portfolios. Furthermore, incorporating multi-objective mathematical programming enables facility managers to navigate complex trade-offs between embodied carbon, direct financial expenditure, and local labor generation.

Study Limitations

Several methodological limitations should be considered when interpreting the findings of this review; 1) Language and Source Constraints: The systematic search was restricted to peer-reviewed articles published in English, potentially omitting relevant national maintenance guidelines published in local languages in non-English speaking jurisdictions. 2) Publication Bias: Published literature exhibits a potential publication bias toward successful technology implementations and positive optimization outcomes, with limited reporting on failed digital twin deployments or abandoned IoT networks. 3) Scarcity of Longitudinal Field Data: A significant portion of current research relies on cross-sectional survey data, expert Delphi panels, or short-term pilot studies. Long-term field trials tracking real-world embodied carbon savings and maintenance cost trajectories over multi-year operational horizons remain limited.

Practical And Policy Implications

Practical Implications for Facility Managers

For facility managers and building owners, this study outlines actionable implementation strategies; 1) Phased Digital Adoption: Facilities with limited capital should avoid immediate, high-cost IoT sensor rollouts and instead establish structured CBR case libraries and digital defect logging via mobile devices. 2) Lifecycle Procurement Weighting: Facility managers should transition from lowest-bid contractor selection to multi-criteria procurement models (such as AHP-TOPSIS) that weigh contractor sustainability performance, carbon commitment, and workforce competence. 3) Standardized Inspection Protocols: Routine inspections should be aligned with ISO 55000 standards to generate standardized defect data capable of feeding future predictive machine learning models.

Policy and Regulatory Implications

Policy frameworks play a critical role in shaping building maintenance practices; 1) Enforceable Mandatory Inspection Laws: Regulatory frameworks such as Hong Kong's Mandatory Building Inspection Scheme (MBIS)

demonstrate that compulsory inspection mandates require three supporting policy pillars: (1) unambiguous technical guidelines, (2) targeted financial subsidies and technical assistance for low-income property owners, and (3) public education campaigns (Chan, 2019). 2) Procurement Reform: Public sector procurement guidelines should mandate lifecycle carbon evaluation and circularity criteria in maintenance contracts, encouraging contractors to invest in sustainable repair materials and staff training (Masmoudi et al., 2026). 3) Workforce Skills Mandates: Governments and industry bodies in emerging economies should fund specialized training programs in building pathology, 4IR diagnostic technologies, and historic preservation techniques (Sodangi et al., 2014; Ngcobo et al., 2025).

Concrete Research Agenda

To address key knowledge gaps identified in current literature, future research should prioritize four specific domains; 1) Open-Access Building Defect Datasets: Developing standardized, anonymized, open-access image and sensor datasets of building defects to train, benchmark, and validate computer vision and machine learning diagnostic algorithms (Olanrewaju, 2025). 2) Dynamic IFC-BMS Interoperability Standards: Establishing open-standard data exchange protocols between static BIM schemas (IFC) and dynamic Building Management Systems (BACnet, Modbus) to enable real-time digital twin operations without proprietary vendor lock-in (Mittal et al., 2025). 3) Longitudinal Field Trials in Residential & Global South Contexts: Conducting multi-year field studies in social housing and emerging economy infrastructure (e.g., Sub-Saharan Africa, Southeast Asia, Latin America) to quantify actual lifecycle carbon, cost, and social equity impacts under real-world operating conditions (Dithebe et al., 2025; Zainal Abidin et al., 2025). 4) Climate Resilience & Extreme Weather Degradation Modeling: Formulating predictive degradation functions that simulate the accelerating impact of extreme heat waves, flooding, and thermal cycling on repair material durability and maintenance frequencies.

CONCLUSION

Transitioning building maintenance from reactive, failure-driven repairs to integrated sustainable management is vital for operational efficiency, climate change mitigation, and urban resilience. This paper conducted a systematic review synthesizing conceptual frameworks, diagnostic technologies, and decision-support models. The analysis demonstrates that while high-cost IoT and AI systems offer advanced predictive capabilities, low-cost inspection-driven CBR models and multi-objective optimization provide highly effective, scalable alternatives for resource-constrained residential and public portfolios.

By proposing a four-stage modular decision framework and an ISO 55000-aligned KPI architecture, this study offers facility managers and policymakers a practical roadmap. Expanding the sustainability lens to include embodied carbon of repair materials, circularity, occupant health equity, and climate adaptation ensures that building maintenance actively contributes to long-term environmental stewardship and societal well-being.

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