AI–BIM–Digital Twin Integration for Architectural Design and Lifecycle-Value Decision Support in Nigerian Housing Estate Management

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ABSTRACT

Housing-estate performance depends on whether architectural design information remains usable through construction, occupation, maintenance, renewal and valuation. This critical structured narrative review examines how artificial intelligence (AI), Building Information Modelling (BIM) and digital twins can support architectural design quality, information continuity and lifecycle-value decision-making in Nigerian housing estates. The analytical corpus comprises 42 peer-reviewed journal articles published between 2014 and 2026, supplemented by standards, legal instruments and institutional sources. Evidence indicates complementary but distinct roles: BIM structures architectural and asset information; AI can augment prediction, classification and option evaluation; and digital-twin functions can connect maintained digital representations with operational and post-occupancy evidence. Nigerian evidence consistently identifies skills, interoperability, infrastructure, client demand, investment and organisational capacity as implementation constraints. However, most local studies remain sector-wide rather than longitudinal studies of occupied housing estates. The review therefore contributes three applied decision tools: a five-stage architecture–estate-valuation implementation framework, a Nigeria-specific data-governance and access-responsibility matrix, and an illustrative lifecycle-cost break-even test for selective sensing. The economic rule requires discounted decision benefits to equal or exceed discounted acquisition, connectivity, maintenance, replacement and governance costs before sensor expansion. Because the framework has not yet been empirically validated on Nigerian housing estates, the proposed thresholds are decision rules for pilot testing rather than demonstrated performance effects. Digital investment should be judged by measurable improvements in information quality, maintainability, operational performance and valuation-relevant evidence rather than technological novelty alone.

Keywords: artificial intelligence; Building Information Modelling; digital twins; architectural design; estate valuation; lifecycle-value decision-making; Nigerian housing estates

INTRODUCTION

Housing estates are long-lived real-property assets whose performance reflects architectural decisions on site organisation, dwelling form, orientation, envelope, circulation, infrastructure interfaces, public space, accessibility and maintainability. These decisions influence operating conditions, resident experience, maintenance and renewal requirements after construction, while fragmented drawings, specifications, BIM data, inspection records and maintenance histories weaken continuity between design intent and performance in use (Bello & Ayegba, 2025; Ikediashi et al., 2025; Opoku et al., 2021). For estate valuation, traceable condition, cost and asset information also supports clearer interpretation of depreciation, obsolescence and value-related assumptions (International Valuation Standards Council [IVSC], 2024; Royal Institution of Chartered Surveyors [RICS], 2024).

A lifecycle perspective connects architectural decisions with operating performance, maintenance and renewal requirements, resource use, asset condition, cost and property evidence over time. Buildings account for around 30% of global energy demand, according to the International Energy Agency (IEA, 2025), while the buildings and construction sector remains central to decarbonisation and climate-resilience strategies (United Nations Environment Programme [UNEP], 2026). Post-occupancy and digital-asset literature supports retaining condition and performance evidence across the asset lifecycle, while international valuation standards require transparent bases of value, appropriate data and inputs, documented methods and accountable professional judgement (Dávila Delgado & Oyedele, 2021; IVSC, 2024; RICS, 2024). For this review, lifecycle value refers to the decision-relevant benefits and costs associated with design performance, information continuity, operation, maintenance, renewal, condition and property evidence across the asset lifecycle. It does not imply that digitalisation independently increases market value; any valuation effect remains dependent on the valuation purpose, market evidence, asset condition, recognised valuation methods and professional judgement (IVSC, 2024; RICS, 2024).

Artificial intelligence (AI), Building Information Modelling (BIM) and digital twins provide complementary but analytically distinct capabilities across this lifecycle. Within this review, BIM is treated as a model-based information-management process through which geometry, spaces, specifications, quantities and asset attributes can be structured, coordinated and exchanged; the common data environment and associated information-management responsibilities are treated separately in accordance with ISO 19650 information-management principles (International Organization for Standardization [ISO], 2018; Sacks, Girolami, & Brilakis, 2020; Volk et al., 2014). AI is distinguished from conventional BIM, simulation and rule-based analysis and refers here to data-driven or learning-based methods supporting prediction, classification, computer vision, optimisation, pattern recognition and decision support (Pan & Zhang, 2021, 2023; Sacks, Girolami, & Brilakis, 2020). Digital-twin approaches extend maintained digital asset information by linking it with operational observations such as inspections, meters, maintenance histories, sensor data and resident feedback, subject to defined information-management, data-flow and update responsibilities (Dávila Delgado & Oyedele, 2021; Fuller et al., 2020; ISO, 2020; Opoku et al., 2021; Sepasgozar, 2021). Their integration is therefore most useful where architectural and asset information remains traceable into operation and can subsequently inform maintenance, renewal and valuation decisions.

The Nigerian construction-sector evidence reviewed recurrently identifies cost, skills, awareness, interoperability, client demand, infrastructure and fragmented post-construction information as barriers to BIM and digital-twin adoption (Bamgbose et al., 2024; Bello et al., 2025; Ekemode, 2024; Ibrahim et al., 2026; Ikediashi et al., 2025). Because much of this evidence is sector-wide rather than specific to occupied housing estates, its application to housing-estate implementation is treated as contextually relevant but not estate-specific proof. The findings nevertheless indicate that digital maturity and information reliability are implementation constraints rather than secondary issues, supporting staged adoption in which basic design, as-built and operational records are verified before more complex real-time systems are introduced (Alnaser et al., 2024; Bello & Ayegba, 2025; Bello et al., 2025).

For analytical clarity, the professional framework focuses on the interface between architecture and estate valuation. This focus does not imply that implementation is a two-profession process; engineering, building-performance, facilities-management, quantity/cost, information-management, ICT and data-governance expertise may also be required according to project scope and digital maturity. In Nigeria, the architecture profession is regulated by the Architects Registration Council of Nigeria under the Architects (Registration, Etc.) Act, Cap. A19, Laws of the Federation of Nigeria 2004. Estate surveying and valuation is regulated by the Estate Surveyors and Valuers Registration Board of Nigeria under the Estate Surveyors and Valuers (Registration, Etc.) Act, Cap. E13, Laws of the Federation of Nigeria 2004. The Nigerian Institution of Estate Surveyors and Valuers (NIESV) provides professional-institution context, while IVSC and RICS standards provide additional guidance for professional valuation practice (Architects (Registration, Etc.) Act, 2004; Estate Surveyors and Valuers (Registration, Etc.) Act, 2004; IVSC, 2024; NIESV, n.d.; RICS, 2024).

Three questions guide the review: (1) how can AI–BIM–digital twin integration support architectural design and lifecycle-value decision-making in Nigerian housing estates; (2) which technical, organisational, professional and governance constraints shape its adoption; and (3) how can architectural information, post-occupancy evidence and valuation data be connected through a staged and context-sensitive implementation framework? The resulting model treats digital technology as decision support for architects and estate valuers rather than as an autonomous design, management or valuation authority. Its applied contribution is operationalised through a five-stage implementation pathway, a data-governance and access-responsibility matrix, and a lifecycle-cost break-even rule for deciding when selective sensing and analytics are economically defensible.

Review Design and Analytical Approach

A critical structured narrative review was adopted because the subject intersects architectural design, digital construction, building performance, post-occupancy evidence, property valuation, lifecycle cost and AI governance. Narrative synthesis is suited to heterogeneous conceptual, review, survey, modelling and case-study evidence that cannot be meaningfully pooled, while explicit selection and thematic comparison improve transparency (Grant & Booth, 2009; Green et al., 2006; Snyder, 2019). The analytical emphasis is therefore on evidence convergence, contextual limits and the development of an architecture-valuation framework.

Scopus, Web of Science and Google Scholar were used as the principal literature-discovery sources, supplemented by targeted searches of ScienceDirect and authoritative institutional sources including ISO, IVSC, RICS, NIESV, IEA, UNEP and the Global Alliance for Buildings and Construction (GlobalABC), UNESCO, OECD, and Nigerian legal and regulatory materials. The retained analytical corpus comprises 42 peer-reviewed journal articles published between 2014 and 2026. Search concepts were organised into thematic blocks covering BIM and information management; digital twins; AI and data-driven analysis; architectural design and building performance; post-occupancy evaluation; lifecycle cost and asset condition; real-property valuation; interoperability/openBIM; ISO 19650; housing estates; and Nigeria. Supplementary Table S1 reproduces the search expressions in auditable form. A PRISMA-informed reporting aid is used to make the selection stages explicit, while recognising that this study is a critical structured narrative review rather than a PRISMA systematic review (Page et al., 2021). The historical database export logs did not retain database-level retrieval totals or individual search dates; unavailable historical values are therefore reported as NR in Supplementary Figure S1. A reference and corpus audit completed on 25 August 2026 verified the 42-study analytical corpus and supplementary authoritative sources without changing the evidence base.

Screening proceeded through title and abstract review followed by full-text assessment and thematic coding. Sources were retained where they demonstrated built-environment relevance, methodological clarity and a traceable relationship to architectural design, digital information, post-occupancy performance, asset condition, lifecycle cost, real-property valuation or governance. Promotional software material, duplicates and publications without sufficient relevance to design or lifecycle-value decisions were excluded. The final analytical corpus comprised 42 topical peer-reviewed journal articles. Supplementary Figure S1 reports the known selection outcome and marks historical identification, duplicate-removal and exclusion counts as NR because those values were not retained in the original search log. The article therefore does not claim full PRISMA systematic-review compliance.

Nigerian evidence was prioritised for adoption and transferability because technically mature demonstrations from other contexts cannot be assumed to transfer directly to estates affected by skills gaps, weak client demand, limited post-construction BIM use, unreliable infrastructure or fragmented asset data (Bello & Ayegba, 2025; Bello et al., 2025; Ibrahim et al., 2026; Ikediashi et al., 2025). Evidence of technological possibility was therefore distinguished from evidence capable of supporting architectural and valuation decisions under Nigerian conditions.

Table 1: Review protocol and analytical focus

Element	Operationalisation
Review type	Critical structured narrative synthesis for architecture-valuation framework development; no meta-analysis.

Evidence base	42 peer-reviewed journal articles published between 2014 and 2026, supplemented by standards, legal instruments and institutional sources.
Primary databases	Principal literature-discovery sources: Scopus, Web of Science and Google Scholar; targeted supplementary searches: ScienceDirect and authoritative institutional/legal sources.
Core search concepts	BIM and information management; digital twins; AI/data-driven analysis; architectural design; building performance; post-occupancy evaluation; housing estates; lifecycle cost; asset condition; real-property valuation; openBIM/IFC; ISO 19650; Nigeria.
Inclusion logic	Built-environment relevance, methodological clarity, traceable connection to architectural design, digital information, post-occupancy performance, valuation or lifecycle value.
Analytical themes	Architectural information management; BIM-to-digital-twin evolution; AI-enabled design analysis; post-occupancy evidence; asset condition; estate valuation; Nigerian digital readiness; governance; lifecycle value.
Quality judgement	Cross-design appraisal of methodological transparency, data/validation adequacy, directness to lifecycle decisions, contextual relevance to Nigerian housing estates, transferability, recency where technologically relevant, source authority, and usefulness for architectural, operational or valuation decisions. Peer-reviewed status is an eligibility condition rather than a quality score.
Screening transparency	PRISMA-informed reporting of selection stages; final included corpus n = 42. Historical retrieval, duplicate-removal and exclusion counts not retained in the original search log are reported as NR rather than reconstructed.

Note. The analytical corpus comprises 42 topical peer-reviewed journal articles published between 2014 and 2026. Review-methodology papers (Grant & Booth, 2009; Green et al., 2006; Snyder, 2019), standards, legal instruments and institutional sources were used as supplementary methodological or authoritative materials and were excluded from the 42-study analytical corpus.

To make evidential roles explicit, each retained study was appraised across common cross-design domains: methodological transparency, adequacy of data or validation, directness to lifecycle decisions, contextual relevance to Nigerian housing estates, and transferability of the reported findings. Nigerian empirical studies are given greater contextual weight for readiness and adoption, whereas international technical, conceptual and review evidence informs technological capability, information-management requirements and implementation logic. A single numerical risk-of-bias score was not imposed across reviews, conceptual papers, technical demonstrations, bibliometric studies and empirical adoption studies because such scoring would create false comparability across fundamentally different designs; Table 2 instead reports the dominant contribution and limiting domain for every included study.

Table 2: Characteristics and critical appraisal of the 42-study analytical corpus

Study	Context/evidence type	Technology/focus	Principal contribution to synthesis	Critical limitation/transferability
Alnaser et al. (2024).	International construction; assessment framework	BIM–digital twin readiness	Defines readiness dimensions linking BIM foundations to later twin capability.	Not housing-estate-specific; framework requires Nigerian empirical validation.
Arisekola & Madson (2023).	International asset management;	Digital twins; asset management	Maps digital-twin asset-management	Secondary evidence; direct Nigerian housing

	review/network analysis		themes and lifecycle uses.	performance effects not demonstrated.
Bamgbose et al. (2024).	Nigeria; construction SMEs; empirical adoption study	BIM adoption	Direct Nigerian evidence on cost, skills and organisational adoption barriers.	Sector/SME context; not specific to occupied housing estates or post-occupancy use.
Bello & Ayegba (2025).	Nigeria; post-construction practice; empirical study	BIM post-construction	Direct evidence on barriers and strategies for post-construction BIM use.	Nigeria-specific but not a longitudinal housing-estate performance study.
Bello et al. (2025).	Nigeria; construction industry; structural-equation study	Digital-twin adoption	Direct Nigerian evidence on interrelated digital-twin adoption barriers.	Industry-wide readiness evidence; estate-specific operational transfer remains untested.
Boje et al. (2020).	International AEC; conceptual/review	Semantic construction of digital twin	Establishes semantic, interoperability and information requirements for digital twins.	Conceptual/secondary evidence; implementation effects require project-level validation.
Bortolini et al. (2022).	International building-energy literature; review	Digital twins; energy efficiency	Synthesises digital-twin applications for building-energy monitoring and optimisation.	Energy-focused review; limited direct evidence on valuation or Nigerian estates.
Dávila Delgado & Oyedele (2021).	International built environment; conceptual/process review	Digital twins	Clarifies built-environment twin processes and transfer from manufacturing concepts.	Conceptual synthesis; context-specific operational benefits are not quantified.
de Wilde (2023).	International building-performance literature; systematic review	AI, simulation and digital twins	Distinguishes simulation, AI and twin-enabled performance analysis.	Secondary evidence; applicability depends on local data, models and validation.
M. Deng et al. (2021)	International AEC-FM; systematic review	BIM-to-digital-twin evolution	Explains evolution from BIM representations to intelligent operational twins.	Review evidence; no direct Nigerian housing-estate validation.
T. Deng et al. (2021).	International smart-city literature; systematic review	Urban digital twins	Links digital twins with urban governance and city-scale decision support.	City-scale evidence; transfer to estate-level architecture and valuation is indirect.
Douglas et al. (2021).	International infrastructure/AEC; conceptual analysis	BIM, digital twins, cyber-physical systems	Clarifies boundaries and overlaps among digital	Conceptual; limited empirical evidence on lifecycle-value outcomes.

			representations and connected systems.	
Ekemode (2024)	Residential property development; empirical adoption study	BIM adoption	Provides adoption evidence directly relevant to residential property development.	Not an operational digital-twin study; estate lifecycle outcomes are not established.
Fuller et al. (2020).	Cross-sector/international; review	Digital-twin enabling technologies	Identifies enabling technologies, challenges and open research requirements.	Broad cross-sector synthesis; built-environment transfer requires contextualisation.
Hakimi et al. (2024).	International facility-management literature; bibliometric review	Digital twins; facility management	Maps smart-FM applications and research concentration.	Bibliometric/secondary evidence; does not establish causal maintenance or value effects.
Hosamo et al. (2022).	International AEC-FM; review	Digital-twin technology	Summarises AEC-FM applications, data needs and implementation challenges.	Secondary evidence; heterogeneous applications limit direct estate-level inference.
Ibrahim et al. (2026).	Nigeria; AEC industry; empirical barriers study	Digital twins / Construction 4.0	Provides recent Nigerian evidence on digital-twin barriers and sustainable-construction context.	Industry-wide adoption evidence; occupied-housing operational outcomes remain untested.
Ikediashi et al. (2025).	Nigeria; facilities management; multivariate empirical study	BIM for FM	Direct evidence on infrastructure, education, awareness and implementation barriers.	FM adoption study; no evidence of digital-twin effectiveness or property-value change.
Lee et al. (2023).	Building/human interface; design research	Digital twins; resident interaction	Supports human-building interfaces and user participation in operational twins.	International design evidence; social and institutional transfer to Nigeria needs testing.
Lei et al. (2023).	Urban digital twins; systematic review + Delphi	Urban digital twins; governance	Identifies technical, organisational and governance challenges.	Urban-scale evidence; housing-estate applicability is indirect and context-sensitive.
Lu et al. (2020).	Existing buildings; technical application	Geometric digital twinning	Demonstrates semi-automatic creation of geometric twins from images/CAD.	Technical feasibility does not establish operational, valuation or Nigerian benefits.
Mazzetto (2024)	Smart-city literature review	Urban digital-twin integration	Synthesises urban-twin integration challenges and future directions.	Urban focus; estate-level architectural and valuation use requires adaptation.

Omrany et al. (2023).	International construction; comprehensive review	Digital twins	Synthesises implementations, enabling technologies and future directions.	Secondary evidence; construction-wide rather than Nigerian housing-estate specific.
Opoku et al. (2021).	International construction; literature review	Digital-twin applications	Identifies applications and implementation requirements across construction.	Review evidence; operational and valuation effects require field validation.
Pan & Zhang (2021).	International construction; critical review	Artificial intelligence	Defines AI roles including prediction, classification and decision support.	AI-construction focus; outputs depend on data quality and professional interpretation.
Pan & Zhang (2023).	International smart construction; review	BIM–AI integration	Clarifies BIM–AI integration and smart-construction use cases.	Construction-management focus; not equivalent to housing-estate lifecycle evidence.
Pan et al. (2022).	Building digital twins; technical/experimental study	AI computer vision + scanning	Shows AI-based recognition can enrich geometric twins with small components.	Technical demonstration; condition and value implications are indirect.
Pregnolato et al. (2022).	Existing infrastructure; concept/workflow/ application	Digital twins	Provides staged digital-twin workflow and application logic for existing assets.	Civil-infrastructure context; transfer to housing estates requires adaptation.
Ramonell et al. (2023).	Built assets; technical system study	Knowledge graphs; data integration	Demonstrates semantic data integration for digital-twin information management.	Technical integration evidence; organisational and Nigerian deployment not tested.
Revolti et al. (2024).	Construction; conceptual framework	BIM-to-construction digital twin	Provides a conceptual transition framework from BIM to digital twin.	Conceptual construction context; operational estate validation absent.
Sacks, Brilakis, et al. (2020).	Construction; information-systems research	Digital-twin information systems	Supports structured, semantically linked digital-twin information systems.	Construction focus; limited direct evidence on occupied housing or valuation.
Sacks, Girolami, & Brilakis (2020).	Built environment; synthesis/position paper	BIM, AI and construction technology	Clarifies complementary roles of BIM, AI and construction technology.	Broad conceptual synthesis; context-specific performance effects are not estimated.

Sepasgozar (2021)	Built environment; conceptual/taxonomy study	Digital model, shadow and twin	Provides a useful distinction among digital model, digital shadow and digital twin.	Taxonomies vary across literature; categories should be treated as analytical conventions.
Su et al. (2023).	Construction; state-of-art review + framework	Digital twins	Synthesises applications and proposes a conceptual implementation framework.	Secondary evidence; Nigerian readiness and value outcomes not directly tested.
Tuhaise et al. (2023).	Construction; technology review	Digital-twin technologies	Identifies sensing, integration and enabling technologies for twin applications.	Technology-focused review; lifecycle decision value depends on governance and use case.
Volk et al. (2014).	Existing buildings; literature review	BIM for existing assets	Establishes challenges of BIM information for existing buildings and FM.	Pre-digital-twin review; context differs from contemporary Nigerian workflows.
Wang & Chen (2024).	Buildings/facility management; model/application	NLP; digital-twin FM	Demonstrates NLP-supported management of facility information.	Prediction/information extraction is not diagnosis or valuation; local validation needed.
Weil et al. (2023).	Urban digital twins; systematic review	Urban digital twins	Synthesises sustainability opportunities and implementation challenges.	City-scale secondary evidence; direct estate valuation implications are limited.
White et al. (2021).	Smart city; application/case study	Digital twin; citizen feedback	Demonstrates integration of citizen feedback into a digital-twin environment.	City context; estate resident-feedback use requires governance and privacy adaptation.
Xia et al. (2022).	Smart-city literature; review/bibliometric analysis	GIS–BIM integration; city twins	Explains GIS–BIM integration for city-scale digital-twin development.	Urban scale; not direct evidence of building-level lifecycle-value outcomes.
Yang et al. (2024)	Construction; review	Digital-twin architecture and applications	Synthesises architectures, applications, trends and challenges.	Secondary construction evidence; transfer to Nigerian housing requires local readiness.
Zhang et al. (2022).	Construction sites; concept/LoD/application study	Digital twins; level of detail	Clarifies digital-twin concepts, information detail and construction applications.	Construction-stage focus; post-occupancy and valuation relevance is indirect.

Note: The table distinguishes direct Nigerian adoption/readiness evidence from international technical, conceptual and review evidence. It reports a structured cross-design appraisal of evidential role, methodological transparency, directness, contextual relevance and transferability rather than a pooled numerical risk-of-bias score. The 42-study corpus excludes the three review-methodology papers and supplementary standards, legal instruments and institutional sources.

AI, BIM and Digital Twins as an Architectural and Valuation Information System

Across built-environment AI literature, prediction, classification, optimisation, computer vision and language-processing methods support design-option evaluation, performance analysis, defect or component recognition and information classification (de Wilde, 2023; Pan et al., 2022; Pan & Zhang, 2021, 2023; Sacks, Girolami, & Brilakis, 2020). For estate valuation, digital methods may assist information organisation, structured comparison, anomaly flagging and evidence retrieval; however, they do not independently determine a basis of value or value opinion, which remains dependent on appropriate inspection, inputs, assumptions, market evidence, recognised methods and professional judgement (de Wilde, 2023; IVSC, 2024; Pan & Zhang, 2021, 2023; RICS, 2024). Computer-vision applications can further enrich building digital twins by identifying and semantically mapping smaller building components from image and scan data, thereby strengthening asset information for condition monitoring and facility-management applications (Pan et al., 2022).

BIM literature and ISO 19650 converge on structured information management rather than three-dimensional representation alone, with emphasis on information requirements, roles, exchange, versioning and collaborative management across the asset lifecycle (ISO, 2018; Volk et al., 2014). In housing estates, coordinated BIM can organise dwelling types, spaces, components, roads, drainage, utilities, landscape assets, schedules and specifications. A common data environment provides the managed process for information exchange and version control rather than being synonymous with BIM itself. These records can complement inspection and market evidence in valuation when provenance, update status and limitations are explicit (ISO, 2018; IVSC, 2024; RICS, 2024).

Digital-twin approaches extend this information environment by connecting physical assets with operational observations. They may combine BIM, GIS, asset registers, sensors, inspections, meters, maintenance histories, resident reports and valuation records. For analytical consistency, this review adopts a working distinction in which a digital model is updated mainly through manual processes, a digital shadow incorporates predominantly one-way physical-to-digital updating, and a digital twin maintains an operationally updated relationship between physical and digital assets capable of supporting feedback and decision-making (Fuller et al., 2020; Sepasgozar, 2021). Because digital-twin taxonomies vary across the literature, these categories are used as analytical conventions rather than universal definitions. The distinction matters because lifecycle-value claims require evidence that is current, traceable and suitable for the decision being made.

Table 3: Architectural and valuation functions across the housing-estate lifecycle

Lifecycle phase	Architecture / BIM contribution	Digital, computational and AI/digital-twin contribution	Estate valuation use
Feasibility	Site constraints, housing mix, area schedules, climate response and information requirements.	Demand, affordability, climate and risk scenario analysis.	Development feasibility, property attributes, cost assumptions and market context.
Design	Coordinates spatial form, envelope, accessibility, structure, services, roads, drainage, utilities and specifications.	Option comparison using BIM and performance simulation; rule-based checking and clash detection; daylight and energy analysis; and, where suitable data exist, AI-assisted prediction, classification or optimisation.	Evidence on specification, utility, adaptability and anticipated operating or renewal implications.

Construction and handover	Verified as-built information, asset IDs, product data, warranties, schedules and design changes.	Defect tracking, progress intelligence, image analysis and validation.	Traceable record of condition at completion, components, tenure-relevant attributes and capital expenditure.
Occupation	Asset and spatial information base for post-occupancy evaluation and alteration control.	Energy/water monitoring, complaints, anomaly detection and maintenance analytics.	Inspection support, operating-cost evidence, service-charge context, depreciation and marketability indicators.
Renewal and valuation	Condition feedback informs retrofit design, adaptation, material replacement and future prototypes.	Failure prediction, retrofit prioritisation and lifecycle analytics.	Renewal liability, obsolescence, lifecycle cost, income and market evidence for value analysis.

Sources: Boje et al. (2020), M. Deng et al. (2021), Douglas et al. (2021), ISO (2018, 2020, 2024), Opoku et al. (2021), Pan and Zhang (2021, 2023), Sepasgozar (2021), Omrany et al. (2023), Tuhaise et al. (2023), Yang et al. (2024), IVSC (2024), and RICS (2024).

The transition from BIM to digital-twin operation requires stable asset identifiers, reliable data flows, interoperable schemas, governance and defined update responsibilities (Boje et al., 2020; M. Deng et al., 2021; Douglas et al., 2021; Omrany et al., 2023; Opoku et al., 2021; Revolti et al., 2024; Tuhaise et al., 2023; Yang et al., 2024). ISO 16739-1:2024 establishes Industry Foundation Classes for open BIM information exchange, while ISO 19650-1:2018 provides information-management principles and ISO 19650-3:2020 addresses information management during the operational phase of assets (ISO, 2018, 2020, 2024). For architectural and valuation use, the literature and valuation standards link persistent information quality to traceable provenance, update history and their relationship with physical inspection (IVSC, 2024; RICS, 2024).

Taken together, the literature supports a layered rather than strictly technological sequence: BIM and information-management processes establish the structured asset-information base; operational records and digital-twin functions maintain links with performance in use; AI may augment prediction, classification and optimisation where justified; and estate valuation interprets relevant condition, cost, income, market and risk evidence within recognised valuation bases and methods (Boje et al., 2020; M. Deng et al., 2021; IVSC, 2024; RICS, 2024). Accordingly, the proposed framework evaluates the combined system by its contribution to information continuity, traceability and decision usefulness rather than by technological complexity alone.

Nigerian Digital Readiness and Adoption Constraints

Nigerian construction-sector evidence relevant to housing estates indicates uneven BIM and digital-twin maturity, with recent studies reporting software and training costs, skills shortages, limited awareness and client demand, interoperability problems, fragmented supply chains and weak institutional support (Bamgbose et al., 2024; Bello & Ayegba, 2025; Bello et al., 2025; Ekemode, 2024). Post-construction BIM use is similarly constrained by infrastructure, education, awareness and implementation capacity (Ikediashi et al., 2025). These sector-wide findings are treated as contextual readiness evidence rather than direct proof of conditions in every Nigerian housing estate.

Operational digital twins add requirements for reliable asset data, connectivity, data ownership, security, update responsibility and interpretive capacity. Nigerian studies identify system integration, organisational capability, data management, investment and human-resource constraints, reinforcing the wider readiness literature that treats information maturity as a prerequisite for more advanced twin functions (Alnaser et al., 2024; Bello et al., 2025; Ibrahim et al., 2026).

The synthesis therefore proposes a dependable information base as an initial implementation threshold comprising coordinated BIM records, stable dwelling and component identifiers, georeferenced infrastructure information, verified digital handover, inspection and defect registers, maintenance histories, utility records and valuation-relevant property data (Alnaser et al., 2024; Bello & Ayegba, 2025; Ikediashi et al., 2025; Omrany et al., 2023). This is presented as a proposed readiness threshold requiring empirical testing rather than an established Nigerian standard. Selective sensing and predictive analytics are more defensible when these records are complete, maintained and linked to defined architectural or valuation decisions.

Interoperability affects the long-term usability of design and asset information when architects, clients, contractors, estate valuers and service providers use different platforms. IFC provides an open international standard for BIM information exchange across construction and facility-management applications (ISO, 2024). Open exchange can support alteration, condition assessment, renewal analysis and valuation when accompanied by governance, inspection and clear information responsibilities (ISO, 2018, 2024; IVSC, 2024; RICS, 2024).

Architectural Information Coordination and Performance Feedback in Housing Estates

Housing-estate architecture operates across dwelling, block and site scales, linking orientation, access, roads, parking, drainage, utilities, landscape, public space, accessibility and maintenance access. BIM and information-management literature indicates that coordinated digital models and common information environments can make quantities, component identities, interfaces and coordination conflicts more visible before construction, while performance information can be retained for later evaluation (Pan & Zhang, 2023; Sacks, Girolami, & Brilakis, 2020; Zhang et al., 2022). AI methods may augment selected analytical tasks where appropriate datasets and evaluation criteria are available. This continuity connects spatial quality and maintainability with evidence from the occupied estate.

Architectural digital analysis may include rule-based checking and simulation-supported option comparison, while AI-specific applications include pattern recognition, classification, prediction and data-driven optimisation. These categories should remain analytically distinct because rule checking and conventional simulation are not inherently AI. Evidence across AI-construction and building-performance studies indicates that these methods are more reliable when evaluation criteria are explicit, and outputs remain subject to professional review against site, climate, regulation, culture, affordability and buildability (de Wilde, 2023; Pan & Zhang, 2021, 2023).

Briefing-stage information requirements can include plot and dwelling identifiers, spaces, materials, envelope components, roofs, openings, shared assets, meters, drainage, landscape elements, warranties, maintenance intervals, alteration histories and responsible parties. Lifecycle-information research indicates that records embedded and verified before handover provide a more durable basis for post-occupancy learning, condition assessment and later digital-twin integration (Dávila Delgado & Oyedele, 2021; Opoku et al., 2021; Su et al., 2023).

Lifecycle-information and digital-twin research supports extending architectural information beyond construction documentation so that inspection, maintenance, alteration, renewal and performance evidence can be related to design decisions (Dávila Delgado & Oyedele, 2021; Opoku et al., 2021; Su et al., 2023). Defect, overheating, energy, drainage, access and maintenance records can then inform later prototypes, details, material specifications, service routes and estate layouts rather than remaining disconnected operational records.

Estate Valuation, Asset Performance and Lifecycle Value

Estate valuation provides the economic interpretation of physical and operational evidence generated across the housing-estate lifecycle. Condition, as-built information, inspection findings, maintenance histories, service performance and renewal requirements can affect assumptions about depreciation, obsolescence, operating expenditure, risk and future expenditure. IVS requires appropriate data and inputs, recognised valuation approaches and documented models, while the RICS Red Book requires transparent investigation, valuation

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methods and reporting (IVSC, 2024; RICS, 2024). Digital information can support these processes when it supplements rather than substitutes physical inspection and market evidence.

Across facility-management and digital-twin studies, the practical value of operational data lies in the consistency of condition, service and maintenance records rather than in full automation alone. Recurrent roof leaks, drainage complaints, pump or streetlight downtime and maintenance-response patterns may indicate persistent design, service or operational problems when corroborated by inspection, work-order and asset-condition evidence (Arisekola & Madson, 2023; Hakimi et al., 2024; Hosamo et al., 2022; Wang & Chen, 2024). For valuation, the same histories can help distinguish isolated defects from recurrent conditions, cost and obsolescence issues when interpreted alongside physical inspection and market evidence (IVSC, 2024; RICS, 2024).

AI can support classification, forecasting, anomaly detection and information extraction from operational records through natural-language processing, computer vision and related methods; however, predictive output is neither a physical diagnosis nor a property-value opinion. Any resulting inference requires verification, contextual interpretation and documented professional judgement before informing architectural or valuation decisions (de Wilde, 2023; IVSC, 2024; Pan & Zhang, 2021; RICS, 2024; Wang & Chen, 2024).

Lifecycle evidence becomes valuation-relevant when condition and operational information can be related, where appropriate to the valuation purpose, to maintenance expenditure, deterioration, obsolescence, renewal liabilities, income, risk and market evidence, while recognised valuation approaches and professional judgement remain controlling requirements (IVSC, 2024; RICS, 2024). A digital estate-information system can therefore improve traceability, but the basis of value, assumptions and market evidence remain explicit professional requirements.

Table 4: Illustrative lifecycle-performance evidence for architectural feedback and estate-valuation analysis

Domain	Illustrative indicators	Primary evidence	Architectural / valuation use
Building condition	Defects by dwelling; roof leaks; water ingress; cracks; component age; alteration history.	Inspections; defect logs; complaints; as-built BIM.	Detailing and specification feedback; condition, depreciation and renewal evidence.
Water and drainage	Pump downtime; water availability; leakage; blocked drains; stormwater incidents.	Meters; pump logs; maintenance records; rainfall inspections.	Service and drainage redesign; operating-cost and service-risk evidence.
Energy and lighting	Energy intensity; abnormal use; streetlight uptime; solar-system downtime.	Meters; bills; inverter logs; inspections.	Envelope and systems feedback; utility-cost, efficiency and marketability evidence.
Maintenance efficiency	Response time; backlog; repeat failures; preventive-maintenance compliance.	Work orders; contractor reports; helpdesk records.	Maintainability feedback; lifecycle-cost and renewal-liability evidence.
Resident experience	Comfort; perceived safety; accessibility complaints; unresolved requests; public-space use.	Surveys; helpdesk; resident reports; post-occupancy evaluation.	Liveability design feedback; contextual evidence on utility and marketability.
Financial and lifecycle value	Service-charge recovery; cost per unit; arrears; sinking-fund adequacy; renewal backlog; and vacancy evidence, where relevant to estate tenure, management arrangement and valuation purpose.	Accounts; valuation reports; budgets; asset registers; market evidence.	Affordability, depreciation/obsolescence, renewal funding, income and value analysis.

Sources: Arisekola and Madson (2023), Bortolini et al. (2022), Hakimi et al. (2024), Hosamo et al. (2022), Lee et al. (2023), Wang and Chen (2024), IVSC (2024), and RICS (2024).

Note: These measures are illustrative evidence inputs for architectural feedback, asset management and valuation analysis. They are not standalone value determinants, and no causal effect on property value should be inferred without an appropriate valuation purpose, physical inspection, reliable market evidence, stated assumptions and application of a recognised valuation approach (IVSC, 2024; RICS, 2024).

Liveability, Resident Evidence and Data Governance

For this review, housing-estate liveability is considered through access, safety, comfort, public-space quality, service reliability, environmental resilience and patterns of social use, while digital-twin research increasingly integrates building, infrastructure and geospatial information at neighbourhood and city scales (T. Deng et al., 2021; Lei et al., 2023; Mazzetto, 2024; United Nations Human Settlements Programme, 2024; Weil et al., 2023; Xia et al., 2022). Resident experience and service reliability may provide contextual evidence concerning functional utility, recurrent service problems and, where supported by market evidence, marketability; they should not be treated as direct proxies for property value (IVSC, 2024; RICS, 2024).

Resident-feedback studies show that operational evidence is more complete when users participate in identifying faults and evaluating services rather than when datasets reflect only managerial or technical records (Lee et al., 2023; White et al., 2021). Complaints concerning comfort, access, security, drainage, water, lighting and shared spaces can therefore support architectural post-occupancy evaluation and provide estate valuers with contextual evidence about recurrent service or condition problems.

Housing-estate systems processing personal or potentially identifiable data—including access-control records, utility-use data, complaints, movement information or security data—require lawful, proportionate and purpose-limited governance. In Nigeria, the Nigeria Data Protection Act, 2023 and its General Application and Implementation Directive require organisations to identify controller/processor roles, lawful purposes, data categories, access arrangements, security and retention controls, and to assess higher-risk processing before deployment (Nigeria Data Protection Act, 2023; Nigeria Data Protection Commission, 2025). AI-supported processing additionally requires proportionate risk management, transparency, accountability and human oversight (ISO, 2023; OECD, 2024; UNESCO, 2021).

Table 5: Housing-estate data governance and access-responsibility matrix

Data class	Likely steward/role	Access for architecture/ management	Valuation use	Required controls
BIM, as-built and asset-register data	Owner/client information function; CDE custodian; appointed project/FM teams	Architects, FM and authorised contractors according to role	Property attributes, condition baseline, capital works and inspection preparation	Contractual custodianship; version history; role-based access; export/exit rights; audit trail
Maintenance, defect and condition records	Estate owner/manager or FM entity; processor status determined by actual processing role	FM, maintenance teams and architects for verified performance feedback	Condition, recurrence, depreciation/obsolescence and renewal evidence	Purpose limitation; minimum necessary fields; retention schedule; access logging

Utility, meter and sensor data	Controller/processor status depends on who determines purpose and means	Aggregate operational access by default; individual dwelling detail only where justified	Operating-cost and service-performance evidence where relevant	Data minimisation; aggregation/pseudonymisation; security; DPIA where processing is high risk
Resident complaints and POE responses	Estate manager/research or service function according to purpose	Aggregated feedback for design and service improvement	Contextual evidence on recurrent service or functional issues; not a direct value proxy	Privacy notice; lawful basis; restricted identifiers; retention limit; data-subject rights
Access, security and movement records	Estate/security function subject to controller/processor assessment	Strict need-to-know access; not routine architectural access	Normally excluded unless demonstrably relevant to the valuation purpose	Strong access control; high-risk assessment; limited retention; breach-response procedure
Valuation and market evidence	Valuer/client roles determined by engagement and processing purposes	Shared only where required for coordinated decision-making	Inspection, market, income, cost, condition and assumption evidence	Professional confidentiality; provenance; model/input documentation; restricted reuse; auditability

Source: Authors' governance synthesis based on ISO (2018, 2020), IVSC (2025), the Nigeria Data Protection Act (2023), and the Nigeria Data Protection Commission (2025). Controller/processor status must be determined from the actual processing arrangement; the table is an implementation guide, not a legal determination for every estate.

Data ownership or contractual custodianship should not be conflated with data-protection controllership. Controller and processor status depends on the actual determination of processing purposes and means. At the same time, ownership, licence, portability, handover and permitted reuse of BIM and estate records should be allocated contractually through the common data environment, estate-management agreements and professional appointments. Role-based access should follow a minimum-necessary principle: architects require design and post-occupancy evidence relevant to performance feedback; property and facilities managers require operational records; and estate valuers should receive only the condition, cost, income, market and service evidence required for the valuation purpose. Resident-level data should be aggregated or pseudonymised where individual identification is unnecessary, with identifiable data restricted to a lawful and documented purpose. Retention periods, audit logs, breach response, export/exit rights and deletion or return arrangements should be defined before deployment (ISO, 2018, 2020; IVSC, 2025; Nigeria Data Protection Act, 2023; Nigeria Data Protection Commission, 2025).

Architecture-Led Implementation Framework for Lifecycle-Value Decision Support

The reviewed evidence supports a proposed incremental pathway in which verified architectural and asset information, defined lifecycle use cases and valuation-relevant data requirements precede investment in more complex sensing, analytics or digital-twin functions. Advanced real-time twins depend on reliable as-built records, stable asset identifiers, inspection histories, cost and market data, connectivity, update responsibilities and trained personnel (Alnaser et al., 2024; Bello et al., 2025; Ikediashi et al., 2025; IVSC, 2024; Omrany et al., 2023). The five-stage framework therefore links architectural briefing and BIM coordination with operational evidence and estate valuation, adding AI and sensing only where a defined lifecycle use and measurable decision benefit can be demonstrated.

Table 6: Proposed incremental architecture and estate-valuation implementation pathway

Stage	Architectural action	Estate valuation action	Digital outcome
1. Brief and readiness	Define spatial, environmental and performance criteria; BIM uses; information requirements and post-occupancy measures.	Define valuation-relevant property, cost, condition, income and market data requirements.	Digital objectives are tied to design performance and lifecycle value.
2. BIM coordination	Coordinate dwelling, envelope, access, landscape, infrastructure and service information; verify model quality.	Review property attributes and information needed for later inspection, cost and value analysis.	Consistent architectural and asset information base.
3. Digital handover	Deliver verified as-built model, schedules, warranties, alterations, asset identifiers and access information.	Establish baseline property and condition records and link relevant capital-cost information.	Traceable handover suitable for post-occupancy use and valuation evidence.
4. Operational evidence	Capture post-occupancy comfort, defects, utilities, maintenance, accessibility and resident feedback.	Track condition, operating costs, service charges, renewal backlog, vacancy and market-relevant changes.	Evidence base for design feedback, condition analysis and lifecycle-value assessment.
5. Selective operational integration and digital-twin capability	Introduce sensing, operational data links, AI or simulation selectively where each method supports a defined performance, maintenance, retrofit or future-design decision.	Use validated digital evidence only where it is relevant to lifecycle-cost, obsolescence, renewal or professional valuation analysis.	Iterative architectural learning and more traceable evidence for lifecycle-cost, renewal and professional valuation decisions.

Sources: Alnaser et al. (2024), Bello and Ayegba (2025), Bello et al. (2025), de Wilde (2023), Ikediashi et al. (2025), ISO (2017, 2018, 2020, 2024), Omrany et al. (2023), Pan and Zhang (2021, 2023), Tuhaise et al. (2023), IVSC (2024), and RICS (2024).

Within the analytical scope of the framework, architecture leads briefing, spatial and environmental design, BIM information requirements, asset-information coordination and interpretation of post-occupancy evidence. At the same time, estate valuation interprets property, condition, cost, service, income and market evidence within recognised valuation bases and methods. Implementation may additionally require engineering, facilities-management, cost, information-management and data/AI expertise. These linked roles preserve discipline-specific professional judgement while using a shared information environment (ISO, 2018; IVSC, 2024; Opoku et al., 2021; RICS, 2024).

Readiness studies and valuation standards support defining digital maturity by the usefulness, reliability and governance of information rather than by the number of sensors or software platforms. Each additional sensing, analytics or digital-twin layer therefore requires a stated decision purpose, information owner, validation procedure and measurable outcome, particularly where acquisition and maintenance costs are material (Alnaser et al., 2024; Bello et al., 2025; IVSC, 2024; RICS, 2024). Economic viability can be tested through life-cycle costing by comparing the present value of acquisition, installation, connectivity, calibration, maintenance, replacement, cybersecurity, training and governance costs against monetised benefits such as avoided emergency maintenance, reduced utility losses, reduced inspection effort or avoided service downtime (ISO, 2017).

For a decision horizon n and discount rate r, selective sensing is financially defensible when net present value NPV = Σ[Bt/(1+r)^t] − {C0 + Σ[Ct/(1+r)^t]} is at least zero and the discounted benefit-cost ratio is at least 1.00, where C0 is initial investment, Ct is recurring/replacement cost and Bt is monetised decision benefit. Benefits that cannot be defensibly monetised should be reported separately rather than converted into speculative cash values. Table 7 provides a worked break-even example using hypothetical inputs solely to demonstrate the calculation.

Table 7: Illustrative lifecycle-cost break-even test for selective sensing

Parameter	Illustrative input/result	Decision interpretation
Estate scale	100 dwellings	Worked example only; not an observed project.
Initial hardware, installation and integration (C0)	₦6.00 million	Hypothetical procurement input.
Annual connectivity, calibration, maintenance and governance cost	₦1.20 million/year	Recurring cost included for years 1–10.
Major replacement/upgrade	₦2.00 million in year 5	Illustrative mid-life replacement allowance.
Analysis horizon and discount rate	10 years; 15%	Scenario assumptions, not a prescribed Nigerian rate.
Present value of lifecycle costs	₦13.02 million	Initial + discounted recurring + discounted replacement costs.
Break-even equivalent annual quantified benefit	₦2.59 million/year	Minimum annual monetised benefit required for NPV ≥ 0 at the stated assumptions.
Discount-rate sensitivity	10%: ₦2.38m/yr; 20%: ₦2.82m/yr	Higher discount rates raise the annual break-even benefit.
Deployment rule	Proceed only if NPV ≥ 0 and BCR ≥ 1.00	Information maturity, governance, data quality and professional need must also be satisfied.

Source: Authors' illustrative calculation using ISO 15686-5 life-cycle-costing principles (ISO, 2017). The monetary values are hypothetical test inputs, not Nigerian market quotations or empirical findings. A real pilot should replace them with supplier quotations, observed staff time, utility losses, maintenance costs and measured service-performance benefits.

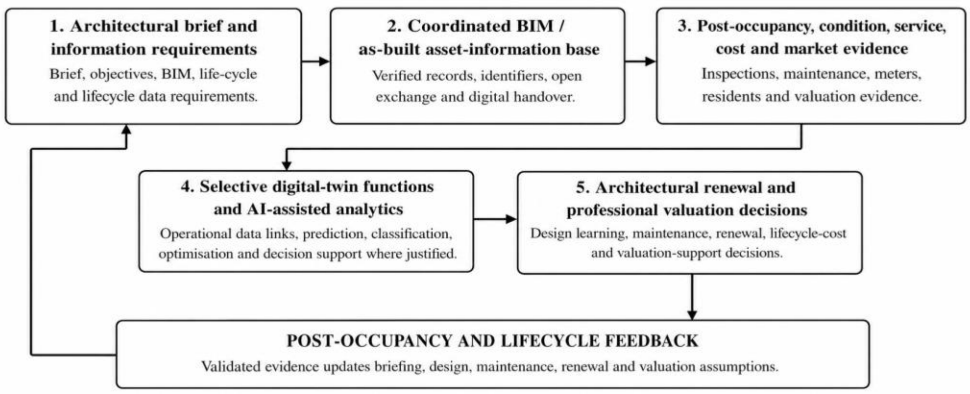

Figure 1: Proposed architecture–estate valuation lifecycle-information framework integrating BIM, operational evidence, selective digital-twin functions and AI-assisted analytics for Nigerian housing estates.

Sources: Dávila Delgado and Oyedele (2021), ISO (2018, 2020, 2024), Lu et al. (2020), Opoku et al. (2021), Pan and Zhang (2021, 2023), Pregnolato et al. (2022), Revolti et al. (2024), Mazzetto (2024), Bello and Ayegba (2025), Bello et al. (2025), Ikediashi et al. (2025), IVSC (2024, 2025), and RICS (2024).

DISCUSSION

The synthesis supports an architecture-led lifecycle-information model rather than technology accumulation as an end in itself. BIM and information-management processes provide the structured architectural and asset baseline; operational data and digital-twin functions maintain links with performance in use, and AI can add analytical capacity where data quality and decision purpose justify its use. The central trade-off is between analytical capability and information maturity: additional sensing, AI or digital-twin functionality can increase decision support but can also amplify poor data, interoperability problems, maintenance burdens, cybersecurity exposure and professional uncertainty where the underlying asset-information base is incomplete (Boje et al., 2020; M. Deng et al., 2021; Opoku et al., 2021; Revolti et al., 2024; Sacks, Brilakis, et al., 2020). The architectural significance lies in preserving design intent and learning from performance; the valuation significance lies in improving the traceability of condition, cost and asset evidence.

The Nigerian studies reviewed indicate that local adoption constraints materially influence the level of BIM and digital-twin maturity that can be implemented reliably. Where BIM adoption and post-construction information are weak, this review therefore cautions that additional digital-twin complexity may reproduce existing data-quality and information-management limitations rather than resolve them. Nigerian adoption studies therefore support verified architectural records, digital handover, condition information and consistent operational evidence as the initial information base (Bello & Ayegba, 2025; Bello et al., 2025; Ikediashi et al., 2025).

Lifecycle-value analysis should distinguish life-cycle cost analysis from property valuation. Life-cycle cost analysis can compare relevant acquisition, operation, maintenance, renewal and disposal costs over an agreed analysis period, while property valuation remains governed by recognised valuation bases, relevant market evidence and professional judgement (ISO, 2017; IVSC, 2024; RICS, 2024). Digital investment should therefore be evaluated against demonstrable decision benefits rather than technological novelty alone.

Professional accountability remains a governing condition of digitally and AI-supported design and valuation. AI may rank alternatives, detect patterns, classify records or support modelling, but such outputs do not displace statutory or professional responsibilities within the applicable discipline. For valuation, current IVSC guidance specifically reinforces the continuing requirement for competent professional judgement in AI-enabled valuation processes (Architects (Registration, Etc.) Act, 2004; Estate Surveyors and Valuers (Registration, Etc.) Act, 2004; IVSC, 2024, 2025; RICS, 2024). Responsible-AI implementation additionally requires transparent assumptions, proportionate risk management and human oversight (ISO, 2023; OECD, 2024; UNESCO, 2021).

Taken together, Nigerian adoption evidence and international digital-twin literature support a staged pathway beginning with information management and digital handover, followed by measured performance and selective predictive functions once the evidence base is reliable (Alnaser et al., 2024; Bello & Ayegba, 2025; Bello et al., 2025; Ikediashi et al., 2025; Opoku et al., 2021). For architecture, this preserves feedback between design and performance in use; for estate valuation, it improves the traceability of condition, cost, income, risk and market inputs without displacing inspection or professional judgement (IVSC, 2024; RICS, 2024).

Implications for Practice, Policy and Research

For project inception, the reviewed evidence supports defining estate information requirements around specific architectural, maintenance, renewal and valuation use cases. BIM uses, dwelling and asset identifiers, open handover formats, access rights, update responsibilities and minimum post-occupancy records provide a traceable basis for later digital-twin and valuation use (Bello & Ayegba, 2025; ISO, 2018, 2020, 2024; IVSC, 2024).

For architectural practice, digital and AI-assisted analysis is most defensible when performance criteria, information quality, maintainability and post-occupancy feedback are documented and reviewed. Relevant criteria include climate response, accessibility, spatial quality, material performance, service coordination, maintenance access and adaptability, with operational evidence returned to later estate briefs and prototypes (de Wilde, 2023; Opoku et al., 2021; Pan & Zhang, 2023). Rule-based BIM checking and conventional performance simulation should be distinguished from AI-specific prediction or optimisation.

For estate valuation, BIM and digital-twin information can improve access to property, condition and lifecycle records, but recognised valuation approaches, physical inspection, market evidence, stated assumptions, data quality and professional judgement remain controlling requirements (IVSC, 2024; RICS, 2024). Condition evidence can be linked with lifecycle cost, depreciation, obsolescence, renewal funding, service-charge context, marketability and property value only where relevant to the valuation purpose and supported by appropriate market evidence.

For Nigerian housing-estate pilots, the evidence supports testing a staged approach beginning with defined architectural and asset-information requirements, interoperable digital handover and consistent operational records before investment in comprehensive real-time digital-twin systems. A minimum validation design should establish a pre-intervention baseline, document information completeness and existing maintenance/service performance, introduce only use-case-specific digital functions, and track the same outcomes for at least 12 months; a matched comparison estate should be used where feasible. Pre-specified outcomes should include information completeness, defect recurrence, maintenance response time, utility/service downtime, staff inspection time, resident complaints, valuation-file completeness, implementation cost and lifecycle-cost performance. Procurement can specify open exchange, data-protection compliance, update responsibilities and the condition, cost, income or renewal data required for defined decisions; each additional layer should be linked to an explicit use case, responsible information owner, validation procedure and measurable outcome (Bello & Ayegba, 2025; Bello et al., 2025; ISO, 2018, 2024; Nigeria Data Protection Act, 2023).

Professional development for architects should increasingly address BIM information management, interoperability, building-performance analysis, post-occupancy evaluation, digital handover and responsible data use. Estate-valuation education should correspondingly strengthen competence in digital asset information, data quality, lifecycle-cost analysis, condition evidence, valuation modelling and responsible AI-supported analysis. Professional judgement and statutory responsibility nevertheless remain discipline-specific.

Empirical research should test the framework across Nigerian public, private, institutional and cooperative housing estates using longitudinal multi-case designs. Comparative baseline or control cases should be used where feasible to determine whether digital interventions produce measurable incremental benefits in information quality, defect recurrence, environmental and service performance, maintenance response, lifecycle cost, user experience, interoperability and valuation evidence. Cost evaluation should report acquisition, installation, connectivity, calibration, replacement, cybersecurity, training and governance separately, then apply NPV and benefit-cost criteria using observed project data. The illustrative threshold in Table 7 is therefore a test structure, not a market-cost claim; empirical pilots should replace every assumed input with verifiable quotations and measured benefits.

Limitations

This review is limited by its critical structured narrative design, heterogeneous evidence base and absence of pooled effect estimation. The original database search log did not retain database-level retrieval totals, duplicate-removal counts, full-text exclusion counts or individual search dates; Supplementary Figure S1 therefore reports those unavailable historical values as NR rather than reconstructing them. PRISMA terminology is used only as a reporting aid, and the review is not presented as a fully PRISMA-compliant systematic review. A single numerical risk-of-bias instrument was also not applied because the corpus combines reviews, conceptual studies, technical demonstrations, bibliometric analyses and empirical adoption studies; the structured appraisal instead reports methodological transparency, directness, contextual relevance and transferability. Much of the Nigerian evidence concerns construction-sector BIM and digital-twin readiness rather than longitudinal operation of occupied housing estates. Evidence directly linking AI–BIM–digital twin adoption to property-value outcomes is particularly limited; valuation claims are therefore restricted to improvements in information quality and decision support rather than demonstrated market-value effects. The proposed framework, governance matrix and financial decision rule remain to be validated with estate-specific longitudinal data.

CONCLUSION

The reviewed evidence supports a connected architectural and lifecycle-value decision-support system in which BIM and information-management processes structure design and asset information, AI can extend analytical capacity where appropriate data exist, and digital-twin functions can connect maintained information with condition, operation and resident evidence. Its potential value lies in reducing information discontinuity, strengthening performance feedback, improving maintenance and renewal evidence, and providing more traceable inputs for professional valuation; the magnitude of these benefits remains to be established empirically in Nigerian housing estates.

Architecture provides the design lens through briefing, spatial and environmental response, BIM information requirements, coordination, maintainability and post-occupancy learning. Estate valuation provides a complementary economic lens by interpreting inspection, condition, cost, depreciation, obsolescence, market, income and renewal evidence within recognised valuation bases and methods. Shared digital information can support both disciplines when provenance, quality, update status and limitations are documented. At the same time, implementation may additionally require engineering, facilities-management, cost, information-management and data/AI expertise.

For Nigerian housing estates, the synthesis supports information quality before automation, verified digital handover before advanced digital-twin deployment, explicit data-governance roles before resident-level data integration, and documented professional judgement before reliance on algorithmic outputs. The five-stage implementation pathway, governance matrix and lifecycle-cost break-even rule translate these principles into testable decisions. However, none constitutes evidence of realised performance or market value until validated on occupied estates. Digital systems should therefore be evaluated against measurable architectural, operational, maintenance, renewal and valuation-support outcomes rather than the presence or sophistication of technology alone.

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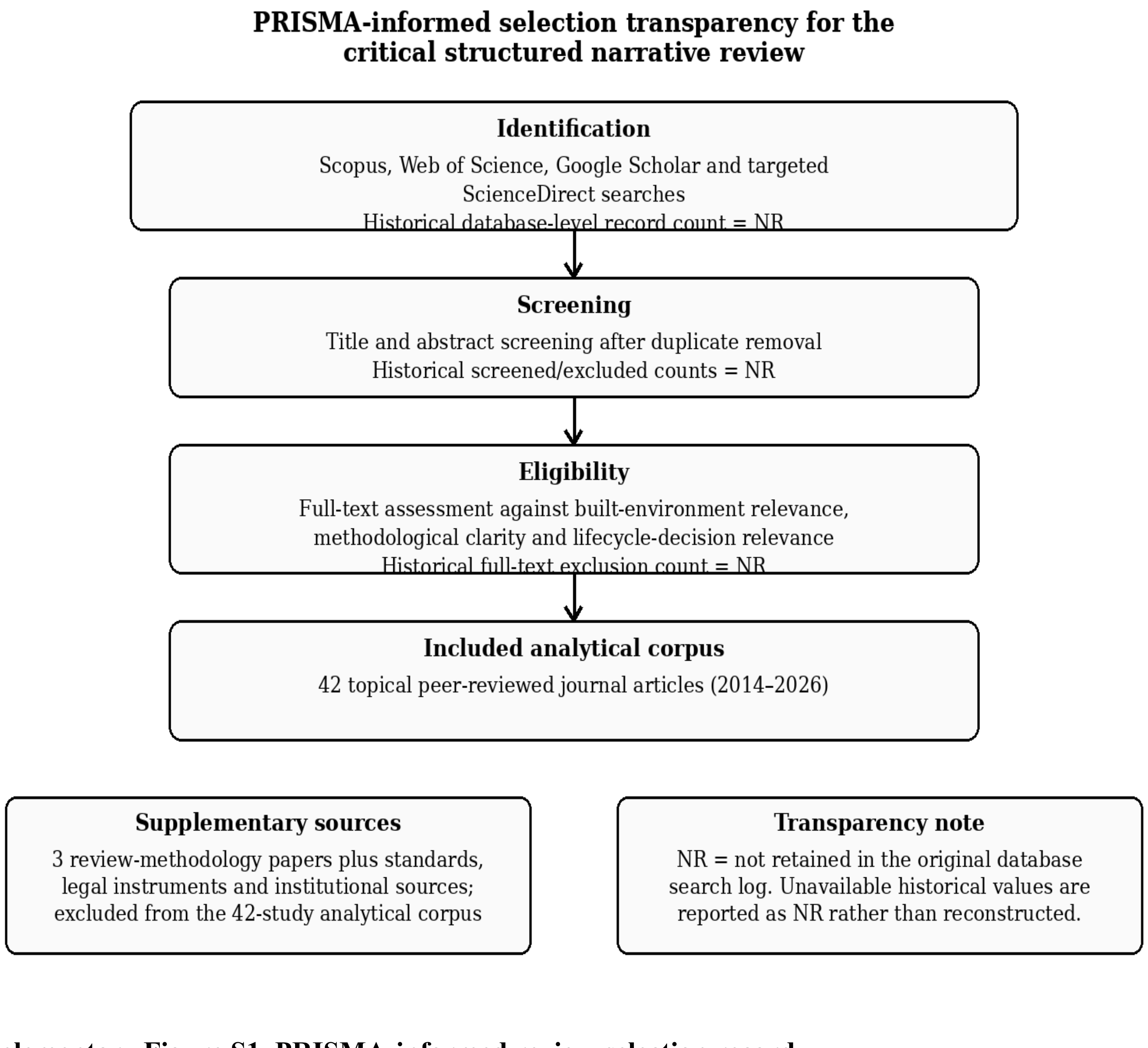
Supplementary Material



Supplementary Figure S1. PRISMA-informed review-selection record

Note: Reporting structure informed by PRISMA 2020 (Page et al., 2021). NR = not retained in the original database search log. The figure improves screening transparency but does not represent the article as a PRISMA systematic review.

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Supplementary Table S1. Reproducible search strategy and evidence-source framework

Search domain	Sources	Reproducible search expression	Analytical purpose	Eligibility/role
Core AI–BIM–digital twin integration	Scopus; Web of Science; Google Scholar; targeted ScienceDirect	("building information modelling" OR BIM OR openBIM OR IFC) AND ("digital twin*" OR "digital shadow") AND ("artificial intelligence" OR AI OR "machine learning")	Peer-reviewed built-environment studies on integrated digital workflows, information continuity and analytical capability.	2014–2026 topical analytical literature.
Architectural design and building performance	Scopus; Web of Science; Google Scholar; targeted ScienceDirect	("architectural design" OR "building performance" OR "design coordination") AND (BIM OR "digital twin*" OR "artificial intelligence")	Design coordination, performance evaluation, option comparison and post-design learning.	Built-environment relevance; methodological clarity.
Post-occupancy, FM and asset condition	Scopus; Web of Science; Google Scholar; targeted ScienceDirect	("post-occupancy evaluation" OR "facility management" OR maintenance OR "asset condition") AND (BIM OR "digital twin*" OR AI)	Operational evidence, condition monitoring, maintenance histories and information handover.	Evidence linked to lifecycle decisions.
Lifecycle cost and real-property valuation	Scopus; Web of Science; Google Scholar	("lifecycle cost" OR "life cycle cost" OR valuation OR "real-property valuation" OR depreciation OR obsolescence) AND (BIM OR "digital twin*" OR "asset information")	Evidence connecting digital asset information with cost, condition, renewal and valuation-relevant decisions.	Digital information treated as decision support, not a substitute for recognised valuation methods.
Interoperability and information management	Scopus; Web of Science; Google Scholar; ISO	(openBIM OR IFC OR "ISO 19650" OR interoperability OR "common data environment") AND (BIM OR "digital twin*")	Information requirements, exchange, provenance, identifiers, governance and handover.	Standards used as authoritative supplementary sources, not counted in 42-study corpus.
Nigeria and adoption/readiness	Scopus; Web of Science; Google Scholar; targeted ScienceDirect	(Nigeria* OR Nigerian) AND (BIM OR "building information modelling" OR	Context-specific evidence on cost, skills, infrastructure, awareness, client demand,	Nigerian evidence prioritised for adoption and transferability judgements.

		"digital twin*" OR "Construction 4.0") AND (adoption OR readiness OR barrier* OR "facility management" OR residential)	interoperability and organisational capacity.	
Governance, ethics and professional requirements	Institutional/legal sources: Nigeria Data Protection Act; Nigeria Data Protection Commission GAID; OECD; UNESCO; IVSC; RICS; NIESV; Architects Act; Estate Surveyors and Valuers Act	Targeted document-title and institutional searches for data protection, controller/processor duties, privacy-by-design, responsible AI, valuation standards, professional scope, access governance and auditability.	Authoritative governance, privacy, valuation and professional requirements for implementation.	Supplementary authoritative sources; excluded from the 42 peer-reviewed analytical corpus.

Note: This supplementary table operationalises the search concepts reported in the manuscript and provides an auditable framework for future reruns. Historical database-level retrieval totals and individual search dates were not retained in the original search log; these values are therefore reported as NR in Supplementary Figure S1. The final 42-study analytical corpus and reference list were audited for internal consistency and source validity on 25 August 2026.