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Smart Building Commissioning Framework for Fire Alarm, ELV and MEP Systems in Saudi Giga-Projects under Vision 2030

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Abstract- Commissioning of smart buildings in Saudi giga-projects requires more than discipline-by-discipline completion testing because fire alarm, extra-low-voltage (ELV), mechanical, electrical and plumbing (MEP), building automation, ICT, security and operational platforms interact during normal, abnormal and emergency conditions. This state-of-the-art review develops an integrated commissioning framework by synthesising recent peer-reviewed evidence from commissioning, fault detection and diagnostics, building automation, fire-safety sensing, BIM, digital twins, facility management, cybersecurity and Saudi digital-delivery research. The synthesis shows that reliable acceptance depends on lifecycle assurance, interface-centred functional and scenario testing, validated sensing and point-level data quality, a governed digital thread linking requirements to accepted states, and explicit organisational, contractual and cybersecurity controls. The proposed framework uses staged readiness and acceptance gates from owner requirements through design, pre-functional verification, functional performance testing, integrated systems testing, handover, soft landing and continuous commissioning. It preserves the authority of certified fire systems while requiring deterministic verification of dependent MEP and ELV responses. For Saudi giga-projects, the framework is aligned with the Saudi Building Code and Civil Defense approval environment, with additional HCIS obligations where applicable. BIM and digital twins add value only when they improve traceability, information continuity and operational decision-making. The framework is literature-derived and requires future expert and project-based validation before it should be treated as a validated Saudi benchmark.

Keywords: Smart building commissioning; fire alarm; ELV systems; MEP systems; integrated systems testing; BIM; digital twin; Saudi Arabia; Vision 2030

I. INTRODUCTION

Saudi Arabia's giga-projects combine unusual scale, accelerated delivery programmes, dense digital infrastructure, mixed-use occupancy, and stringent expectations for safety, reliability, sustainability, and operational readiness. In this environment, commissioning cannot be reduced to a late-stage checklist performed after installation. It is a lifecycle assurance process that converts design intent into demonstrable system performance and provides evidence that interconnected building services behave correctly in normal, degraded, and emergency modes. This requirement is particularly important for fire alarm, extra-low-voltage (ELV), and mechanical, electrical and plumbing (MEP) systems because their interfaces determine whether a smart building responds coherently to alarms, occupancy changes, utility failures, smoke-control commands, access events, and equipment faults.

Recent commissioning research shows that systematic verification can deliver measurable operational value, but performance can deteriorate without follow-up (Crowe et al., 2020; Ruffin et al., 2021; Ssembatya et al., 2021). Building automation and fault-detection studies similarly indicate that data quality, sensor configuration, control logic, and diagnostic capability materially affect whether installed systems achieve intended outcomes (Lin et al., 2020; Mirnaghi and Haghighat, 2020; Zhang et al., 2021). These findings are relevant to Saudi giga-projects, but they do not by themselves resolve the coordination problem created when life-safety systems, ICT networks, security platforms, building management systems, power infrastructure, vertical transportation, HVAC, water systems, and smart applications are procured through different packages and accepted by different stakeholders.

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The commissioning challenge is therefore a system-of-systems problem. Fire alarm systems must remain code-compliant and independent while exchanging carefully governed signals with smoke control, lifts, access control, public address or voice evacuation, emergency power, and the BMS. ELV systems add another layer of gateways, network services, time synchronisation, identity management, cybersecurity, and data ownership. MEP systems contribute dynamic plant sequences whose performance depends on sensors, actuators, balancing, controls, and utility availability. The building management system is conventionally treated as an integration layer connecting HVAC, electrical, fire, and security functions; this review extends that structure into a commissioning-focused lifecycle framework rather than reproducing its technical narrative.

The Saudi context adds an implementation dimension. Studies of BIM adoption in the Kingdom identify continuing needs around skills, organisational readiness, information exchange, contractual frameworks, and coordinated government or client initiatives (Al-Hammadi and Tian, 2020; Al-Yami and Sanni-Anibire, 2021; Alaboud and Alshahrani, 2023; Algahtany et al., 2023; Iqbal et al., 2025). For giga-projects aligned with Vision 2030, these issues matter because digital delivery is valuable only when information requirements, test evidence, asset data, and operational responsibilities survive handover. This review therefore examines commissioning as a digitally enabled governance process that links requirements, design, installation, testing, integrated scenario verification, acceptance, handover, and continuous performance assurance. This paper should also be read alongside the companion manuscript, 'AI-Enabled Fire Detection and Predictive Safety Monitoring for Smart Buildings in Saudi Arabia under Vision 2030' (2026). The companion paper addresses detection, prediction and AI-enabled situational intelligence; the present paper addresses the commissioning and assurance regime required to verify and accept such capabilities. The division of labour is therefore explicit and avoids treating the two frameworks as duplicate contributions.

II. AIM OF THE STUDY

The study aims to develop an evidence-based smart building commissioning framework for fire alarm, ELV, and MEP systems in Saudi giga-projects. It synthesises commissioning, building automation, fault diagnostics, BIM, digital twin, fire safety, cybersecurity, facility management, and Saudi digital-delivery research to identify how technical verification, information management, interface governance, and operational readiness can be integrated across the project lifecycle.

III. RESEARCH OBJECTIVES

1. To synthesise recent evidence on commissioning effectiveness, continuous commissioning, and diagnostic verification for complex building services.
2. To identify critical interfaces and failure pathways linking fire alarm, ELV, BMS, electrical, HVAC, plumbing, security, and vertical-transport systems.
3. To evaluate how BIM, digital twins, structured asset data, sensing, and fault diagnostics can strengthen commissioning evidence and handover quality.
4. To examine organisational, contractual, cybersecurity, and capability conditions affecting integrated commissioning in the Saudi construction context.
5. To propose a staged commissioning framework and research agenda suitable for large, digitally intensive Saudi giga-projects.

IV. RESEARCH QUESTIONS

RQ1. Which lifecycle commissioning activities are most important for assuring performance of interconnected fire alarm, ELV, and MEP systems?
RQ2. How should cross-system interfaces and emergency sequences be verified without weakening the functional independence of life-safety systems?
RQ3. How can BIM, digital twins, sensors, and fault-detection analytics improve traceability, test quality, and operational handover?
RQ4. Which governance, cybersecurity, contractual, and workforce factors shape implementation in Saudi large-capital and giga-project environments?
RQ5. What integrated commissioning framework can connect requirements, field testing, scenario

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validation, acceptance evidence, and continuous performance assurance?

V. REVIEW METHODOLOGY

A state-of-the-art review with structured thematic synthesis was selected because the topic spans engineering commissioning, fire safety, controls, ELV, information management, cybersecurity and facility operations. The objective is not to claim exhaustive systematic-review coverage or a statistically pooled evidence base, but to critically synthesise recent, directly relevant literature and translate it into a testable commissioning framework. This framing is appropriate because the available studies use heterogeneous outcomes, building types, test procedures and technology maturity levels.

Searches were organised across Scopus, Web of Science Core Collection, IEEE Xplore, and major publisher platforms including ScienceDirect, SpringerLink, Taylor & Francis, Emerald Insight, and MDPI. The principal publication window was January 2020 to December 2025. We executed search strings as several linked streams rather than one restrictive Boolean chain. Core terms included “building commissioning”, “continuous commissioning”, “retro-commissioning”, “functional performance testing”, “building automation”, “fault detection and diagnostics”, “fire detection”, “fire alarm”, “life safety”, “ELV”, “MEP”, “BIM”, “digital twin”, “facility management”, “asset information”, “interoperability”, “BACS cybersecurity”, “Saudi Arabia”, and “Vision 2030”. Snowball checks were used only to locate recent peer-reviewed papers directly relevant to an identified theme.

Eligible records were English-language, peer-reviewed journal articles published within the stated period, relevant to non-trivial building or infrastructure systems, and capable of informing at least one commissioning stage: requirements, design review, installation verification, functional testing, integrated testing, handover, or ongoing optimisation. We included Saudi studies when they informed BIM adoption, organisational readiness, governance, or digital delivery. Records were excluded when they were vendor marketing materials, standards without peer review, duplicate versions, residential smart-home studies with limited transferability, isolated algorithms lacking a building-systems implication, or publications whose bibliographic details or DOI could not be verified. Standards remain important in practice, but they were not counted within the scholarly evidence base because the synthesis is restricted to peer-reviewed journal literature; they are discussed in the text where they govern acceptance.

Records were screened through successive title, abstract and full-text relevance checks where available. Because a complete database-export and duplicate-removal log was not preserved across all publisher platforms, this paper does not report reconstructed retrieval, exclusion or PRISMA-style counts. The evidence base should therefore be interpreted as a bounded state-of-the-art synthesis rather than an exhaustive systematic review. This transparent limitation avoids false precision and is carried into the interpretation of the proposed framework.

Quality assessment used a qualitative five-domain checklist: methodological transparency; relevance to building-system verification; clarity of data, case, or review boundaries; transferability to complex multi-system projects; and usefulness for lifecycle or operational decision-making. During synthesis, evidence was classified as direct commissioning evidence, enabling digital evidence, safety or integration evidence, or Saudi implementation evidence. We assigned higher interpretive weight to multi-building commissioning analyses, systematic reviews, and studies with explicit operational validation, while using conceptual digital-twin papers primarily to explain information architectures rather than to claim proven commissioning outcomes.

The synthesis followed a coded matrix linking each study to commissioning phase, system domain, evidence type, interface risk, digital mechanism, and implementation constraint. Comparison across codes produced five themes: lifecycle assurance and persistence; interface-centred integrated testing; data, sensing and fault diagnostics; BIM and digital-twin continuity; and governance, cybersecurity and Saudi delivery capability. Figure 1 summarises this evidence pathway, while Table 1 maps literature domains to

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commissioning implications. Methodological limitations arise from English-language selection, heterogeneous study designs, scarce published evidence from Saudi giga-project commissioning itself, and the rapid evolution of ELV and smart-building technology. These constraints are treated as boundaries on inference rather than filled with unsupported assumptions.

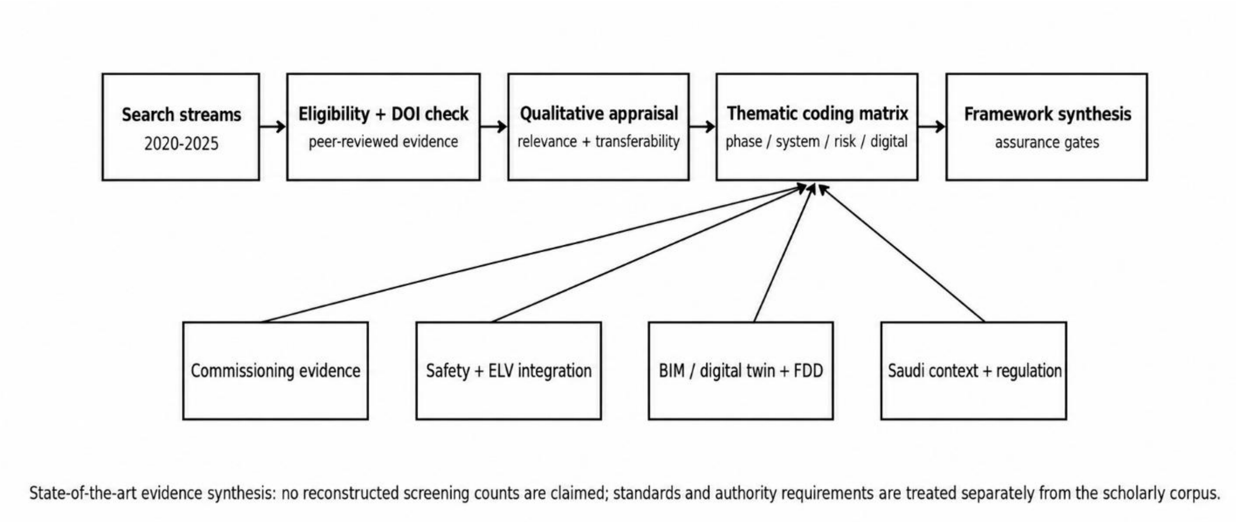

Figure 1. State-of-the-art evidence-synthesis pathway for commissioning framework development.

Table 1. Evidence domains and their implications for smart-building commissioning.

Evidence domain	Synthesized finding	Commissioning implication	Representative evidence
Commissioning and persistence	Verification produces operational benefits, but performance can drift after initial intervention.	Define baselines, acceptance metrics, retest logic and ongoing commissioning from the outset.	Crowe et al. (2020); Ruffin et al. (2021); Ssembatya et al. (2021); Jradi et al. (2020)
Sensors and FDD	Diagnostic performance depends on sensor selection, calibration, data quality and evaluation method.	Commission points, timestamps, ranges, units, alarms and analytics as an evidence system, not only as controls hardware.	Lin et al. (2020); Mirnaghi and Haghighat (2020); Zhang et al. (2021); Nelson and Culp (2022)
Fire and smart-building safety	Detection and evacuation functions increasingly interact with IoT and smart-building services.	Verify cause-and-effect end-to-end while preserving certified fire-system authority and fail-safe behaviour.	Birajdar et al. (2020); Sharma et al. (2020); Shaharuddin et al. (2023)
BIM, digital twins and FM	Lifecycle value depends on connected, semantically consistent and operationally usable information.	Link requirements, assets, points, tests, defects, retests and accepted states in a governed digital thread.	Boje et al. (2020); Lu et al. (2020); Deng et al. (2021); Tsay et al. (2022); Hakimi et al. (2024)
Saudi implementation context	Adoption is shaped by skills, organization, information exchange and contractual or policy support.	Make commissioning evidence, responsibilities and operational information explicit in employer requirements and contracts.	Al-Hammadi and Tian (2020); Alaboud and Alshahrani (2023); Algahtany et al. (2023); Iqbal et al. (2025)

VI. THEMATIC LITERATURE REVIEW AND CRITICAL ANALYSIS

Commissioning effectiveness is best understood as risk reduction through structured verification rather than as a single energy-conservation intervention. Crowe et al. (2020) show, across a large North American dataset, that commissioning delivers recurring energy and non-energy value, while Ruffin et al. (2021) demonstrate substantial savings across multiple building types. Ssembatya et al. (2021) add a critical lifecycle insight: savings degrade without follow-up, supporting a shift from one-time acceptance to ongoing assurance. Jradi et al. (2020) operationalise this idea through continuous performance testing using measured data and model-based comparison. For Saudi giga-projects, the transferable lesson is not the magnitude of overseas savings but the governance principle that acceptance should establish baselines, trend points, alarm logic, and testable performance criteria to support later recommissioning.

This evidence also exposes a limitation in conventional completion practices. Package-level inspections can confirm that devices are installed and individually functional while missing emergent interface failures. A smoke detector may correctly signal its fire alarm control panel. Yet, the building-level response can still fail if smoke-control fans do not start, dampers remain in normal position, access-controlled doors stay locked, lift recall is incorrectly mapped, or an emergency-power transition interrupts networked controllers. Fire-safety research emphasises early detection, reliable sensing, evacuation support, and coordinated smart-building response (Birajdar et al., 2020; Sharma et al., 2020; Shaharuddin et al., 2023). The commissioning implication is that life-safety acceptance requires both discipline integrity and cross-system scenario testing. Integration should never make the BMS the primary life-safety decision maker; instead, the BMS and other ELV platforms should receive or execute explicitly defined secondary commands while the certified fire system remains authoritative.

The second theme concerns sensors, controls, and fault diagnostics as commissioning infrastructure. Lin et al. (2020) show that fault detection and diagnostics can generate operational savings and that algorithm performance needs repeatable evaluation. Mirnaghi and Haghighat (2020) identify advantages and limitations of data-driven HVAC diagnostics, while Zhang et al. (2021) demonstrate that sensor placement, calibration, selection, and maintenance are inseparable from diagnostic performance. Nelson and Culp (2022) and Melgaard et al. (2022) further show that automated fault detection spans multiple methods and fault taxonomies rather than a universal algorithm. These studies shift attention from "smart" analytics as an add-on to data quality as a commissioning requirement.

Accordingly, a smart commissioning plan should define a point-level evidence model before functional testing begins. Every critical sensor and actuator should have a unique asset identifier, engineering range, units, calibration status, network address where applicable, alarm class, trend interval, command authority, fail-safe state, and relationship to the sequence of operations. Pre-functional checks should verify physical installation and I/O mapping; functional tests should then prove control sequences across expected operating envelopes. Where analytics are deployed, commissioning should challenge them with known fault conditions or controlled deviations and document sensitivity to missing, delayed, or erroneous data. This is especially important for giga-projects, where thousands of points can create a misleading impression of observability. At the same time, inconsistent naming, duplicate addresses, disabled alarms, or low-quality timestamps make the dataset operationally unreliable.

A third theme is information continuity from BIM to facility operations. Boje et al. (2020) argue that digital twins require more dynamic and semantically connected information than static BIM representations. Lu et al. (2020) demonstrate digital-twin-enabled anomaly detection using structured asset and operational data, while Deng et al. (2021) show the evolution from BIM toward intelligent representations integrating IoT and lifecycle information. Davila Delgado and Oyedele (2021) distinguish digital-twin conceptual and process models, and Opoku et al. (2021) identify applications and implementation challenges in construction.

Shahzad et al. (2022) and Hakimi et al. (2024) reinforce the importance of real-time integration, semantic interoperability, predictive maintenance, and lifecycle asset management.

For commissioning, these studies support a “digital thread” rather than a technology label. A useful digital twin is not a visually impressive model disconnected from test records. It is a governed relationship between requirement, asset, location, system, point, test script, defect, corrective action, retest, and final accepted state. BIM can provide spatial and asset context; the common data environment can control documents and workflows; BMS and ELV platforms provide dynamic telemetry; and analytics can expose deviations. The commissioning authority should therefore define information requirements early, including naming conventions, equipment hierarchies, interface matrices, cause-and-effect identifiers, test evidence formats, and ownership of operational data. Tsay et al. (2022) show that asset-information delivery remains challenging even when owner requirements are formalised, while Pinti et al. (2022) demonstrate that BIM-FM implementation is often fragmented. These findings caution against assuming that a model automatically becomes a usable operational information system.

The fourth theme is interface architecture and cybersecurity. O'Grady et al. (2021) show that building automation research spans architecture, benefits, and occupant interaction, highlighting the need for integrated feedback. Graveto et al. (2022) show that increasing connectivity of building automation and control systems expands the attack surface across management, automation, and field levels. In commissioning terms, interoperability and security must be tested together. A gateway that successfully exchanges BACnet, Modbus, KNX, API, or IP data is not necessarily acceptable if it uses default credentials, excessive privileges, flat network zones, insecure remote access, ungoverned cloud endpoints, or undocumented dependencies.

ELV commissioning should therefore include network segmentation checks, role-based access, credential handover, time synchronisation, backup and restore, logging, firmware baselines, secure remote-support arrangements, and failure-mode tests for loss of network or upstream services. Cybersecurity tests should not interfere with certified fire functions. Still, the project should verify that ancillary integrations fail safely and that a cyber event cannot silently suppress alarms, alter setpoints, or corrupt trend evidence. This creates a governance boundary: the commissioning team must coordinate safety, OT, ICT, cybersecurity, and vendor responsibilities without collapsing them into a single ownerless “integration” package.

The fifth theme concerns Saudi regulatory and delivery conditions. The Saudi Building Code provides the national building-control framework, with SBC 201 setting general building requirements and SBC 801 governing fire-protection requirements. Fire-alarm and associated life-safety systems are also subject to Saudi Civil Defense approval, inspection and witnessing processes, including the Salamah regulatory environment. Where a project or asset falls within the supervisory scope of the High Commission for Industrial Security (HCIS), applicable industrial-security and safety directives add further project-specific requirements. NFPA 72 may also form part of the adopted technical basis for fire-alarm documentation, record of completion, inspection, testing and maintenance where specified by the owner or approving authority. These instruments are implementation constraints rather than peer-reviewed evidence and therefore sit outside the scholarly corpus. Against that regulatory background, Al-Hammadi and Tian (2020) identify awareness, expertise, demand and data-sharing issues affecting BIM adoption. Al-Yami and Sanni-Anibire (2021) similarly describe benefits and barriers, while Alaboud and Alshahrani (2023), Algahtany et al. (2023) and Iqbal et al. (2025) emphasise competencies, organisational strategies and enabling structures. For giga-projects, authority interfaces must therefore be designed into the commissioning plan: the matrix should identify which systems require statutory approval or witnessed testing, which party owns submissions and records, and how project-level integrated tests complement rather than replace discipline-specific authority acceptance.

This context supports a staged framework in which commissioning begins with owner requirements and interface governance, continues through design and construction evidence, culminates in integrated scenario testing, and then transitions into data-enabled operational assurance. Li et al. (2022) show the value of predicting post-commissioning outcomes from multiple building parameters, reinforcing the need to consider commissioning as a multi-dimensional performance intervention. The proposed framework therefore uses acceptance gates rather than a single completion milestone. Each gate requires evidence that technical work, digital information, unresolved defects, safety dependencies, and operational responsibilities are mature enough to proceed. Table 2 defines these gates, and Figure 2 illustrates their lifecycle relationships.

A central analytical contribution of this review is the distinction between four evidence layers that are often conflated: installation conformity, functional conformity, integrated response and sustained performance. Installation evidence proves that equipment, cabling, labels, power supplies, addressing and field devices match approved documents. Functional evidence proves that each subsystem executes its own sequence under controlled stimuli. Integrated evidence proves that dependencies between systems produce the required building response. Sustained-performance evidence shows that the accepted configuration remains stable after occupancy, seasonal changes, software updates and maintenance intervention. Treating these as separate evidence classes improves defect attribution, acceptance decisions and post-handover traceability, and provides the conceptual bridge between the literature synthesis and the six-gate framework.

Fire alarm and ELV interfaces illustrate why this distinction matters. A cause-and-effect matrix is not itself proof of performance; it is a testable specification of intended relationships. Commissioning should select representative and worst-case scenarios covering alarm initiation, supervisory signals, fault conditions, power loss, network interruption, device isolation, staged evacuation where applicable, smoke-control mode changes, lift interfaces, door releases, and restoration to normal service. Each scenario needs preconditions, initiating action, expected response time, expected equipment states, operator indications, required confirmations, and safe reset criteria. Where several systems depend on a common network or gateway, tests should include loss of that dependency so the team can demonstrate graceful degradation. The objective is not to maximise interconnection. It is to prove that necessary interconnection is deterministic, documented, observable, and safe.

MEP commissioning similarly benefits from testing beyond nominal design points. Plant sequences should be challenged at minimum and maximum credible loads, lead-lag transitions, sensor failures, pump or fan trips, communication loss, utility restoration, and manual override conditions. Analytics can support this process, but automated diagnostics should complement, not replace, witnessed functional tests. Li et al. (2022) show that commissioning outcomes depend on multiple building parameters, reinforcing the need for context-sensitive acceptance rather than generic pass thresholds. A giga-project commissioning database should therefore preserve test context: outdoor condition, operating mode, occupancy assumption, equipment availability, software version, and temporary works status. Without this metadata, apparently successful trend plots may be impossible to interpret during disputes or later recommissioning.

Handover quality is the final bridge between construction and operations. The accepted point database, graphics, alarm priorities, schedules, passwords and role definitions, network drawings, backups, calibration records, final sequences, test scripts, open-item status, and operator training evidence should be treated as controlled operational assets. Digital-twin and BIM literature repeatedly identifies interoperability and lifecycle information continuity as unresolved challenges (Deng et al., 2021; Davila Delgado and Oyedele, 2021; Opoku et al., 2021). Commissioning can operationalise these concepts by requiring every critical handover object to link to an accepted system state. This prevents the familiar gap in which the physical building is commissioned, but the digital representation delivered to facilities staff reflects an earlier design or construction revision.

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Table 2. Proposed staged commissioning gates for Saudi smart-building giga-projects. Cx denotes commissioning.

Gate	Required evidence	Principal cross-system tests	Acceptance decision
G1: Owner requirements	OPR, system boundaries, authority interfaces, information requirements, cybersecurity principles.	Requirements workshops; interface-risk review.	Scope and decision rights sufficiently defined for design.
G2: Design readiness	Sequences, cause-and-effect matrix, network architecture, point schedules, BIM/asset schema, test philosophy.	Design simulations and interface reviews; failure-mode walk-throughs.	Design is testable and interfaces have owners.
G3: Pre-functional readiness	Installation checks, calibration, labels, addressing, I/O mapping, balancing status, software baselines.	Point-to-point checks; device and power-failure checks.	Subsystems are stable enough for functional testing.
G4: Functional performance	Approved scripts, stable sequences, trends, alarms, setpoints, local safeties, equipment responses.	Part-load, standby, failure, restart, manual override and recovery tests.	Each discipline proves intended functional performance.
G5: Integrated systems	Closed critical defects, current cause-and-effect, synchronized clocks, witnessed scenario scripts.	Fire/MEP/ELV scenarios, utility loss, network loss, access/lift/smoke-control dependencies.	Building-level responses are deterministic, safe and traceable.
G6: Handover + continuous Cx	Accepted asset data, backups, training, open-item plan, baselines, trend/FDD rules, seasonal plan.	Soft-landing reviews; repeated fault and seasonal tests.	Operations accept a maintainable evidence set and performance baseline.

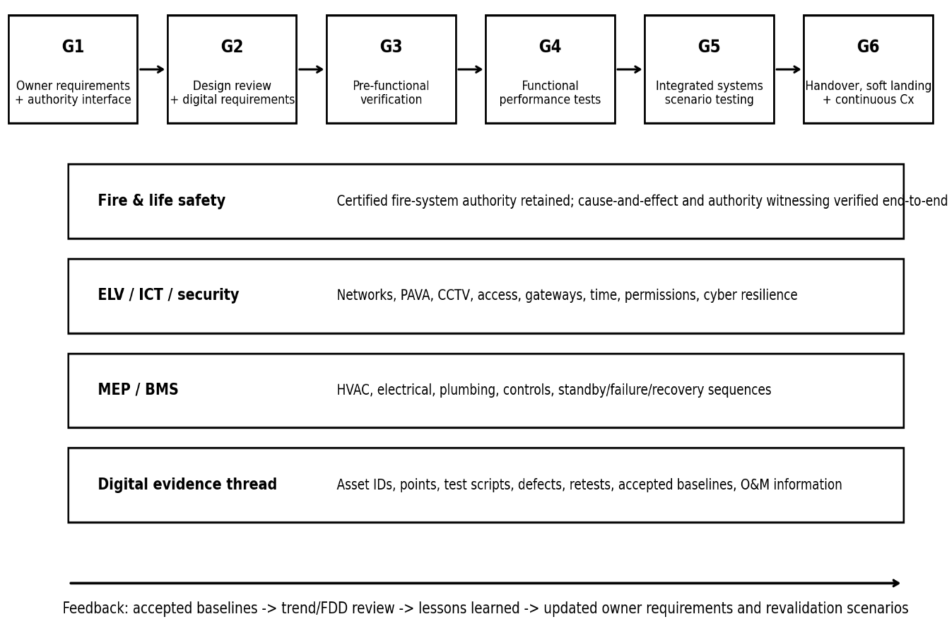

Figure 2. Lifecycle smart-building commissioning framework with authority interfaces, digital evidence and continuous assurance.

VII. DISCUSSION

The reviewed evidence suggests that the central commissioning risk in smart giga-projects is fragmentation. Fire alarm, ELV, MEP, BIM, ICT, and facility-management packages may each satisfy their local scope while the asset remains unproven as an integrated operational system. The proposed framework responds by making interfaces explicit commissioning objects. This changes the commissioning question from "has each contractor completed its tests?" to "is every required building response traceable from initiating condition through control logic, communication path, physical action, feedback signal, operator display, and recovery state?" Such traceability matters most for emergency sequences, because hidden assumptions between packages are most consequential under abnormal conditions.

The literature also distinguishes between digital evidence and digital complexity. BIM, digital twins, and analytics improve commissioning only when they reduce ambiguity and preserve reliable relationships between requirements and observed performance. Boje et al. (2020), Lu et al. (2020), and Hakimi et al. (2024) show the potential of connected lifecycle data. Still, Tsay et al. (2022) and Pinti et al. (2022) demonstrate that information delivery remains difficult. Consequently, a giga-project should prioritise controlled identifiers, asset schemas, point lists, interface matrices, test records, and defect closure before advanced visualisation. A simple but governed digital evidence chain is more valuable than a sophisticated twin fed by incomplete or unvalidated data.

A further implication concerns acceptance authority. Commissioning requires independence from installation progress reporting while remaining collaborative with designers, contractors, systems integrators, ICT teams, cybersecurity specialists, and facility operators. The framework therefore separates verification from ownership: contractors execute and rectify; designers clarify intent; specialist authorities confirm regulated functions; the commissioning authority coordinates evidence and challenges performance; and the owner decides acceptance based on defined criteria. This division reduces the risk that schedule pressure converts unresolved integration defects into post-handover operational problems.

Finally, treat continuous commissioning as a planned continuation of initial commissioning rather than a separate energy-management initiative. Baselines, trend logs, fault rules, test scripts, and accepted setpoints generated before handover can become the reference for early-life monitoring. Evidence on performance drift and ongoing commissioning (Jradi et al., 2020; Ssembatya et al., 2021) supports a soft-landing period in which alarms, overrides, comfort complaints, equipment cycling, network faults, and repeated defects are reviewed against the original acceptance evidence.

VIII. RESEARCH GAPS AND FUTURE RESEARCH

Five research gaps are evident. First, little peer-reviewed evidence documents integrated fire alarm, ELV, and MEP commissioning on Saudi giga-projects; future studies should report anonymised interface-defect taxonomies, retest cycles, and handover outcomes without compromising security-sensitive details. Second, commissioning research remains weighted toward energy and HVAC, whereas life-safety and ELV interface performance needs comparable empirical treatment.

Third, digital-twin research should move beyond conceptual capability toward controlled trials that compare commissioning productivity, defect detection, evidence quality, and post-handover fault recurrence with and without a structured digital thread. Fourth, cybersecurity commissioning needs methods that connect building OT acceptance to practical failure-mode testing, privilege verification, backup recovery, and secure vendor access while preserving fire-system independence. Fifth, Saudi-specific organisational research should examine how owner information requirements, contractual allocation, authority interfaces, multilingual project teams, and operator capability affect commissioning outcomes.

Future work could develop a standardised commissioning ontology linking assets, points, sequences, tests, defects, and acceptance states. Multi-project longitudinal datasets would enable analysis of which interface defects recur across typologies such as hotels, transport hubs, entertainment venues, hospitals, offices, and mixed-use districts. Research should also test whether FDD algorithms validated during commissioning remain reliable after occupancy changes, sensor replacement, software upgrades, and seasonal operation. These studies would turn the proposed framework from a synthesis-based model into a quantitatively calibrated Saudi commissioning benchmark.

A further gap concerns human factors during integrated testing. Research should examine how alarm presentation, naming conventions, graphics, escalation rules, and operator workload affect response accuracy during complex scenarios. Simulation-based training using accepted commissioning scripts could provide a repeatable method for testing both system behaviour and operator readiness before public opening.

IX. PRACTICAL, MANAGERIAL AND POLICY IMPLICATIONS

For practitioners, the framework implies that commissioning specifications should be written around measurable outcomes and interfaces, not only equipment lists. The commissioning plan should contain an interface register, system boundaries, cause-and-effect matrix, integrated test scripts, data-point requirements, defect severity rules, retest procedures, and evidence templates. Witness fire scenarios end-to-end, and cover MEP functional testing for part-load, standby, failure, restart, alarm, and recovery conditions. ELV acceptance should include network, permissions, time, backup, logging, and resilience checks in addition to device operation. A Saudi authority-interface register should accompany the technical interface register and identify SBC 201/SBC 801 obligations, Civil Defense submissions and witnessing points, applicable HCIS controls, adopted NFPA 72 documentation requirements, responsible parties and evidence required for final acceptance.

For project managers, commissioning readiness should become a schedule gate supported by objective prerequisites. Integrated testing should not begin while point lists remain unstable, major balancing is incomplete, software versions change daily, or cause-and-effect mappings remain unresolved. A controlled readiness review can protect the programme from repeated failed tests that consume specialists' time without generating trustworthy evidence. Interface owners and discipline owners should manage defects, so they cannot close cross-package issues unilaterally. For owners and policy makers, the broader implication is that digital requirements should extend through operation. Saudi BIM studies consistently identify capability, organisational, and contractual factors as determinants of adoption (Alaboud and Alshahrani, 2023; Algahtany et al., 2023; Iqbal et al., 2025). Large public and quasi-public clients can therefore improve outcomes by standardising minimum asset information, commissioning evidence, cybersecurity, and soft-landing requirements across portfolios while allowing project-specific technical criteria. Such standardisation should define evidence and accountability rather than prescribe a single vendor platform, supporting interoperability and reducing avoidable lock-in.

Portfolio-level learning is equally important. Owners should code commissioning defects consistently so they can compare recurring interface, controls, documentation, cybersecurity, and training failures across projects. Aggregated lessons can then improve future employer requirements, standard test libraries, design reviews, and vendor prequalification without exposing project-sensitive security information.

X. LIMITATIONS

This review has five principal limitations. It synthesises heterogeneous evidence and does not estimate pooled effect sizes. Direct peer-reviewed studies of Saudi giga-project commissioning are scarce, so the proposed framework transfers findings from international commissioning and smart-building research and combines them with Saudi digital-delivery evidence. The review does not claim exhaustive systematic-search coverage because complete retrieval and duplicate-removal logs were not preserved. Non-peer-reviewed standards and authority documents are discussed as governing implementation constraints but are not treated as scholarly evidence. Most importantly, the six-gate framework has not yet been empirically validated by a Saudi expert panel or project case study. It should therefore be interpreted as a literature-derived assurance architecture pending structured validation.

A credible validation programme should combine two complementary steps. First, a two-round Delphi or structured expert-panel exercise with approximately 12-20 Saudi commissioning managers, fire consultants, systems integrators, facility operators and engineers experienced with Civil-Defense-facing approvals should rate each gate for importance, feasibility, current practice and evidence sufficiency using pre-defined consensus criteria. Second, at least one anonymised giga-project retrospective should map actual interface defects, failed tests, retest cycles and handover issues to the six gates. This would convert the present conceptual framework into an empirically calibrated model without inventing evidence that has not yet been collected.

The framework also does not replace discipline-specific statutory inspections, authority witnessing, or specialist certification. It connects those obligations through a common assurance logic. Project teams must determine which tests are mandatory, which are risk-based enhancements, and which evidence may be digitally reused without compromising independence or regulatory acceptance.

XI. CONCLUSION

Smart building commissioning in Saudi giga-projects should be conceived as lifecycle assurance of an interconnected operational asset, not as a collection of end-stage equipment tests. The evidence reviewed here shows that commissioning creates value when requirements are explicit, functional performance is challenged under realistic conditions, data quality is verified, defects are closed through retesting, and performance evidence remains usable after handover. It also shows that benefits can erode without ongoing attention, supporting a planned transition from initial acceptance to continuous commissioning.

The proposed framework integrates five ideas. First, owner requirements and interface governance must precede detailed testing. Second, discipline commissioning of fire alarm, ELV, and MEP systems must establish trustworthy component and subsystem performance before cross-system scenarios begin. Third, integrated tests must trace initiating events through communications, control actions, physical responses, feedback, operator visibility, and recovery while preserving the authority and independence of certified life-safety functions. Fourth, BIM, digital twins, BMS data, and analytics should form a governed digital evidence chain rather than an isolated technology showcase. Fifth, acceptance should be followed by soft landing, baseline monitoring, fault diagnostics, and periodic recommissioning.

For the Saudi context, the framework is intentionally governance-oriented. Local research indicates that digital transformation depends as much on competencies, organisational arrangements, information exchange, and contractual support as on software. Giga-project commissioning therefore requires clear decision rights, stable information requirements, coordinated authority interfaces, trained operators, and auditable evidence across packages. Combined with staged readiness gates and scenario-based testing, these conditions can link construction completion to safe, resilient, maintainable operation. The paper's main contribution is a synthesis that places fire alarm, ELV, MEP, digital information, cybersecurity, and facility operations inside one commissioning logic. Future Saudi case studies should test and refine that logic using measurable defect, retest, handover, reliability, and operational-performance outcomes.

This framing also changes the meaning of “smart.” A building is not smart because it contains many connected devices; it is smart when those devices support verifiable, secure, maintainable, and intelligible operational decisions. Commissioning is the discipline that tests whether the promised intelligence survives contact with the installed asset. By making interfaces, evidence, and operational continuity explicit, the proposed approach offers a practical research foundation for giga-project clients seeking repeatable assurance across diverse buildings and delivery packages. It also offers a transparent basis for benchmarking commissioning maturity, comparing recurring defects, and converting lessons from early operations into better requirements for subsequent Saudi projects.

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