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Original Research Article

Strengthening Fire Safety Resilience in Saudi Giga-Projects through Advanced Inspection, Testing and Commissioning Practices

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Abstract: The vast number of projects carried out by Saudi Arabia involve a great deal of construction, a wide range of different kinds of buildings, modern building services, and very strict deadlines for completion. Under these circumstances, fire safety resilience depends not only on the design complying with the relevant codes but also on the systems installed being clearly complete, capable of working together, and able to be restored before the projects are handed over. This study treats inspection, testing and commissioning (ITC) as a continuous process for making sure that the fire protection and life-safety systems work in Saudi giga-projects. A structured and integrative review was carried out in accordance with the PRISMA 2020 reporting guidelines and included peer-reviewed studies, standards and Saudi policy documents published between 2020 and 2025. The evidence was divided into five themes: the quality of inspection, the functional testing of subsystems, integrated system testing, digital verification and lifecycle governance. The review shows that resilience is reduced when verification is left to the individual contractors, when the documentation is fragmented, when interface tests are delayed, or when acceptance is based on the activation of components rather than on the system's performance in a given scenario. On the other hand, risk-based inspection, functional testing that is witnessed, integrated sequences covering alarm systems, smoke control, emergency power and egress systems, and digitally traceable evidence all increase the likelihood that the safety functions will operate if a real fire takes place. Even though digital twins, IoT sensing, computer vision and BIM can improve traceability and situational awareness, they do not substitute for competent inspection or independent witnessing. The paper presents a seven-stage Fire Safety Resilience Assurance Framework which is in line with the Saudi Fire Protection Code and with current NFPA commissioning practices. The framework unites the design intent, the verification of installation, pre-functional checks, functional tests, integrated scenarios, handover evidence and periodic retesting. It provides owners, regulatory authorities, commissioning teams and contractors with a flexible approach for reducing latent defects and for guaranteeing operational dependability in the context of complex Vision 2030 developments.

Keywords: Fire Safety Resilience, Inspection, Testing and Commissioning (ITC), Fire Protection Systems, Life-Safety Systems, Saudi Giga-Projects.

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1. INTRODUCTION

The current reforms in Saudi Arabia are giving rise to a number of developments which, in terms of the breadth of their scope, the variety of functions they cover and the complexity of the systems involved, differ from ordinary building programs. The Public Investment Fund says that there is a great deal of activity linked to the giga-projects in NEOM, Qiddiya, Red Sea Global, Diriyah and ROSHN, and Vision 2030 has placed these developments in the context of its wider aims concerning economic diversification, tourism, urban quality and technology-based infrastructure (Public Investment Fund, 2024; Saudi Vision 2030, 2024). As a result, construction is underway on hotels, entertainment facilities, transport infrastructure, high-rise buildings, industrial sites, residential areas and public facilities, all of this typically being carried out via separate design and construction packages. Even though the use of digital delivery, off-site manufacturing and international supply chains can help to speed up the implementation of the projects, they also mean that a greater number of interfaces have to be checked before the buildings can be occupied. Gohar (2025) also points out that the delivery of the Saudi giga-projects is becoming more and more dependent on integrated digital planning and coordination between different disciplines. With regard to fire safety, this raises a major issue concerning assurance: a project may have components that are each in compliance on their own but still fail as a life-safety system if the interfaces, the cause-and-effect logic, the power continuity, the dampers, the fans, the doors, the lifts, the suppression or alarm sequences do not work together.

The national regulatory standard for fire and life safety known as SBC 801 specifies the requirements for fire protection systems and for egress, as well as addressing the problem of hazardous conditions, including the requirement for inspections (Saudi Building Code Center, 2024). Yet true resilience is only obtained if the original design's design intentions are kept at all stages of the process—that is, throughout procurement, installation, software configuration, testing, handover, and also when the systems are actually in operation. It is worth noting that a number of defects are latent; for example, a fire damper may be installed but still remain inaccessible, a sprinkler valve may be monitored incorrectly, a smoke-control fan may rotate in the wrong direction, or an alarm command may fail to cause the required shutdown. Simply examining the documents will not reveal these issues. Because of this, international practice regards commissioning as a means of making sure that fire protection and life-safety systems fulfill the performance objectives stated in the documentation, while integrated testing is used to check how the various systems interact (NFPA, 2024a; NFPA, 2024b). Water-based systems also need regular inspection, testing, and maintenance, and smoke control and emergency power each have their own acceptance criteria and specifications for periodic verification (NFPA, 2023; NFPA, 2024c; NFPA, 2025b).

The view that fire safety should be considered a connected cyber-physical issue is endorsed by recent research. Digital-twin systems can combine data from sensors, models, and assets in order to aid fire management (Almatared *et al*., 2024), and surveys relating to the Internet of Things have shown that early detection, automation, evacuation procedures, and integration with BIM are common features in smart buildings (Shaharuddin *et al*., 2023). It has already been proven on a large scale that digital fire models based on sensor input are able to estimate changing fire conditions with low latency (Zhang *et al*., 2022), and other studies have associated digital twins with evacuation monitoring, fire-risk assessment, and the management of tunnel fires (Ding *et al*., 2023; Zhang *et al*., 2024; Kim *et al*., 2024). However, even though these studies have technical potential, they mainly concentrate on tactical intelligence. For large-scale projects, a different question must be tackled right from the start: how can project teams demonstrate, before handover, that the physical and digital safety systems have been installed, tested, integrated, and documented with sufficient confidence to remain reliable in an emergency situation?

The absence of a relevant research area is not due to there being unduly few individual fire technologies or standards; rather, the issue stems from the lack of a lifecycle synthesis which defines the proper sequence for carrying out inspection, functional testing, integrated testing and commissioning as part of a single chain of evidence for very complex projects in Saudi Arabia. Although the existing evaluations of smart construction and urban digital twins offer useful methodological models for thematic synthesis and for combining various technologies (Mazzetto, 2024), research carried out in the Saudi construction sector has shown the importance of risk-based safety management (Sanni-Anibire *et al*., 2020). However, the connection between these areas and fire-safety acceptance has still not been well established. This review intends to close that gap by proposing a lifecycle resilience framework that treats ITC as a single assurance process rather than as a series of separate closeout activities. The framework has the following objectives: (i) to synthesise the evidence from 2020 to 2025 on recurring weaknesses in assurance and on newly emerging confirmation methods; (ii) to compare the contribution in support

regarding resilience of inspection, subsystem testing and integrated commissioning; (iii) to evaluate digital tools that are capable of improving the quality of the evidence and traceability; (iv) to align the synthesis with the Saudi code and the existing fire-protection standards; and (v) to suggest measurable gates and retesting triggers that are appropriate for portfolios of giga-projects.

2. REVIEW METHODOLOGY

An integrative review based on a formal approach was chosen since the research question includes peer-reviewed fire-safety studies as well as evidence from the fields of construction management and digital technologies, together with technical standards and materials from Saudi regulatory sources. The report followed the PRISMA 2020 principles in respect to the transparent identification, selection and synthesis of the studies, even though it was not presented in the form of a clinical-style meta-analysis (Page *et al*., 2021). The articles attached to the report were used as structural references: Mazzetto (2024) provides an example of a database-driven review that has clearly defined inclusion criteria and thematic classification, and Gohar's (2025) paper on construction in Saudi Arabia offers background information on giga-project delivery. The search period was limited to January 2020 to December 2025 in order to make sure that the study included the most up-to-date information. The search terms consisted of those relating to fire safety, inspection, commissioning, integrated testing, life-safety systems, smoke control, fire alarm, sprinklers, emergency power, BIM, digital twin, IoT, computer vision, Saudi Arabia, mega-projects and giga-projects. The publisher platforms, scholarly discovery services and the official repositories containing the Saudi codes, the Vision 2030 documents and the NFPA standards were examined.

Eligibility was decided according to the extent to which the material was related to fire safety as this applies to buildings or infrastructure. The sources considered were peer-reviewed journal articles and reviews, established fire-protection standards, official Saudi codes or strategies, and studies on verification technologies that offered a clear way to carry out inspection or commissioning. Research into materials or combustion chemistry that had nothing to do with detection, system performance or assurance was excluded. Sources published outside the 2020 to 2025 period were excluded, as were duplicate records, opinion articles lacking technical evidence, and those dealing with non-building applications that did not allow for transferability. Since the body of evidence is diverse, it would have been misleading to try to pool the data statistically; that is why a thematic matrix was used to record, for each source, the system area, the failure or risk it dealt with, the verification mechanism, the type of evidence, and the consequences for the lifecycle. The synthesis was then broken down into five themes: inspection assurance, subsystem functional testing, integrated system testing, electronic evidence, and governance or lifecycle retesting. Standards were regarded as normative requirements and academic studies as empirical or conceptual evidence; the two were not combined.

When the quality assessment was being carried out, due attention was paid to the credibility of the source, the transparency of the methods, the direct relevance to the review question, and the practical usefulness. A considerable amount of importance was attached to well-established standards, to official publications from Saudi Arabia, and to studies which had been peer-reviewed and which included clearly described experiments and datasets. However, review metatypes that were in the early stages of development were included on the condition that the relevant testing and the results derived from them were not carried beyond the scope of the context in which they had been validated. This is especially important in the case of technologies such as AI-enabled inspection, digital twins, and augmented reality, since the performance of these technologies can be greatly influenced by the quality of the data, the environmental conditions, and the way in which the system is integrated. The review therefore depends on technological evidence to pinpoint possible areas of assurance rather than asserting that any one tool can take the place of traditional acceptance procedures. Figure 1 illustrates the evidence-to-framework pathway that was followed in the review.

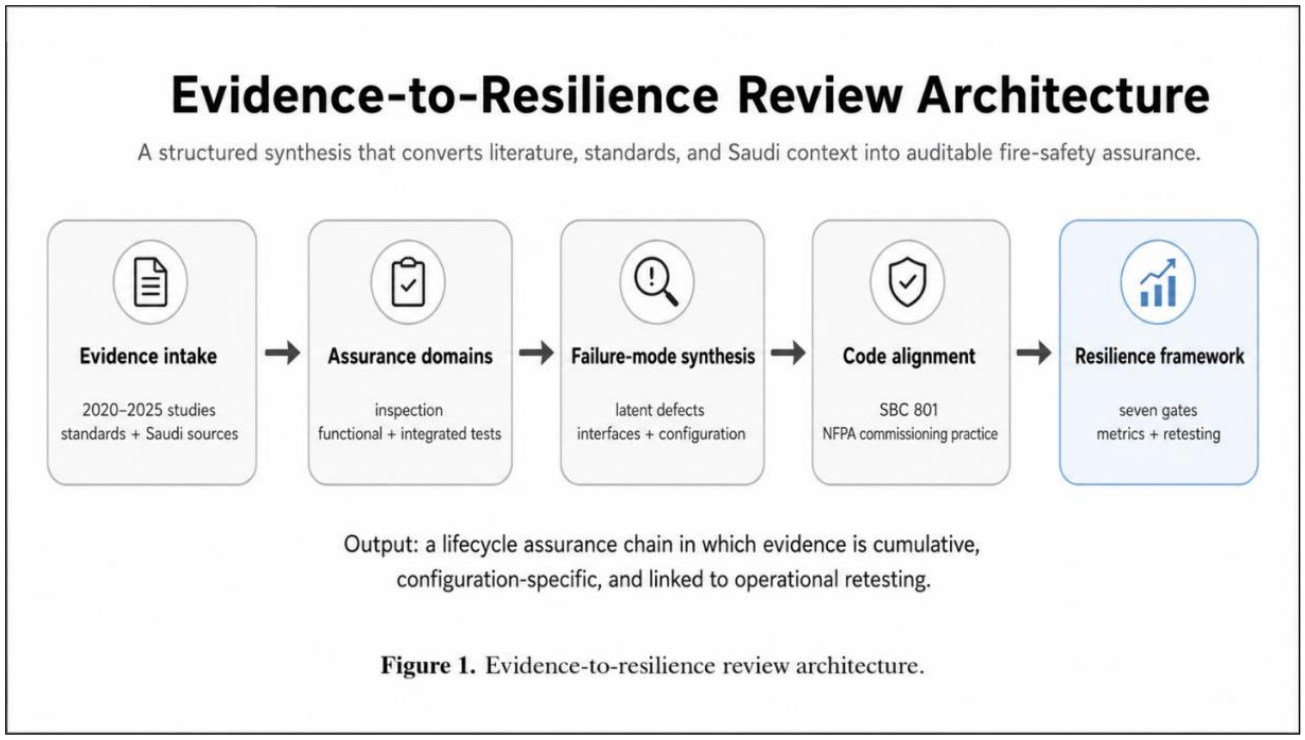

Figure 1. Evidence-to-resilience review architecture.

3. Fire Safety Resilience as a Lifecycle Assurance Problem

Fire safety resilience refers to a building's ability to carry out its key life-safety functions when a fire takes place, to assist in the safe evacuation of people and the carrying out of emergency responses, and to get back to reliable operation following a disruption. This definition puts the focus on maintaining function rather than on the presence of equipment. In order for a system to be resilient it has to detect a credible event, communicate that event, carry out its predetermined controls, keep essential power running, maintain acceptable conditions where necessary, release or secure interfaces as appropriate, and give reliable status information. These functions involve a range of organizational and technical areas. The alarm contractor has no control over the smoke-management panels; the mechanical contractor does not own the emergency power; another vendor may be responsible for the lift controls; and the finishes could conceal the passive fire-stopping before the integrated test team arrives. The risk in question is not simply a single serious failure, but rather the cumulative effect of a number of small interface defects which only become apparent during an emergency.

A lifecycle approach shows why it is inadequate to depend solely on late-stage testing since inspection provides evidence that the physical prerequisites are correct before the system is switched on; pre-functional checks verify that the system is ready; functional tests prove that each subsystem carries out the function it is meant to; integrated tests examine the relationships and sequences; commissioning verifies that the entire process meets the owner's fire-safety requirements; and periodic retesting checks whether the performance is retained following software changes, maintenance, tenant fit-outs or the replacement of components. NFPA 3 and NFPA 4 have officially defined the difference between commissioning and integrated testing, while NFPA 72, NFPA 92, NFPA 25 and NFPA 110 set out the exact expectations for alarm systems, smoke control, water-based protection and emergency power (NFPA, 2024a; NFPA, 2024b; NFPA, 2025a; NFPA, 2024c; NFPA, 2023; NFPA, 2025b). Therefore, in giga-projects resilience is based on a step-by-step, controlled progression through verified states rather than on a final set of test certificates.

4. Inspection: Converting Hidden Work into Evidence

The first step in making sure that the conditions in question can either be addressed or not addressed at a low cost or in a manner that is impossible is inspection. Instead of using a general administrative approach, effective inspection should be based on risk. Examples of items which have serious consequences are fire-resistance continuity, penetrations, dampers, fire doors, sprinkler obstructions, valve accessibility, pump-room arrangements, detector placement, cable survivability, fire-command interfaces and smoke-control construction. As noted in the construction risk literature from Saudi Arabia, hazards should be given priority according to both their severity and the

level of exposure, not simply by depending on generic checklists (Sanni-Anibire *et al*., 2020). In the case of giga-projects, this principle can be put into practice with regard to inspection hold points by making sure that concealed passive protection is checked before it is closed, that the equipment identity is verified against the approved submittals, and that interface-critical devices are tagged using the same asset hierarchy that is used during testing and handover.

Digital tools may increase the consistency of inspections by acting as evidence amplifiers. Alayed and colleagues (2024) trained a computer-vision model using thousands of images of fire-safety equipment and found that it had strong object-detection capabilities, which shows that automated identification can take place during field inspections. The Weqaa mobile application, which is based on this method, was developed in order to help inspectors to record more efficiently the condition of extinguishers and to report violations (Alidrisi *et al*., 2024). These tools are appropriate for use on large sites in Saudi Arabia, where thousands of repeatable assets have to be inspected in various areas. Their main contribution is not automatic acceptance yet rather faster detection of exceptions, geotagged records and auditable photographic evidence. The inspector must still assess accessibility, the installation context, certification, damage and compliance with the code. The same caution should be applied in the case of both fixed and mobile fire-alarm monitoring: reliability studies have demonstrated that environmental conditions and false alarms remain major operational problems (Wiśnios *et al*., 2024; Pietrzak *et al*., 2022). Inspection quality therefore needs to take into account both the visible defects in the installation and the conditions that later affect the credibility of the signal.

Table 1: Evidence and standards synthesis matrix for fire-safety assurance

Assurance domain	Typical latent weakness	Verification focus	Key evidence / standard	Resilience contribution
Passive protection	Unsealed penetrations, inaccessible dampers, damaged doors	Concealed-work hold points, location-tagged inspection, continuity checks	SBC 801 (2024); risk-based inspection	Preserves compartmentation and limits smoke/fire spread
Fire alarm and detection	Incorrect addressing, nuisance alarms, incomplete cause-and-effect mapping	Point tests, notification checks, interface commands, signal credibility	NFPA 72 (2025); He *et al*., (2022); Yu *et al.,* (2023); Liu *et al*., (2023)	Reliable initiation and emergency-control signalling
Water-based protection	Closed/mis-supervised valves, pump or flow deficiencies	Water supply, pump, valve, supervision and flow verification	NFPA 25 (2023)	Sustains suppression readiness and exposes impairments
Smoke control	Wrong fan direction, damper position, pressure imbalance, override conflicts	Measured airflow/pressure, sequence tests, standby and failure modes	NFPA 92 (2024)	Maintains tenability and protects egress/response routes
Emergency power	Transfer or load failure during fire mode	Loss-of-normal-power tests with life-safety loads operating	NFPA 110 (2025)	Maintains critical safety functions during utility interruption
Integrated interfaces	Subsystems pass individually but combined sequence fails	Scenario-based integrated testing against approved cause-and-effect logic	NFPA 3 and NFPA 4 (2024)	Demonstrates system-of-systems performance
Digital evidence	Fragmented records, wrong asset IDs, unverifiable closeout	BIM/asset mapping, photo evidence, point-to-point data checks, digital baseline	Almatared *et al*., (2024); Alayed *et al*., (2024); Alidrisi *et al*., (2024)	Improves traceability, retestability and portfolio learning

5. Functional Testing and Commissioning

Functional testing determines if a subsystem which has been installed actually carries out the function that has been defined. In the case of water-based fire protection, this requires checking the water supply, the pumps, the valves, supervision, the flow devices and tests relating to discharge; NFPA 25 sets out the framework for continuing inspection, testing and maintenance following acceptance (NFPA, 2023). With regard to fire alarm systems, testing has to confirm the operation of the initiating devices, the notification process, the supervising

signals, the power supplies and the emergency control interfaces, not just the energisation of the panel (NFPA, 2025a). Research into detection shows the importance of quality. He *et al*., (2022) outline developments designed to attain faster and more selective early warning, while methods using multiple detectors have been developed in order to reduce uncertainty by means of spatiotemporal signal relationships or Bayes' estimation (Yu *et al*., 2023; Liu *et al*., 2023). Li *et al*., (2022) do the same by reviewing early-stage warning mechanisms which aim for sensitivity before the fire reaches a fully developed stage. Although these improvements improve capability, they also increase the commissioning workload: configurable algorithms, networking and multi-sensor logic demand clearly stated acceptance criteria and repeatable test stimuli.

The extent to which smoke control is accepted shows the limits of device-level acceptance. A fan may start up successfully even though the entire system fails since the dampers fail to reach the positions commanded, the doors produce unexpected pressure relationships, the controls are overridden, or the switch to emergency power alters the system's performance. NFPA 92 therefore regards acceptance and regular testing as part of the reliability of smoke control (NFPA, 2024c). The same system-of-systems approach applies to emergency power. NFPA 110 bases its treatment of emergency and standby power on the requirement for dependable performance when the normal power is lost (NFPA, 2025b). As a result, for a complex development the meaningful test is not 'generator starts' but whether the generator, the transfer equipment and the downstream life-safety loads are able to maintain the required functions while the building is going through a fire sequence. Test scripts should specify the initial conditions, the initiating event, the expected sequence, the measurable acceptance criteria, the observation points, the witnesses responsible and the steps to be taken for restoration. Without these items, test records can show that activity has taken place without demonstrating that performance has been achieved.

It is at the stage of integrated system testing that resilience can be observed. NFPA 4 deals with the testing of the interactions between fire protection and life-safety systems, thereby supplementing the more general commissioning procedure outlined in NFPA 3 (NFPA, 2024b; NFPA, 2024a). A realistic scenario may entail the use of a detector or a sprinkler flow as a trigger to set off an alarm, activate voice announcements, start smoke exhaust or pressurisation, close dampers, unlock the designated egress doors, recall the lifts, stop nonessential air-handling equipment, send the status to a fire command centre and continue to operate following a loss of normal power. The sequences should be tested in combinations that mirror the approved cause-and-effect matrix, including abnormal conditions such as a failed device, loss of communication, a manual override or a switch to standby power. The aim is not to simulate every possible fire, but rather to show representative pathways through the safety system and to reveal any single-point or interface failures before the building is occupied.

The selection of scenarios must be based on a risk assessment and should be clearly connected to the fire strategy. In a giga-project, repeatedly triggering a single alarm in a number of different zones results in a large amount of testing but provides only limited assurance. A more effective approach is to group the areas according to their occupancy, the system architecture, the smoke control concept, the evacuation strategy, the power arrangement and the interface topology, and then to choose from each group a representative and most adverse combination of scenarios. Scenarios that are given high priority are those which involve a simultaneous demand on both the smoke control and emergency power systems, those that occur in areas having complex atria or underground links, events which impact on the zones that are evacuated in phases, the loss of a network segment, the failure of a duty fan together with the automatic switching to a standby fan, and fire modes that cause changes to the operation of the lifts or access controls. The design of the tests also needs to take into account seasonal and construction-stage conditions. In Saudi projects it is possible to move from temporary services and networks that are only partially commissioned to permanent operation while other adjacent packages are still being constructed; dust, heat and frequent software modifications can affect the sensors, the equipment and the stability of the tests. The acceptance team should therefore note the environmental conditions, any temporary overrides and any interfaces that are unavailable, so that a test result that is accepted does not get mistaken for proof of performance under a different configuration. Where it is not safe to carry out a full end-to-end test, the limitation should be recorded and supported by a combination of witnessed partial tests, verified simulations and a scheduled completion test before the area in question is released. This method protects the schedule without turning temporary restrictions into permanent assumptions. It additionally improves reproducibility since future retests can recreate the first initiating conditions, the expected response and the instrumentation used. For portfolio governance, a scenario library can be used to standardise the basic tests while at the same time permitting project-specific additions. Lessons learned from deficiencies can then be used to update the library, transforming commissioning experience

into a controlled feedback mechanism rather than keeping it as isolated knowledge from individual projects. An independent review of the scenario coverage prior to testing can detect interfaces that have not been challenged, decrease redundant work, and make sure that high-consequence sequences are adequately witnessed, instrumented, have follow-up measures for deficiencies, and undergo documented regression testing after any corrective changes.

The order in which the testing is carried out is also significant. If integrated testing is carried out too early, false failures will occur since the preliminary work has not been completed; if it is delayed, it will create scheduling pressure which in turn leads to the granting of waivers or to superficial retests. A solid commissioning plan therefore establishes readiness gates. The first of these is that the approved design intent and the cause-and-effect logic are made sufficiently final so that testing development can proceed. The second is that the installation inspections and the certification of components have been completed. The third is that the contractors have finished the pre-functional checklists and the calibrations. The fourth is that each subsystem has passed its functional testing. Only after that point should the integrated scenarios be observed. Any deficiencies should be recorded using a unique identifier, together with an assigned consequence and owner, corrected and then retested until closure is achieved. When changes are made after a test has been passed, an impact assessment should be carried out rather than relying on the first test result. Through adopting this approach, commissioning is converted from a mere ceremonial handover into configuration control for safety-critical systems.

The ways in which evacuation systems are managed show that commissioning needs to go beyond simply activating equipment and should focus on the outcomes for human use. Yakhou *et al.,* (2023) created a two-way framework that links BIM and evacuation modelling in order to improve the coordination between building models and egress analysis. Kanangkaew *et al*., (2023) combined BIM with augmented reality to give real-time evacuation instructions, and Ding *et al*., (2023) applied computer vision in a digital-twin environment to keep an eye on the evacuees. These methods indicate a move in the direction of more comprehensive scenario testing, in which the responses of technical systems can be assessed together with movement, communication and wayfinding. In the case of giga-projects that include arenas, resorts, transit areas or mixed-use districts, emergency plans may entail phased evacuation, the use of refuge areas, crowd management or complicated staff responsibilities. Commissioning should therefore involve carrying out realistic operational drills following technical testing, with clear distinctions being made between engineered acceptance tests and organisational emergency exercises.

6. Digital Enablement and Traceable Assurance

Digital transformation has the potential to overcome one of the persistent flaws in the commissioning of large projects: the fragmentation of evidence. By using BIM-based asset registers, each device can be linked to its location, specification, inspection status, test results and record of deficiencies. Digital twins go a step further by connecting static asset data with real-time operational signals. Almatared *et al*., (2024) have proposed a digital-twin framework for fire-safety management and point out barriers such as cost, integration, training and data management. Mazzetto (2024) does likewise by identifying interoperability and data governance as continuing issues concerning the use of digital twins in smart-city applications. In the case of commissioning, it is clear that a digital platform is of no use unless identifiers, naming conventions, point lists and evidence structures are established at an early stage. It is not possible to create a usable digital thread by uploading inconsistent PDFs at handover.

The possible benefits of a stronger data thread are shown by experimental digital twins of fire. In a full-scale demonstration, Zhang *et al*., (2022) combined wireless sensors, cloud data, artificial intelligence and a three-dimensional interface to estimate how a fire would develop. Later, Zhang *et al*., (2024) used an AIoT-enabled digital twin for tunnel fire safety, and Kim *et al*., (2024) employed informative digital twins as a means of carrying out an expected fire-risk assessment. Although these systems are mainly used operationally rather than during the commissioning phase, their design points to a future acceptance model in which selected sensors, control points and test results feed into a verified baseline that is then kept available during operations. Data obtained during commissioning could define 'known-good' states for damper positions, fan responses, transfer times, alarm latencies or network health, enabling later detection of any abnormalities. Thus, the project closeout would be linked to predictive maintenance rather than viewing the handover as an information break.

Digital verification still has to be carefully managed. Even if a model is accurate it cannot make up for a component that has been wrongly installed, and automated analytics can give a false sense of confidence when sensor calibration, timestamps or mappings are inaccurate. As Birajdar *et al*., (2020) point out, fire detection and evacuation systems in buildings already involve a variety of sensors and

communication components, which increases their need on reliable integration. Furthermore, Shaharuddin *et al.*, (2023) highlight the interdisciplinary use of IoT in the areas of detection, automation and evacuation. It therefore follows that digital commissioning should involve checks on data quality such as point-to-point verification, time synchronisation, reconciliation of asset IDs, cybersecurity access controls, version control for the cause-and-effect logic and the retention of raw test evidence. The principle to be followed is 'digitally traceable, physically witnessed'. The role of technology should be to reduce omissions and speed up the analysis while at the same time maintaining accountable engineering judgment.

7. Proposed Fire Safety Resilience Assurance Framework

The synthesis presents a seven-gate Fire Safety Resilience Assurance Framework for Saudi giga-projects. Gate G0 establishes the fire-safety basis, specifies the relevant provisions of SBC 801, references the applicable standards, defines the system scope, sets out the performance objectives and assigns the commissioning responsibilities. Gate G1 checks the design coordination, the cause-and-effect matrices, maintainability and testability before the procurement process is finalised. Gate G2 ensures the quality of installation by means of risk-based inspections and concealed work hold points. Gate G3 confirms pre-functional readiness, this including certification, calibration, flushing, continuity checks, the software versions and point-to-point verification. Gate G4 calls for functional tests of the subsystems together with measurable acceptance criteria. Gate G5 carries out integrated scenarios under both normal and abnormaL conditions, including in the case of a loss of power and critical interface failures. Gate G6 carries out the handover only when defects have been closed, the as-built information agrees with the field configuration, the staff have been trained and a periodic retesting plan has been accepted. Table 2 converts these gates into project controls.

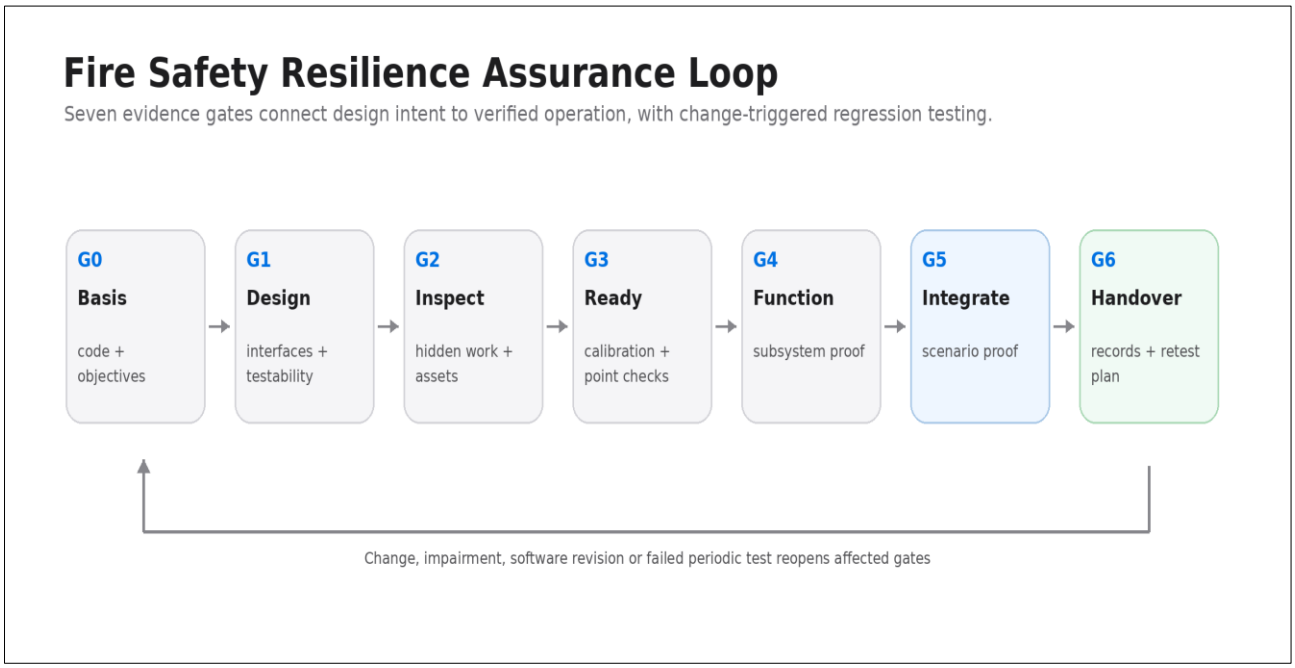

Figure 2: Seven-gate Fire Safety Resilience Assurance Loop with change-triggered feedback

The framework differs from traditional closeout in three respects. The first is that evidence is cumulative: if there is missing proof at an earlier gate, a later gate cannot make up for it. The second point is that the degree of independence increases as the consequence does so; while contractors are allowed to carry out routine pre-checks, high-risk integrated tests must include independent commissioning leadership and authority or owner witnessing where applicable. The third aspect is that acceptance is specific to configuration; if there are any changes to the software logic, the equipment, the interfaces or the major room arrangements, the relevant evidence chain has to be reopened. This is especially important in cases where several packages are handed over at different times or where temporary systems are used to enable phased occupancy. Thus, the framework can be applied at the building, zone and portfolio levels, on the condition that the asset hierarchy and acceptance status are visible across the packages.

Table 2: Proposed seven-gate Fire Safety Resilience Assurance Framework

Gate	Project timing	Assurance objective	Minimum evidence	Release condition / retest trigger
G0 - Basis	Concept / fire strategy	Define code basis, performance objectives, system boundaries and roles	SBC 801 matrix; commissioning plan; responsibility matrix	Approved basis; reopen if strategy or occupancy changes
G1 - Design	Design coordination	Confirm interfaces, cause-and-effect logic, access, maintainability and testability	Coordinated drawings; sequence matrix; test specifications	Design interfaces resolved; reopen after material sequence change
G2 - Inspect	Installation	Verify physical installation and concealed work before closure	Inspection records; certifications; tagged photos; deficiency log	Critical inspections accepted; reopen after rework or damage
G3 - Ready	Pre-functional	Prove readiness for functional tests	Calibration; flushing; continuity; point-to-point checks; software versions	Prerequisites complete and configuration controlled
G4 - Function	Subsystem testing	Demonstrate each subsystem against measurable criteria	Witnessed functional scripts; readings; first-pass/deficiency records	Subsystem accepted; failed or modified functions retested
G5 - Integrate	Integrated commissioning	Demonstrate cross-system fire scenarios and abnormal conditions	Integrated test scripts; trend logs; normal-power-loss and failure-mode results	Representative scenarios pass without unresolved high-risk defects
G6 - Handover	Occupancy / operations	Preserve verified configuration and establish lifecycle retesting	As-builts; O&M data; training; closed defects; periodic test plan	Occupancy release; changes, impairments or failed periodic tests trigger regression testing

Performance indicators ought to focus on assurance quality rather than on the amount of paperwork. Useful indicators are the percentage of concealed-work inspections carried out before closure, the first-pass functional-test rate, the number of open life-safety deficiencies according to risk class, the percentage of integrated scenarios passed without the need for a workaround, the mean time taken to close deficiencies, the proportion of devices that have complete electronic evidence, the number of post-test changes that require regression testing, and the percentage of periodic retests completed on time. It is also necessary to monitor false-alarm trends since repeated unwanted alarms can reduce operator trust and may indicate a problem with detection, the environment, or maintenance (Pietrzak *et al*., 2022; Wiśnios *et al*., 2024). Portfolio dashboards can then detect systemic weaknesses, for example repeated damper failures or incomplete point naming, and pass on the knowledge acquired to future design packages.

8. DISCUSSION

The review shows that the greatest increase regarding resilience is obtained by changing the unit of assurance from 'equipment' to 'function'. Although inspection is still necessary, it becomes more useful when each observation is linked to the functional test which depends on it. Functional testing is necessary, but it acquires more significance when the acceptance criteria are based on the design intent rather than on the vendor's default settings. Integrated testing is the deciding factor since it reveals the interactions between systems, but it can only be trusted when all the prerequisite gates have been completed. Digital tools help to increase both the scale and traceability of the process, but their value is determined by disciplined data governance. It is these relationships that explain the fact that commissioning failures usually occur at the boundaries—such as those between passive and active protection, between controls and power, between design and field installation, between contractors and operators, or between project databases and operational systems.

For the owners of the large-scale projects in Saudi Arabia, the practical conclusion is that they should arrange for fire-safety commissioning governance early on so as to have an impact on the design and the procurement process. In the case

where commissioning only starts close to the end of the project, the teams end up with interfaces that are hard to test, dampers that are inaccessible, incomplete control points and contractual uncertainty regarding who is responsible for demonstrating the sequences. By planning early it is possible to specify the locations of test ports, define access zones, state the temporary power requirements, assign witnessing duties, determine the formats for electronic evidence and establish the obligations relating to regression testing. It is also possible to coordinate the phased handover with the fire safety strategy. This is in line with the general lesson from Saudi digital construction, namely that the delivery of complex projects is better served by shared information environments and by deliberate coordination among the various stakeholders (Gohar, 2025). Fire-safety assurance should be regarded as a key element of project control, with its own schedule logic and constraints, not simply as a final inspection by an authority.

The framework also promotes regulatory and industry development; SBC 801 establishes the basic code requirements, but the project specifications can improve the way it is carried out by specifying the integrated commissioning deliverables, the competence requirements and the need to retain evidence all in a consistent manner. Standardised templates used in the major programmes could decrease the variation in cause-and-effect matrices, deficiency classification and test reporting. Training is just as important; the people carrying out the commissioning need a sufficient level of knowledge about a range of systems so that they can identify the interactions between the mechanical, electrical, controls, vertical transportation, security and fire protection disciplines. Operators should take part before the final acceptance is given so that the knowledge gained from the testing is not lost when the project is handed over. The outcome is the creation of a strong culture in which the project team do not simply ask whether a system has been installed but also whether its intended safety function has been proven, documented and made repeatable.

9. Limitations and Future Research

The review does have some limitations. By focusing on the period from 2020 to 2025, it puts a strong emphasis on up-to-date information while at the same time omitting older foundational literature on commissioning. There is more research available on detection, digital twins, and evacuation than on empirical data regarding failure rates from integrated commissioning programmes, mainly since data on project acceptance are commercially sensitive. There are currently few peer-reviewed studies in Saudi Arabia relating to fire-safety commissioning, which is why the framework in question combines the context of the national building code with international technical evidence rather than asserting that it has been validated locally. Future research needs to involve the analysis of anonymised deficiency datasets from major Saudi projects, determine which interface failures occur most frequently and at the greatest cost, and compare first-pass rates among different delivery models. Field studies should also investigate whether electronic evidence systems reduce the need for reinspection, whether automated image recognition stays accurate in dusty or incomplete environments, and which commissioning indicators are best at predicting the functional reliability of fire protection systems.

The second priority should be to ensure lifecycle continuity. Research into the assets should extend from the opening stage in order to examine the effects of tenant modifications, software updates, maintenance interventions and temporary impairments on sequences that have previously been accepted. If commissioning baselines are kept and connected to operational data, digital twins could assist with this task. Controlled studies should compare regular periodic testing with risk-based retesting which takes into account alarms, faults, sensor drift and the change history. Attention must also be paid to the human factors, particularly with regard to alarm credibility, operator workload and the usability of fire-command information. These issues would shift fire-safety commissioning from being just a discipline carried out at the end of a project to becoming a measurable resilience-management system.

10. CONCLUSION

Because of their size, the density of their systems and the scope of their operations, the giant projects carried out by Saudi Arabia require a corresponding degree of fire safety assurance. The review indicates that resilience cannot be achieved simply by relying on design approval or the certification of individual components; it has to be developed through an evidence chain which starts with risk-based inspections, moves on to pre-functional and subsystem tests, puts the interfaces to the test by means of integrated scenarios, and then continues via handover, training and periodic retesting. The most effective assurance approach is therefore one that is based on the product's entire lifecycle and on its functions. The national code framework is provided by SBC 801, while modern NFPA standards covering commissioning, integrated testing, alarms, smoke control, water-based protection and emergency power supply offer additional process controls. Digital twins, BIM, IoT and computer vision can make the evidence chain more scalable and more traceable, but they should

serve to support rather than replace sound engineering judgment. The proposed seven-gate Fire Safety Resilience Assurance Framework gives a practical structure for owners, authorities, commissioning teams and contractors so that latent defects can be exposed before occupation, configuration changes can be managed and the verified safety functions can be preserved during operation. When applied consistently across a portfolio of giant projects, advanced ITC can become a strategic tactic for guaranteeing resilience rather than merely being an exercise in meeting requirements at a late stage.

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