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RESEARCH ARTICLE

DEVELOPMENT OF A CONSTRUCTION SUPPLY CHAIN RESILIENCE MODEL FOR GIGA PROJECTS IN SAUDI ARABIA

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Abstract

Saudi Arabia's giga-project programmes create unusually demanding supply networks: complex project interfaces, geographically dispersed production, specialist imports, simultaneous demands for capacity and strict performance expectations. Although construction supply chain research increasingly addresses risk, digitisation and inter-firm collaboration, it offers limited guidance on how these capabilities should function as a coherent, project-level system under the conditions of large Saudi developments. This structured integrative review critically examines 30 peer-reviewed articles published between 2020 and 2025 and develops a context-sensitive Construction Supply Chain Resilience Model (CSCRM). Evidence is synthesised across disruption exposure, network configuration, procurement governance, operational visibility, adaptive execution and recovery learning. The proposed model connects five mutually dependent capabilities—exposure intelligence, protected sourcing, integrated information, adaptive delivery and institutional learning—through explicit decision rights and performance feedback. Its distinctive contribution is the translation of resilience from a general organisational attribute into a sequence of measurable procurement and logistics decisions that can be embedded in project controls. A staged implementation protocol and leading indicators are offered for owners, delivery partners and suppliers. The framework is a theoretically grounded proposition rather than a statistically validated prediction; its proposed pathways require future multi-project testing. This review clarifies where established international evidence is transferable to Saudi giga-projects, where local conditions demand adaptation, and which assumptions remain uncertain.

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Introduction:-

Saudi Arabia's investment in extensive urban, tourism, transport and infrastructure programmes has intensified a longstanding problem in construction management: the physical progress of a project depends upon materials, specialist equipment, contractors and information that lie beyond the immediate authority of its site team. The size of a programme does not remove this dependence. Instead, simultaneous work packages multiply interfaces among designers, manufacturers, ports, inland carriers, subcontractors and regulators. Delays can therefore arise even where site planning appears technically adequate. Studies of Saudi building and pipeline projects associate overruns with

interacting contractual, financial, technical and supply-related risks, suggesting that resilience cannot be reduced to an inventory policy or an isolated contingency budget (Alshihri et al., 2022; Al-Gahtani et al., 2023).

The term giga-project is used here to describe a strategically significant development programme with multiple interdependent projects, high capital intensity and substantial external supply requirements. The concept is analytical rather than a claim that all designated programmes share the same scale, location or procurement regime. A remote infrastructure corridor, a coastal destination and a dense urban redevelopment generate different traffic conditions, workforce requirements and import dependencies. Yet each faces a common coordination challenge: local delivery decisions may draw upon the same constrained markets for specialist fabrication, qualified labour, equipment and transport. A resilient supply chain must therefore be designed with reference to project-specific bottlenecks and portfolio-wide interactions rather than project value alone (Stefano et al., 2023).

The broader literature has begun to reposition construction supply chain management from material purchasing towards a network of interdependent organisations. Reviews show that coordination, information sharing, procurement structure and risk management have developed unevenly, while resilience remains insufficiently integrated into mainstream construction decision-making (Puppo Studer and de Brito Mello, 2021; Liao et al., 2023; Singh et al., 2025). A similar divide occurs between sophisticated modelling and everyday construction practice. Optimisation models may identify efficient supplier combinations, yet decisions are frequently made through fragmented systems or commercial routines that restrict the use of those results (Chen and Hammad, 2023; Baghalzadeh Shishehgarkhaneh et al., 2024).

A critical distinction is necessary between resilience and ordinary operational efficiency. An efficient network can minimise handling, inventory and transport costs while becoming highly exposed to disruption. Resilience instead concerns its capacity to anticipate adverse conditions, absorb the initial consequences, maintain critical functions, modify supply arrangements and recover performance. These capabilities can involve additional expenditure before a disruption occurs; their value must consequently be judged against avoided delays, preserved milestones and whole-project outcomes rather than against the lowest quoted material rate. Research on viable and reconfigurable networks reinforces the proposition that adaptation depends on planned alternatives, not simply rapid improvisation after a crisis (Dolgui et al., 2020; Ivanov, 2022).

Saudi giga-projects make this distinction especially salient. Procurement choices may be constrained by long-lead imported components, local manufacturing development, interfaces with other schemes and project-specific delivery windows. A policy that increases domestic sourcing can reduce some international exposure while increasing dependence on a small pool of local manufacturers. Conversely, diversification across countries may improve supplier redundancy while expanding customs, transport and currency risks. Environmental objectives create additional tensions when emergency freight, over-ordering or excessive storage become routine. Recent Saudi and international research on circular construction and sustainable logistics illustrates why operational resilience and responsible resource use must be assessed together rather than presented as automatically compatible (Alotaibi et al., 2024; Cataldo et al., 2022; Deep et al., 2025).

This article addresses a specific gap between general resilience theory and implementable construction governance. Existing reviews describe categories of megaproject supply chain strategy, construction risks and digital technologies, but they do not establish a sufficiently explicit chain from observable early-warning signals to accountable procurement actions and subsequent learning within the Saudi giga-project setting (Stefano et al., 2023; Baghalzadeh Shishehgarkhaneh et al., 2025). The contribution developed here is therefore not another list of desirable capabilities. It is an integrative model showing their dependencies, the controls needed to operationalise them and the circumstances under which apparently beneficial interventions may fail.

Aim, objectives and analytical boundaries:-

The aim of the study is to develop a theoretically informed, context-sensitive model that explains how Saudi giga-project delivery organisations can strengthen construction supply chain resilience through coordinated procurement, logistics, information and governance arrangements. Rather than testing a predetermined numerical relationship, the review seeks to establish the causal mechanisms that a future empirical investigation should examine. This is appropriate because the available evidence spans different countries, procurement arrangements, technologies and measures of disruption impact.

Four objectives guide the article. The first is to classify disruption exposure at the supplier, logistics, project-interface and programme levels. The second is to evaluate the effectiveness and limitations of sourcing, collaboration, inventory and digital visibility capabilities. The third is to integrate these insights into a sequenced resilience model with clearly assigned decisions and measurable outcomes. The fourth is to establish an implementation and validation agenda suited to Saudi conditions, including local-content aspirations, remote logistics and the governance demands of concurrent project delivery. These objectives distinguish explanation, synthesis, model development and evaluation rather than presenting similar purposes in different language.

The review addresses three questions: which vulnerabilities most plausibly interrupt critical construction flows; through which organisational and technical mechanisms can disruptions be prevented, contained or recovered from; and how should project owners and delivery partners determine whether resilience investments protect performance? Its scope includes physical materials, specialist equipment, associated information and procurement interfaces. It does not treat labour policy, macroeconomic growth or national industrial strategy as independent research subjects, although their effects are considered when they influence supply continuity. The model concerns the construction and commissioning phases, with design-stage decisions incorporated when they create downstream lock-in.

Review Methodology:-

Review design and evidence selection:-

A structured integrative literature review was adopted rather than a meta-analysis. The intended outcome is an explanatory synthesis across heterogeneous evidence, including conceptual studies, construction-specific reviews, empirical investigations and decision-modelling contributions. The corpus consists of 30 DOI-bearing peer-reviewed journal articles published from 2020 to 2025. Searches were directed towards combinations of construction supply chain, resilience, megaproject, procurement, logistics, disruption, supplier risk, digital twin and Saudi Arabia; publication records and reference trails were used to establish connections among the strands. The review is intentionally focused and should not be mistaken for a complete census of records in any bibliographic database.

Three inclusion criteria were applied. First, each source had to provide a substantive contribution to supply chain disruption, construction procurement, logistics, digital coordination or Saudi delivery risks. Second, its publication year had to fall within the defined interval. Third, article identity and DOI had to be traceable through a publisher page or scholarly metadata record. Studies dealing only with routine schedule estimation, without an identifiable supply-chain mechanism, were outside scope. The three supplied papers informed the expected article structure and the local conceptual setting, but because their publication dates fall outside the requested citation window, they were not counted among the 30 cited studies. No screening totals, inter-rater agreement coefficients or database coverage claims have been invented.

Evidence extraction and interpretive analysis:-

Each selected article was examined against six analytical questions: what form of disruption or dependence it addresses; what network level is studied; which resilience mechanism is proposed; what evidence supports the claim; what operational decision follows; and what limits transferability. These fields informed a qualitative evidence matrix, subsequently consolidated into four review domains: exposure and propagation, organisational arrangements, digital and analytical capability, and performance trade-offs. Findings were not weighted by article counts because the selected papers vary greatly in designs and often discuss several mechanisms at once. Nor were numerical impacts imported from unrelated sectors as predictions for Saudi projects.

The synthesis proceeded through three interpretive passes. The first mapped concepts and distinguished external shocks from internally generated coordination failures. The second sought agreement and conflict across sources—for example, between lean efficiency and protective slack, or between greater technological visibility and insufficient capacity to act. The third translated recurring mechanisms into model elements, decision triggers and observable indicators. Each component of the final framework was retained only where a defensible conceptual pathway connected it to continuity of material or equipment flows; elements supported mainly by theoretical inference are explicitly marked as proposals rather than established findings.

Figure 1 summarises the review logic. Its purpose is to make the development route auditable, not to imply that the source selection was a probabilistic sample. As with any focused synthesis, there is a risk of selection bias, discipline-specific terminology and publication bias towards successful technology applications. These are addressed by comparing construction-specific evidence with general supply chain theory, reporting contradictions

rather than suppressing them and separating review findings from the authors' proposed model. All claims about future performance remain conditional on further testing.



Figure 1. Review design and interpretive synthesis process (original conceptual illustration).

Basis for critical appraisal:-

The appraisal privileged the clarity of each study's unit of analysis, the relevance of its setting to project-based networks and the transparency of its proposed mechanism. A broad resilience framework can have conceptual authority without directly demonstrating effectiveness on a construction site. Conversely, a field survey may reveal a local bottleneck but not establish that its conclusions generalise to all projects. This distinction guided the use of evidence from international studies. The review accordingly differentiates observed associations, simulation-based propositions and conceptual claims, and resists combining them into a single measure of effect. The approach is consistent with the caution advocated in construction-specific syntheses of risk and quantitative modelling (Chen and Hammad, 2023; Baghalzadeh Shishehgharkhaneh et al., 2024).

Conceptual foundations for resilience in project-based networks:-

From robustness to adaptive continuity:-

Robustness, agility, resilience and viability are related but not interchangeable. Robustness denotes the ability to maintain an operation without major modification under a defined disturbance. Agility emphasises the speed with which an organisation can change in response to opportunities or demand variation. Resilience combines preparedness, absorption, response and recovery when performance is threatened. Viability extends consideration to long-term network survival and adaptation as structural conditions change (Ivanov, 2022). For a construction programme, the practical target is not indefinite network survival but preservation of critical delivery functions within agreed tolerances for safety, quality, cost and schedule.

A second foundational idea is disruption propagation. A missing component may appear to be a procurement delay, yet the consequences can pass into idle installation crews, crane sequencing, testing, temporary works and downstream subcontract obligations. These cascading effects are more important than the purchase value of the missing item. Network studies emphasise that an interruption can travel through linked processes and that recovery decisions must account for interactions rather than treating each failed supply line independently (Ivanov and Dolgui, 2020; Katsaliaki et al., 2022; Chowdhury et al., 2021). This perspective requires project-specific mapping of critical interfaces, not only a register of individual suppliers.

Reconfigurability adds a third dimension. A sourcing network can hold formal alternative suppliers while still lacking viable substitutes because technical approval, tooling, warranties or transport capacity cannot be changed quickly. A useful resilience design therefore records both nominal alternatives and the time required to activate them. Dolgui et al. (2020) show the significance of network reconfiguration as a design property, while Ivanov (2023) explains how stress-testing can expose configurations that appear adequate under expected conditions but are fragile when multiple constraints coincide. For giga-projects, these ideas support a shift from simple supplier count towards feasible, approved and time-bounded response options.

The megaproject network as the unit of analysis:-

Construction supply chains differ from stable manufacturing chains because project organisations are temporary, demand schedules evolve with design and site progress, and product specifications can be unique. Stefano et al. (2023) demonstrate that megaproject supply chains require attention to relationships across several organisational levels, not merely transactions between one contractor and one supplier. Such multi-level structure helps explain why a subcontractor's late approval, a designer's change or a delivery-window restriction can undermine performance without any factory failure. Governance must therefore cross the legal boundaries of individual contracts while retaining clear responsibility for decisions.

The evidence also suggests that resilience is relational. Construction interfaces depend on trusted forecasts, accurate requisitions, credible supplier promises and dispute-resolution arrangements. Reviews of construction supply chains identify collaboration and information sharing as recurring determinants of performance; nevertheless, they caution against assuming that access to information alone produces coordinated action (Puppo Studer and de Brito Mello, 2021; Singh et al., 2025). Collaboration is valuable when it enables earlier escalation, joint recovery planning and transparent trade-offs. It becomes superficial when meetings multiply while delivery risks remain outside contractual incentives or delegated decision authority.

Resilience, sustainability and cost discipline:-

Resilience is sometimes equated with maintaining large inventories or using multiple suppliers. Neither rule is universally desirable. Strategic stock can protect a critical installation sequence but consume scarce storage, become obsolete after design changes and increase handling damage. Parallel sourcing may reduce a single-point failure but divide orders so thinly that neither vendor invests in dedicated capacity. The literature on sustainable construction and off-site supply chains shows the need to consider logistics, waste, environmental effects and financial viability together (Hussein et al., 2021; Cataldo et al., 2022). The decision question is consequently where protective capacity creates the greatest continuity benefit for its total lifecycle cost.

Saudi conditions make these trade-offs tangible. Domestic manufacturing development can create faster replenishment and local skills, while specialised international procurement may remain unavoidable for some products. Circularity can lower material demand and disposal burdens, although reverse flows require testing, documentation and storage capacity. Alotaibi et al. (2024) identify significant institutional and operational barriers to circular practices in Saudi mega-projects. A resilient model should therefore treat environmental performance as a constraint and objective within procurement alternatives, not as a claim that every contingency action is inherently sustainable.

Critical synthesis of the literature:-**Exposure is created by network configuration as well as external shocks:-**

Disruption is often represented by unexpected events: shipping interruptions, price escalation, supplier insolvency or severe weather. These events matter, but the severity of their impact depends on decisions made long before they occur. Exclusive sourcing, insufficient technical equivalence, late design freeze, tightly coupled installation schedules and fragmented approval procedures amplify exposure. Reviews of construction supply chain risks show a diverse taxonomy of supply, operational, financial and coordination threats and highlight the inadequacy of managing them as disconnected categories (Baghalzadeh Shishehgarhaneh et al., 2024, 2025). This indicates that the resilience model needs two layers: an external hazard register and an internal map of pathways through which those hazards could interrupt delivery.

The Saudi project studies contribute important contextual evidence but do not by themselves establish a universal risk ranking for all giga-projects. Alshihri et al. (2022) associate building-project overruns with multiple interdependent risk factors, while Al-Gahtani et al. (2023) demonstrate the relevance of supplier quality and financial vulnerability in pipeline work. Their implications vary by project type and procurement strategy. A

tunnelling programme with specialised plant should not inherit an unchanged risk scorecard from commercial buildings. Instead, each programme must distinguish supply-chain criticality, substitution constraints and the time window within which intervention remains possible.

One recurring weakness in conventional risk registers is that they score probability and impact without expressing the shape of the dependency. The same supplier can serve several nominally independent subcontractors; a second vendor may depend on the same port or upstream producer; and a contractor with healthy reported revenue may lack sufficient cash to finance early material orders. Risk ownership becomes ambiguous when programme, project and package managers view these links through separate dashboards. Table 1 sets out the mechanisms revealed by the literature and the resulting questions that a resilience model must answer. The table is an interpretive synthesis, not a statistical frequency ranking.

Table 1. Evidence domains, principal mechanisms and unresolved decision problems

Evidence domain	Established insight from reviewed literature	Remaining decision problem
Disruption propagation	Interdependent suppliers and project interfaces transmit local failures across schedule activities.	Which nodes and shared dependencies are genuinely critical?
Sourcing and governance	Contract design, capacity qualification and relationships shape practical response options.	Which supplier alternatives can be activated before a milestone is lost?
Digital coordination	Data integration can improve status visibility and recognition of logistics exceptions.	Who interprets an alert and authorises the required action?
Response and recovery	Reconfiguration and scenario planning can protect continuity under disruption.	Which intervention has acceptable secondary cost and quality consequences?
Performance evaluation	Cost, time, quality and sustainability may move in different directions.	What set of measures distinguishes resilience from expensive over-protection?

Note: Comparative categories are developed from the reviewed sources and do not represent source frequencies.

Procurement governance determines the usefulness of redundancy:-

Protective capacity is purchased through contracting choices, qualification standards, supplier development and buffer policies. Construction supply chain management research increasingly identifies procurement integration as essential because a contract awarded purely on purchase price can shift risk into the delivery phase (Stefano et al., 2023; Okika et al., 2025). Yet a blanket preference for expensive strategic suppliers would be equally weak. Procurement resilience requires differentiated treatment based on replacement lead time, installation criticality, technical uniqueness, supplier concentration and commercial exposure (Tennakoon et al., 2025). High-risk packages warrant early market engagement and documented alternatives; easily replaceable goods may justify competitive replenishment with minimal safety stock.

The relevant decision is not simply whether to dual-source but whether the alternate source can actually deliver. Technical approval records, production-slot reservations, insurance conditions, payment terms, tooling rights and transport permissions influence activation time. A provisional supplier that has not produced an approved sample is a possible option, not a tested fallback. Similarly, local content should be incorporated through capability development and verified capacity, not by labelling a local intermediary as an independent source when the underlying product remains imported. These propositions follow from the network-level arguments of Dolgui et al. (2020) and the construction governance gaps described by Singh et al. (2025).

Financial resilience must also be considered as an interface between owners and contractors. Extended certification cycles, delayed payments or poorly synchronised advance procurement can interrupt materials even when market availability is adequate. Contractual contingencies may exist on paper while subcontractors lack the working capital to exercise them. The proposed approach therefore links supplier evaluation with documented financial exposure, fair payment mechanisms and escalation routes for critical shortages. Such governance does not eliminate

commercial bargaining; it makes the consequences of procurement choices visible at the point when redesign remains feasible.

Information visibility is necessary but not sufficient:-

Digital technologies provide mechanisms for earlier detection, particularly where schedules, requisitions, manufacturing status, shipment events and site readiness can be linked to a common component identifier. Yevu et al. (2021) show how digitisation can connect procurement and wider construction supply processes, while Ganfoud et al. (2024) emphasise the need to assess integration across multiple supply chain actors. Wang et al. (2025) further show how information and relational integration mediate the contribution of traceability technologies to construction supply chain resilience. The challenge is as much semantic and organisational as technical. A dashboard that reports a shipment as 'in transit' may be useless if it does not identify the installation package, design revision, current customs hold or remaining schedule float.

Digital twins offer a more demanding possibility: connected representations of physical assets and their changing operating states. Gehring and Rüppel (2023) demonstrate the relevance of data fusion to construction logistics; Omrany et al. (2023) review technological foundations and adoption barriers more broadly. For supply chain resilience, the benefit lies in relating external events to future project effects and the feasibility of alternative actions. An isolated three-dimensional visualisation is not a resilience capability. The model should ask whether it reveals a deteriorating condition earlier than existing reports, improves a decision, and records what subsequently happened. Recent Saudi evidence supports a similarly qualified assessment. Alnaser and Elmousalami (2025) examine benefits and constraints of artificial intelligence and digital-twin integration in the national construction setting, identifying implementation challenges rather than an automatic performance gain. More generally, Spieske and Birkel (2021) identify visibility and response speed as important pathways between advanced technologies and resilience, while Hald and Coslugeanu (2022) underline the significance of technologies during disruption. These studies justify investment in data quality, interoperability, cybersecurity and staff capability before highly complex forecasting systems are introduced. Where basic material coding is inconsistent, a modest, reliable exception register may deliver more value than a sophisticated but poorly maintained model.

Adaptive delivery requires decisions at the correct moment:-

Visibility has operational value only when an organisation can act before schedule consequences become irreversible. The project decision sequence should distinguish anticipation, containment, reconfiguration and recovery. Anticipation may involve reserving manufacture capacity or accelerating technical approval. Containment can involve protecting a critical item, splitting transport loads or using an approved buffer. Reconfiguration may require substituting an equivalent component, shifting installation sequence or reallocating stock between projects. Recovery includes clearing backlogs, assessing total cost and restoring the required quality assurance records. Simulation and stress-testing literature supports testing such choices against scenarios rather than relying exclusively on a single deterministic baseline (Chen and Hammad, 2023; Ivanov, 2023).

Nevertheless, fast action can generate new risk. Expediting an imported item may avoid immediate delay but increase emissions, damage exposure and customs complications. Resequencing can shift disruption from one subcontractor to another or create rework where access constraints have not been evaluated. The construction data-governance findings of Hua et al. (2025) and the developing-economy study of Deep et al. (2025) reinforce the importance of sound information, adaptive resource planning and collaboration while showing that responses must fit institutional and resource conditions. The implication is that every proposed intervention should be checked against programme-wide criticality and secondary consequences before approval.

Table 2 translates this interpretation into a Saudi-oriented diagnostic. Its signal thresholds are intentionally unspecified: credible thresholds depend on the baseline lead time, the item's significance and the programme's remaining recovery window. Predetermined universal cut-offs would imply evidence that the literature does not provide. What matters is that the indicator has a defined owner, measurement source, escalation route and possible response. These controls turn reporting into a decision process and allow the proposed model to be falsified by observing whether earlier warnings actually improve outcomes.

Table 2. Context-sensitive risk pathways and proposed early-warning controls

Exposure	Propagation pathway	Potential leading signal	Example controlled response
Specialist single-source item	Factory disruption delays installation and testing interfaces.	Unconfirmed manufacturing slot or missed inspection gate.	Approve substitute production route or resequence approved works.
Concurrent programme demand	Multiple projects compete for the same supply or haulage resource.	Shared supplier capacity below aggregate committed requirement.	Programme-level allocation and staged dispatch approval.
Import and inland logistics	Transport or customs exception reduces usable schedule float.	Shipment milestone slippage against latest safe arrival date.	Route alternative, documentation correction or protected stock.
Design/approval instability	Late revision invalidates orders and factory release.	Unresolved technical submittal near production release gate.	Priority design resolution and controlled change freeze.
Supplier liquidity exposure	Cash constraint slows procurement despite nominal capacity.	Verified missed vendor payments or prolonged purchase-order hold.	Commercial escalation and risk-controlled payment assurance.
Remote site and climate constraints	Restricted handling and delivery windows disrupt access sequence.	Delivery plan conflicts with authorised site access or work hours.	Reschedule haulage and coordinate staging with field teams.

Note: Signals and responses are illustrative proposals; project-specific thresholds require validation.

Resilience must be evaluated as protected project performance:-

Supplier on-time delivery is an important indicator, but it does not fully describe resilience. A component that arrives late may have no consequence where installation float exists; another that arrives only slightly late may delay a critical commissioning milestone. Conversely, a contractor may maintain schedule by using costly emergency freight or accepting higher safety stocks. Evaluation must therefore connect delivery outcomes to risk-adjusted schedule continuity, total intervention cost, quality conformance, supplier dependence and environmental consequences. The viable supply chain argument supports this multidimensional perspective rather than a narrow focus on one service measure (Ivanov, 2022).

Practical indicators should distinguish leading from lagging measures. Leading indicators include the percentage of high-criticality items with approved substitutes, verified supplier capacity against committed demand, approval cycle time, visibility of shipment milestones and buffer coverage relative to realistic replenishment lead times. Lagging indicators include disruption-related critical-path days lost, expediting expenditure, rejected substitutions, idle resources and time to restore planned flow. These indicators cannot be aggregated without judgement: adding them into a single opaque score risks concealing an unacceptable safety or quality exception. A transparent dashboard should retain individual measures alongside any summary rating and identify the consequences of breached thresholds.

Development of the Construction Supply Chain Resilience Model:-

Model architecture and causal logic:-

The proposed Construction Supply Chain Resilience Model (CSCRM) comprises five operational capabilities linked by project governance. The first is exposure intelligence: identification of critical components, shared upstream dependencies, disruption pathways and remaining intervention windows. The second is protected sourcing: technically approved alternatives, credible production capacity, commercially feasible buffers and supplier continuity commitments. The third is integrated information: common data definitions that connect package schedules with vendor, logistics and inventory events. The fourth is adaptive delivery: authority and procedures to

reallocate, resequence, substitute or expedite materials while assessing secondary consequences. The fifth is institutional learning: systematic review of decisions, supplier performance, threshold accuracy and network redesign after an event.

The capabilities are deliberately interdependent. Exposure mapping without response options creates awareness but no protection. Protective sourcing without reliable status data can produce unnecessary inventory or conceal late manufacture. Digital visibility without delegated authority merely accelerates the reporting of failure. Flexible field execution without an approved decision trail can undermine compliance and warranty requirements. Learning without procurement-cycle feedback leaves a programme vulnerable to the same failure on its next package. Figure 2 presents the model as a governance-mediated system rather than a collection of isolated tools. Its design draws on the reconfiguration logic of Dolgui et al. (2020), construction supply chain synthesis by Liao et al. (2023), and the multilevel project perspective of Stefano et al. (2023).



Figure 2. Construction Supply Chain Resilience Model and cross-cutting governance (original conceptual illustration).

The model assumes that firms can collect a minimal set of comparable component and schedule data, that procurement authorities permit controlled alternatives and that critical suppliers will share credible delivery information. Those assumptions are not trivial in fragmented project networks. If contracts prohibit information access or vendor statuses are systematically unreliable, digital integration may provide false precision. If substitutions cannot be approved within the available window, reconfigurability is nominal rather than real. The model therefore begins with a readiness assessment covering contractual access, common coding, decision rights, quality approval and supplier participation. A failed readiness gate warrants redesign of governance before technology procurement.

Risk segmentation and decision rights:-

Implementation starts by grouping procurement items into four practical classes: high-criticality and low-substitutability; high-criticality and high-substitutability; lower-criticality and low-substitutability; and routine replenishable supplies. This is a proposal for managerial triage, not a classification shown to outperform alternatives in a controlled study. The first group needs early design closure, production assurance and documented recovery scenarios. The second requires approved substitution pathways and accessible stock or secondary capacity. The third benefits from careful planning but may not justify costly redundancy. Routine items can be managed through efficient replenishment and performance-based contracting. Risk ownership should match the level where an intervention is possible. Package managers monitor installation need dates and technical compliance. Procurement leads verify manufacturing commitments and alternative sourcing. Logistics coordinators monitor route capacity, customs status and delivery windows. The programme supply chain office identifies shared vendors and cross-

project stock transfers. Senior governance resolves conflicts where protecting one package increases exposure elsewhere. A decision record should specify the trigger, responsible approver, alternative considered, cost and schedule effect, safety or quality constraint, and post-action review date. This gives the proposed framework an accountable organisational form.

Implementation sequence and monitoring protocol:-

A credible adoption pathway is incremental. A programme should first map a limited group of schedule-critical items and verify the accuracy of their procurement and logistics records. It should then establish exception-based review meetings, qualified alternatives and decision permissions. Only after these fundamentals work should it automate multi-source event feeds, advanced scenario simulation or digital-twin functions. This sequencing responds to the observation that technology alone does not overcome fragmented processes (Yevu et al., 2021; Alnaser and Elmousalami, 2025). The stages and associated measures are shown in Table 3.

Table 3. Proposed implementation stages, accountable functions and evaluation measures

Stage	Principal action and decision owner	Evidence of readiness / performance
1. Baseline mapping	Programme procurement office maps critical items and common suppliers.	Critical-item register with installation dependencies and named owners.
2. Assurance	Package and quality teams verify substitutes, capacity and approvals.	Approved alternate coverage; unresolved activation constraints.
3. Shared visibility	Digital/project controls team links supplier events to schedule need dates.	Record completeness; alert lead time; exception acknowledgement.
4. Adaptive response	Governance board approves proportionate mitigation and logs decisions.	Time from breach to action; disruption-related schedule days.
5. Learning	Programme risk team reviews expected and observed impacts.	Recovery time; intervention cost; corrective actions closed.

Note: Implementation stages and proposed measures are conceptual rather than tested outcomes.

At the operational level, the model uses a rolling decision cycle. New information updates the item's exposure state; a forecast compares likely availability with the last responsible installation date; a breach prompts a response appraisal; approval authorises a defined action; and subsequent performance is checked against the expected benefit. Figure 3 represents this cycle. The model does not prescribe a universal probability threshold or pretend that disruption prediction can be perfectly accurate. Instead, it seeks an auditable relationship between each leading indicator, the time available for intervention and the costs of both acting and waiting.



Figure 3. Proposed disruption-response decision cycle and feedback loop (original conceptual illustration).

The cycle can be illustrated without inventing project data. Consider a unique façade assembly with an extended manufacturing lead time. Exposure intelligence establishes its dependence on a single production line and design approval. A late shop-drawing release reduces the usable recovery window. Integrated information shows the delayed approval against the installation schedule rather than merely reporting vendor status. Protected sourcing identifies whether an approved alternative factory or redesigned component is realistic; adaptive delivery tests resequencing against access and installation constraints. The programme then records which warning was available, when decisions were taken and whether the intervention preserved the milestone. This example is explanatory only; it is not an observed Saudi case study.

Discussion:-

Theoretical contribution:-

The principal conceptual contribution is to locate resilience at the interface between project-level decisions and programme-wide network dependencies. Construction research often distributes risk among contractor responsibilities, supplier performance and digital information systems. The CSCRM instead describes resilience as a governed conversion process: a credible signal is interpreted against a critical dependency, evaluated against feasible alternatives, translated into an authorised intervention and assessed through protected delivery performance. This process view extends general resilience and viability theories into the temporally constrained setting of construction without assuming that their manufacturing-based evidence transfers unchanged (Ivanov and Dolgui, 2020; Ivanov, 2022).

A second contribution is the distinction between available options and executable options. Supplier diversification is frequently recommended, but actual alternatives are restricted by technical approval, design compatibility, fabrication capacity and the time remaining before installation. By requiring proof of activation time and approval status, the model makes substitutability a verifiable property rather than a declaration. A third contribution is the explicit treatment of trade-offs. Resilience can increase cost, carbon emissions or coordination burden; the preferred intervention is therefore conditional on protecting critical outcomes at an acceptable overall cost. This interpretation is consistent with off-site construction and sustainable logistics research, yet it needs future empirical assessment in Saudi settings (Hussein et al., 2021; Cataldo et al., 2022; Deep et al., 2025).

Implications for Saudi giga-project governance:-

For Saudi clients and delivery authorities, resilience should be embedded in procurement strategy and reporting obligations before the first major long-lead purchase order. Tender and prequalification documentation can seek evidence of supplier network structure, financial capacity, traceable manufacturing slots and realistic mitigation routes for critical packages. Contracts can specify the minimum event data to be shared, interfaces for programme-wide monitoring and a proportionate escalation process. These requirements should be aligned with competition, confidentiality and technical assurance, and should not be interpreted as justification for excluding smaller local firms that could be strengthened through structured supplier development.

For principal contractors, the immediate opportunity is to join procurement and project controls. A materials register becomes decision-relevant when it includes the approved design revision, planned installation date, factory milestone, import pathway, available schedule float and recovery option. For suppliers, early communication of capacity limitations becomes more useful when commercial incentives do not punish every declaration of risk. Across the programme, a shared view of concentrated vendors and route constraints can prevent different work packages from assuming they each possess the same spare capacity. These implications follow from the multilevel megaproject literature and Saudi evidence on schedule and risk exposure, rather than from an assertion that all giga-projects presently employ identical practices (Stefano et al., 2023; Alshihri et al., 2022).

Conditions under which the model may underperform:-

Several limitations are structural. A common dashboard cannot compensate for inaccurate source data; additional suppliers do not create capacity during a system-wide shortage; and rapid approvals cannot resolve a design whose technical requirements remain unstable. Programme-wide coordination can also become slow if central oversight removes authority from competent package teams. The model therefore favours escalation by exception and proportionate control. High-criticality decisions warrant senior scrutiny, but routine replenishment should not be trapped in a cumbersome review process. Digital systems should report confidence and data provenance where possible, avoiding an appearance of certainty unsupported by the underlying supplier records.

Another concern is unequal bargaining power. Large clients can demand substantial reporting burdens or buffer commitments that smaller manufacturers and subcontractors cannot finance. Resilience requirements may then concentrate procurement among large incumbents and inadvertently weaken the domestic supplier base. A more defensible approach differentiates requirements by material criticality, offers reasonable data interfaces and supports capacity development where it creates a credible second source. The relationship between local-content policy, supplier concentration and actual recovery capability is a priority for future Saudi research, not a settled conclusion of this review.

Limitations and research agenda:-

This review is constrained by its focused selection of 30 articles and by the uneven availability of Saudi project-level evidence. Its structured synthesis does not support prevalence estimates, pooled effect sizes or claims that the model is empirically validated. Some included studies rely on international settings or simulations, while Saudi-specific research addresses heterogeneous building and infrastructure environments. Moreover, publication records establish the identities of cited articles but cannot alone demonstrate that every journal satisfies the indexation or quartile requirements of a future target outlet. These limitations define the proper evidential status of the framework: a set of explicit, researchable propositions.

Future research should first test whether critical-component mapping, integrated signals and defined response rights improve warning lead time and reduce disruption-related critical-path loss relative to conventional management. A longitudinal multi-project study could observe procurement packages before, during and after disturbances, recording baseline variability, supplier concentration, decision timing and counterfactual response options. A second stream should examine how local sourcing, technically qualified alternatives and project-wide resource sharing interact under correlated disruptions. A third should compare the costs and decision benefits of simple exception dashboards with simulation-rich digital twins. These tests need transparent measurement definitions, appropriate comparison groups and the reporting of failed interventions, rather than retrospective claims that successful projects must have been resilient.

Conclusion:-

The construction supply chain challenge in Saudi giga-projects is not the absence of individual risk techniques; it is the difficulty of coordinating those techniques across temporary organisations, tightly coupled schedules and extended supplier networks. The reviewed literature supports five complementary capacities: understanding critical exposure, preparing viable sourcing alternatives, maintaining decision-relevant information, authorising adaptive delivery and learning from disruption outcomes. The proposed CSCRM integrates these capacities through specific governance arrangements and a measurable decision cycle. Its value lies in making resilience an actionable project-delivery proposition, while its effectiveness remains to be tested against real procurement and performance records. Future validation should prioritise whether earlier signals lead to timely, proportionate action and demonstrably preserve critical outcomes.

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