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Designing a Digital Innovation Model for Exploitation Based on Maximum Operational Performance in the Mining Industry

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A B S T R A C T

The purpose of this study was to design a digital innovation model for mining operations in Iran, with an emphasis on enhancing performance, sustainability, and competitiveness. The research adopted a mixed-methods grounded theory approach (qualitative–quantitative). A review of the literature indicated that existing international models are unable to fully address the needs of Iran's mining sector due to infrastructural and cultural differences, highlighting the necessity of a localized model. The qualitative sample consisted of 15 experts and managers from the mining industry who were selected through purposive sampling based on expertise, experience, and diversity criteria. Data were collected through semi-structured interviews and analyzed using grounded theory. In the quantitative phase, data from 220 questionnaires completed by mining managers and specialists across the country were collected through stratified sampling and analyzed using Structural Equation Modeling (SEM). Qualitative findings identified weak technological infrastructures, the absence of an innovation-oriented culture, and the lack of data-driven governance frameworks as key barriers. Critical factors included managerial support, transformational leadership, technology localization, and the integration of management software systems. The results indicate that strengthening human capital, promoting data-driven decision-making, and implementing macro-level policy interventions can facilitate maximum operational efficiency, profitability, and sustainability throughout the mining value chain. Quantitative findings confirmed the validity and goodness-of-fit of the proposed model and provided practical strategies for advancing digital innovation. This study offers a novel foundation for policymaking and the development of a localized digital transformation model in Iran's mining industry.

Keywords: *Digital Innovation, Digital Transformation, Exploitation, Mining Industry.*

1. Introduction

The construction industry plays a fundamental role in economic growth, infrastructure development, employment generation, and societal well-being. At the same time, it is recognized as one of the most resource-intensive industries, contributing substantially to energy consumption, environmental degradation, waste generation, and greenhouse gas emissions. Consequently, increasing attention has been directed toward integrating sustainability principles into construction project management and supply chain operations. Sustainable construction supply chain management (SSCM) has emerged as a strategic approach that seeks to balance economic performance, environmental stewardship, and social responsibility throughout the lifecycle of construction projects. The growing emphasis on sustainability is driven not only by regulatory requirements and stakeholder expectations but also by the recognition that sustainable practices can improve project resilience, competitiveness, and long-term organizational performance (Ika & Pinto, 2022; Johnsson et al., 2020). As construction projects become increasingly complex and interconnected, supply chain management has evolved from a traditional logistics function into a strategic capability that directly influences project success, operational efficiency, and organizational sustainability (Altekar, 2023; Hugos, 2024).

Construction supply chains are characterized by multiple stakeholders, fragmented processes, uncertain environments, and extensive interdependencies among suppliers, contractors, consultants, project owners, and regulatory institutions. These characteristics create substantial challenges for effective decision-making and risk management. Modern supply chains must simultaneously address issues such as resource scarcity, market volatility, environmental regulations, labor safety, technological adaptation, and stakeholder expectations. Consequently, resilience and sustainability have become central objectives in construction supply chain management. Research has shown that organizations capable of developing resilient supply chain structures are better positioned to manage disruptions, maintain operational continuity, and achieve sustainable performance outcomes (Attia & Uddin, 2024; Brusset & Teller, 2017). Furthermore, effective supply chain integration improves coordination among project participants and creates sustainable competitive advantages through enhanced information sharing, collaboration, and process optimization (Fernie, 2023; Shou et al., 2022).

The growing complexity of construction projects has intensified the importance of identifying and managing risks that affect project performance and sustainability. Construction supply chains are exposed to numerous risk categories, including economic, environmental, social, technical, operational, and organizational risks. Economic risks often arise from price fluctuations, inflation, financial instability among suppliers, and changing market conditions. Environmental risks are associated with resource depletion, pollution, climate-related disruptions, and regulatory compliance requirements. Social risks encompass labor rights, community impacts, stakeholder conflicts, and workforce safety concerns. Technical and structural risks involve design deficiencies, engineering failures, quality issues, and project execution challenges. These risks interact dynamically, creating cascading effects that may compromise project objectives if not appropriately managed (Fang et al., 2013; Qazi et al., 2021). Previous studies have emphasized that effective risk assessment and prioritization are essential for ensuring sustainable project outcomes and minimizing the adverse impacts of uncertainty on project performance (Ma et al., 2021; Zanjani et al., 2021).

Recent advances in sustainable construction management have highlighted the importance of integrating sustainability considerations into supply chain decision-making processes. Sustainable supply chains are expected not only to deliver projects efficiently but also to contribute positively to environmental conservation, social welfare, and economic development. The transition toward sustainability has accelerated the adoption of innovative technologies, circular economy principles, green procurement strategies, and digital transformation initiatives across supply chain networks. Smart technologies, digital platforms, and data-driven decision systems are increasingly used to improve visibility, coordination, and performance monitoring throughout supply chains. These technological developments facilitate real-time decision-making and support the implementation of sustainable practices across project lifecycles (Ada et al., 2023; Hanaysha & Alzoubi, 2022). In particular, the adoption of Internet of Things (IoT) technologies and digital management systems has demonstrated considerable potential for enhancing operational efficiency, reducing waste, and improving supply chain resilience (Hanaysha & Alzoubi, 2022; Hugos, 2024).

Despite the growing emphasis on sustainability, construction supply chains continue to face significant challenges in balancing economic efficiency with environmental and social responsibilities. The construction sector remains vulnerable to disruptions caused by financial uncertainties, material shortages, climate-related events, and operational inefficiencies. Moreover, sustainability objectives often require organizations to make complex trade-offs among competing criteria. Traditional decision-making approaches frequently struggle to capture the multidimensional and interdependent nature of sustainability challenges. As a result, researchers have increasingly turned to multi-criteria decision-making (MCDM) methodologies to support complex evaluations involving multiple stakeholders, objectives, and performance criteria (Ciardiello & Genovese, 2023; Patel-Jena & Dwivedi, 2023). MCDM techniques provide structured frameworks for evaluating alternatives, prioritizing risks, and selecting optimal strategies under conditions of uncertainty and conflicting objectives.

Among the various MCDM techniques, the Analytic Network Process (ANP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) have gained considerable attention in construction management research. ANP extends traditional hierarchical decision-making approaches by accounting for interdependencies and feedback relationships among decision criteria. This capability makes ANP particularly suitable for evaluating complex systems such as construction supply chains, where multiple factors influence one another simultaneously. Studies have demonstrated the effectiveness of ANP in prioritizing supply chain risks, evaluating sustainability indicators, and supporting strategic decision-making in construction projects (Alamdari et al., 2023; Natalia et al., 2020). At the same time, TOPSIS has emerged as one of the most widely applied methods for ranking alternatives based on their relative proximity to ideal solutions. Its simplicity, computational efficiency, and ability to accommodate multiple criteria have made it a valuable tool for sustainability assessments and strategic prioritization exercises (Chakraborty, 2022; Ciardiello & Genovese, 2023).

The integration of ANP and TOPSIS methodologies offers substantial opportunities for addressing the limitations of conventional risk management frameworks. By combining ANP's ability to model complex interdependencies with TOPSIS's capability for alternative ranking, hybrid decision-support systems can provide comprehensive evaluations of sustainability risks and management strategies. Such integrated frameworks have been increasingly recommended for addressing contemporary supply chain challenges. For example, studies focusing on sustainable supply chain governance, risk assessment, and strategic planning have highlighted the value of combining multiple analytical approaches to improve decision quality and support sustainable outcomes (Alshehri et al., 2022; Jamalnia et al., 2023). Similarly, integrated decision-support systems have been shown to facilitate more effective supplier evaluations, risk prioritization processes, and sustainability assessments across various industrial sectors (Natalia et al., 2020; Patel-Jena & Dwivedi, 2023).

Construction projects present unique challenges that further justify the need for hybrid analytical approaches. The dynamic nature of project environments, combined with extensive stakeholder involvement and uncertain operating conditions, creates a highly complex decision context. Research on construction supply chain management has identified numerous critical success factors, including material quality, supply chain integration, workforce competency, safety performance, technological capability, and stakeholder collaboration (Hasaniyan Pourfereidani et al., 2025; Wuni & Shen, 2020). Moreover, sustainable project delivery requires organizations to address health and safety concerns, environmental impacts, quality management requirements, and cost constraints simultaneously. Studies investigating occupational safety, modular construction, and procurement management have consistently emphasized the importance of proactive risk management and integrated planning in achieving sustainable project outcomes (Boadu et al., 2022; Mohandes et al., 2022).

The growing availability of digital technologies has further transformed the landscape of construction risk management and supply chain optimization. Artificial intelligence, machine learning, neural networks, and Building Information Modeling (BIM) have introduced new possibilities for predictive analytics, risk forecasting, and performance monitoring. These technologies enable organizations to identify emerging risks, simulate alternative scenarios, and support evidence-based decision-making processes. Previous research has demonstrated the effectiveness of artificial neural networks and machine learning techniques in improving project monitoring, safety management, and construction planning accuracy (Ma et al., 2021; Mossalam & Arafa, 2017). Likewise, BIM-based management frameworks have enhanced coordination among project stakeholders and improved schedule and cost management performance (Chen & Tang, 2019). The integration of digital technologies with sustainability-oriented decision-support systems represents a promising direction for future construction supply chain management research (Ada et al., 2023; Torp et al., 2016).

Although the literature has made substantial progress in understanding sustainable construction supply chains, several important research gaps remain. First, many studies focus on individual dimensions of sustainability without adequately capturing the interrelationships among economic, social, environmental, and structural factors. Second, existing risk assessment frameworks often lack empirical validation within geographically unique and rapidly developing construction environments. Third, while numerous studies have applied MCDM methods independently, relatively few have integrated statistical analyses with hybrid ANP–TOPSIS frameworks to support comprehensive sustainability assessments. Furthermore, methodological concerns associated with traditional decision-making approaches continue to motivate the development of more robust analytical frameworks capable of capturing uncertainty, interdependency, and contextual complexity (Munier & Hontoria, 2021; Shiliang et al., 2012). Reliable data collection and measurement instruments remain critical for ensuring the validity of expert-based decision models and risk assessments (Tiira & Lohi, 2014).

Given these limitations, there is a clear need for integrated and empirically validated frameworks that combine statistical analysis with advanced MCDM techniques to evaluate sustainability risks and prioritize management strategies in construction supply chains. Such frameworks can provide decision-makers with actionable insights for improving resource allocation, enhancing resilience, strengthening sustainability performance, and supporting long-term strategic planning. The development of context-specific models is particularly important for regions experiencing rapid urbanization and infrastructure expansion, where supply chain challenges may differ significantly from those observed in more mature construction markets (Hussein et al., 2021; Lepistö et al., 2024).

Therefore, the aim of this study is to develop and empirically validate a hybrid statistical–MCDM framework integrating one-sample statistical analysis, ANP, and TOPSIS to identify, prioritize, and evaluate sustainability-related risks and management strategies in construction supply chains.

2. Methods and Materials

In this study, data were collected through expert surveys using the Delphi method. Initially, an initial list of risks and sustainability strategies was prepared based on a literature review and expert opinions. Subsequently, this list was presented as a questionnaire to 33 experts in the field of construction management and sustainability. In this phase, consensus on the final criteria and main risks was achieved using the Delphi method. For data analysis, the TOPSIS and ANP software tools were employed. The ANP model was applied to prioritize risks, while the TOPSIS model was used to prioritize strategies. The criteria for risk assessment and prioritization included financial risks, material quality, climatic conditions, infrastructural constraints, and stakeholder coordination. The criteria for strategy assessment and prioritization included cost reduction, quality improvement, time reduction, and increased stakeholder satisfaction. These criteria were determined based on expert opinions and the results of literature analyses, and were utilized for the prioritization of risks and strategies.

A practical, survey-based research design was adopted to analyze the sustainable construction supply chain structure within Qeshm. The study population consisted of project managers, engineers, contractors, and supply managers. Data collection relied on structured questionnaires administered across six major construction projects representing significant urban, commercial, and residential developments (Table 1).

A two-stage approach was employed. First, the Delphi technique was applied to gather expert consensus regarding critical factors affecting the sustainability of local supply chains. Second, the validated questionnaire items were tested for internal consistency using Cronbach's Alpha. The research is descriptive–inferential: the descriptive dimension identifies and classifies sustainability-related criteria within Qeshm's construction context, while the inferential aspect investigates the interrelationships between the identified variables and assesses the integration of sustainable supply chain management models in practice.

Table 1

Characteristics of Studied Construction Projects in Qeshm City

Construction Project	Usage	Area (m²)	Number of Floors	Facilities Description
Qeshm City Center Tower	Commercial and Residential	35,000	12	750 commercial units; a combination of shopping, service, and accommodation spaces; a major modern center
Qeshm Top Island Tower	Commercial and Residential	8,000	33	Specialized concrete and bolt installation; structure resistant to harsh climate; sea proximity
Amin Complex Qeshm	Commercial, Residential, Tourist	100,000	25	600+ commercial units, 600 residential units; largest multi-story parking; helicopter pad; emergency clinic
Milad Complex Qeshm	Commercial, Office, Recreational, Residential	50,000	18	790 commercial units; offices; amusement park; restaurant
Atlantis Complex Qeshm	Commercial, Office, Hotel, Residential	55,000	10	Mixed traditional and modern design; diverse facilities including parking, restaurant, and café
Qeshm Twin Towers	Commercial and Residential	44,860	24	Modern design; under construction

The first questionnaire section examined risks affecting the supply chain structure across four dimensions: economic, social, environmental, and structural (Table 2). A 23-item, 5-point Likert scale questionnaire facilitated statistical analysis of risk impacts. A one-sample t-test was conducted using SPSS, comparing sample means to specified benchmarks to determine significant deviations. Hypotheses for the test were:

Null Hypothesis (H0): Sample mean equals specified value (H0: $\mu = \mu 0$)

Alternative Hypothesis (H1): Sample mean differs from specified value (H1: $\mu \neq \mu 0$)

Table 2

Risks Affecting the Supply Chain Structure in Qeshm City

Criteria (dependent variables)	Risks (Independent Variables)
Economic	Financial Challenges of Suppliers; Price Fluctuations; Exchange Rate Variability; Delays Cost Increases; Transport Cost Increases; Specification Changes Costs
Social	Environmental/Cultural Pressures; Lack of Local Expertise; Strategic Procurement Management; Local Procurement Social Impact; Community Impact and Involvement; Workers' Rights Violations
Environmental	Material Quality Concerns; Safety Adherence; Environmental Health Standards Pollution; Natural Resource Depletion; Non-Renewable Resource Usage
Structural	Design Errors; Engineering Non-Compliance; Material Quality; Weather Conditions; Design Precision

The second questionnaire section aimed to identify, evaluate, and prioritize drivers influencing the supply chain success for Qeshm construction projects from a sustainable development perspective. Four key drivers and 14 sub-criteria (Table 3) were weighted using the Analytic Network Process. ANP facilitates modeling of complex decision relationships where lower-level elements influence higher levels, representing dependencies in a network format. Its strengths include handling interdependencies and calculating decision consistency.

Table 3

Drivers Affecting Supply Chain Success in Qeshm City

Driver	Sub-criterion
Material Supply Management	Quality Domestic Materials; Tools And Equipment; Optimized Transport; Import/Export
Power Supply and Safety	Experienced Consulting/Contracting; Skilled Labor Provision
Design and Engineering	Optimal Designs; Construction Methodologies; Mechanical/Electrical System Design
Manufacturing and Production	Structural Component Manufacturing; System Assembly; Quality Control; Project Delivery Time

The consistency of pairwise comparisons was evaluated using the Consistency Ratio (CR) in ANP, with CR ≤ 0.1 indicating acceptable judgment consistency (Munier and Hontoria 2021). The research process included problem definition, network structure development, expert pairwise comparisons (33 respondents), priority calculation, consistency assessment, and decision-making. A summary of ANP steps for this study including to:

Define the Decision Problem: Prioritization of drivers affecting the success of the supply chain structure of construction projects in Qeshm city

Develop the Network Structure: based of Driver (dependent variable) and Sub-criterion (independent variable) in table 3

Perform Pairwise Comparisons: 33 people questioned

Calculate Priority Weights: with ANP matrix

Calculate Consistency Index: formula of 1 and 2

Make the Decision

After evaluating the predictive model of performance level in construction project structures, a comprehensive model should be developed that integrates the previous outputs to provide practical solutions. The TOPSIS model, utilizing expert judgment and based on multiple criteria, facilitates the prioritization of these solutions. Originally introduced by Hwang and Yoon in 1981, TOPSIS identifies the most suitable option as the one with the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution. This method is recognized as one of the most effective multi-criteria decision-making techniques, capable of considering interdependencies among criteria when evaluating alternatives. The TOPSIS decision matrix comprises criteria weights, criteria types (beneficial or non-beneficial), and alternatives. The procedural steps of the TOPSIS method include:

- Constructing the decision matrix
- Normalizing the decision matrix
- Determining the weight vector for the criteria
- Forming the weighted normalized decision matrix
- Identifying the positive and negative ideal solutions
- Calculating the distances to the positive and negative ideal solutions
- Computing the relative closeness to the positive ideal solution

Based on the collected responses from the questionnaire, a database was established and the TOPSIS modeling technique was applied. The output of the TOPSIS model facilitates the prioritization of 11 proposed strategies:

1. Selection of sustainable materials and resources (recycled, local, low-carbon, long lifespan)
2. Reduction of energy and water consumption (solar systems, solar panels and thermal insulation, rainwater harvesting and reuse in building applications)
3. Optimization of transportation processes (distance reduction, order consolidation)
4. Management of construction waste (recycling and reuse)
5. Enhancement of social commitments (creating local job opportunities, fair wages, maintaining worker safety)
6. Risk management through identification and assessment (raw material shortages, price fluctuations, environmental regulations) and contingency planning
7. Effective communication with stakeholders (contractors, suppliers, local community) and transparency in activities
8. Training project personnel and raising awareness in the local community
9. Use of sustainable supply chain management software (for tracking and managing raw materials and resources/improving efficiency and productivity)
10. Sustainability certifications
11. Building insurance

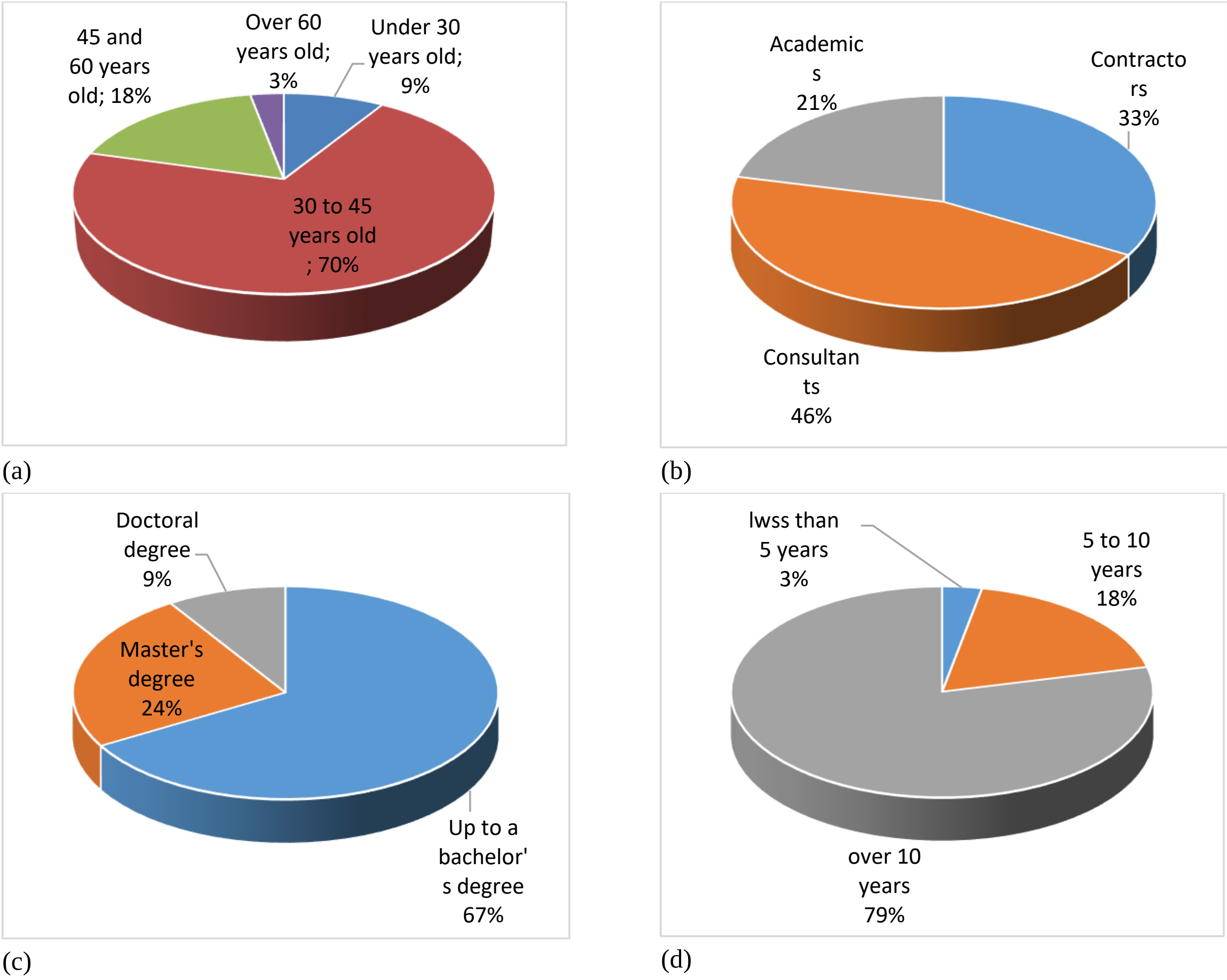
It is determined which strategy is most appropriate for sustainable supply chain management in construction projects in Qeshm city, considering the identified drivers and risks. The strategies evaluated include: (1) materials supply management, (2) workforce supply and safety management, (3) design and engineering management, and (4) construction and production management. In this section, the weights of the four stimuli, as derived from the doctoral dissertation used in this study, were obtained as follows: 0.553, 0.059, 0.294, and 0.094, respectively.

3. Findings and Results

Demographic analysis of 33 experts engaged in construction projects in Qeshm reflected a mature and experienced professional community. Figure 1 indicates that 70% were aged between 45 and 60 years, 46% were consultants, 66% Up to a bachelor's degree, and 78% had over 10 years of work experience. This sample composition supports the validity of insights for supply chain management in the region. The high expertise level bolsters confidence in collected data; however, the relatively limited size and narrow age range suggest cautious interpretation when generalizing beyond this cohort.

Figure 1

Characteristics of the Statistical Population: (a) Age distribution, (b) Occupation, (c) Education level, (d) Work experience



The reliability of the questionnaire was assessed based on the responses of 33 expert professionals involved in construction projects in Qeshm City. The experts rated the importance of several criteria related to impactful risks and key drivers affecting the success of the supply chain structure in construction projects, using a 1 to 5 scale. The reliability test results are detailed in Tables 4 and 5.

Table 4 reports the reliability tests for risks affecting the supply chain structure, presenting standard deviations and Cronbach's alpha coefficients for four risk criteria: economic, social, environmental, and structural. The Cronbach's alpha coefficient for the economic risk category was 0.861 with a low standard deviation of 0.268, indicating high internal consistency and reliability of the responses in this category. The social, environmental, and structural risk categories had higher standard deviations of 0.352, 0.462, and 0.371 respectively, but their Cronbach's alpha values, though not detailed in the table, are presumably acceptable given the overall assessment indicating validity.

Table 5 summarizes reliability tests for the key drivers influencing supply chain success. The categories analyzed include Material Supply Management, Power Supply and Safety Management, Design and Engineering Management, and Manufacturing and Production Management. The Material Supply Management criterion showed a standard deviation of 0.426 and a Cronbach's alpha of 0.778, demonstrating acceptable internal consistency. The remaining categories had standard deviations of 0.111, 0.421, and 0.762 respectively, though their alpha values were not explicitly provided.

The Cronbach's alpha coefficients surpassing the 0.7 threshold suggest that the questionnaire is a reliable instrument for measuring expert opinions on both risks and success drivers in Qeshm's construction supply chain context. The low standard deviation in the economic risk category indicates consensus among experts, reflecting potentially universally acknowledged economic risks such as financial volatility and material price fluctuations. Conversely, the higher standard deviations in environmental and structural risks suggest a diversity of perceptions or experiences, which may stem from varied project conditions or differing awareness of environmental and structural challenges.

For key drivers, the relatively lower variability in Power Supply and Safety Management might indicate an agreement on the critical nature of qualified personnel and consistent power supply in project success, while higher variability in Manufacturing and Production Management may reflect the complexity and variability of manufacturing processes across projects.

The demonstrated reliability of the questionnaire ensures confidence in the subsequent analyses based on these data. High consensus on economic risks underscores the necessity for policymakers and construction managers to prioritize strategies for financial risk mitigation and supply cost stabilization. The divergent views on environmental and structural risks imply the need for tailored, context-specific risk management approaches that consider project variability and localized conditions.

Regarding success drivers, material supply management's validated reliability supports its central role in project outcomes, emphasizing quality assurance and efficient logistics as crucial elements. The insights on power and safety, design and engineering, and manufacturing management highlight multifaceted factors that require integrated management attention. These findings align with the journal's focus on construction economy, technology, management, and intelligent decision systems, contributing valuable knowledge for enhancing supply chain resiliency and sustainability in complex regional contexts such as Qeshm.

Table 4

Results of reliability tests for risks affecting the supply chain structure of construction projects in Qeshm city

Criteria (dependent variables)	Standard Deviation	Cronbach's Alpha
Economic	0.268	0.861
Social	0.352	
Environmental	0.462	
Structural	0.371	

Table 5

Results of the Reliability Test for Effective Stimuli on the Success of Supply Chain Structure in Construction Projects

Criteria (dependent variables)	Standard Deviation	Cronbach's Alpha
Material Supply Management	0.426	0.778
Power Supply and Safety Management	0.111	
Design and Engineering Management	0.421	
Manufacturing and Production Management	0.762	

Table 6 summarizes the results of the one-sample Student's t-test analyzing the perceived risks affecting the supply chain structure of construction projects in Qeshm City across four major criteria: economic, social, environmental, and structural. Responses were measured on a Likert scale from 1 (very low) to 5 (very high) and analyzed for significance against a mean value.

Economic risks identified as significant ($p < 0.05$) include financial challenges of material and equipment suppliers (t=12.14), sudden fluctuations in material and equipment prices (t=15.69), exchange rate variations for imported materials (t=15.32), cost increases due to delivery delays (t=11.41), and transportation-related cost increases (t=15.13). However, cost increases from changes in project requirements showed no significant effect (p=0.108, t=2.8).

Social risks with significant impacts include environmental and cultural pressures on managers (t=11.72), managerial strategic orientation towards procurement (t=13.66), violation of workers' rights (t=12.54), and local community involvement (t=4.32). Contrarily, insufficient knowledge among local managers and suppliers (p=0.40) and the impact of local material procurement on local lives (negative mean, t=-15.59) were not significant.

Environmental risks were uniformly significant, including inadequate quality of materials (t=11.72), attention to human safety (t=10.99), adherence to environmental health standards (t=5.69), pollution creation due to local material use (t=13.28), destruction of natural resources (t=12.73), and use of non-renewable resources (t=15.16).

Structural risks significantly affecting the supply chain included design errors (t=10.78), non-compliance with engineering requirements (t=13.54), weather conditions (t=13.03), and proper engineering and supervision (t=12.44). Low-quality materials were not statistically significant (p=0.152).

Table 6

Results of the One-Sample T-Test for Risks Affecting the Supply Chain Structure of Construction Projects in Qeshm City

Criteria (dependent variables)	Risks (Independent Variables)	t	Df	Sig.(p)	Mean difference
Economic	Financial challenges of suppliers	12.14	32	0.007	1.33
	price fluctuations	15.69	32	0.004	1.77
	exchange rate variability	15.32	32	0.004	1.68
	delays cost increases	11.41	32	0.008	1.09
	transport cost increases	15.13	32	0.004	1.66
	specification changes costs	2.80	32	*0.108*	0.21
Social	Environmental/cultural pressures	11.72	32	0.01	1.15
	lack of local expertise	1.06	32	*0.400*	0.08
	Strategic procurement management	13.66	32	0.005	1.42
	Local procurement social impact	-15.59	32	0.004	-0.81
	community impact and involvement	4.32	32	*0.050*	0.34
	workers' rights violations	12.54	32	0.006	1.27
Environmental	Material quality concerns	11.72	32	0.007	1.12
	safety adherence	10.99	32	0.008	1.05
	environmental health standards	5.69	32	0.03	0.46
	pollution	13.28	32	0.006	1.38
	natural resource depletion	12.73	32	0.006	1.29
	non-renewable resource usage	15.16	32	0.004	1.71
Structural	Design Errors	10.78	32	0.009	1.03
	engineering non-compliance	13.54	32	0.005	1.45
	material quality	2.27	32	*0.152*	0.17
	Weather Conditions	13.03	32	0.006	1.32
	design precision	12.44	32	0.006	1.26

The economic risks show strong consensus among respondents, reflecting the financial volatility and cost pressures highly characteristic of material and logistics provisioning in Qeshm's construction projects. The insignificance of cost changes due to project requirement modifications may suggest that these changes are either infrequent or well-managed, thus not perturbing supply chain performance measurably. The results emphasize the multifaceted nature of risks affecting construction supply chains, with pronounced economic and environmental dimensions. Addressing financial risks such as price fluctuations and supply delays is imperative for stabilizing construction operations in Qeshm. Developing robust procurement and logistics strategies can alleviate these vulnerabilities.

Social risks reveal a nuanced picture. While managerial pressures and worker rights are strongly perceived as risks, knowledge gaps among local managers and the influence of community procurement appear less critical. Interestingly, local material procurement's negative mean suggests a complex or possibly mitigating role in supply chain dynamics, a point warranting further qualitative scrutiny. Social dimensions, while less uniformly impactful, highlight the importance of managerial orientation and labor protections. The ambiguous effect of local material procurement suggests potential opportunities or challenges in integrating local resources sustainably without compromising supply chain integrity.

Environmental risks exhibit uniform statistical significance, underscoring their prominence in supply chain risk profiles. Pollution, resource depletion, and adherence to environmental standards emerge as critical concerns, indicative of the environmental sensitivity of construction projects in Qeshm and aligning with sustainability goals. Environmental risks are predominant, demanding stringent environmental management practices, supplier accountability, and sustainable material sourcing. This aligns with the journal's focus on sustainable construction technology and management.

Structural risks are critical, particularly design and regulatory compliance and weather impacts—factors likely exacerbated by the region's climatic and geographical features. The non-significance of low-quality materials may reflect standard quality assurance mechanisms or limited variation in material quality within the sample scope. Structural risks related to design accuracy and regulatory compliance highlight the necessity for rigorous engineering oversight and adaptive design procedures, especially under challenging local weather conditions.

Collectively, these insights provide actionable knowledge for construction managers and policymakers aiming to foster resilient, sustainable supply chains in Qeshm. Tailored risk mitigation strategies targeting these dimensions can optimize project delivery, cost-efficiency, and sustainability performance.

Tables 7 to 11 present pairwise comparison matrices for sub-criteria under four main drivers of the supply chain structure in construction projects in Qeshm City.

Material Supply Management: The provision of high-quality domestic building materials received the highest weight (0.549).

Power Supply and Safety Management: Provision of skilled labor was prioritized highest (weight 0.660).

Design and Engineering Management: Optimal initial and foundation design was the top priority (weight 0.731).

Manufacturing and Production Management: Manufacturing of structural components was weighted highest (0.548).

Figure 6 shows that among the four main drivers, Material Supply Management was the most critical with a weight of 0.554. Combining driver and sub-driver weights produced comprehensive priorities (Figure 7), placing high-quality material provision (weight 0.304) and optimal foundation design (0.215) as top overall priorities. Construction tools and equipment provision ranked third (0.136), while project delivery time and experienced contractor contracts ranked lowest.

Table 7

Pairwise Comparison Matrix for Material Supply Management Drivers

Sub-criterion	C1	C2	C3	C4	Geometric mean	Eigenvector
Provision of High-Quality Domestic Building Materials (C1)	1	5	3	5	2.943	*0.549*
Provision of Building Tools and Equipment (C2)	0.2	1	3	5	1.316	0.246
Optimized Transportation (C3)	0.333	0.333	1	3	0.76	0.142
Import and Export of Building Products (C4)	0.2	0.2	0.333	1	0.34	0.063

Table 8

Pairwise Comparison Matrix for Power Supply and Safety Management Drivers

Sub-criterion	C1	C2	C3	Geometric mean	Eigenvector
Procurement of Experienced Consulting Contracts (C1)	1	5	3	2.943	0.184
Procurement of Experienced Contracting Contracts (C2)	0.2	1	3	1.316	0.156
Provision of Labor and Skilled Workforce (C3)	0.333	0.333	1	0.76	*0.660*

Table 9

Pairwise Comparison Matrix for Design and Engineering Management Drivers

Sub-criterion	C1	C2	C3	Geometric mean	Eigenvector
Optimal Preliminary and Foundation Design (C1)	1	5	7	3.271	*0.731*
Construction Methodology (C2)	0.2	1	3	0.843	0.188
Design of Mechanical and Electrical Systems (C3)	0.143	0.333	1	0.362	0.081

Table 10

Pairwise Comparison Matrix for Manufacturing and Production Management Drivers

Sub-criterion	C1	C2	C3	C4	Geometric mean	Eigenvector
Manufacturing of Structural Components (C1)	1	5	3	7	3.201	*0.548*
Assembly and Installation of Mechanical and Electrical Systems (C2)	0.2	1	0.33	5	0.758	0.130
Quality Control in Construction (C3)	0.333	3.03	1	7	1.631	0.279
Project Delivery Time (C4)	0.143	0.2	0.143	1	0.253	0.043

Table 11

Pairwise Comparison Matrix for Manufacturing and Production Management Drivers

Sub-criterion	C1	C2	C3	C4	Geometric mean	Eigenvector
Material Supply Management (C1)	1	5	3	7	3.201	*0.554*
Power Supply and Safety Management (C2)	0.2	1	0.2	0.33	0.339	0.059
Design and Engineering Management (C3)	0.333	5	1	5	1.699	0.293
Manufacturing and Production Management (C4)	0.143	3.03	0.2	1	0.542	0.094

Figure 2

Prioritization of Material Supply Management

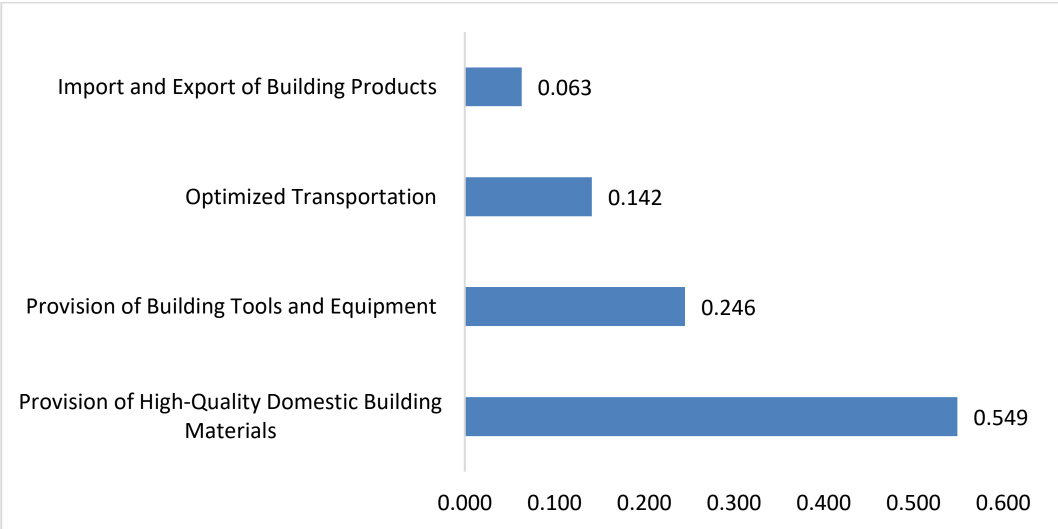


Figure 3

Prioritization of Power Supply and Safety Management

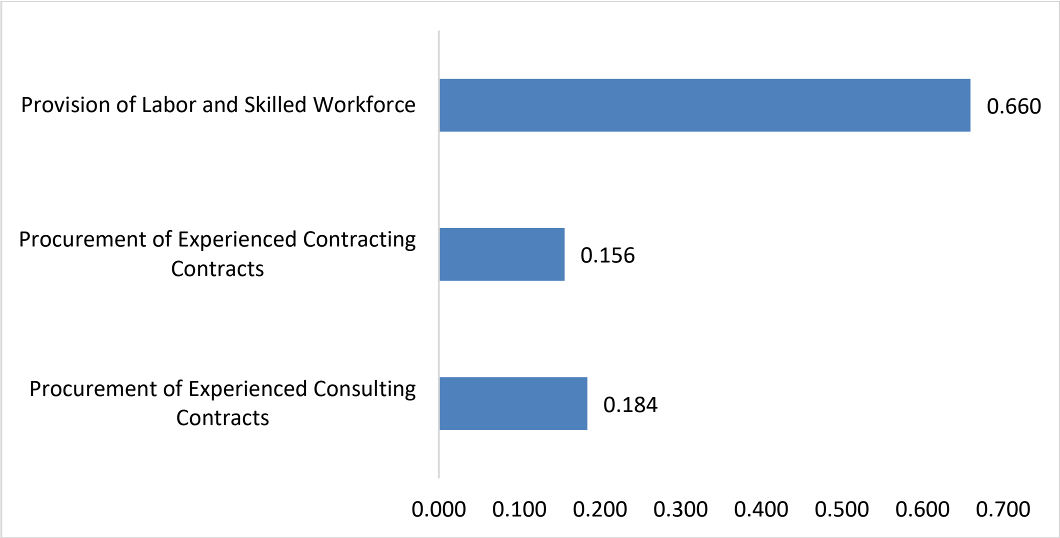


Figure 4

Prioritization of Design and Engineering Management

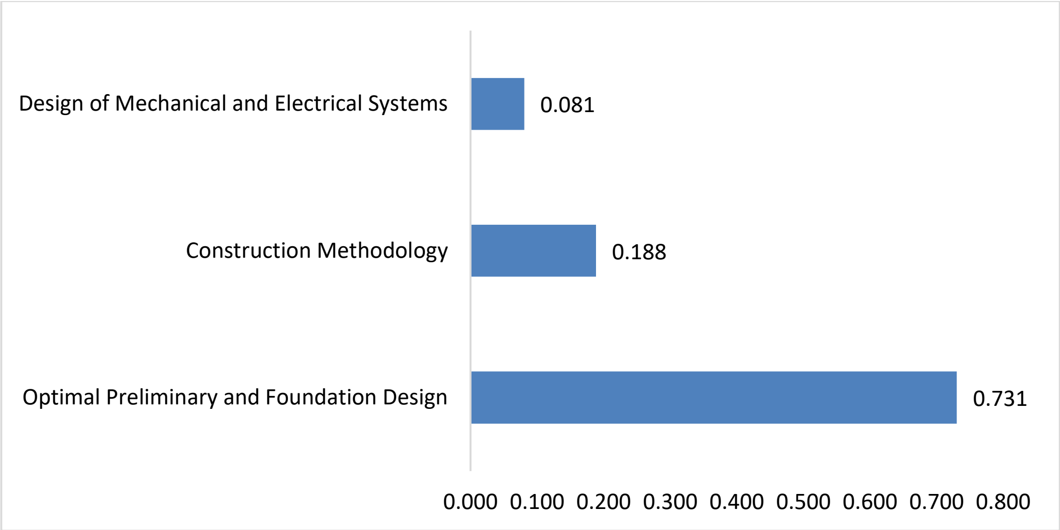


Figure 5

Prioritization of Manufacturing and Production Management

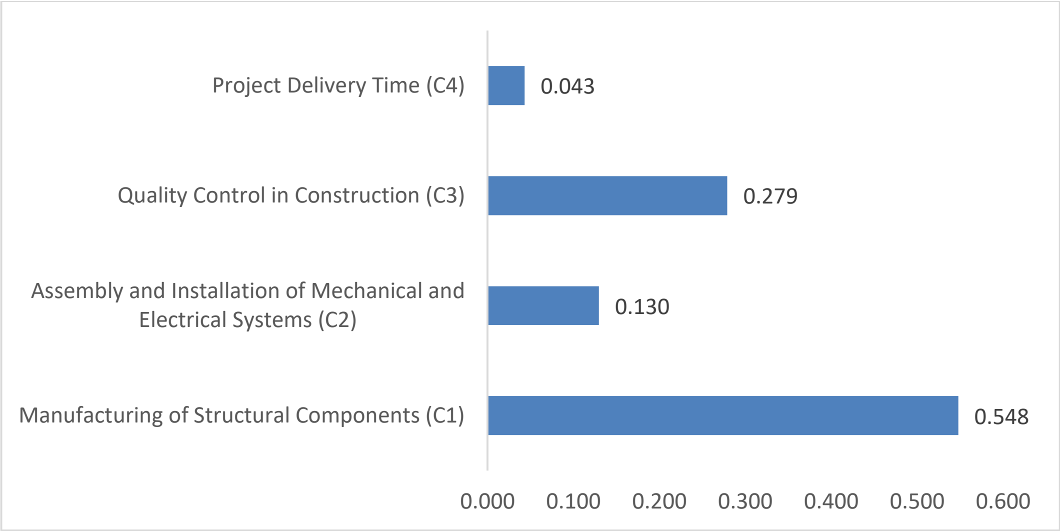


Figure 6

Prioritization of Key Drivers in the Supply Chain Structure of Construction Projects in Qeshm City

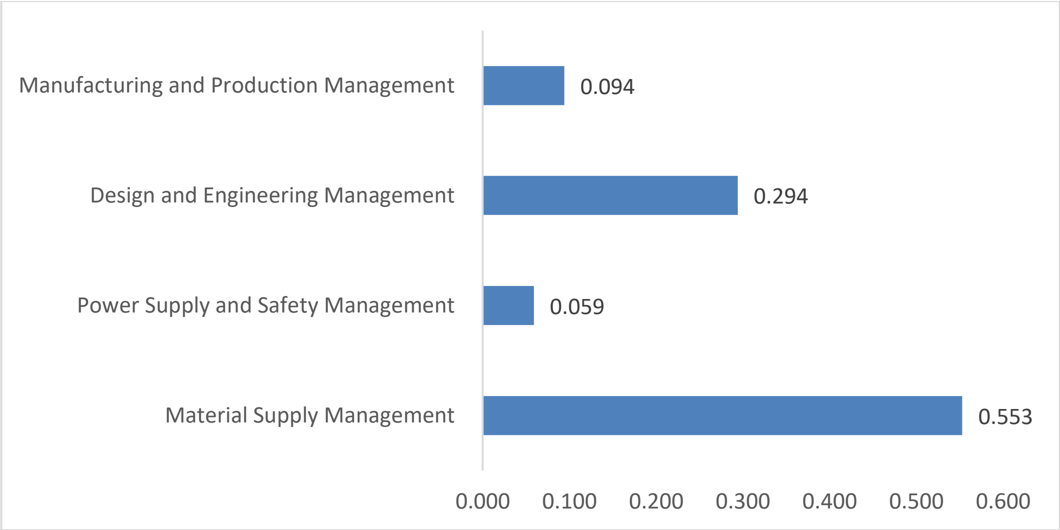


Figure 7

Prioritization of all sub-criteria in the Supply Chain Structure of Construction Projects in Qeshm City

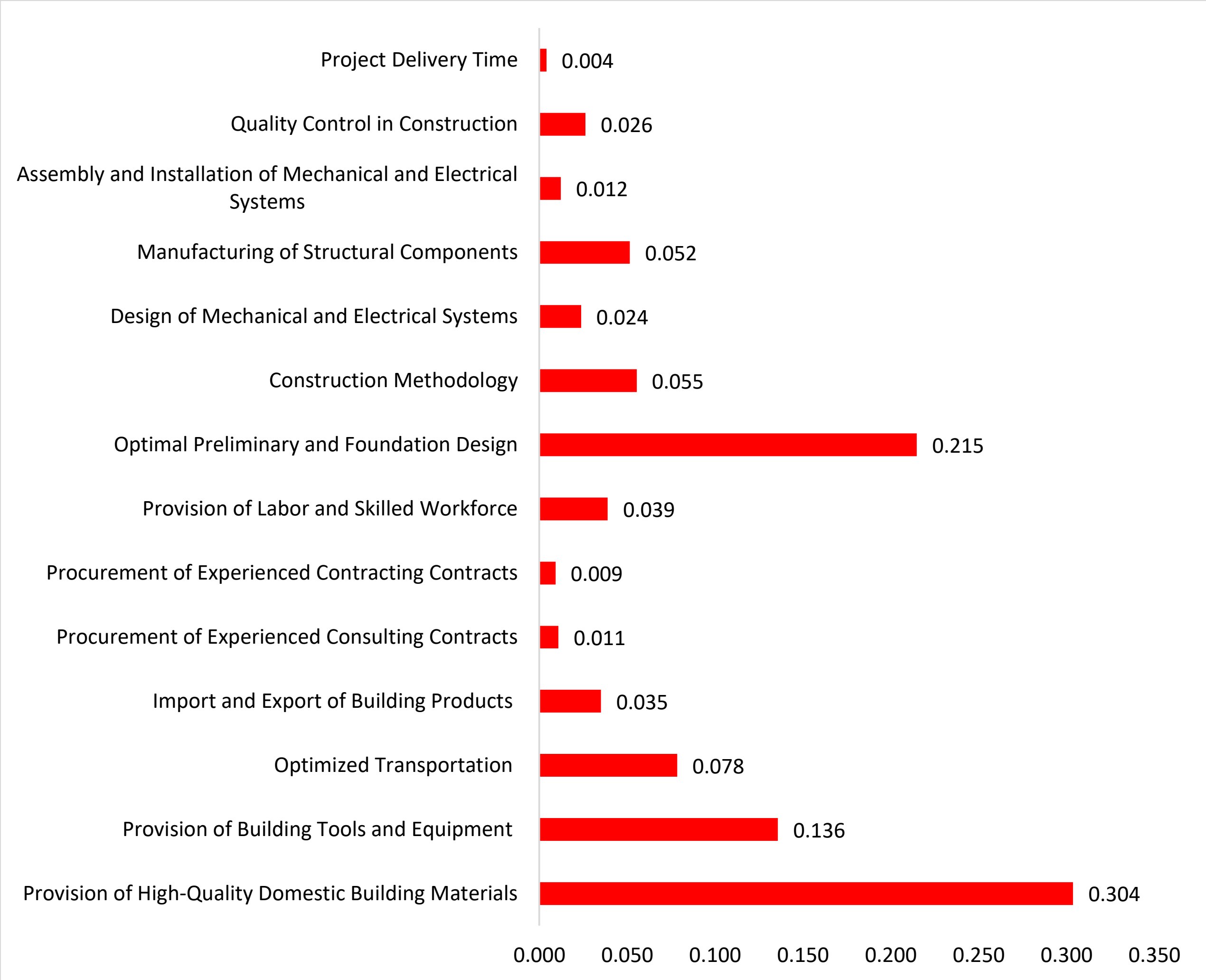


Table 12 reports the consistency ratio (CR) for all ANP pairwise comparison matrices, with all values below 0.1, confirming model consistency. Critical Analysis The prioritization results emphasize the dominance of material quality and design factors as critical success drivers in Qeshm’s construction supply chain, reflecting the practical challenges in sourcing quality inputs and ensuring sound foundational engineering. High weighting of skilled labor signals recognition of human capital as a vital enabler for project success, consistent with construction management literature stressing workforce competency.

The lower rankings of project delivery time and contracting experience may indicate either acceptable baseline standards already met or lack of perceived impact in the local context, suggesting research could explore drivers beyond traditional scheduling and procurement formalities.The consistency ratios below 0.1 support the validity of expert judgments, enhancing confidence in the ANP results. However, the limited sample size and potential cultural or regional bias should be considered in generalizing the findings.

These results provide actionable insights for construction managers and decision-makers in Qeshm, highlighting priority areas for resource allocation, quality control, and personnel development. Emphasizing local material quality and design optimization aligns with sustainable construction practices by potentially reducing cost overruns, rework, and environmental impacts.

Table 12

The inconsistency ratio results for the ANP model

Criteria (Drivers)	λ	CI	RI	CR
Material Supply Management	4.38	0.127	1.49	0.085
Power Supply and Safety Management	3.028	0.014		0.009
Design and Engineering Management	3.065	0.032		0.022
Manufacturing and Production Management	4.24	0.080		0.054
all	4.33	0.109		0.073

After determining the weights of the drivers influencing the success of the supply chain structure in construction projects in Qeshm city using the Analytic Network Process (ANP), the TOPSIS method was subsequently applied to prioritize supply chain management strategies. In this stage, the TOPSIS model was implemented based on questionnaire data, as illustrated in Table 13, which presents the decision matrix according to the TOPSIS approach. The table reports the geometric mean of expert opinions. All criteria are considered as beneficial (positive), indicating a direct relationship between each criterion and the supply chain structure of construction projects in Qeshm. Furthermore, the weights of the influential drivers, previously calculated through the ANP method, are incorporated into the decision-making framework.

Table 13

Valuation of a management solution based on the TOPSIS model

Strategy	Criteria (Drivers)			
	Construction and Production Management	Design and Engineering Management	Workforce and Safety Supply Management	Materials Supply Management
Selection of sustainable materials and resources	7	8	3	9
Reduction of energy and water consumption	8	9	4	5
Optimization of transportation processes	8	6	2	7
Management of construction waste	9	5	4	6
Enhancement of social commitments	6	4	9	3
Risk management through identification and assessment and contingency planning	8	7	7	8
Effective communication with stakeholders and transparency in activities	7	6	6	7
Training project personnel and raising awareness in the local community	6	5	8	4
Use of sustainable supply chain management software	9	8	5	9
Sustainability certifications	6	7	4	8
Building insurance	5	4	5	3
Criteria type	+	+	+	+
Weight	0.094	0.294	0.059	0.553

Table 14 presents the optimal solutions for the positive and negative ideal criteria. Two virtual options were generated, representing the worst and best solutions, respectively. It is observed that the criterion of Material Supply Management, with a score of 0.2265, plays the most significant role as the positive ideal solution. Conversely, the criterion of Labor Supply and Safety Management, with a score of 0.0064, serves as the most influential negative ideal solution in the supply chain management of construction projects in Qeshm city.

Table 14

Optimal Solutions for Positive and Negative Ideal Criteria in the TOPSIS Model

Optimal Solution	Supply Chain Management	Workforce and Safety Management	Design and Engineering Management	Production and Manufacturing Management
Positive Ideal (+)	0.2265	0.0288	0.1232	0.0350
Negative Ideal (−)	0.0755	0.0064	0.0548	0.0194

Table 15 shows the coefficient of proximity to positive and negative ideal solutions as well as the ranking of options. It is observed that the use of sustainable supply chain management software with a proximity coefficient of 0.8962 has been identified as the superior option, followed by the selection of sustainable materials and resources with a proximity coefficient of 0.8664. Additionally, building insurance and enhancement of social commitments are in the lowest priority. Therefore, the use of sustainable supply chain management software and the selection of sustainable materials and resources are the most important management solutions for the structure of building projects based on the sustainable development approach in Qeshm city, while building insurance and enhancement of social commitments have the least impact.

Table 15

Ranking of Options Based on Proximity to the Ideal Positive and Negative Solution

Strategy	Closeness Coefficient
Use of Sustainable Supply Chain Management Software	0.8962
Selection of Sustainable Materials and Resources	0.8664
Risk Management through Identification, Evaluation, and Planning	0.7791
Certification for Sustainability	0.7589
Effective Stakeholder Communication	0.6144
Optimization of Transportation Processes	0.6040
Reduction of Energy and Water Consumption	0.4575
Management of Construction Waste	0.4536
Training of Project Personnel and Community Awareness	0.2012
Enhancement of Social Commitments	0.1202
Building Insurance	0.0543

One of the primary objectives of this study was to identify and structure construction projects based on the principles of sustainable development. The results indicate that sustainable development is not merely an abstract concept but a practical framework that can be integrated into the planning, execution, and evaluation of construction projects. For instance, the study emphasizes the importance of aligning project goals with environmental, social, and economic sustainability criteria. This alignment ensures that construction projects contribute positively to the local community while minimizing adverse environmental impacts.

A significant finding is the identification of four key strategies for sustainable supply chain management in construction projects: (1) materials supply management, (2) workforce supply and safety management, (3) design and engineering management, and (4) construction and production management. These strategies are weighted differently based on their perceived importance, with materials supply management receiving the highest weight (0.553). This underscores the critical role of sustainable material sourcing in reducing the ecological footprint of construction projects. By prioritizing eco-friendly materials, construction projects can significantly contribute to carbon neutrality and resource conservation.

The second strategy, workforce supply and safety management, although assigned a lower weight (0.059), highlights the importance of human resources in achieving sustainability goals. Ensuring the safety and well-being of workers not only aligns with ethical considerations but also enhances productivity and reduces the likelihood of costly accidents. Similarly, design and engineering management (0.294) and construction and production management (0.094) play pivotal roles in integrating sustainability principles into every phase of the project lifecycle. These strategies collectively emphasize the need for a systemic approach to sustainable development, where each component of the project is meticulously planned and executed.

4. Discussion and Conclusion

The present study developed and empirically validated a hybrid statistical–multi-criteria decision-making framework for identifying, prioritizing, and evaluating sustainability-related risks and strategic interventions within construction supply chains. The findings revealed that economic risks constituted the most influential category of threats affecting the sustainability and performance of construction projects. Specifically, financial challenges faced by suppliers, fluctuations in material prices, exchange-rate volatility, transportation cost increases, and delays in material delivery emerged as statistically significant risk factors. These findings highlight the vulnerability of construction supply chains to macroeconomic instability and market uncertainty. Construction projects rely heavily on extensive networks of suppliers and contractors, making them particularly sensitive to financial disruptions. The prominence of economic risks identified in this study is consistent with prior research emphasizing the critical influence of financial constraints, procurement costs, and market fluctuations on project performance and supply chain resilience (Qazi et al., 2021; Zanjani et al., 2021). Similarly, studies focusing on supply chain risk prioritization have demonstrated that economic uncertainties frequently represent the most challenging obstacles to sustainable project implementation because they affect resource availability, planning accuracy, and investment decisions (Alamdari et al., 2023; Attia & Uddin, 2024). The significance of these risks also supports the broader literature suggesting that financial sustainability forms the foundation upon which environmental and social sustainability initiatives can be successfully implemented (Altekar, 2023; Hugos, 2024).

The findings further demonstrated that environmental risks were among the most significant determinants of sustainable supply chain performance. Concerns related to pollution, depletion of natural resources, utilization of non-renewable resources, environmental health standards, and material quality were all identified as statistically significant. These results reinforce the increasing recognition that environmental sustainability is no longer a peripheral consideration but rather a central component of construction project success. The construction industry consumes substantial quantities of raw materials and energy resources while generating considerable waste and emissions. Consequently, organizations face growing pressure from regulators, communities, and stakeholders to reduce their environmental footprint. The significance of environmental risks identified in the present study aligns with research emphasizing the necessity of integrating environmental considerations into supply chain management frameworks and sustainability governance structures (Jamalnia et al., 2023; Johnsson et al., 2020). Moreover, studies investigating sustainable and circular supply chains have highlighted the importance of resource efficiency, pollution reduction, and environmentally responsible procurement practices as key determinants of long-term organizational resilience (Ada et al., 2023; Shou et al., 2022). The present findings therefore support the argument that environmental risk management should be treated as a strategic priority rather than merely a compliance obligation.

Social risks also emerged as important contributors to supply chain sustainability. Environmental and cultural pressures, community involvement, strategic procurement orientation, and violations of workers' rights were identified as significant concerns. These findings indicate that sustainability in construction supply chains extends beyond economic and environmental dimensions to encompass social responsibility and stakeholder engagement. Construction projects frequently influence local communities through employment opportunities, resource consumption, land utilization, and infrastructure development. Consequently, stakeholder perceptions and community relationships can substantially affect project legitimacy and long-term success. The significance of worker rights and stakeholder involvement identified in this study is consistent with previous investigations emphasizing the role of social sustainability in achieving balanced project outcomes (Attia & Uddin, 2024; Boadu et al., 2022). Research has increasingly demonstrated that organizations capable of integrating social considerations into procurement, supplier management, and project execution processes are more likely to achieve sustainable performance outcomes and stakeholder satisfaction (Fernie, 2023; Lepistö et al., 2024). Therefore, effective social risk management should be viewed as an integral component of comprehensive supply chain sustainability strategies.

Another important finding concerns the structural risks associated with design errors, engineering non-compliance, weather conditions, and design precision. These factors were identified as statistically significant threats to construction supply chain performance. The prominence of structural risks reflects the highly technical nature of construction projects and the extensive interdependencies among design, engineering, procurement, and execution activities. Even minor design deficiencies can generate cascading effects throughout project lifecycles, resulting in delays, cost overruns, safety incidents, and sustainability challenges. These findings are consistent with studies highlighting the importance of engineering quality, risk-informed design practices, and adaptive project management approaches in reducing construction-related uncertainties (Fang et al., 2013; Shiliang et al., 2012). Furthermore, research addressing construction safety and risk prediction has emphasized the critical role of systematic engineering oversight and continuous monitoring in mitigating structural vulnerabilities (Ma et al., 2021; Mohandes et al., 2022). The current findings therefore reinforce the necessity of integrating technical excellence into broader sustainability and risk management frameworks.

The ANP results revealed that material supply management was the most influential driver affecting sustainable construction supply chain performance. Within this category, the provision of high-quality domestic building materials received the highest overall priority. This finding reflects the central role of materials in determining project quality, environmental performance, cost efficiency, and supply chain resilience. Construction materials represent a significant proportion of project expenditures and environmental impacts. Consequently, material quality directly influences durability, maintenance requirements, waste generation, and lifecycle sustainability outcomes. These findings are highly consistent with previous research identifying material sourcing, procurement efficiency, and supplier performance as critical success factors in construction supply chains (Hasaniyan Pourfereidani et al., 2025; Wuni & Shen, 2020). Similarly, investigations into off-site and modular construction have demonstrated that effective material management significantly enhances operational efficiency and sustainability performance (Hanaysha & Alzoubi, 2022; Hussein et al., 2021). The prioritization of domestic materials may additionally reflect concerns regarding supply disruptions, transportation costs, and import dependencies within the regional context examined in this study.

The second most influential driver identified through the ANP analysis was design and engineering management, particularly optimal foundation and preliminary design. This finding underscores the importance of strategic planning and technical decision-making during the early stages of project development. Effective design processes establish the foundation for resource efficiency, risk mitigation, environmental performance, and long-term operational success. The results support contemporary perspectives on project success, which emphasize proactive planning, stakeholder alignment, and lifecycle thinking rather than solely focusing on traditional cost, time, and quality objectives (Ika & Pinto, 2022). Furthermore, advances in BIM-based project management and digital engineering have demonstrated the value of integrated design approaches in improving project coordination and reducing uncertainty (Chen & Tang, 2019). The current findings therefore highlight the necessity of investing in high-quality design and engineering capabilities as part of broader sustainability-oriented project strategies.

An additional contribution of this study lies in the prioritization of management strategies through the TOPSIS methodology. The results identified sustainable supply chain management software as the most effective intervention, followed by sustainable material selection and comprehensive risk management planning. These findings demonstrate the growing importance of digital transformation in sustainable construction management. Contemporary construction environments generate substantial quantities of data related to procurement, logistics, project progress, risk indicators, and stakeholder interactions. Digital management systems enable organizations to process this information efficiently, enhance visibility across supply chain networks, and support evidence-based decision-making. The prominence of digital supply chain management software aligns with studies emphasizing the transformative potential of digital technologies, artificial intelligence, and intelligent monitoring systems in improving sustainability and operational performance (Ada et al., 2023; Mossalam & Arafa, 2017). Likewise, research investigating digitalization and IoT applications has shown that technological integration enhances supply chain coordination, risk identification, and resource optimization (Hanaysha & Alzoubi, 2022; Torp et al., 2016).

The effectiveness of sustainable material selection as the second-highest-ranked strategy further reinforces the interconnected relationship between environmental responsibility and operational performance. Sustainable materials contribute to reduced environmental impacts, improved lifecycle performance, and enhanced compliance with sustainability objectives. These findings are consistent with research emphasizing circular economy principles and environmentally responsible procurement as essential components of sustainable supply chains (Ada et al., 2023; Johnsson et al., 2020). Additionally, the high ranking of risk management planning highlights the continued importance of proactive approaches to uncertainty management. Studies employing Monte Carlo simulations, fuzzy decision-making techniques, and integrated risk assessment frameworks similarly emphasize the necessity of systematic risk identification and mitigation to achieve sustainable project outcomes (Adem et al., 2018; Qazi et al., 2021).

From a methodological perspective, the findings demonstrate the value of integrating statistical analysis with ANP and TOPSIS techniques. Traditional risk assessment methods often struggle to capture the multidimensional and interconnected nature of sustainability challenges. The hybrid framework developed in this study enabled the identification of statistically significant risk factors while simultaneously prioritizing drivers and management strategies according to their relative importance. This integrated approach responds directly to calls for more comprehensive decision-support systems capable of addressing complex sustainability problems (Jamalnia et al., 2023; Patel-Jena & Dwivedi, 2023). Furthermore, the use of ANP addresses limitations associated with hierarchical decision-making methods by explicitly considering interdependencies among criteria, while TOPSIS provides an efficient mechanism for ranking alternatives according to multiple performance dimensions (Chakraborty, 2022; Munier & Hontoria, 2021). The consistency and reliability of the findings also support the appropriateness of the data collection instrument and expert-based assessment process, consistent with recommendations regarding questionnaire reliability and validity evaluation (Tiira & Lohi, 2014).

Overall, the results demonstrate that sustainable construction supply chains are influenced by a complex interaction of economic, environmental, social, and structural factors. The findings support existing theoretical perspectives emphasizing the multidimensional nature of sustainability while extending previous research through the development of an empirically validated hybrid decision-support framework. By identifying key risks, prioritizing critical drivers, and evaluating strategic interventions, the study contributes both theoretically and practically to the growing field of sustainable construction supply chain management.

Several limitations should be acknowledged when interpreting the findings of this study. First, the sample consisted of a relatively small number of experts drawn from a specific geographical context, which may limit the generalizability of the results to other regions and construction environments. Second, the study relied on expert judgments and perceptions, which may introduce subjective biases despite the use of reliability assessments and structured data collection procedures. Third, the cross-sectional design captured expert opinions at a single point in time and therefore may not fully reflect evolving market conditions, technological developments, or sustainability priorities. Finally, the study focused primarily on selected risk categories and management strategies, potentially overlooking additional contextual factors that may influence supply chain sustainability.

Future studies should examine the applicability of the proposed framework across different countries, project types, and organizational contexts to evaluate its external validity. Longitudinal research designs could be employed to investigate how sustainability risks and priorities evolve over time in response to changing environmental, economic, and technological conditions. Researchers may also incorporate additional analytical techniques such as machine learning, system dynamics, Bayesian networks, and predictive analytics to enhance decision-support capabilities. Comparative investigations between conventional and sustainable construction projects may further improve understanding of contextual differences in risk profiles and management strategies. Moreover, future studies could explore the integration of emerging technologies such as blockchain, digital twins, and the Internet of Things into sustainable supply chain assessment frameworks.

Construction managers should prioritize proactive risk management systems that address economic, environmental, social, and structural dimensions simultaneously. Organizations should invest in digital supply chain management platforms to improve visibility, coordination, and decision-making across project networks. Greater emphasis should be placed on sourcing high-quality sustainable materials and strengthening supplier relationships to enhance resilience and environmental performance. Project stakeholders should integrate sustainability considerations into design and engineering decisions from the earliest stages of project development. Training programs focused on sustainability competencies, risk awareness, and digital technologies should be expanded to improve workforce capabilities. Policymakers and industry leaders should also encourage the adoption of integrated sustainability assessment frameworks to support evidence-based decision-making and long-term infrastructure resilience.

Authors' Contributions

Authors contributed equally to this article.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were considered.

References

Ada, E., Sezer, M. D., & Khaleel, R. (2023). Towards the Smart Sustainable and Circular Food Supply Chains through Digital Technologies. *International Journal of Mathematical, Engineering and Management Sciences*, *8*(3), 022. https://doi.org/10.33889/ijmems.2023.8.3.022

Adem, A., Çolak, A., & Dağdeviren, M. (2018). An Integrated Model Using SWOT Analysis and Hesitant Fuzzy Linguistic Term Set for Evaluation Occupational Safety Risks in Life Cycle of Wind Turbine. *Safety Science*, *106*, 184-190. https://doi.org/10.1016/j.ssci.2018.02.033

Alamdari, A. M., Jabarzadeh, Y., Adams, B., Samson, D., & Khanmohammadi, S. (2023). An Analytic Network Process Model to Prioritize Supply Chain Risks in Green Residential Megaprojects. *Operations Management Research*, *16*(1), 141-163. https://doi.org/10.1007/s12063-022-00288-2

Alshehri, S. M. A., Jun, W. X., Shah, S. A. A., & Solangi, Y. A. (2022). Analysis of Core Risk Factors and Potential Policy Options for Sustainable Supply Chain: An MCDM Analysis of Saudi Arabia's Manufacturing Industry. *Environmental Science and Pollution Research*, *29*(17), 25360-25390. https://doi.org/10.1007/s11356-021-17558-4

Altekar, R. V. (2023). *Supply Chain Management: Concepts and Cases*. PHI Learning Pvt. Ltd.

Attia, E. A., & Uddin, M. S. (2024). Hybrid Assessment for Strengthening Supply Chain Resilience and Sustainability: A Comprehensive Analysis. *Sustainability*, *16*(10), 4010. https://doi.org/10.3390/su16104010

Boadu, E. F., Sunindijo, R. Y., Wang, C. C., & Frimpong, S. (2022). Client-Led Promotion of Health and Safety through the Procurement Process on Public Construction Projects in Developing Countries. *Safety Science*, *147*, 105605. https://doi.org/10.1016/j.ssci.2021.105605

Brusset, X., & Teller, C. (2017). Supply Chain Capabilities, Risks, and Resilience. *International Journal of Production Economics*, *184*, 59-68. https://doi.org/10.1016/j.ijpe.2016.09.008

Chakraborty, S. (2022). TOPSIS and Modified TOPSIS: A Comparative Analysis. *Decision Analytics Journal*, *2*, 100021. https://doi.org/10.1016/j.dajour.2021.100021

Chen, C., & Tang, L. (2019). BIM-Based Integrated Management Workflow Design for Schedule and Cost Planning of Building Fabric Maintenance. *Automation in Construction*, *107*, 102944. https://doi.org/10.1016/j.autcon.2019.102944

Ciardiello, F., & Genovese, A. (2023). A Comparison between TOPSIS and SAW Methods. *Annals of Operations Research*, *325*(2), 967-994. https://doi.org/10.1007/s10479-023-05339-w

Fang, C., Marle, F., Xie, M., & Zio, E. (2013). An Integrated Framework for Risk Response Planning under Resource Constraints in Large Engineering Projects. *Ieee Transactions on Engineering Management*, *60*(3), 627-639. https://doi.org/10.1109/TEM.2013.2242078

Fernie, J. (2023). Relationships in the Supply Chain. In *Logistics and Retail Management: Insights into Current Practice and Trends from Leading Experts* (pp. 23-46). CRC Press.

Hanaysha, J. R., & Alzoubi, H. M. (2022). Investigating the Impact of Benefits and Challenges of IoT Adoption on Supply Chain Performance and Organizational Performance: An Empirical Study in Malaysia. *Uncertain Supply Chain Management*, *10*(2), 537-550. https://doi.org/10.5267/j.uscm.2021.11.005

Hasaniyan Pourfereidani, A., Feili, A., Nikmanesh, M., & Sorooshian, S. (2025). An Analysis of Success in Supply Chain Management for Construction Projects: Fuzzy Inference System Application. *Journal of Soft Computing in Civil Engineering*, *9*(2), 167-195. https://doi.org/10.22115/scce.2024.416971.1721

Hugos, M. H. (2024). *Essentials of Supply Chain Management*. John Wiley & Sons.

Hussein, M., Eltoukhy, A. E., Karam, A., Shaban, I. A., & Zayed, T. (2021). Modelling in Off-Site Construction Supply Chain Management: A Review and Future Directions for Sustainable Modular Integrated Construction. *Journal of Cleaner Production*, *310*, 127503. https://doi.org/10.1016/j.jclepro.2021.127503

Ika, L. A., & Pinto, J. K. (2022). The Re-Meaning of Project Success: Updating and Recalibrating for a Modern Project Management. *International Journal of Project Management*, *40*(7), 835-848. https://doi.org/10.1016/j.ijproman.2022.08.001

Jamalnia, A., Gong, Y., Govindan, K., Bourlakis, M., & Mangla, S. K. (2023). A Decision Support System for Selection and Risk Management of Sustainability Governance Approaches in Multi-Tier Supply Chain. *International Journal of*

Production Economics, *264*, 108960. https://doi.org/10.1016/j.ijpe.2023.108960

Johnsson, F., Karlsson, I., Rootzén, J., Ahlbäck, A., & Gustavsson, M. (2020). The Framing of a Sustainable Development Goals Assessment in Decarbonizing the Construction Industry: Avoiding Greenwashing. *Renewable and Sustainable Energy Reviews*, *131*, 110029. https://doi.org/10.1016/j.rser.2020.110029

Lepistö, K., Saunila, M., & Ukko, J. (2024). Enhancing Customer Satisfaction, Personnel Satisfaction and Company Reputation with Total Quality Management: Combining Traditional and New Views. *Benchmarking*, *31*(1), 75-97. https://doi.org/10.1108/BIJ-12-2021-0749

Ma, G., Wu, Z., Jia, J., & Shang, S. (2021). Safety Risk Factors Comprehensive Analysis for Construction Project: Combined Cascading Effect and Machine Learning Approach. *Safety Science*, *143*, 105410. https://doi.org/10.1016/j.ssci.2021.105410

Mohandes, S. R., Abdelmageed, S., Hem, S., Yoo, J. S., Abhayajeewa, T., & Zayed, T. (2022). Occupational Health and Safety in Modular Integrated Construction Projects: The Case of Crane Operations. *Journal of Cleaner Production*, *342*, 130950. https://doi.org/10.1016/j.jclepro.2022.130950

Mossalam, A., & Arafa, M. (2017). Using Artificial Neural Networks (ANN) in Projects Monitoring Dashboards' Formulation. *HBRC Journal*, *14*(3), 385-392. https://doi.org/10.1016/j.hbrcj.2017.11.002

Munier, N., & Hontoria, E. (2021). Shortcomings of the AHP Method. In *Uses and Limitations of the AHP Method: A Non-Mathematical and Rational Analysis* (pp. 41-90). Springer International Publishing. https://doi.org/10.1007/978-3-030-60392-2

Natalia, C., Surbakti, I. P., & Oktavia, C. W. (2020). Integrated ANP and TOPSIS Method for Supplier Performance Assessment. *Jurnal Teknik Industri*, *21*(1), 34-45. https://doi.org/10.22219/JTIUMM.Vol21.No1.34-45

Patel-Jena, R. K., & Dwivedi, Y. (2023). Prioritizing the Barriers to Tourism Growth in Rural India: An Integrated Multi-Criteria Decision Making (MCDM) Approach. *Journal of Tourism Futures*, *9*(3), 393-416. https://doi.org/10.1108/JTF-10-2020-0171

Qazi, A., Shamayleh, A., El-Sayegh, S., & Formaneck, S. (2021). Prioritizing Risks in Sustainable Construction Projects Using a Risk Matrix-Based Monte Carlo Simulation Approach. *Sustainable Cities and Society*, *65*, 102576. https://doi.org/10.1016/j.scs.2020.102576

Shiliang, S., Min, J., Yong, L., & Runqui, L. (2012). Risk Assessment on Falling from Height Based on AHP-Fuzzy. Procedia Engineering,

Shou, Y., Kang, M., & Park, Y. W. (2022). A Systematic Literature Review of Supply Chain Integration. In *Supply Chain Integration for Sustainable Advantages* (pp. 15-40). Springer. https://doi.org/10.1007/978-981-16-9332-8_2

Tiira, K., & Lohi, H. (2014). Reliability and Validity of a Questionnaire Survey in Canine Anxiety Research. *Applied Animal Behaviour Science*, *155*, 82-92. https://doi.org/10.1016/j.applanim.2014.03.007

Torp, O., Belay, A. M., Thodesen, C., & Klakegg, O. J. (2016). Cost Development over Time at Construction Planning Phase: Empirical Evidence from Norwegian Construction Projects. *Procedia Engineering*, *145*, 1177-1184. https://doi.org/10.1016/j.proeng.2016.04.152

Wuni, I. Y., & Shen, G. Q. (2020). Critical Success Factors for Modular Integrated Construction Projects: A Review. *Building Research & Information*, *48*(7), 763-784. https://doi.org/10.1080/09613218.2019.1669009

Zanjani, M. E., Najafi, A., Naghilou, A., & Mohammadi, N. (2021). Identification and Assessment of Critical Risks of Sustainable Supply Chain in the Iranian Lead and Zinc Industry. *International Journal of Industrial Engineering & Production Research*, *32*(3), 1-22. http://ijiepr.iust.ac.ir/article-1-1149-en.html