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Disruption to construction supply chains during COVID-19 in developing economies: A strategic framework for sustainable and resilient logistics

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ABSTRACT

The COVID-19 pandemic exposed critical vulnerabilities in construction supply chains, specifically in the case of developing economies. These disruptions affected not only performance and resilience but also the ability to maintain low-carbon and sustainable logistics operations. This study explores the root causes of construction supply chain disruption during the pandemic and aims to propose a strategic framework to enhance resilience and sustainability. For this purpose, a Likert-scale questionnaire was developed from literature. The survey was administered online across India, and 360 valid responses were received. The resulting dataset analyzed using exploratory factor analysis and second-order confirmatory factor analysis was used to measure the criticality of the causes of supply chain disruption identified from the literature. The importance of the factors was evaluated based on the factor loading (FL) of the variables. From the analysis it was observed that stakeholder constraints were the main cause of disruption (FL = 0.64), with significant impacts also from external pressures and resource constraints (FL = 0.534 and 0.45). Additionally, operational (FL = 0.28) and financial challenges (FL = 0.28) indicated a moderate effect but played a crucial role. Based on these findings resource–stakeholder adaptability framework was recommended to manifest the development of resilient and low-carbon construction logistics. The study offers practical insights for policymakers and supply chain managers by recommending targeted strategies such as improved stakeholder coordination, adaptive resource planning, and digital integration. The research contributes to sustainable logistics literature by exploring the causes of a major disruption event within a high-emission, resource-intensive sector in the context of a developing economy.

1. Introduction

The construction supply chain (CSC) plays a critical role across all phases of a project lifecycle, because of which it is an enabler of efficient, sustainable, and low-carbon project delivery (Ghansah and Lu, 2023; Liao et al., 2023). Therefore, efficient CSCs are essential for successful completion of projects and play a significant role in attaining low-carbon logistics and green supply chains (Jacobsson et al., 2017). However, complexities and fragmentation associated with construction projects influence CSC, influencing long-term benefits. In this context, unprecedented disruptions caused by COVID-19 significantly influence the operational stability of CSC, exposing vulnerabilities that also increase its carbon footprint (Ghansah and Lu, 2023). This can be observed during the year 2020, where a decline of 3.5 % was observed in construction output due to cost escalations and labour shortages (McKinsey & Company, 2022). This influenced around 90 % of global construction projects, making the construction sector one of the worst-affected sectors due to the COVID-19 pandemic (Cherian and Arun, 2022; Meier and Pinto, 2024). Therefore, these disruptions impacted project delivery and resulted in increased waste generation, which enhanced the sector's carbon footprint (Canwat, 2024; Osunsanmi et al., 2021). Therefore, it can be argued that these issues affected the capability of construction firms to contribute towards responsible consumption and low-carbon logistics.

Moreover, the pandemic resulted in high inflation rates and geopolitical instability, which made supply chain disruption a global concern (McKinsey & Company, 2022; Meier and Pinto, 2024). Factors such as the fear of virus relapses and new variants of COVID that could lead to

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lockdowns created uncertainty within the construction industry's supply chain (Ayat et al., 2023). Travel restrictions further escalated the situation, as they resulted in clogged supply chains across all sectors and resulted in significant financial losses (Deep et al., 2022b; Sherratt and Dainty, 2022). Since disruption to the supply chain influences organizational performance, sustainable construction emerged as one of the most significant performance-related constraints for the construction industry in recent years (Stanitsas and Kirytopoulos, 2023).

The construction industry's struggles with supply chain disruptions have been well-documented in the past. A PwC (2020) report showed that the pandemic had a detrimental effect on project success rates and delivery. According to this report, 56 % of construction professionals acknowledged that the pandemic negatively influenced construction operations. Additionally, 40 % of construction businesses reported severe disruptions to their supply chains (Deloitte, 2021; Mahasuar, 2023). This highlights a research gap in understanding the causes of supply chain disruptions within the construction industry during the COVID-19 pandemic and the ongoing geopolitical events. The COVID-19 pandemic has caused disruption in construction supply chains around the world, affecting their performance and long-term sustainability. Especially in emerging economies, where construction logistics are complex and emission-intensive, these disruptions further constrained the low-carbon and sustainability transitions of CSCs. To overcome the adverse impact of these challenges, it is essential to develop a framework that can ensure low-carbon logistics and sustainable supply chains. Additionally, identification of the causes of supply chain disruptions would be an essential aspect of developing strategic guidelines that enhance resilience in project-based supply chains while supporting low-carbon and sustainable logistics practices. Therefore, this study aims to identify the causes of supply chain disruption within the construction industry during the COVID-19 pandemic.

The study addresses this need by examining the Indian construction industry, which faced significant supply chain challenges during the COVID-19 pandemic. The choice of India as the geographical focus was made considering the scale and growth of its construction sector. As of 2022, the Indian construction industry accounted for approximately 9 % of the country's GDP and was projected to become the third largest globally by 2022 (Statista, 2023). Moreover, India's construction sector employed over 51 million people, making it a vital component of its economy (IBEF, 2023). The unique context of India, with its vast, diverse, and rapidly developing construction sector, provides a distinct backdrop to investigate supply chain resilience and sustainability. Additionally, the pandemic significantly influenced India's growth because of lockdowns and the resulting disruptions, which led to significant operational challenges for the construction industry. Therefore, the results of the study would be beneficial for both developing and developed countries. The study will also identify the causes of supply chain disruptions to contribute to the following United Nations Sustainable Development Goals (SDGs):

- **SDG 9: Industry, Innovation, and Infrastructure:** The study focuses on enhancing resilience and sustainability in the construction supply chain, which is crucial for robust infrastructure and innovative industrial practices. This aligns with SDG 9 by addressing the vulnerabilities demonstrated by the COVID-19 pandemic in the construction sector.
- **SDG 8: Decent Work and Economic Growth:** By focusing on resilient supply chains and low-carbon logistics, the study supports job preservation and economic growth during crises, in line with SDG 8.
- **SDG 12: Responsible Consumption and Production:** The study advocates for sustainable practices in construction supply chains, aligning with SDG 12. It contributes to efficient resource utilization and waste reduction, promoting sustainable consumption and production patterns.

Furthermore, this research aims to contribute to practice by identifying causes of disruptions and using empirical results to propose a roadmap for resilient and low-carbon construction supply chains.

1.1. Novelty and significance of the study

While supply chain disruptions have been examined in other sectors, there are limited studies that focus on issues of supply chain disruption in the construction sector of developing economies. Besides this, there are limited studies that focus on addressing the issue of resilience and sustainability in case of large-scale crises in the context of construction sectors of developing economies. This study addresses this gap by focusing on the Indian construction industry during the COVID-19 pandemic. Additionally, the construction sector is well known for its high resource dependency, fragmented logistics, and institutional constraints. However, existing literature has focused on resilience and sustainability as isolated themes or addresses them in broad terms, with limited focus on causes of supply chain disruption in the construction sector.

Moreover, the study contributes to the literature on clean supply chain and logistics by systematically identifying the root causes of disruption and linking them to outcomes related to resilience and sustainability. It introduces a resource–stakeholder adaptability framework that connects empirical findings to theoretical insights drawn from the resource-based view and contingency theory. The framework highlights how construction supply chains in a developing economy can adopt structured, adaptive strategies to improve performance under crisis conditions. By doing so, the study advances current understanding of how low-carbon and sustainable supply chain practices, with logistics as a critical component, can be operationalized in vulnerable, resource-intensive sectors. This contribution is relevant for researchers and practitioners looking for guidance on managing construction logistics in uncertain conditions. In addition, the resource stakeholder adaptability framework adds to ongoing efforts to connect sustainability and resilience with clean and low-carbon supply chain management.

The paper is organized into four sections. The first section deals with the literature review. In this section, the theoretical background establishing the significance of this study and various causes of supply chain disruption are identified. In the next section, justification is provided for the research approach identified in this study, and the data collection method is introduced. Next, the collected data is analyzed using exploratory factor analysis and second-order confirmatory factor analysis, which helped identify the main causes. In the subsequent section, a discussion is provided for the results. Finally, in the fourth section, the social and practical implications, along with the roadmap, are developed.

2. Theoretical background

The implications of the global COVID-19 pandemic were observed across different sectors, and the construction industry was no exception. The industry has been affected by significant losses and faced numerous challenges (Duong et al., 2022; Singh and Bolpagni, 2023). Additionally, unprecedented socioeconomic and health crises due to the pandemic resulted in a global economic slowdown, causing disrupted supply chains across project-based sectors. These disruptions in supply chains resulted in macroeconomic uncertainties, which resulted in increased emissions that negatively affected the low-carbon performance of construction logistics and supply chains (Canwat, 2024; Meier and Pinto, 2024).

2.1. Theoretical lens

The primary focus of the study was to explore the causes of supply chain disruption because of COVID-19 pandemic-imposed restrictions on the construction industry. For this purpose, theoretical lenses of resource-based view (RBV) (Kraaijenbrink et al., 2010) and contingency theory (CT) (Donaldson, 2001) were chosen to explore the problem. To understand resource constraints and their influence on sustainable and low-carbon supply chain performance, RBV was used as a theoretical lens (Kraaijenbrink et al., 2010). This was vital to ensure effective resource management and support effective resource management. Also, the use of RBV directly contributes towards reducing carbon emissions and waste generation by ensuring responsible consumption (Ivanov, 2024). This further plays an important role in creation of low-carbon logistics and green supply chain management strategies for the construction sector.

Additionally, knowledge, skills, and organizational culture are vital for organizational success, as these elements influence the formation of responsive strategies in dynamic environments (Canwat, 2024; Ma et al., 2020; Meier and Pinto, 2024). In this context, to explore the ways organizations can align their supply chain strategies with low-carbon and sustainable logistics objectives, contingency theory is a suitable lens. The theory states that bureaucratic decision-making plays a vital role in developing adaptation strategies for organizations in frequently changing business environments (Donaldson, 2001). This also helps decision makers to understand the influence of external constraints that cause supply chain disruptions.

Combining RBV and CT, this study explores the causes of supply chain disruption at two important dimensions, i.e., stakeholder coordination and resource handling. Dealing with these elements is essential for the enhancement of supply chain efficiency, which would in turn ensure low-carbon and sustainable construction logistics. Based on the findings of the study, a theoretical framework would be proposed that integrates stakeholder values and ensures efficient utilization of resources to reduce the carbon footprints of the sector. Furthermore, a roadmap would be prepared to facilitate the development of sustainable and low-carbon logistics and resilient supply chains in construction sectors. In the following section, a detailed discussion on the root causes of supply chain disruption is provided.

2.2. Importance of resilience and sustainability

Resilience and sustainability have thus become central tenets in investigating these disruptions. The concept of resilience in supply chains is defined as the ability to recover and bounce back after facing severe disruption (Ponomarov and Holcomb, 2009). It was demonstrated in the case of some manufacturing companies shifting production to alternative facilities to maintain operations during lockdowns. Sustainability, on the other hand, is about integrating environmental, social, and economic considerations into long-term strategies (Seuring and Müller, 2008). An example of sustainability is the trend towards sourcing materials locally to reduce carbon emissions associated with transportation and support local economies, thereby maintaining environmental and economic balance (Ivanov and Dolgui, 2020). Therefore, it can be stated that the concepts of sustainability and resilience are interrelated. The adoption of sustainable practices would result in resilient construction supply chains.

Moreover, the COVID-19 pandemic demonstrated the importance of sustainable practices for CSCs. In this context, the sustainability and resilience of supply chains are ensured by efficient communication and workforce mobility (Liao et al., 2023). These elements ensure agility and responsiveness to supply chain operations and play a vital role in ensuring low-carbon logistics. Therefore, agility plays an important role in developing coping mechanisms for organizations to adapt to changing circumstances (Meier and Pinto, 2024). These coping mechanisms are employed to formulate responses to ensure workforce availability in pandemic situations that disrupt construction supply chains. In this case, standardization of labour and equipment plays a vital role in developing agile construction process ensuring low-carbon logistics (Kazancoglu et al., 2022). Additionally, efficient utilization of resources is important to reduce waste and is an important aspect of standardization that ensures low-carbon logistics (Karunarathna et al., 2023). Furthermore, the localization of materials supply contributes towards low-carbon logistics, which results in the creation of resilient supply chains (Piila and Sarja, 2024). This process reduces the environmental costs of transport and promotes local socio-economic development in a manner that enhances socio-economic sustainability (Oyegoke et al., 2023). Therefore, it is an important means to solve the challenges such as labour shortage and lockdown alike that enhances the resilience of CSC (Fu et al., 2023).

During the pandemic, it was identified from the literature that the resilience of CSC was affected by skilled labour migration, logistical bottlenecks, operational inflexibility, and disrupted communication (Ivanov, 2024; Kholaif et al., 2023; Meier and Pinto, 2024). Furthermore, the sustainability of CSC was affected by high carbon emission, high waste generation, social inequity, and limited adoption of green technologies (Ghansah and Lu, 2023; Iranmanesh et al., 2023). The application of digital technologies, e.g., Building Information Modelling (BIM), enhances the transparency that facilitates efficient resource utilization and would result in sustainable outcomes (Luo et al., 2022; Meier and Pinto, 2024). Use of these technologies therefore enables efficient planning and reduces waste, resulting in efficient utilization of materials (Chong et al., 2017). This improves the efficiency of the process through optimized resource allocation and continuous improvement, minimizes waste, and enhances sustainability and resilience, which is essential for project success (Liu et al., 2021). Fig. 1 shows interrelations between resilience and sustainability constraints that influence CSC.

2.3. The state of developing economies

Developing economies were affected because of the adverse impacts of the pandemic. This was observed even in the case of strong developing economies such as India, where the construction sector was worst affected by the pandemic and disrupted supply chains. This was primarily because of limited construction material availability and inflation (Mahasuar, 2023). In this context, the Associated General Contractors of America also reported a 20 % increase in construction material prices in 2021 (Thibault, 2022). In India, the average price of building materials increased by 12–14 % across cities (Babar, 2022). This shows that managing price fluctuations and material shortages is key to creating resilient and sustainable supply chains. The content analysis shown in Table 1 identifies the factors that caused supply chain disruptions during the pandemic. From the literature, it was observed that researchers focused on themes, e.g., the impact of COVID on supply chains (Donkor et al., 2021; Duong et al., 2022), the economic impacts of supply chain disruption (Canwat, 2024; Ekanayake et al., 2022a; Ekanayake et al., 2022b; Meier and Pinto, 2024), defining resilience for construction supply chains (El Korchi, 2022; Liao et al., 2023), supply chain management strategies (Kazancoglu et al., 2022; Kholaif et al., 2023), and the role of innovative technologies (Hamledari and Fischer, 2021b) and BIM (Hernadewita and Saleh, 2020). But the past studies have had a limited focus on identification of causes of supply chain disruption during the COVID-19 pandemic. Additionally, the following observations were also drawn from extant literature:

- **COVID-19 highlighted supply chain vulnerabilities**: The COVID-19 pandemic exposed vulnerabilities in construction supply chains, for example, shortages in labour and materials (Mahasuar, 2023; Meier and Pinto, 2024).
- **Vulnerabilities demonstrate the need for resilience measures:** These vulnerabilities provide the basis for developing resilience measures that can fill the gap in existing research. This can be ensured by developing a roadmap to create resilient and sustainable supply chains (Ivanov, 2024; Liao et al., 2023).
- **Critical Role of Strategic Planning:** Strategic planning plays a crucial role considering the implications of these vulnerabilities. It involves diversifying suppliers to mitigate the risks associated with

Fig. 1. Interrelation between resilience and sustainability constraints that affect CSC.

single-source dependencies (Karunarathna et al., 2023; Kholaif et al., 2023).

- **Sustainability for Resilience:** Sustainability measures, e.g., reducing waste or using eco-friendly materials, improving energy efficiency, and optimizing resource utilization, should be integrated into resilience plans to manage disruptions (Iranmanesh et al., 2023; Karunarathna et al., 2023; Oyegoke et al., 2023).

While extant literature demonstrated the effects of disruptions in supply chains, a lack of research focuses on identifying the causes of supply chain disruptions in the construction industry during the COVID-19 pandemic. Fig. 2 lists the challenges that influenced the resilience and sustainability of CSC and the reason behind the occurrence of these constraints. Furthermore, identification of the causes of supply chain disruption is necessary to develop an understanding of how resilience and sustainability can be manifested. According to Mohammed et al. (2021), sustainability and resilience are interrelated aspects of developing efficient supply chains. As per Gölgeci and Gligor (2022), researchers have a limited focus on the concepts of resilience and sustainability in the construction supply chain. This demonstrates another significant gap in body knowledge that can be resolved by exploring the causes of construction supply chain disruptions during the COVID-19 pandemic.

2.4. Discourse on the main causes of supply chain disruption

It was also found that significant operational challenges arose from communication barriers and the health of the workforce (Sierra, 2022). Also, an increase in transportation demand and inflation of raw material prices affected the construction logistics, demonstrating the role of external pressures. Additionally, resource constraints and availability of working capital were also responsible for severely disrupting the supply chains (Ayat et al., 2023). In this context, conflicts among key stakeholders and an increase in prices of labour resulted in significant financial constraints (Duong et al., 2022). Furthermore, reviewing the extant literature it was found that price inflation and limited availability of resources were caused by inadequate logistics, limited technological advancements, and inefficient supplier selection mechanisms (Ekanayake et al., 2022a). An in-depth exploration of these causes will be helpful in formulation of strategies to manage future uncertainties, which will manifest low-carbon logistics and enhance supply chain resilience. Primary causes of supply chain disruption are discussed in the following subsections, and the measures of these are shown in Table 2.

2.4.1. Operational challenges

Operational challenges (OCs) influence resilience and sustainability by impacting the performance of supply chains. From a CT lens, it was observed that organizations should adapt to environmental influences to attain operational efficiency (Kalaiarasan et al., 2022). These external influences, e.g., communication issues, limited availability of manpower, and lack of standardization, disrupted the supply chains during COVID-19 (Li et al., 2022). Additionally, post the lifting of lockdown, it was noted that firms had limited preparedness for challenges arising from labour migration and limited inventory, which influenced their resilience (Sadeh et al., 2022). Operational disruptions also influenced sustainability because of resource wastage, specifically in the case of consumables that had a negative environmental impact (Sarfraz et al., 2023).

2.4.1.1. External pressures. External pressures (EPs) influence the resilience and sustainability of the construction supply chain by affecting the capabilities of firms. From an RBV lens, external factors influence a firm's ability to effectively use its resources to gain a competitive advantage (Kim et al., 2022; Ma et al., 2020). This was primarily observed due to increased raw material prices, transportation demands, and the effects of global trade and tariffs (King et al., 2022; Pham et al., 2023). This made construction firms choose short-term survival strategies over the adoption of long-term sustainable practices (Al-Mhdawi et al., 2022; Moretto and Caniato, 2021).

2.4.1.2. Resource constraints. Resource constraints (RCs) arising due to the influence of lockdown and geopolitical conflicts significantly influence the resilience and sustainability of supply chains. The main factors that caused disruption were limited use of technology for project

Table 1
Past studies on supply chain disruption.

Study	Theme	Key Findings
Donkor et al. (2021); Duong et al. (2022)	Impact of COVID-19 on construction supply chains	• Significant disruptions in construction industry's supply chains during the pandemic • Delays in the project timelines • Cost overruns • Increased reliance on alternative suppliers.
Ekanayake et al. (2022a); Ekanayake et al. (2022b); Ekanayake et al. (2021)	Economic consequences of supply chain disruptions	• Negative impact of supply chain disruptions on the construction industry's economic performance • Decline in output. • Increase in project costs
Liao et al. (2023)	Supply chain resilience in the construction industry	• Construction firms with more resilient supply chains better navigated disruptions • Maintained operational efficiency during the pandemic. • Importance of supply chain resilience highlighted
Kazancoglu et al. (2022)	Supply chain management strategies	• Construction firms adopted various strategies to manage disruptions. • Strategies included supplier diversification, investment in digital technologies, and enhanced risk management practices
Yevu et al. (2021)	Technological innovations in supply chain management	• Examined the role of innovative technologies in supply chain resilience. • Technologies included BIM, RFID, and blockchain. • Technologies improved traceability, transparency, and collaboration, reducing disruption
Hamledari and Fischer (2021a)	Impact of digital technologies on supply chains	• Digital technologies played a crucial role in improving the efficiency and adaptability of construction supply chains. • The adoption of innovative technologies, such as BIM, RFID, and blockchain, promoted resilience and enabled firms to better respond to disruptions. • By enhancing supply chain traceability, transparency, and collaboration, digital technologies helped firms maintain project performance despite disruptions.
Chen and Nguyen (2019); Hernadewita and Saleh (2020)	BIM adoption in the construction industry	• BIM adoption reduces the likelihood of supply chain disruptions, thereby improving project outcomes. • BIM promotes efficient communication, collaboration, and data exchange among stakeholders, enhancing transparency and traceability in the supply chain. • BIM-enabled construction firms can quickly identify and address potential supply chain risks, making them more resilient to disruptions. • The use of BIM in construction supply chain management is still relatively low but is expected to increase in the future due to its benefits.

monitoring, limited availability of materials, and inadequate process innovation capabilities (Al-Mhdawi et al., 2022; King et al., 2022). These influenced construction firms' resilience by impacting their ability to recover from pandemic-induced challenges (Kraaijenbrink et al., 2010; Ma et al., 2020). This shows that construction firms possess limited capability to ensure effective resource management. This resulted in irresponsible consumption, leading to waste and thereby limiting access to resources. This, in turn, affected the capability of organizations to innovate and develop environment-friendly practices that influenced sustainability (Ling et al., 2022).

2.4.1.3. Financial challenges. Financial challenges (FCs) influenced the resilience and sustainability of supply chains as firms started focusing on short-term survival (Kim et al., 2022). A chief reason was the insufficient availability of working capital for construction firms, which influenced their capability to manage demand and supply in ongoing projects, affecting their resilience. The COVID-imposed lockdown resulted in limited availability of logistics for transportation. This made supply chains vulnerable to disruptions (Wang et al., 2022). Therefore, from the contingency theory lens, it can be stated that construction organizations lack proactive financial decision-making capability, which influences supply chain resilience (Donkor et al., 2021). The failure to manage financial challenges influenced economic sustainability, while firms focused on short-term measures to attain financial feasibility over adopting long-term sustainable practices (Kazancoglu et al., 2022).

2.4.1.4. Stakeholder constraints. Stakeholder Constraints (SCs) in construction projects were primarily a result of a lack of coordination among stakeholders because of a lack of consensus. From a CT lens, this reflects the bureaucratic challenges within the construction firms that impacted their decision-making. These challenges resulted in conflicts among stakeholders, inadequate management of legal complexities due to COVID-19 restrictions, and limited focus on labour's health and safety concerns (Donkor et al., 2021; Kazancoglu et al., 2022). In this context, Donaldson (2001) stated that an organization's ability to adapt to its stakeholders' varying demands influences performance. However, as observed in the case of construction organizations, their organisational decision-making was not effective in managing these challenges, which affected sustainability and resilience. This shows that there was limited stakeholder coordination to address the supply chain disruptions caused by COVID-19 (Duong et al., 2022). Thus, it can be stated that it is necessary to address stakeholder constraints to achieve resilient and sustainable construction supply chains.

2.5. The conceptual framework

From the extant literature, five latent variables were developed. These are operational challenges (OC), external pressures (EP), financial challenges (FC), resource constraints (RC), and stakeholder constraints (SC). OC involves communication barriers and health and safety concerns. EP comprises fluctuating raw material costs and geopolitical instability. FC includes stakeholder conflicts and rising costs, while RC highlights logistical issues and technology shifts. SC focuses on stakeholder disputes and legal challenges. Understanding these is useful to develop strategies to mitigate future disruptions, thereby enhancing

Fig. 2. Root Causes of Supply Chain Disruption.

supply chain resilience and sustainability (see Fig. 3).

3. Research methodology

The study aimed to explore the causes of supply chain disruptions in the construction industry because of the COVID-19 pandemic. Therefore, to accomplish the aim of the study, a quantitative approach was chosen, and a survey questionnaire was developed using the literature. To develop the questionnaire literature, a search was performed for the range 2020 to 2023 on Google Scholar, Scopus, ScienceDirect, etc. Industry reports and white papers were accessed using the databases of the Government of India, McKinsey, PwC, and Deloitte. The search resulted in around 200 research papers and reports, out of which 100 were found suitable after the analysis of their abstracts and executive summaries. And since the study focused on supply chain disruptions because of the pandemic, 50 documents were found suitable to analyze the literature. The questionnaire developed from the literature is included in Table 2, and the research approach followed is shown in Fig. 4. The data collection was performed in India in the states of Tamil Nadu, Gujarat, Rajasthan, Punjab, Maharashtra, Karnataka, Uttar Pradesh, and the Delhi NCR region, as major construction activities were being carried out in these regions. The decision to focus this study on India was driven by the severe impact of the COVID-19 pandemic on its large-scale construction industry (Cherian et al., 2022). The participants in the study represented a diverse group of professionals with extensive experience and expertise in the construction industry and were selected using a random sampling approach. Firstly, a pilot study was conducted with 30 construction professionals, i.e., 10 resident engineers, 8 billing engineers, and 12 project managers with 10 to 15 years of experience. Out of these, 12 professionals were from residential construction, and 18 belonged to infrastructure projects, e.g., roads. Cronbach's alpha for the pilot study was 0.85, which was excellent as recommended by Hair et al. (2022).

For the full-scale study, the survey was distributed among 1200 construction industry professionals. The demographic details of the participants are mentioned in Table 3. This exceeded the required minimum sample size of 200 based on recommendations of Hair et al. (2013) and Astrachan et al. (2014). The survey was responded to by 400 industry professionals, and a response rate of 33.3 % was observed. The survey was administered online using SurveyMonkey's database, and the link to the survey was sent to participants using email and text messages. To ensure ethical data collection, personal information of respondents, e.g., name, age, income, name, name of employer, etc., was not asked, and the questionnaires were also masked to ensure the anonymity of the responses. Among the 400 responses received, 40 questionnaires were incomplete and were not suitable for analysis. Hence, the dataset that was used for analysis consisted of 360 complete responses. The dataset was analyzed using exploratory factor analysis and second-order confirmatory factor analysis as per the recommendation of Hair et al. (2022). The results of the analysis are presented in subsequent sections. The data was analyzed using SPSS v21 and AMOS v21 software.

4. Results and analysis

4.1. Reliability and validity of the dataset

Before online administration, the questionnaire was pretested with 30 professionals in the experience categories of 5–10 years (10 professionals), 11–15 years (10 professionals), and over 15 years (10 professionals). The respondents comprised architects (6), resident engineers (7), site engineers (3), project managers (10), and billing engineers (4). The reliability of the survey instrument was evaluated using SPSS, and a Cronbach's Alpha (CA) value of 0.77 was obtained, demonstrating good internal consistency. Table 4 presents CA values for the individual variables in the pilot studies. A subgroup of less than 5 years was included in the main survey to maximize the number of responses. Validity of online questionnaire measurements for survey data of the main study When data of the main study is considered, the validity of survey questionnaire measurements was examined using the Cronbach's alpha and the composite reliability metrics (Hair et al., 2022). The analysis outcomes were all higher than the threshold values of 0.6 and 0.7, respectively, indicating acceptable internal consistency and reliability (Hair Jr et al., 2016). The model's convergent validity was checked by analyzing the Average Variance Extracted (AVE) and indicator cross-loading (Hair et al., 2012). The results indicated that the AVE

Table 2
Causes of supply chain disruption.

Variable	Measures	References
Operational Challenges (OC)	Communication efficiency (OC 1) Workforce mobility (OC 2) Standardization of labour and equipment (OC 2) Supply chain collaboration (OC 3) Use of technology in project monitoring (OC 4) Supply chain flexibility (OC 5) Skilled labour availability (OC 6) Adaptability to new processes (OC 7)	Jamalnia et al. (2023); Kalaiarasan et al. (2022); Li et al. (2022); Ronchini et al. (2021); Sadeh et al. (2022); Sarfraz et al. (2023)
External Pressures (EP)	Speed of transportation (EP 1) Stability of raw material prices (EP 2) Impact of trade restrictions (EP 3) Adherence to health and safety norms (EP 4) Buyer payment practices (EP 5) Technology advancement pace (EP 6)	Al-Mhdawi et al. (2022); Kim et al. (2022); King et al. (2022); Ma et al. (2020); Moretto and Caniato (2021); Pham et al. (2023)
Resource Constraints (RC)	Supply chain visibility (RC 1) Material availability (RC 2) Support during pandemic (RC 3) Effective resource allocation (RC 4) Balance between supply and demand (RC 5)	Al-Mhdawi et al. (2022); King et al. (2022); Kraaijenbrink et al. (2010); Ling et al. (2022); Ma et al. (2020)
Financial Challenges (FC)	Financial flow (FC 1) Labour costs (FC 2) Working capital availability (FC 3) Commodity pricing (FC 4) Supplier selection efficiency (FC 5)	Donkor et al. (2021); Kazancoglu et al. (2022); Khan et al. (2022); Kim et al. (2022); Wang et al. (2022)
Stakeholder Constraints (SC)	Stakeholder coordination (SC 1) Pandemic restrictions management (SC 2) Stakeholder alignment (SC 3) Stakeholder skills and expertise (SC 4) Stakeholder commitment to resilience. (SC 5)	Donkor et al. (2021); Duong et al. (2022); Kazancoglu et al. (2022)

values exceeded 0.5, indicating adequate convergent validity. The discriminatory validity of the model is tested by Fornell-Larker criterion, and as is evident from Table 4.

4.2. Exploratory factor analysis

To evaluate the validity of the latent factors (and corresponding measures), an Exploratory Factor Analysis (EFA) was conducted based on the recommendation of Hair et al. (2012). In EFA, Likert scale items were grouped under 5 components, e.g., operational constraints (OC), resource constraints (RC), stakeholder constraints (SC), financial constraints (FC), and external pressures (EP). The first component was operational challenges with an eigenvalue of 4.945, explaining 17.008 % of the total variance, and the factor loadings are between 0.727 and 0.818. Next were resource constraints with an eigenvalue of 3.589 explained 11.732 % of the variance with the factor loading range of 0.730 to 0.765. Stakeholder constraints had an eigenvalue of 2.682 and accounted for 11.521 % of the variance, and the range of the factor loading was 0.690–0.808. This factor loaded onto the financial difficulties part of the instrument and had an eigenvalue of 2.205, accounting for 10.56 % of the variance, with loadings ranging from 0.730 to 0.804. Finally, the external pressures had an eigenvalue of 1.851 and explained 10.271 % of the variance with factor loadings between 0.752 and 0.808. Exploratory factor analysis results are shown in Table 5.

4.3. Second-Order confirmatory factor analysis

The study used second-order confirmatory factor analysis (SCFA) to understand relationships between observed factors and latent constructs. As noted by Rindskopf and Rose (1988), SCFA is useful in explaining the complex relationships and underlying structures of latent constructs without providing a direct metric for their relative significance. The model fit was evaluated through various indices such as the goodness of fit index (GFI), normalized fit index (NFI), Tucker-Louis index (TLI), cumulative fit index (CFI), root mean square error of approximation (RMSEA), and root mean square residual (RMR), as suggested by Hu and Bentler (1999). The indices exhibited 'excellent' values, signifying a robust model fit (see Table 6).

The effect sizes demonstrated stakeholder constraints to be significantly associated with supply disruptions, with an estimate of 0.638. External pressures and resource constraints followed with estimates of 0.534 and 0.45, respectively. Among operational challenges, standardisation of labour and equipment had a high estimate of 0.778. Material availability (0.721) was prominent within resource constraints, while stakeholder commitment to resilience stood at 0.707 within stakeholder constraints. Commodity pricing (0.765) was notable within financial challenges, and technology advancement pace (0.828) was crucial among external pressures, results of SCFA are shown in Fig. 5.

5. Discussion of findings

The study aimed to identify the causes of supply chain disruption within the construction industry amidst the COVID-19 pandemic. Identification of these causes would help develop a roadmap to provide strategies to the practitioners to create resilient and sustainable supply chains. As per the results (see Fig. 5), the most significant causes are stakeholder challenges (FL = 0.64), external pressures (FL = 0.53), and resource constraints (FL = 0.45). Though operational challenges (FL = 0.28) and financial challenges (FL = 0.25) also had a significant but moderate influence. These factors demonstrate the vulnerability of construction supply chains in the event of the COVID-19 pandemic with geopolitical disruption that can result in lockdown-like situations.

In the context of stakeholder constraints, primary causes are stakeholders' commitment to resilience, pandemic restrictions management and stakeholders' skill and expertise. These challenges were primarily attributed to instability in the supplier networks due to lockdowns, which constrained the supply chains resulting in increased competition amongst the stakeholders (Ivanov, 2024; Ivanov and Dolgui, 2020). Additionally, factor like high attrition of skilled workers and migration of workers demonstrated limited commitment of stakeholders towards building resilience (Canwat, 2024). This resulted in limited availability of workers that caused stakeholder conflicts due to delayed project delivery (Deep et al., 2023; Deep et al., 2022a). To address these, stakeholders should focus on capacity-building initiatives and should adopt decentralized labor allocation to build resilience. This is a solution to the problems highlighted by Ivanov and Dolgui (2020), Canwat (2024) and Ivanov (2024).

Moreover, the external pressures comprising technology

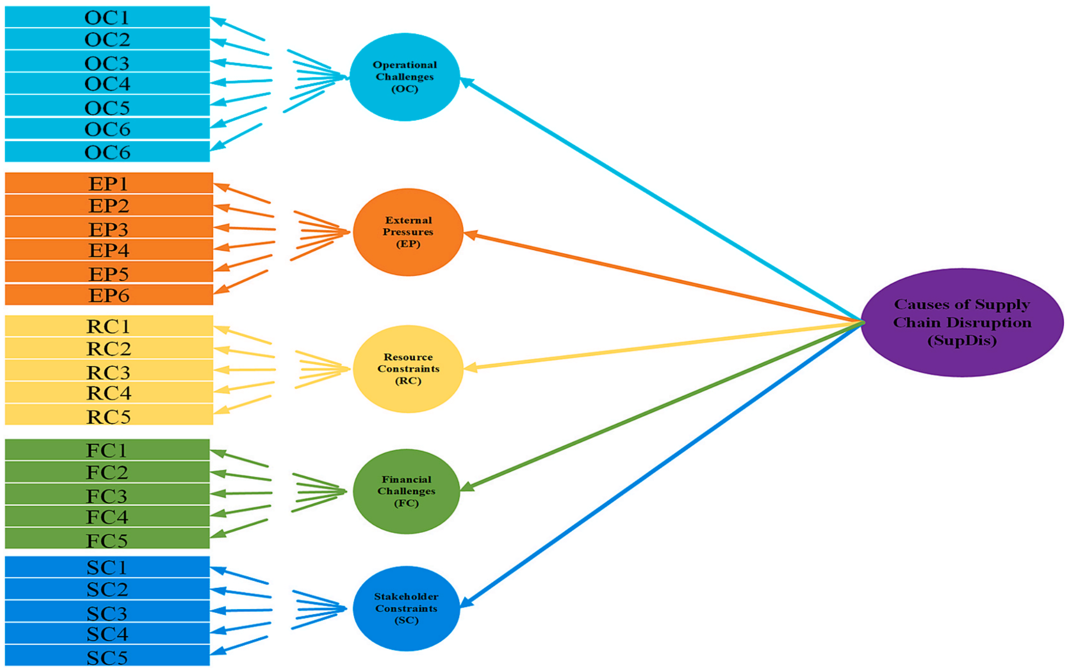

Fig. 3. Conceptual framework.

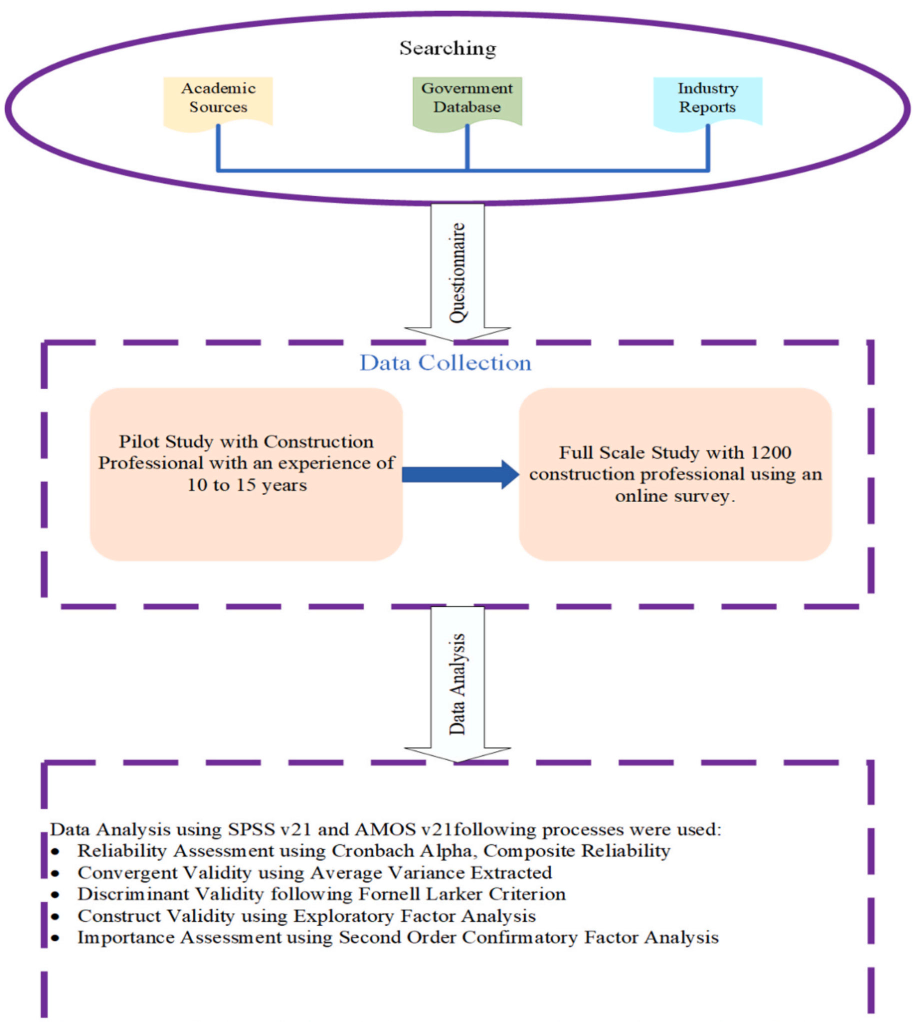

Fig. 4. Research Approach.

Table 3
Demographic profile of respondents.

Demographic Profile		Frequency
Experience	Less than 5 years	119
	5–10 years	81
	11–15 years	87
	> 15 years	73
Organization Type	Commercial	68
	Infrastructure	97
	Interior fit outs	68
	MEP works	24
	Residential	103
Nature of Job	Client	86
	Consultancy	129
	Contractor	107
	Material/Equipment Supplier	38
Job Role	Architect	91
	Resident Engineer	89
	Site-Engineer	83
	Project Manager	21
	Billing Engineer	76

advancement pace, buyer payment practices and stability of raw material prices were another significant cause. In this context, Oyegoke et al. (2023) have acknowledged the lockdown exposed the regional trade vulnerabilities. By focusing on the construction sector, the study shows that an increase in material prices resulted in project delays. Furthermore, there was a lack of a compliance mechanism to respond to the regulatory guidelines. This is another reason for instability in supply chains, which delayed the recovery after lockdowns were lifted (Ivanov, 2024). Additionally, the geopolitical tension further contributed to the increase in logistical costs due to delays in the shipment of imported materials. This adds to the observation of Mahasuar (2023), who found that alongside the pandemic, geopolitical tensions impacted the supply chains.

Resource constraints comprising material availability, effective resource allocation and supply chain visibility were a significant cause of supply chain disruption. As highlighted by Ivanov and Dolgui (2020) and Piila and Sarja (2024), during the pandemic, supply chains were constrained by limited availability of resources which also indicated a lack of focus on sustainable practices and limited focus on supply chain visibility. The findings of the study show that poor supply chain visibility resulted in imbalanced supply chains. To mitigate the effect of resource constraints, it is recommended to adopt multitier supply chains and adopt collaborative procurement systems to ensure availability of materials.

The operational constraints primarily indicated standardisation of labour and equipment, use of technology in project monitoring, supply chain flexibility, and supply chain collaboration that resulted in inefficient workflows. In developing countries, use of old equipment and lack of standardisation disrupted the process (Meier and Pinto, 2024). Therefore, project delays occurred due to equipment breakdowns and technology obsolescence, demonstrating a shortage of skilled workers, which was evident in the pre-pandemic era as well (Kholaif et al., 2023). This primarily occurred as there was limited focus on the adoption of technologies like BIM and IoT in the construction sector in developing countries. Additionally, practitioners can restructure the process as well, which would help reduce the impact of supply chain disruptions and would ensure long-term sustainability.

Financial constraints mainly occurred because of supplier selection efficiency, working capital availability, and commodity pricing. The suppliers in the construction sector primarily comprise of micro, small, and medium enterprises (MSME). In this context, Canwat (2024) observed that MSMEs face the worst financial crisis across all sectors. In the construction industry, the primary reason for this was delayed payments due to limited cash flow. This demonstrated a lack of proactive financial management in construction firms. It is recommended that construction firms should use proactive financial mechanisms like hedging and early payment release and focus on developing structured payment mechanisms.

As stated by Ghansah and Lu (2023), the influence of operational and financial challenges can be reduced by effective decision-making from the stakeholders. This decision should be made considering the external conditions. In this context, stakeholder constraints like labour shortages are major operational challenges as they increase the cost of labour, impacting the supply of human resources (Singh and Bolpagni, 2023). Furthermore, external pressures from regulatory changes, like additional safety provisions for COVID management, strained the finances of construction firms (Singh and Bolpagni, 2023). Therefore, based on empirical findings, it can be mentioned that stakeholder constraints, external pressures, resource constraints, operational challenges, and financial challenges are the root causes of construction supply chain disruption. To reduce the effect of these, workforce training, multi-sourcing, contingency planning, advanced project management, and financial hedging are the most effective strategies to enhance resilience. Additionally, these strategies also serve as long-term solutions for building a resilient and sustainable construction supply chain.

5.1. *Critical findings and managerial insights*

As established in earlier sections, it was identified that stakeholder constraints, external pressures, and resource limitations were the primary causes of supply chain disruption in the construction sector. These constraints arise due to lack of stakeholder coordination, price volatility, and inadequate planning. This has an adverse impact on the adoption of clean and sustainable logistics practices in the construction sector. In this context it can be stated that stakeholder misalignment restricts timely and flexible responses to disruptions. Dependence on long-distance suppliers increases emissions and reduces reliability. Inadequate resource allocation leads to material waste and inefficient inventory handling. Therefore, addressing these challenges is vital to improve environmental performance, support low-carbon operations, and enhance long-term supply chain resilience.

From a managerial perspective, these findings indicate a need for

Table 4
Results of Reliability and Validity.

	Cronbach alpha		Composite reliability	A.V. E	OC	RC	SC	FC	EP
	Pilot	Main							
OC	0.737	0.842	0.887	0.592	**0.770**				
RC	0.661	0.760	0.793	0.559	0.324	**0.748**			
SC	0.668	0.817	0.793	0.537	0.342	0.319	**0.733**		
FC	0.744	0.790	0.770	0.593	0.255	0.344	0.425	**0.771**	
EP	0.630	0.799	0.798	0.600	0.322	0.322	0.243	0.353	**0.775**
KMO and Bartlett's Test									
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.									0.836
Bartlett's Test of Sphericity								Approx. Chi-Square	3560.358
								df	300
								Sig.	0.000

Table 5
Results of exploratory factor analysis.

Factors		Initial Eigen Values	% of variance captured	Factor Loading
Adaptability to new processes	OC8	4.945	17.008	0.818
Supply chain flexibility	OC6			0.780
Use of technology in project monitoring	OC5			0.777
Standardization of labour and equipment	OC3			0.776
Supply chain collaboration	OC4			0.759
Skilled labour availability	OC7			0.749
Workforce mobility	OC2			0.727
Material availability	RC2	3.589	11.732	0.765
Supply chain visibility	RC1			0.755
Balance between supply and demand	RC5			0.750
Effective resource allocation	RC4			0.738
Support during pandemic	RC3			0.730
Pandemic restrictions management	SC2	2.682	11.521	0.808
Stakeholder coordination	SC1			0.775
Stakeholder commitment to resilience.	SC5			0.696
Stakeholder alignment	SC3			0.691
Stakeholder skills and expertise	SC4			0.690
Supplier selection efficiency	FC5	2.205	10.56	0.804
Financial flow	FC1			0.778
Working capital availability	FC3			0.769
Commodity pricing	FC4			0.730
Technology advancement pace	EP6	1.851	10.271	0.808
Buyer payment practices	EP5			0.773
Impact of trade restrictions	EP3			0.765
Stability of raw material prices	EP2			0.752

Table 6
Results of SCFA ().

Model Fit Indices	Estimate	Threshold	Interpretation	
Chi-square/df	1.512	<3.0	Excellent	
GFI	0.95	> 0.90	Excellent	
AGFI	0.931	> 0.90	Excellent	
NFI	0.908	> 0.90	Excellent	
TLI	0.959	> 0.90	Excellent	
CFI	0.966	> 0.90	Excellent	
RMSEA	0.038	<0.08	Excellent	
RMR	0.064	<0.09	Excellent	
Standardized Regression weights				
Latent Variables/Measures				**Estimate**
Stakeholder constraints	SC	<—	SupDis	0.638
Financial challenges	FC	<—	SupDis	0.235
External pressures	EP	<—	SupDis	0.534
Resource constraints	RC	<—	SupDis	0.450
Operational challenges	OC	<—	SupDis	0.278
Standardization of labour and equipment	OC3	<—	OC	0.778
Use of technology in project monitoring	OC5	<—	OC	0.774
Supply chain flexibility	OC6	<—	OC	0.752
Supply chain collaboration	OC4	<—	OC	0.688
Material availability	RC2	<—	RC	0.721
Supply chain visibility	RC1	<—	RC	0.641
Effective resource allocation	RC4	<—	RC	0.647
Pandemic restrictions management	SC2	<—	SC	0.658
Stakeholder commitment to resilience.	SC5	<—	SC	0.707
Stakeholder skills and expertise	SC4	<—	SC	0.589
Supplier selection efficiency	FC5	<—	FC	0.732
Working capital availability	FC3	<—	FC	0.581
Commodity pricing	FC4	<—	FC	0.765
Technology advancement pace	EP6	<—	EP	0.828
Buyer payment practices	EP5	<—	EP	0.732
Stability of raw material prices	EP2	<—	EP	0.554

Source: results of SPSS-AMOS

targeted strategies to improve supply chain governance and operational readiness in developing economies. By focusing on structured communication, local resource use, and proactive financial planning, construction firms can build more resilient and sustainable operations. Given the context, the following actions are recommended:

- Enhance stakeholder coordination by using real-time communication tools and decentralised labour strategies.
- Improve supply chain visibility through digital tools such as BIM and IoT for tracking resources and workflows.
- Adopt local sourcing and regional procurement to reduce transport-related emissions and increase supply continuity.
- Strengthen resource planning and forecasting using collaborative procurement and multitier supply models.
- Reinforce financial resilience by streamlining payment systems and adopting risk-buffering practices like hedging.

These recommendations provide strategies for management to support clean and low-carbon construction supply chains in developing economies. The strategies to ensure sustainability and resilience are discussed in the next section.

5.2. *Strategies for sustainability and resilience*

The study necessitates the integration of sustainability into supply chain management by identifying the causes of supply chain disruption in the construction supply chain. Further, organisations should adopt proactive strategies such as the use of analytics and fourth-generation technologies to create resilient supply chains. Drawing from the findings, organisations should adopt sustainable procurement practices that include selecting sustainable materials and suppliers who adhere to environmental standards and adopt ethical practices. Adoption of sustainable materials involves using recycled or locally sourced materials, which would reduce the carbon footprint and contribute toward a better society. Another strategy is enhancing collaboration with stakeholders through shared resource planning and forecasting. This would reduce waste and facilitate optimized resource utilization, manifesting responsible consumption. Additionally, investing in sustainable technologies, such as the use of advanced logistics and inventory management systems, would reduce waste produced and energy consumption, creating environment-friendly operations in construction projects. These specific strategies address the immediate challenges posed by disruptions and increase the contribution of construction supply chains towards achieving sustainability. The findings of the study also show that there is a strategic relationship between operational resilience and corporate sustainability.

6. Contribution of the study

6.1. *Theoretical contribution*

By exploring the causes of supply chain disruptions in the construction industry, the study enriches the existing knowledge on creating sustainable and resilient supply chains for the construction sector. In light with the previous literature, it was found that the COVID pandemic exposed the vulnerability due to lack of strategic planning, which highlighted operational resilience needs and sustainability constraints. This exploration results in the identification of causes, e.g., stakeholder

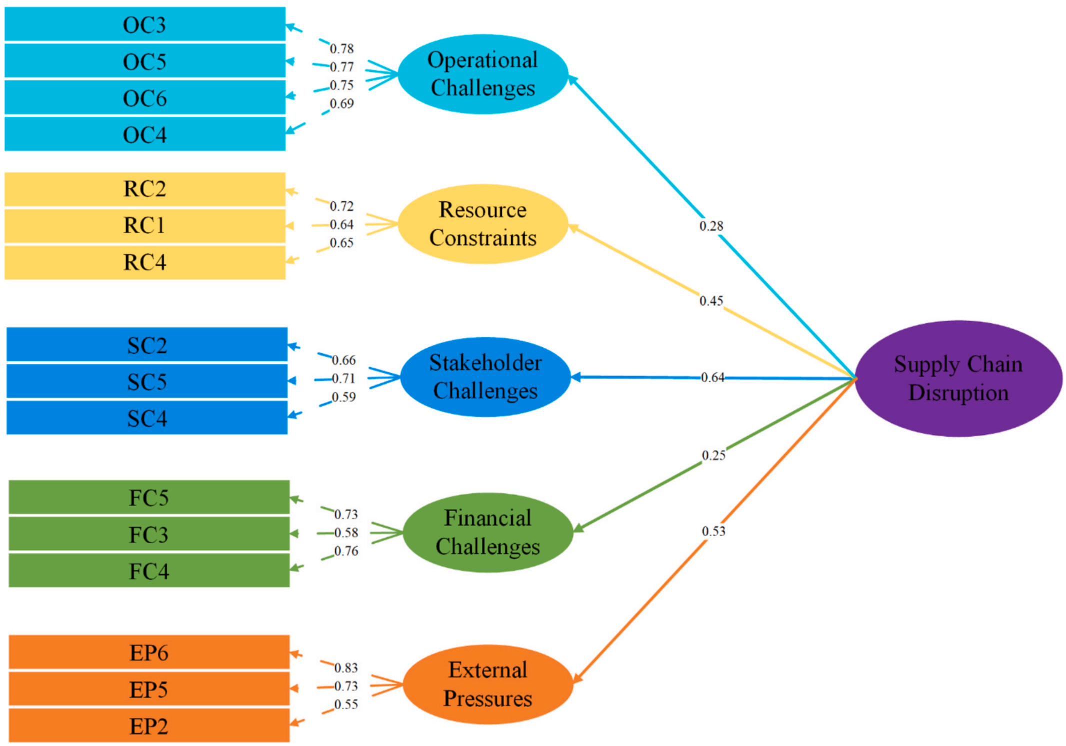

Fig. 5. Results of second order confirmatory factor analysis.

constraints, financial challenges, external pressures, resource constraints and operational challenges. Based on the findings, it is recommended that predictive resource management is an important strategy to stabilise the procurement process in the case of supply chain disruptions. This is because it would mitigate the risk posed by labour and material shortages and would help in developing a contingency to balance inflation-induced price volatility. Also, the adoption of supplier diversification strategy serves as a contingency framework that enables dynamic risk management, making the supply chain resilient to lockdown situations. Furthermore, the use of eco-friendly materials and

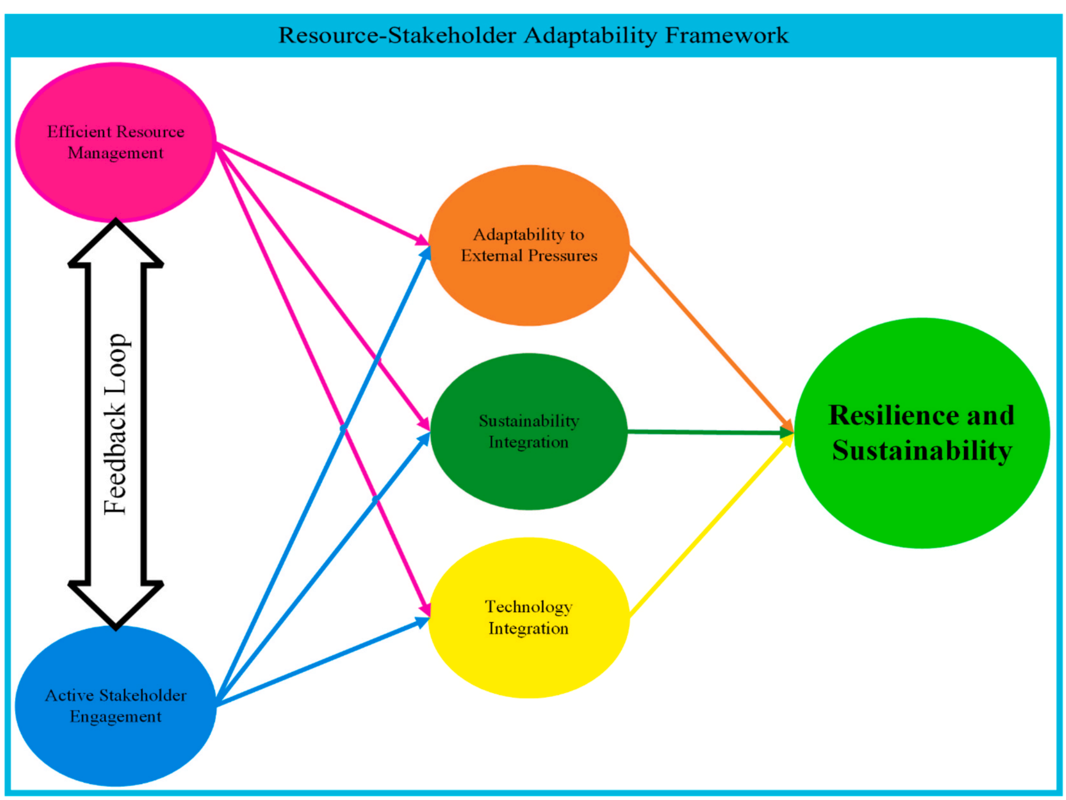

Fig. 6. Resource-Stakeholder Adaptability Framework.

renewable energy would manifest sustainability in the construction supply chains.

Moreover, adoption of digital technologies, e.g., BIM and IoT, would facilitate real-time monitoring and would result in the creation of standardized processes, which will enhance the operational resilience of the supply chain. This approach would also contribute towards the upskilling of the workforce. Hence, it is recommended that strategies to reduce the impact of supply chain disruptions should be developed by focusing on various factors. These factors include workforce training, adaptive financing mechanisms, multi-sourcing, localized procurement, strategic inventories, and optimized logistical planning. Focusing on these strategies, researchers can develop optimized solutions for efficient management of supply chains. This would manifest optimized resource allocation and transparent communication that would enhance stakeholder collaboration and contribute towards building resilience.

Based on this, a resource-stakeholder adaptability framework is proposed (see Fig. 6). This framework advances RBV in two ways: firstly, it links resource efficiency with dynamic environments; and secondly, it integrates sustainability as a key dimension of resource efficiency. Additionally, it advances contingency theory by shifting focus from static 'fit' to data-driven dynamically adaptive model for decision-making in supply chains. In other words, the findings recommend that stakeholder engagement should be facilitated by real-time adaptability to mitigate the effect of disruptions. Hence, the resource-stakeholder adaptability framework is conceptualised as an integrative model that utilises resource efficiency, stakeholder engagement and adaptive strategies to build resilient and sustainable supply chains.

Furthermore, by proposing the resource stakeholder adaptation framework for sustainable and resilient supply chains, the study also contributes towards SDGs, e.g., SDG 8, SDG 9, and SDG 12. As per the study results, it was observed that upskilling and standardization of the workforce contribute towards a stable and productive work environment. This process involves training workers in recent technological advancements. This would manifest a decent work environment that facilitates sustained economic growth. Which contributes towards the accomplishment of SDG 8: decent work and economic growth. Adding to it, it was found that technologies like BIM and IoT enhance supply chain visibility, thereby providing an innovative solution for infrastructure development. Use of these technologies also ensures proactive stakeholder engagement, which further enhances the resilience of construction supply chains. This is useful in addressing strategic planning challenges by virtue of innovation in operation, which is a step towards the accomplishment of SDG 9: industry, innovation, and infrastructure. Ultimately, the findings recommend efficient resource management through local sourcing of material and commodity pricing-based demand forecasting. Additionally, ensuring supply chain visibility would also ensure adoption of eco-friendly materials, which is a strategy to reduce construction waste. These measures, while contributing towards the creation of a resilient supply chain, also promote responsible consumption. Furthermore, since construction is a continuous production process, effective allocation of resources would manifest responsible production. Therefore, the findings also contribute towards the attainment of SDG 12, responsible for consumption and production.

6.2. Contribution to low-carbon logistics and supply chain management

The study adds to the body of knowledge on low-carbon logistics by introducing the Resource-Stakeholder Adaptability Framework. This framework was created by an empirical analysis of causes of supply chain disruption in the construction sector. From the extant literature, it was observed that researchers have treated resilience and sustainability as distinct constructs, which limits the generalizability of the studies. This study addresses that gap by integrating both concepts into a single framework that explains how internal supply chain capabilities and external pressures interact to shape logistics outcomes. Grounded in the resource-based view and contingency theory, the framework identifies stakeholder engagement and resource efficiency as vital constructs for creating efficient logistics and supply chain management policies. Furthermore, it also demonstrates how these elements interact through feedback loops, enabling adaptability, technology integration, and sustainability alignment. This would manifest efficient implementation of clean, green, sustainable, or low-carbon logistics and supply chain management.

As shown in Fig. 6, these mechanisms produce and enable green, low-carbon, and resilient supply systems for resource-intensive sectors. The value of the framework lies in its capacity to translate theoretical constructs into actionable strategies that align operational continuity with emission reduction goals. This framework supports more general application across resource-intensive and disruptive environments and is based on sector-specific dynamics. Additionally, this framework would play a vital role in making coordinated decisions between actors and adaptive resource use in enhancing the low-carbon outcomes of project-based organisations.

6.3. Practical and Policy implications

The results of this study recommend a strategic framework to address the key challenges, including the operational, financial, and stakeholder aspects, in construction supply chains. The framework was developed from an empirical analysis of disruption factors and aims to guide practitioners in the effective management of complex supply chain disruptions. The framework recommends adopting advanced technologies for streamlined, data-driven processes, enhancing resilience through rapid adaptability to market shifts. Additionally, it advocates adaptive resource management to optimize use and reduce waste, alongside enhanced stakeholder engagement for robust, collaborative supply chains that enhance resilience and promote sustainability. The results highlight the importance of a holistic, continuously improving approach to supply chain management, as shown in Fig. 7. This approach equips practitioners to manage COVID-like crises and implement sustainable practices. This prepares supply chains with operational robustness and sustainability for future challenges.

7. Conclusion

This study explored the underlying causes of supply chain disruptions in the construction sector during the COVID-19 pandemic, aiming to provide practical recommendations for enhancing resilience and sustainability. From the analysis, it was identified that stakeholder constraints emerged as the predominant factor with a factor loading of 0.64, followed by external pressures and resource constraints, exhibiting substantial influence with factor loadings of 0.53 and 0.45, respectively. Operational and financial challenges, despite having a lower impact with factor loadings of 0.28 and 0.25, respectively, cannot be discounted, as they too contribute significantly to disruptions. The findings offer actionable insights for policymakers and industry leaders to design targeted interventions that strengthen supply chain resilience while advancing low-carbon and sustainable logistics practices.

The results showed that during the COVID-19 crisis, factors like manpower movement challenges, a lack of standardisation in labour and equipment, stakeholder collaboration challenges, and limited financial flow disrupted the construction supply chains. Therefore, it can be stated that sustainable and resilient supply chains are key for the organisation to gain a competitive advantage. The proposed conceptual framework and roadmap for sustainable construction provide directions for future research on resilient supply chains and serve as a source of inspiration for scholars, practitioners, and policymakers. Additionally, to develop sustainable and resilient supply chains, practitioners should follow strategies like (a) implementation of standard practices, (b) use of technology for project monitoring, and (c) promoting stakeholder engagement. The Resource–Stakeholder Adaptability Framework developed in this study offers a structured basis for advancing low-

Fig. 7. Roadmap for practitioners to create resilient supply chain.

carbon and resilient logistics strategies in resource-intensive sectors e.g. construction and manufacturing.

The study has its limitations as well, besides the strategies recommended. The focus on India's construction industry limits its geographical applicability. The use of a Likert scale in the survey is a good tool to understand respondents' perspectives, however, it would not be able to determine the complexities of supply chain disruptions in a holistic manner. Therefore, future research should consider conducting replication studies in other countries and industries by employing qualitative methods. This would facilitate a better understanding of professionals' experiences during disruptive events, which in turn would determine the complexity associated with supply chain disruption. Future research can apply and extend this framework to other contexts to evaluate its effectiveness in guiding sustainable supply chain transformations under varying disruption scenarios.

CRediT authorship contribution statement

Shumank Deep: Writing – original draft, Supervision, Investigation, Formal analysis, Conceptualization. **Kumar Neeraj Jha:** Writing – review & editing, Software, Resources, Formal analysis, Conceptualization. **Sushant Vishnoi:** Validation, Project administration, Methodology. **Amit Kumar:** Validation, Resources, Methodology. **Pranit B. Shetty:** Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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