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A Comprehensive Approach to Capturing the Impact and Identifying Countermeasures of the COVID-19 Pandemic at Construction Sites in the Republic of Korea

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Abstract: From cost and management perspectives, the sudden outbreak of COVID-19 and the subsequent countermeasures adversely affected labor-intensive construction companies owing to the restrictive guidelines. Following a systematic literature review, this study developed a theoretical framework to assess the impacts of COVID-19 and its countermeasures on construction sites. Based on a developed framework reflecting abroad cases, we explored the Republic of Korea (ROK) situation. Questionnaires were utilized to detect this impact, and were then analyzed using the relative importance index. Through interviews with site managers in the ROK, combined with text-mining and network analysis, this study aimed to pinpoint effective countermeasures and validate the framework. Results revealed that despite policy changes, construction sites in the ROK were not seriously affected during the COVID-19 pandemic. However, while foreign investment remained steady owing to robust financial contracts, labor shortages and cooperative challenges hindered productivity. Additionally, beyond telecommuting and inspections, changing hygiene regulations prompted the adoption of smart technologies. Further, site managers requested the optimization of worker management and smart systems with governance, hygiene, and quarantine policies. Although impacts from other countries have been studied, the experiences of industries in the ROK remain unanalyzed. In addition, the existing literature has only examined the economic viability of the construction industry; therefore, this study assessed the impacts and countermeasures of COVID-19 from the perspective of managers using a unified theoretical framework.

Keywords: COVID-19; site management; impact; countermeasures; relative importance index; text-mining

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1. Introduction

The COVID-19 pandemic significantly impacted labor-intensive industries, resulting in decreased worker participation. This was due to measures such as social distancing, lockdowns, and improved hygiene protocols, which caused delays and cancellations of projects [1,2]. This, in turn, substantially impacted the economic status of many countries. The management of construction sites has also changed in response to COVID-19, with various countermeasures being implemented worldwide. For instance, Nigeria introduced physical distancing protocols and safety policies, whereas the United Kingdom focused on occupational safety and health management [3,4].

The construction industry is a complicated sector of the economy because of the impact of finances, materials, equipment, and labor on stakeholders. However, due to the sudden emergence of COVID-19, various frameworks were devised to subjectively evaluate circumstances and actions related to the pandemic with different criteria for each country [5,6]. Other viruses, such as severe acute respiratory syndrome (SARS) and Middle

East respiratory syndrome (MERS), also impacted the construction industry. However, due to their limited geographical distribution, few pandemic response guidelines were developed [7]. Research on how to respond to and manage these viruses was conducted in the affected nations where infectious cases occurred. Moreover, because these cases could not be studied using a common framework, extrapolating the findings to the circumstances of other nations was restricted, reducing objectivity. Thus, as a result of the sudden emergence of COVID-19, a framework was needed to bridge the conceptual gap between theory and fieldwork. Although the World Health Organization provided basic standards, these were proposed without considering the construction industry's unique challenges and were thus largely ineffective. This study examined systematically reviewed papers published after the COVID-19 outbreak to develop a framework for identifying site impacts and countermeasures [8]. By defining which values are prioritized to enhance construction sites and the required countermeasures, the government can use these common criteria to develop a strategy to respond to a pandemic in advance based on the impact and preventative actions. Therefore, a framework suitable for construction sites is required to facilitate the efficient and effective management of pandemics.

Projects have continued to be conducted in the aftermath of COVID-19. During the pandemic, construction practitioners were exposed to significant risk, while construction site management relied on the capabilities of engineers and supervisors. However, studies investigating the perspectives of site managers are limited compared with those of field workers [9,10]. Although the pandemic's effects on the construction sector and its economic impact have been extensively evaluated, the labor force and productivity at work sites have received little attention [1,11]. Similar to previous pandemics, such as SARS and MERS, the increased price of imported supplies and payment delays often occurred, significantly impacting smaller localities. Extreme measures, such as lockdowns, while rare during previous pandemics, were common during the COVID-19 period; thus, the ability to analyze cases in countries affected by the pandemic is limited.

Through a theoretical analysis, Al-Mhdawi et al. examined the impact of COVID-19 on construction sites in the United States, China, Australia, and South Africa. Based on this, they developed a framework and interviewed construction industry experts in Iraq to understand the pandemic's impact on the construction industry in developing countries [12]. Similarly, Aigbavboa et al. examined the pandemic's effect on the construction industry in the United States, the United Kingdom, and Malaysia. Additionally, a survey of South African clients was conducted to assess the direct and potential effects of COVID-19 on the country [11].

During the COVID-19 pandemic, some major countries implemented measures related to construction costs and schedules to minimize losses [13]. For example, the United States halted work at all construction sites early in the outbreak and provided low-interest loans to small businesses and nonprofit organizations [14], while the United Kingdom delayed Value Added Tax (VAT) payments by about three months for all businesses, including construction firms, and published a public procurement policy that included information on prompt payment, contract advances, and contract changes to minimize losses due to COVID-19 [15]. Similarly, Japan actively responded to the pandemic by allowing construction companies to suspend work and issuing guidelines on construction costs and contract term extension [13]. Therefore, this study proposed the following research questions to understand the situation in ROK during COVID-19.

1. What were the impacts of COVID-19 on construction sites in each country and what were the countermeasures?
2. How severe were the impacts on Korean construction sites during the COVID-19 period, and what countermeasures were effective for site management?
3. What problems existed in Korean construction site management during COVID-19 and what should be done to improve them?
4. How can the countermeasures proposed in ROK during the COVID-19 period be effective for site management in the post-pandemic period?

Therefore, this study conducted a systematic theoretical review to collect research methods, examine COVID-19′s impact on various countries, and analyze the response strategies presented in previous studies. Consequently, a framework was established to understand the impact of COVID-19 on construction sites in the ROK and provide response strategies tailored to the national context, targeting on-site managers.

By narrowing the perception gap between government regulations and site status, this study clarifies the factors considered at construction sites and the opinions of site managers. This research was conducted with the assistance of individuals who managed construction sites in the ROK before COVID-19. It demonstrates the impact of COVID-19 on construction sites without mandatory lockdowns and its countermeasures. In the case of the ROK, mandatory lockdown measures were not implemented, and the complete closure of construction sites was rare. However, measures such as social distancing and a two-week quarantine period for confirmed cases were implemented. Efforts were made to maintain a certain level of productivity by implementing systematic and industry-specific measures to ensure worker safety and productivity [16]. By examining the Korean context and suggesting guidelines for advanced management measures, the findings can provide knowledge for developing effective and ongoing countermeasures against similar infectious diseases and reduce the conceptual gap.

The research process described in Figure 1 is as follows: (1) To identify research trends for measuring the impacts and responses of sites in the ROK, a theoretical framework was developed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. A network analysis to establish clusters was conducted using abstracts and keywords to develop this framework. A research model was then proposed using a robust and reproducible method linking the model to future research directions. (2) The framework factors were thoroughly developed by identifying the groups and categories of site management based on a network of words in systematically extracted papers. Consequently, the impacts of and responses to COVID-19 at construction sites were identified for various projects and countries. (3) Questionnaires and interviews were devised based on the framework's components to gain a more objective and systematic understanding of the impact and countermeasures on Korean construction sites. Samples were collected using target sampling, a direct sample recruitment method offering increased data reliability [17]. (4) Finally, questionnaires were used for quantitative analysis, whereas semi-structured interviews were qualitatively examined to identify the impacts and responses of construction sites in the ROK. The factor ranking was obtained using Al for the quantitative analysis of survey results to determine the effects, and interview results were analyzed by introducing text mining, centrality analysis, and network analysis. The investigation also revealed shortcomings in the ROK's response to COVID-19 in the construction industry, as well as their influence on site management, which can be used to establish countermeasures for future outbreaks. This can assist in developing guidelines for addressing gaps in site management and mitigating the risks of virus transmission at ROK construction sites.

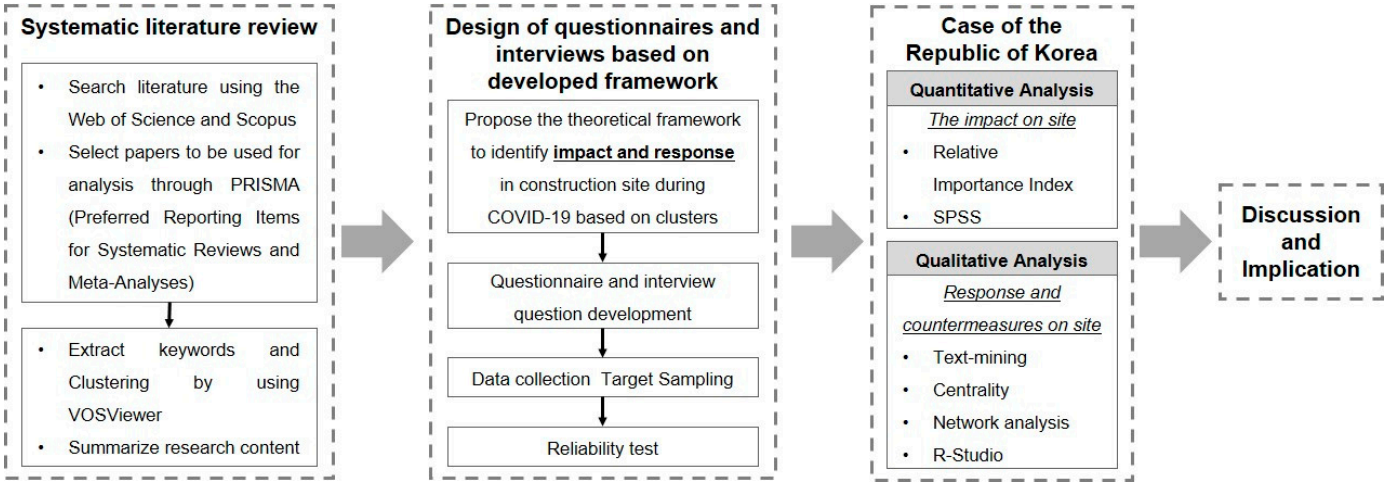

Figure 1. Research Process.

2. Systematic Literature Review for Developing a Theoretical Framework

2.1. Search Strategy and Data Extraction Based on PRISMA

PRISMA's methodological steps were used to conduct the systematic literature review. This was based on a checklist comprising four processes: (1) selecting search engines and keywords, (2) selecting studies based on keywords, (3) a quantitative literature analysis, and (4) an analysis and discussion of the results.

Based on the search strategy, the following is a detailed process for identifying the data used in this study:

Step 1: Multidisciplinary citation search engines, including the Web of Science and Scopus, were used to find relevant papers. This minimized the overlap of papers and reduced content inconsistency. In addition, the keywords were selected with the terms "construction industry" and "construction sites" in mind.

Step 2: Advanced database search strategies on keywords combined with Boolean operators were used to find related papers, such as AND, OR, and NOT. This study aimed to better understand the trends and future research directions related to the impacts and countermeasures of construction sites during COVID-19. As presented in Table 1, research articles based on keywords related to COVID-19, the construction industry, and construction sites were extracted.

Table 1. Advanced search codes for electronic databases with limitations.

Name of Electronic Database	Advanced Search Code
Web of Science	TS = (COVID-19 AND construction industry AND impact) AND AK = (impact AND construction site)
Scopus	(TITLE-ABS-KEY(COVID-19) AND TITLE-ABS-KEY (construction AND industry) AND TITLE-ABS-KEY (impact AND construction site))

Step 3: A quantitative literature analysis was used to extract the following quantities of papers:

- Papers extracted based on the keywords in Table 1: 240 (Web of Science: 58, Scopus: 182)
- Total after excluding papers not written in English: 163 (Web of Science: 54, Scopus: 109)
- Nine overlapping papers were excluded: 154 (Web of Science: 54, Scopus: 100)
- After excluding papers unrelated to the construction industry and construction sites based on reading titles and abstracts, the total was: 56 (Web of Science: 20, Scopus: 36)
- The final number of papers analyzed while conducting qualitative assessments and literature reviews of full papers: 38 (Web of Science: 12, Scopus: 26)

Table 2 summarizes the results of the 38 extracted articles with the title, year, author, and journal.

Table 2. List of extracted papers.

Title	Reference	Journal
The impact of COVID-19 on the construction industry in Ghana: The case of some selected firms	Agyekum et al. [18]	Journal of Engineering, Design and Technology
Unprepared industry meet pandemic: COVID-19 and the South Africa construction industry	Aigbavboa et al. [11]	Journal of Engineering, Design and Technology
Capturing the impact of COVID-19 on construction projects in developing countries: A case study of Iraq	Al-Mhdawi et al. [12]	Journal of Management in Engineering
Early impacts of the COVID-19 pandemic on the United States construction industry	Alsharef et al. [14]	International Journal of Environmental Research and Public Health
The COVID-19 pandemic: The woes of small construction firms in Ghana	Amoah et al. [8]	Smart and Sustainable Built Environment
Modeling the spread of COVID-19 on construction workers: An agent-based approach	Araya [19]	Safety Science
Modeling working shifts in construction projects using an agent-based approach to minimize the spread of COVID-19	Araya [19]	Journal of Building Engineering
Influence between COVID-19 impacts and project stakeholders in Chilean construction projects	Araya and Sierra [20]	Sustainability
Guidelines for responding to COVID-19 pandemic: Best practices, impacts, and future research directions	Assaad and El-adaway [21]	Journal of Management in Engineering
Innovation trends in underground works: The example of the Arnotegi Tunnel in Bilbao	Baraibar et al. [17]	Designs
COVID-19 and construction: Impact analysis on construction performance during two infection waves in Victoria, Australia	Bell et al. [22]	Sustainability
Analysis of COVID-19 concerns raised by the construction workforce and development of mitigation practices	Bou Hatoum et al. [23]	Frontiers in Built Environment
The impact of COVID-19 pandemic on Jordanian civil engineers and construction industry	Bsisu [24]	International Journal of Engineering Research and Technology
Revisiting the built environment: 10 potential development changes and paradigm shifts due to COVID-19	Cheshmehzangi [25]	Journal of Urban Management
Resilience of organizations in the construction industry in the face of COVID-19 disturbances: Dynamic capabilities perspective	Chihh et al. [26]	Journal of Management in Engineering
COVID-19 recovery for the Nigerian construction sites: The role of the fourth industrial revolution technologies	Ebekozien and Aigbavboa [27]	Sustainable Cities and Society
A fuzzy synthetic evaluation of vulnerabilities affecting supply chain resilience of industrialized construction in Hong Kong	Ekanayake et al. [28]	Engineering, Construction and Architectural Management
COVID-19 pandemic lockdown: The consequences towards project success in Malaysian construction industry	Esa et al. [29]	City
COVID-19 pandemic and construction industry: Impacts, emerging construction safety practices, and proposed crisis management	Iqbal et al. [15]	Brazilian Journal of Operations & Production Management
Property development during the COVID-19 pandemic: Challenges and outlook in Malaysia	Jagun et al. [30]	Environmental Science and Pollution Research

Table 2. *Cont.*

Title	Reference	Journal
Adapting to COVID-19 on construction sites: What are the lessons for long-term improvements in safety and worker effectiveness?	Jones et al. [10]	Journal of Engineering, Design and Technology
Critical analysis of pandemic impact on AEC organizations: The COVID-19 case	King et al. [31]	Journal of Engineering, Design and Technology
COVID-19 pandemic and its effects on the usage of information technologies in the construction industry: The case of Romania	Leontieh et al. [32]	Buildings
Impact of COVID-19 pandemic on demand, output, and outcomes of construction projects in Singapore	Ling et al. [7]	Journal of Management in Engineering
The impacts of the COVID-19 pandemic on employment in Cameroon: A general equilibrium analysis	Madai Boukar et al. [33]	African Development Review
Safety and health management response to COVID-19 in the construction industry: A perspective of fieldworkers	Nnaji et al. [9]	Process Safety and Environmental Protection
Lessons learned from the impact of COVID-19 on the global construction industry	Ogunnusi et al. [34]	Journal of Engineering, Design and Technology
Moderating effect of project size on the relationship between COVID-19 safety protocols and economic performance of construction projects	Ogunnusi et al. [1]	Engineering, Construction and Architectural Management
Changes in job situations for women workforce in construction during the COVID-19 pandemic	Oo and Lim [35]	Construction Economics and Building
Digitization in the design and construction industry—Remote work in the context of sustainability: A study from Poland	Orzeł and Wolniak [36]	Sustainability
New modes of operating for construction organizations during the COVID-19 pandemic: Challenges, actions, and future best practices	Raoufi and Fayek [37]	Journal of Management in Engineering
Impact of COVID-19 on project performance in the UAE construction industry	Rehman et al. [38]	Journal of Engineering, Design and Technology
Perception of COVID-19 impacts on the construction industry over time	Rokooei et al. [39]	Cogent Engineering
Coping with the COVID-19 pandemic: An exploration of the strategies adopted by construction firms	Salami et al. [40]	Journal of Engineering, Design and Technology
Impact of COVID-19 on health and safety in the construction sector	Stiles et al. [41]	Human Factors and Ergonomics in Manufacturing & Service Industries
The effects of COVID-19 pandemic on the UK construction industry and the process of future-proofing business	Stride et al. [3]	Construction Innovation
Psychosocial factors for safety performance of construction workers: Taking stock and looking forward	Tong et al. [42]	Engineering, Construction and Architectural Management
Opportunities and challenges for construction health and safety technologies under the COVID-19 pandemic in Chinese construction projects	Yang et al. [43]	International Journal of Environmental Research and Public Health

Step 4: Results analysis and discussion

The extracted papers thoroughly analyzed the impact of COVID-19 on construction sites in different countries and summarized the corresponding response strategies. To identify important information from the 38 articles and present the information in a visual format, we used VOSviewer 1.6.18, a professional software that analyzes and visualizes the interrelationships between keywords, authors, and publications in academic literature and data [5]. As shown in Figure A1, keywords were extracted from the 38 articles to

identify and present important information in the articles, and a total of 56 keywords were derived. The keywords were further subjected to correlation analysis for effective clustering, and each cluster represents a specific topic or research area, allowing researchers to identify major topics or trends in the field. To establish a theoretical framework, the four major clusters, their respective topics, and the related keywords are presented in Table 3. This classification and analysis approach provided a strong theoretical foundation for an in-depth understanding of the impact of COVID-19 on global construction sites.

Table 3. Main framework topics based on a systematic literature review.

Cluster	Main Topic	Other Keywords
Cluster 1	Workforce	Workforce, change, telecommuting, collaboration, education, productivity, self-quarantine
Cluster 2	Management	Construction management, quality, project management, BIM, site management, supply chain management, strategy, psychological factor
Cluster 3	Hygiene and safety	Hygiene management, occupational safety, policy, site safety, technology introduction, protocol, equipment, implementation
Cluster 4	Economic	Economic shortcomings, contract, material delivery, cost, insurance, financial crisis, small construction firm

The topic of the first cluster, "workforce", includes "construction companies", "manpower such as carriers", "employment", and "working shifts". The topic of the second cluster, "construction management", encompasses words related to construction projects and site management, such as "project management", "construction site", and "contract". The third cluster, "hygiene and safety", comprises construction project risk, safety, and health-related content, such as "construction delay", "productivity", and "safety risk". Finally, the fourth cluster, "economic", deals with COVID-19 cost factors in the construction industry, including the "crisis management framework" and "supply chain management". To gain insight into the impact of the pandemic on the Korean construction industry, it is crucial to use questionnaires and interviews to analyze the situation qualitatively and quantitatively. Developing a theoretical framework based on existing research from each country is particularly important. The following sections comprehensively evaluate and collect a detailed assessment of the impact and response strategies of COVID-19 on construction sites in different countries, according to each cluster.

2.2. Impact of COVID-19

2.2.1. Cluster 1: Workforce

(1) Workforce shortages

The adverse effect on construction staffing was one of the first consequences of the pandemic. While other industries could transition to remote working or implement technology to keep their companies running, a smooth transition to non-face-to-face work was impossible for construction companies as they require employees' physical presence [14]. Approximately 40% of construction companies were forced to lay off workers at the pandemic's start due to project cancellations and a lack of equipment and materials [8,15,22,28,32]. In addition, staffing shortages were common due to illness and preventive quarantine. As the construction workforce faltered, construction companies faced insufficient worker protection, such as a lack of sick and paid leave, as well as housing and commuting problems for on-site workers [22]. In addition, due to the unexpected outbreak of confirmed patients, work and site development were often delayed, presenting challenges in allocating time and resources [8].

(2) Low worker productivity

Construction worker shortages, the social isolation of workers infected with COVID-19, and a decreased labor rate due to telecommuting all contributed to a decline in labor productivity [8,18,23,29,31]. Moreover, the absence of subcontractors necessitated

significant changes to existing construction schedules, resulting in additional work and adjustments [22,28]. Work inefficiency due to these adjustments resulted in a decline in productivity. Moreover, contractors and subcontractors experienced cash flow problems, significantly impacting performance. In addition, delayed and unavailable materials, as well as inspections and permit delays, adversely affected construction outcomes [14]. Furthermore, cooperation difficulties occurred due to unfamiliar telecommuting systems. Thus, methods for managing telecommuters were needed [8,37]. However, despite this necessity, complications arose due to a lack of well-defined worker management strategies [14].

2.2.2. Cluster 2: Management

(1) Site management

Group work is essential for construction projects to run smoothly. Therefore, compliance with safety rules, such as social distancing on construction sites, became increasingly difficult. Regular inspections of construction workers and implementing rules complicated site management [8]. In addition, COVID-related costs were not included in some small construction companies' project contingency or health and safety budgets. Therefore, implementing COVID-19 rules on-site incurred additional expenses and caused project execution delays [19,41]. Consequently, in the US, the Occupational Safety and Health Administration (OSHA) updated the rules for preparing building sites for COVID-19. OSHA also attempted to introduce new technology by persuading clients based on the US situation [15,43].

(2) Project suspensions

A widespread recession occurred due to the pandemic, and the resulting uncertainty led owners, investors, and businesses to become increasingly wary of running and investing in construction projects. This resulted in cancellations due to substantial reductions in overseas investment and orders [18]. Alsharef et al. studied the initial impact of COVID-19 on the US construction industry, interviewing an expert who revealed that 90% of construction projects were shelved during the planning phase. Additionally, several projects in the bidding phase were canceled or postponed [14,23,31,34]. The increased demand for re-evaluating mechanical ventilation and other air-cleaning systems also caused project delays [12]. Furthermore, new regulations, such as social distancing and lockdowns, caused setbacks due to a lack of productivity [3,22,24].

(3) Contractual and legal elements

In construction projects, contractual and legal aspects are crucial because most interactions are governed by contracts [21]. During the pandemic, many project owners exercised their contractual rights to terminate or partially or wholly suspend construction projects to minimize adverse economic effects [36]. As a result, contractors and subcontractors attempted to withhold their rights at the expense of additional costs and time. Thus, in the event of force majeure, contractors and subcontractors should consider reviewing escalation provisions in existing contracts or including future remedy provisions [8].

2.2.3. Cluster 3: Hygiene and Safety

(1) Site safety

Many construction companies endeavor to minimize site accidents. Particularly, hygiene and health safety on construction sites have been equally as important as physical safety since the COVID-19 outbreak. Due to concerns regarding the spread of COVID-19, outside access was prevented, occasionally causing difficulties [37]. Bou Hatoum et al. examined COVID-19 complaint data from construction workers [23]. These representative complaints collected from OSHA include physical harm to workers due to the failure to provide sanitizer, constant threats from offline work reports of positive or virus-exposed employees, and the failure to wear masks. Consequently, comprehending the influence of the pandemic on construction practitioners is essential, as COVID-19 substantially affected project performance and the supply chain [15].

(2) Hygiene

Many contractors implemented new work practices and policies, including staff temperature checks, oxygen level measurements, parallax shifts, and disinfecting workspaces, tools, and machinery [17,37,39]. In addition, construction site expenses increased due to continuous disinfection procedures and the installation of quarantine facilities [18,38].

2.2.4. Cluster 4: Economic

(1) Technology introduction costs

The term "smart construction site" was introduced in response to COVID-19. Moreover, as interest in technology in the fourth industry increased, such as virtual reality, laser scanning, and artificial intelligence, technology was actively implemented into construction sites. For example, drones were introduced, and 3D scanners were used to understand the construction process. However, the additional cost of adopting technology necessitates a determination of its affordability [38,43].

(2) Disrupted supply chains

COVID-19 frequently caused breaks in the supply chain due to various global situations. This was particularly problematic when the material supply chain was located abroad [12,29]. For example, many overseas manufacturing plants were shut down in response to the pandemic, disrupting the supply chain. Additionally, delays in delivering materials occurred because some truckers had to quarantine after being exposed to the virus [7,16]. Finally, the supply chain collapse and difficulties obtaining construction materials eventually led to higher prices [18,21,23,31].

(3) Revenue loss

COVID-19 affected all construction-related industries, resulting in profit loss [11,39]. Moreover, the economy's deterioration was problematic, and project suspensions resulted in difficulties in meeting customer orders [23]. This resulted in delays in paying expenses, causing adverse effects [14,18]. COVID-19 thus reduced construction and overseas investment.

2.3. COVID-19 Countermeasures

2.3.1. Cluster 1: Workforce

(1) Education

An interview conducted by Agyekum et al. argued the necessity of wearing protective equipment, such as gloves and masks, as well as hygiene education [18]. Since the emergence of COVID-19, experts have conducted training, especially at construction sites, to educate workers [10]. To prevent the spread of the disease in the field, educational content should continue to be provided, and workers should be able to reconfigure tasks based on updated risk rankings for the virus [19,35].

(2) Working from home (telecommuting)

Construction workers were burdened by COVID-19 due to the implementation of telecommuting, changes in job conditions, and additional responsibilities in caring for family members [35]. However, many companies lacked the digital infrastructure to transition to remote working and faced difficulty accessing software or other necessary resources [25,26]. Some experts argue that the shift towards telecommuting can reduce overhead costs and improve work flexibility, resulting in more efficient office space [33,35]. Moreover, companies are improving their technological infrastructure to facilitate collaboration between suppliers, subcontractors, and other partner companies [14,37].

However, due to the digitization of many tasks, workers unfamiliar with technology face difficulties completing their work.

(3) Self-quarantine

The most important pandemic-related precaution on construction sites was ensuring that workers infected with COVID-19 isolated themselves at home and did not return to work. In addition, infected workers should be identified and quarantined as soon as possible [26]. Importantly, managers must provide the necessary support for those in isolation and consistently communicate with them until the official cessation of their self-

isolation [23,36,40]. Managers should also ensure they receive psychological and physical care [34,42].

2.3.2. Cluster 2: Management

(1) Site management

According to a survey on the impact of COVID-19 on the Ghanaian construction industry, 25% of experts believe that regular and appropriate inspections of construction sites are necessary [18]. The WHO recommended deploying alcoholic disinfectants for construction site workers to encourage frequent hand washing. Additionally, at the beginning and end of each shift, office and public tools, equipment, and machinery should be disinfected [1,40,41]. Spaces used by various people, such as toilets and eating areas, should also be disinfected frequently [27,44]. In managing construction sites for COVID-19, the most critical focus was restricting non-essential personnel from accessing the sites [43]. A construction site is generally accessed by stakeholders such as contractors, designers, subcontractors, and service providers. As COVID-19 infection numbers increased, many construction companies used strategies such as remote meetings, strengthening hygiene protocols, and restricting non-essential personnel from on-site visits to manage the sites [36,37].

(2) Project management

The unexpected occurrence and spread of COVID-19 adversely affected construction project schedules and necessitated schedule management and rescheduling [34]. Poorly managed schedules can cause delays, leading to financial losses [40]. Project management was also conducted in a novel way. In construction, it is essential to maintain regular communication and coordination among project teams [17,25]. However, social distancing measures significantly impacted the ability to hold meetings. Therefore, new communication methods, such as video conferencing, were encouraged. In the future, innovative removed communication methods must be considered and implemented [7,27]. For example, some prominent North American construction companies provided headset-equipped safety helmets to enable real-time communication among construction workers without the need for large-scale in-person project meetings [37]. Another company introduced smart technologies such as sensors to control construction workers' access to the site and the distance between workers. Construction companies should explore and encourage these changes in novel ways [11,20].

2.3.3. Cluster 3: Hygiene and Safety

(1) Hygiene protocols

Even before COVID-19, company policies emphasized the importance of cleanliness and personal hygiene. Following the pandemic's outbreak, a new sanitary protocol was established at construction sites, and temporary teams were formed to strictly enforce it. This new protocol implemented public distancing and safe working distance compliance [30]. Additionally, workers were reminded of these protocols periodically [3]. Gloves and masks were installed at site entrances to prevent virus spread, and their usage was mandatory [18,40].

(2) Countermeasure safety policies

To combat the COVID-19 outbreak, construction companies adopted new safety and health management protocols. These included mandating employees to wear masks, establishing social distancing rules, providing infectious disease training, and availing pre-entry temperature checks [33]. Moreover, taskforces were formed to provide guidelines for mitigating the spread of COVID-19, prepare for construction delays, and actively utilize government support programs [14]. In addition, public health and government announcements were monitored regularly to ensure adherence to the most recent regulations and guidelines [38].

2.3.4. Cluster 4: Economic

(1) Delivery of materials

The construction industry should be prepared for the possibility of delayed or discontinued material deliveries from suppliers and ensure the availability of staffing, equipment, and resources. Thus, it is necessary to consider using local suppliers rather than high-risk foreign suppliers and only diversify internationally if certain materials or services are essential for business or local suppliers cannot conveniently provide them [37].

(2) Contracts and insurance

The construction industry must review measures to identify and mitigate COVID-19-related contractual risks. Construction firms should carefully review contracts to determine if any legal provisions address contractor completion delays [11]. Further, firms should be able to compensate through additional insurance and cover consultation costs [21].

(3) Additional costs due to installing new technology

As previously stated, costs increased as new technologies and quarantine systems were introduced. In particular, costs increased as sensor devices were added or drones and 3D models were actively used to support countermeasures [9,32].

3. Research Method

Through a systematic theoretical review, this study aims to examine the impact and response strategies of COVID-19 on the construction industry. Moreover, it proposes a unified theoretical framework for analyzing the ROK's case. Accordingly, Figure 1 presents the research overview. This study conducted a literature review to compare the impact and response strategies of COVID-19 on the construction industry in various countries. Previous studies have failed to comprehensively analyze the impact of COVID-19 on the construction industry, lacking a systematic theoretical framework and providing country-specific response strategies [22]. Therefore, 38 papers were analyzed in this study. Based on the above theoretical keywords, they were categorized into "workforce", "management", "hygiene and safety", and "economic". The framework's categories and factors were derived through the literature review of the pandemic's impact and countermeasures at construction sites.

Based on these factors, construction site managers in the ROK during COVID-19 were interviewed and surveyed. A 5-point Likert scale survey assessed the direct impact on construction sites. An analysis using the relative importance index (RII) was performed quantitatively. Additionally, semi-structured interviews were conducted with these managers to understand the on-site response strategies for emerging issues, and text-mining techniques were applied.

3.1. Questionnaire and Interview Development

Based on the literature review and analysis criteria from previous cases, a survey and interview questions were derived from analyzing the impact and response strategies of COVID-19 on construction sites in the ROK. A survey was conducted using the factors extracted from the identified keywords in the literature review to understand how the sudden outbreak of COVID-19 affected construction site management. Table A1 was constructed for this purpose, and the survey was evaluated using a 5-point Likert scale. Table A2 summarizes representative countries' countermeasures to address the impact factors presented in Table A1. Based on these countermeasure factors, interview questions were formulated to analyze the situation in Korean construction sites and understand their responses. A semi-structured interview approach was employed, with all questions structured as open-ended, allowing for additional inquiries. A pilot test was conducted with three site managers and two professors to reduce issues and errors in the developed questionnaire, and their feedback was used to refine and review the questionnaire and interview questions [45].

3.2. Data Collection

Survey and interview questions were based on the framework developed from the literature review. Following the study's goals, the survey determined the impact of COVID-19 on construction sites. We gathered information using semi-structured interviews, enabling us to understand the countermeasures in-depth.

We surveyed and interviewed construction site managers who directly managed sites after the outbreak of COVID-19. Because the sample needed to be relevant to the research objectives, a Snowball Sampling method was utilized to gradually expand it by selecting participants with relevant connections [46,47]. Table 4 presents the information about participants who participated in the survey and interviews. The data collection occurred over two months, from March to April 2022. The survey comprised 25 questionnaire items derived from the 25 sub-factors in the four sections shown in Table A1. The interviews were conducted using 18 questions from the 18 sub-response strategies listed in Table A2. As the impact of COVID-19 diminished, site visits were made to directly contact site managers, enabling the collection of firsthand experiences and insights. In addition to the survey, 45- to 60-min semi-structured interviews were conducted in-person with voluntary participants.

Table 4. Participant information for the surveys and interviews.

Survey Participants				Interview Participants			
Career	**n**	**Number of Sites Managed during COVID-19**	**N**	**Career**	**n**	**Number of Sites Managed during COVID-19**	**n**
Less than 10 years	19	1 site 2 sites	21 35	Less than 10 years	6	1 site 2 sites	4 6
More than 10 years	45	3 or more sites	8	More than 10 years	9	3 or more sites	5
Total	64	Total	64	Total	15	Total	15

3.3. Data Analysis

3.3.1. Survey Result Analysis for Understanding Construction Site Impacts

To identify the impact of COVID-19 on construction sites in the ROK, an evaluation based on a 5-point Likert scale was implemented. Construction site managers were surveyed, and their responses were analyzed using the RII method (descriptive analysis) to determine which factors changed significantly during COVID-19. The RII method displays values based on the total responses, which aids in comprehending the relative significance of each factor. A standard deviation is a statistical measure used to indicate the variability within a dataset by comparing the mean and individual values. Conversely, the RII represents values based on overall responses, assessing each factor's relative importance and enabling us to rank them [48]. Consequently, this analysis method demonstrates the results more systematically than comparing the rankings using the mean and standard deviation [49]. Equation (1) shows the formula used to calculate RII. A factor can be considered significant when the value is close to 1. The Statistical Package for the Social Sciences (SPSS) 27.0 was used to perform the calculations. Thus, RII was measured as:

$$\mathrm{RII} = \frac{\sum \mathrm{W}}{(\mathrm{A} * \mathrm{N})} \quad (1)$$

where W is the weight of the individual factors identified by the respondent multiplied by the number of respondents, ranging from 1 to 5. A is the maximum weight, and N is the total number of respondents. Based on this framework, Cronbach's alpha coefficient was used to identify the questionnaire's reliability. To measure internal consistency, the reliability of each factor, category, and group was obtained. Generally, the questionnaire is considered reliable when Cronbach's alpha exceeds 0.7 [50,51]. Based on the framework presented in Table A1, a reliability analysis was conducted using participants' responses for all ten categories within the four groups, which included all the sub-factors. Cronbach's

alpha results for the questionnaire items' reliability before analysis are shown in Table 5. Cronbach's alpha coefficients exceeded 0.7 for each factor, category, and overall scale, indicating sufficient reliability [47].

Table 5. Cronbach's alpha results related to the survey.

Group	Category	Cronbach's Alpha		
		Factor	Category	Overall
Workforce	Workforce shortage	0.757	0.874	0.917
	Workers' low productivity	0.833		
Management	Site management	0.707	0.840	
	Project suspensions	0.703		
	Contractual and legal	0.929		
Hygiene and safety	Site safety	0.884	0.883	
	Hygiene-related	0.795		
Economic	Technology deployment costs	-		
	Disrupted supply chains	0.799	0.891	
	Revenue loss	0.761		

3.3.2. Interview Content Analysis to Understand Construction Site Countermeasures

The semi-structured interview questions were developed using the framework for obtaining COVID-19 construction site countermeasures in the ROK. Through inductive analysis, semi-structured interviews allow an interpretive approach to the situation [52]. These interviews provide insight into how construction site managers felt throughout COVID-19 and show how these sites can be managed. Moreover, the interviews allow us to discover interviewees' experiences and acquire knowledge genuinely and directly through supplementary questions [53].

The interview results were analyzed using text mining to understand the messages' internal structures and complex meanings as well as to better comprehend individual experiences and situations on construction sites. R-studio was used to text mine. Text mining reduces bias caused by researcher's subjectivity compared to manual content analysis or thematic analysis. Manual analysis is susceptible to the personal preferences, interpretations, and inferences of the researcher, whereas text mining results are based on algorithms, thus overcoming the reliability weaknesses of content analysis [54–56]. Using the word frequency of interview content, we assigned additional weights to analyze the responses of construction site managers during COVID-19 in the ROK [57].

Regarding text mining, the objective of the qualitative analysis was to strengthen codification. Personal bias was ruled out before data coding to enhance the reliability and validity of the study. A total of three researchers conducted this investigation using identical coding components [47,58]. Moreover, Cohen's kappa statistics were measured to evaluate the interrater reliability. In this study, Cohen's kappa was 0.69 for all variables at 95% confidence intervals (with a standard deviation of 0.126). Notably, values between 0.61 and 0.80 indicate high agreement among the evaluated data [58].

Experts analyzed this process using an audit trail to obtain the results [59]. For pre-processing the interview data, we conducted stopword removal and selected major keywords. Typical stopwords are prepositions such as "in", "to", and "on". Verbs such as "be", "have", "do", "take", and "happen" were excluded due to repetition in other types of interviews. Synonyms and related words were also organized as much as possible [55,56]. Subsequently, word frequency was determined and counted numerically to identify the words and factors valued by the respondents. Bar-Hillel proposed this method as a measure of word importance, and word frequency studies are common in engaging document analysis [60–62]. The text is coded or broken down into categories, such as words, word sense, phrases, sentences, or themes, to conduct content analysis. However, word frequency is extensively used in interview analysis to determine themes (focus areas) and their relative frequency [62]. Thus, through word analysis, essential words were identified from the

interview content, and the weight importance of the words in each document was derived using the term frequency-inverse document frequency (TF-IDF). TF-IDF is obtained by multiplying term frequency (TF) with inverse document frequency (IDF). Compared to text mining methods that focus only on the number of repetitions of a keyword, the TF-IDF method can derive the importance of a keyword by comparing the number of repetitions of a keyword in a text with the number of repetitions of that keyword in a large set of documents [63]. For example, one word mentioned jointly by 15 field managers may be considered more important than 15 words repeated in the interview transcripts of a single field manager. It is viewed as an essential index for determining the importance of documents [53,64].

TF is obtained via Equation (2). It indicates the frequency of a particular word in a single document. If the TF value is high, it is considered important within the document [65].

$$\text{TF} = \frac{\text{The number of times a particular term appears in a document}}{\text{The document's total words}} \quad (2)$$

DF indicates the frequency of documents wherein a particular word appears, and IDF can be used to confirm the importance of a word within a document group. A higher DF or lower IDF value reduces the word's importance. Equation (3) expresses the relationship between DF and IDF.

$$\text{IDF} = \frac{1}{\text{DF}} = \log\left(\frac{\text{N}}{\text{DF}}\right) \quad (3)$$

Thus, the more a word occurs in documents, the more the TF-IDF increases, which is critical [64]. Consequently, the interview's main keywords can be to understand the impact of COVID-19 on construction sites. The method of calculating the weight importance is shown in Equation (4) [66].

$$\text{TF} - \text{IDF} = \text{TF} \times \frac{1}{\text{DF}} \text{ or } \text{TF} \times \log\left(\frac{\text{N}}{\text{DF}}\right) \quad (4)$$

Through a centrality analysis, the magnitude of a particular word's relative influence in an entire document, as well as the role of a particular word in the relationship among words, can be understood [67]. Therefore, each centrality was summarized and normalized to show the relationship among keywords to capture the changes in sites caused by COVID-19 and reflect the node's importance. The index values of degree centrality, closeness centrality, and eigenvector centrality were applied in this study. Degree centrality yields the sum of directly connected nodes and measures the number of direct contacts to determine a node's level of connectivity. Closeness centrality measures the sum of distances of directly and indirectly connected nodes, showing how frequently the central words appear simultaneously. Finally, eigenvector centrality measures the closeness of a node to well-linked nodes that show the keywords in the interview content [68]. A network analysis using word frequency and adjusted eigenvector centrality values was conducted to organize this information.

4. Results

4.1. Formatting Mathematical Components

Table 6 presents the analysis of the impact of COVID-19 on construction sites in the ROK. The RII was derived using survey data. Because the use of mean and standard deviation has limitations in providing a comprehensive and objective assessment, the RII method, which represents the importance of various influencing factors, was employed to complement it [49].

Due to the sudden increase in COVID-19 cases, construction sites frequently experienced workforce shortages. Consequently, collaboration was challenging, with remote communication being the only option during a two-week self-isolation period. Additionally, based on construction site managers' experience, significant labor-related issues, such as decreased work speed and workforce shortages, existed due to program interruptions.

Furthermore, self-isolation and remote work occurred frequently, drastically declining productivity due to work pattern changes. Thus, labor-intensive construction sites suffered severe damage due to pandemic-related labor issues.

Table 6. RII analysis results.

Group	Category	Factor	Mean	Standard Deviation	RII	Rank
Workforce	Workforce shortage	Decrease in work rates	3.781	0.926	0.756	4
		Workforce shortage due to project suspensions and the virus spread	3.672	0.969	0.734	5
		The sudden outbreak of confirmed cases	3.891	0.903	0.778	1
	Low worker productivity	Infected workers' self-quarantine	3.609	1.070	0.722	7
		Supervising telecommuting	3.547	1.045	0.709	10
		Difficulties in collaboration	3.844	0.833	0.769	2
Management	Site management	Site monitoring	3.578	0.880	0.716	9
		Lack of client support for new technology	2.938	0.788	0.588	21
		Creating new plans as the situation changes	3.391	0.822	0.678	12
	Project suspensions	Increased rules and restrictions from the government	3.516	0.661	0.703	11
		Project delays due to orders from headquarters	2.578	0.981	0.516	24
		Delays in inspections and securing permits	3.234	0.897	0.647	16
		Reduced number of public projects and foreign investment	2.484	1.075	0.497	25
	Contractual and legal	Additional contractual, legal, and insurance aspects	2.797	0.955	0.559	22
		Inability to secure contracts	2.703	0.979	0.541	23
Hygiene and safety	Site safety	Excessive action due to virus concerns	3.609	0.721	0.722	7
		Restriction of outsider access	3.844	0.814	0.769	2
	Hygiene	Disinfection measures	3.281	0.960	0.656	14
		Quarantine equipment	3.219	0.819	0.644	18
	Technology deployment costs	High technology costs	3.156	0.870	0.631	19
Economic	Disrupted supply chains	Material cost increase	3.672	0.811	0.734	5
		Supply chain suspension due to subcontractors and material shortages	3.234	1.027	0.647	16
	Revenue loss	Short-term impact of revenue loss	3.359	0.855	0.672	13
		Excess costs due to economic downturns and project suspension	3.047	0.926	0.609	20
		Payment delays, additional cost payments	3.250	0.791	0.650	15

Construction sites also experienced severe safety issues. Outsiders were restricted from accessing sites, and hygiene and safety regulations and protocols were constantly changing due to virus-related concerns. These extreme measures caused difficulties in site management. The government could not decide on effective countermeasures in the face of the rapidly spreading pandemic, causing delays in decision-making and disruptions in work progress by prohibiting the entry of external personnel and workers. Access to hygiene and safety measures was also limited, making preparing for additional precautions against infectious diseases challenging. Moreover, regarding cost, COVID-19 caused disruptions in the supply of materials from overseas, forcing Korean construction sites to rely on relatively expensive domestic materials, resulting in financial difficulties. However, the reduction in foreign investment did not cause significant economic problems, and cost overruns due to project suspensions were rare.

Due to the sudden onset of the pandemic, managers emphasized site monitoring, which had a limited impact on contract and legal management. Further, the adoption of new technologies was not encouraged. Introducing new technology early can efficiently gain client support and reduce initial costs. However, technologies such as unmanned drones or virtual reality were not adopted while maintaining the existing response methods. Additionally, COVID-19 had a minor impact on Korean construction companies, state-owned enterprises, and foreign investments.

4.2. Qualitative Analysis of Construction Site Manager Responses

4.2.1. Word Frequency Analysis

The interview content was analyzed using word frequency analysis. As shown in Figure 2, the word that appeared the most was "none" (94 times), implying that there were no response methods on construction sites. Traditional methods were used instead of new technologies, education, etc.

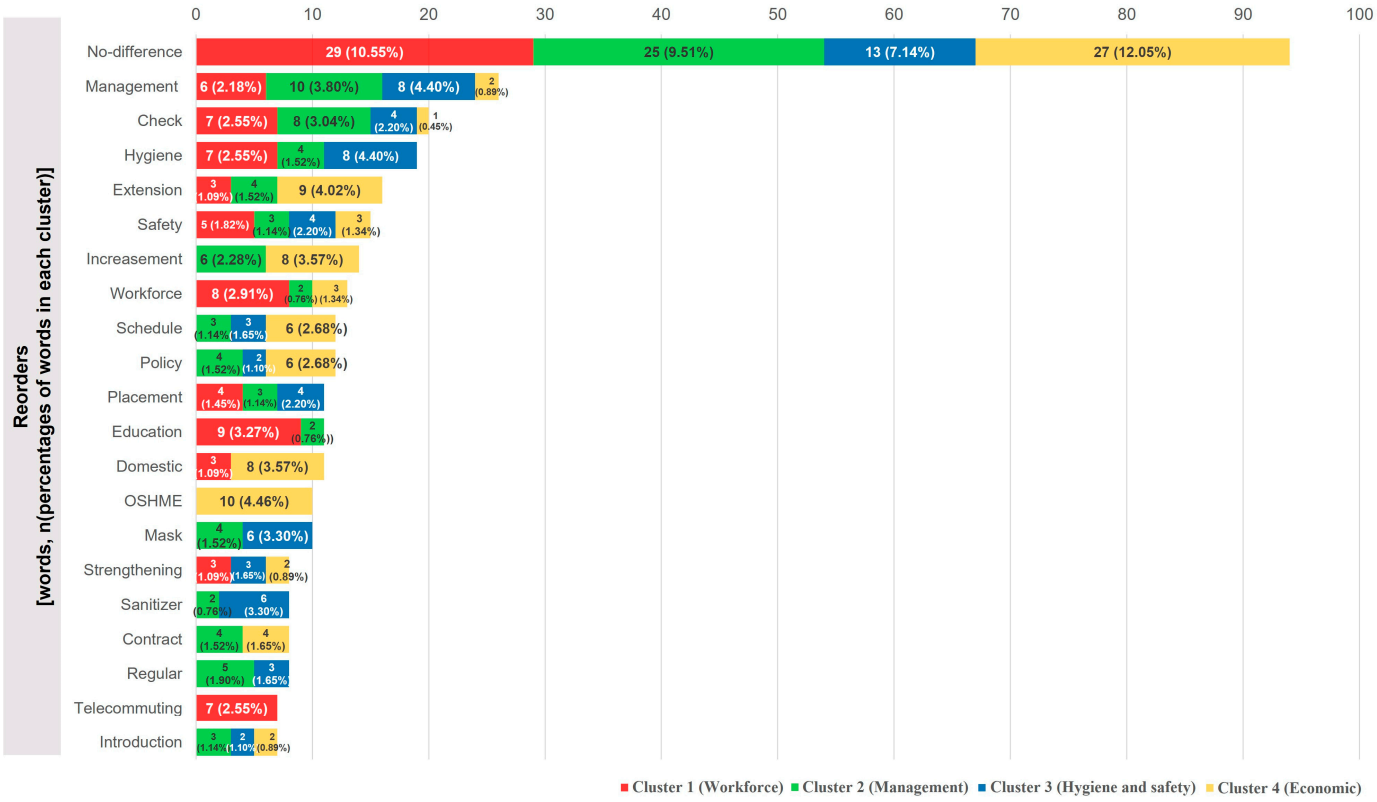

Figure 2. Word frequency results based on interview content analysis.

Nevertheless, the continuous checking and managing of sites received considerable attention. Regarding the labor force, interest in telecommuting and education increased, particularly in worker hygiene education. In addition, regarding management, the emphasis on regular management grew as the government distributed various policies, and on-site inspections and check-ups were strictly enforced. Furthermore, management intensity strengthened as vigilance intensified due to the Severe Disaster Punishment Act. Moreover, hygiene management and disinfection were continuously implemented, and schedule extensions and costs increased. In addition, utilization of the occupational safety and health management expense (OSHME) increased, and economic compensation was provided for conducting material procurement and establishing contracts within the ROK.

4.2.2. TF-IDF Analysis

The frequency of words, IDF, which is the reciprocal of the frequency in the document, was obtained. The TF-IDF was analyzed for each cluster, and the factors managers rated the most were identified. However, because many parts were unrelated, tokenized words, excluding stop words, were analyzed to comprehensively investigate the countermeasures. The results are shown in Figure 3.

Using the theoretical framework presented in Table A2, the categorization results of semi-structured interviews with 15 construction site managers in ROK lasting 45 to 60 min are shown in Figure 3. Using the TF-IDF analysis method, the keywords deemed important by the 15 site managers were identified, and the explanations of the keywords

reflected the responses they applied to construction sites and the challenges they faced during COVID-19.

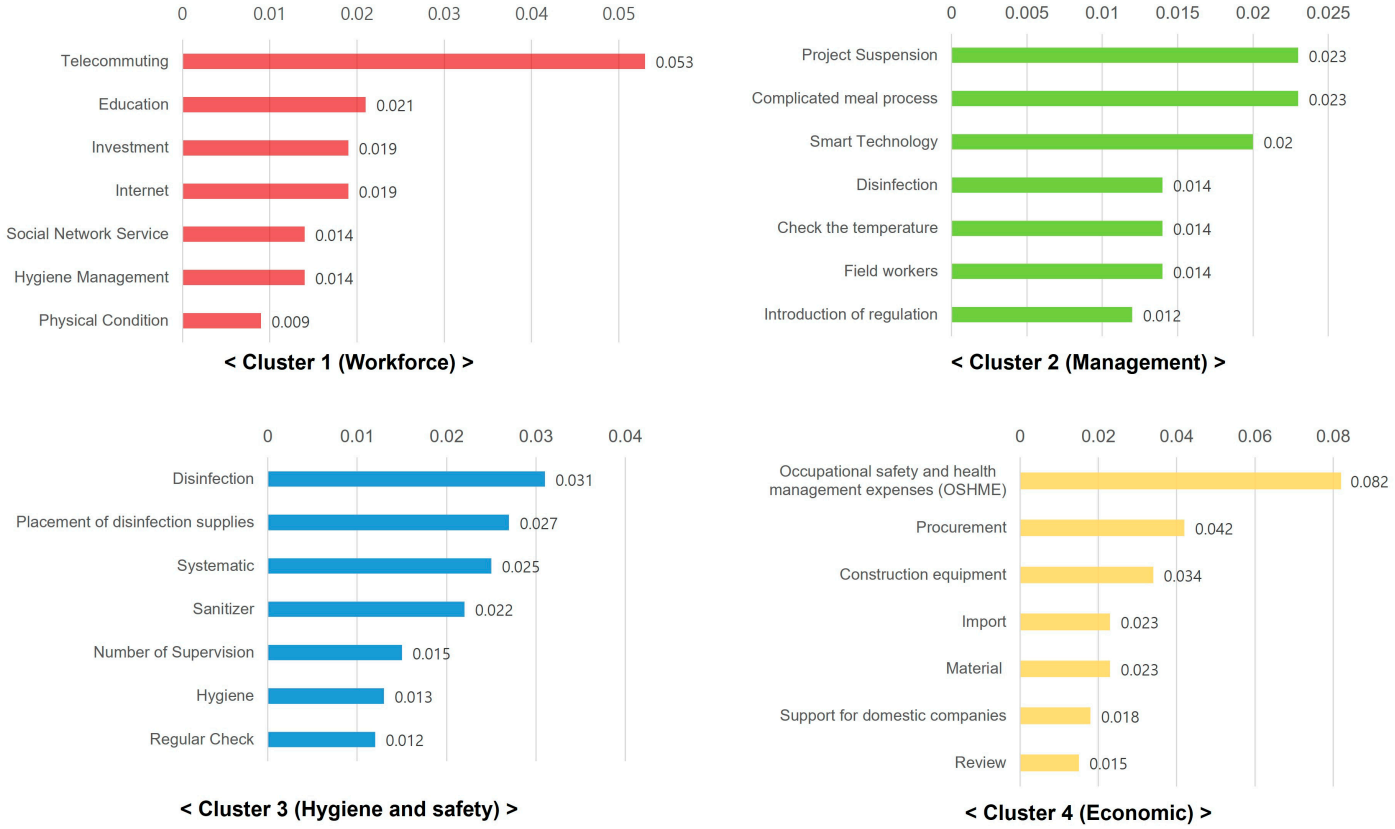

Figure 3. Results of TF-IDF from analyzing the interview content.

Telecommuting was the most frequently mentioned keyword concerning the labor force. The analysis indicated that telecommuting increased, and hygiene-related education programs were conducted. Furthermore, meetings and collaborations were held using the Internet and social network services (SNS).

Discontinuation was the biggest issue regarding management methods. In addition, because the most common time to remove a mask was when eating, on-site restaurants often continued to operate efficiently. Efforts were made to implement various smart management technologies, and sites were managed through continuous disinfection and temperature checks. Regarding hygiene safety, disinfection and maintenance of disinfectants were emphasized, and, instead of the traditional method, inspections were conducted more frequently.

From an economic perspective, the use of OSHME was a critical factor. Consequently, the transparency of cost usage was emphasized after COVID-19, imposed on site managers by headquarters. The most significant economic issues involved procurement. Substantial foreign materials were used; thus, starting a project on time was difficult, and sending materials overseas presented many challenges. Therefore, various solutions to economic issues, such as reviewing support from domestic companies, were proposed.

4.2.3. Identification of Centrality and Network Analysis Results

Network analysis was conducted using the words appearing in each cluster. Based on the top ten words in each centrality, connection degree centrality, closeness centrality, and eigenvector centrality were compared, analyzed, and summarized in Table 7. Consequently, regarding the labor force, the connection center of SNS, which aids in management, communication, and telecommuting, was high. Furthermore, the number of meetings related to the eigenvector

was high. To communicate with more telecommuters and self-quarantined people, SNS was increasingly used for Virtual meetings. Regarding management, the most reflected aspect was the continuous management of conducting regular checks and ensuring the on-site use of masks and disinfectants. Despite constant engineering, staffing, and contract management, there was a difference when it came to the eigenvector. However, the analysis was more focused when relating to personnel shortage and access inspection, and management capabilities were increased by installing sensors and thermometers. This is similar to the analysis of the results related to hygiene practices. The highest degree of centrality was related to regularity; however, hand sanitizer and regularity showed the highest degree related to eigenvectors. Thus, hand sanitizers and regular checks were critical for hygiene. After the pandemic, hygiene-based education and system reorganization were the most important aspects of the construction site response.

Finally, regarding the economy, the most critical way to save costs involves reviewing existing contracts and laws. A detailed repayment and profitability analysis was used to determine compensation. Due to policy changes related to social distancing, economic profitability was affected, and the use of the OSHME was high. Moreover, because of the inability to import materials from abroad, design and construction changes were made regularly, so support for domestic companies was a core part of material procurement.

Table 7. The results of connection centrality.

Group	Words	Degree Centrality	Closeness Centrality	Eigenvector Centrality
Cluster 1 (Workforce)	Management	72	0.0278	1
	SNS	44	0.02	0.781
	Communication	30	0.0175	0.452
	Conference	30	0.0175	0.595
	Check	26	0.0169	0.454
	Staffing	24	0.0167	0.453
	Isolation	24	0.0167	0.438
	Environment	18	0.0159	0.447
	Telecommuting	18	0.0159	0.447
	Cooperation	18	0.0159	0.447
	Smartphone	12	0.0127	0.369
	Negotiation	12	0.0127	0.369
Cluster 2 (Management)	Regular	76	0.0263	1
	Check	50	0.0196	0.703
	Mask	38	0.0175	0.613
	Sanitizer	30	0.0164	0.4
	Interruption	24	0.0156	0.395
	Staffing	24	0.0156	0.395
	Contract	22	0.0154	0.352
	Shortage	22	0.0154	0.352
	Ordering company	22	0.0154	0.352
	Increase	22	0.0154	0.352
	Recognize	22	0.0154	0.352

Table 7. *Cont.*

Group	Words	Degree Centrality	Closeness Centrality	Eigenvector Centrality
Cluster 3 (Hygiene and safety)	Regular	33	0.0789	1
	System	31	0.068	0.99
	Education	31	0.0672	0.94
	Check	30	0.0667	0.703
	Sanitizer	30	0.0667	0.703
	Disinfection	30	0.0667	0.703
	Temperature	30	0.0667	0.703
	Always	24	0.0548	0.535
	Enforce	23	0.0532	0.535
	Hygiene	22	0.0526	0.789
Cluster 4 (Economic)	Transparent	18	0.111	1
	Design	8	0.0714	0.675
	Change	8	0.0714	0.675
	Occupational Safety and Health Management Expenses (OSHME)	8	0.0714	0.675
	Policy	8	0.0714	0.675
	Contract	6	0.0667	0.403
	Extension	6	0.0667	0.403
	Equipment	4	0.0625	0.287
	Support for domestic companies	4	0.0625	0.287

Network analysis was performed using eigenvector centrality and co-occurrence word values to comprehend semantic associations, which quantify relevance by evaluating the weight of each node, as shown in Figure 4. Thus, the relationship between the COVID-19 response mechanism and Korean construction sites can be comprehended. On construction sites, regular management, systems, and transparent cost consumption were considered significant countermeasures, particularly in the hygiene and safety categories. Moreover, field managers overcame workforce issues by increasing telecommuting using new technologies, such as social networking sites. The approach to education and communication has evolved and has been highlighted as highly significant in routine management and disinfection. After COVID-19, construction sites overcame workforce shortages through diverse education, continuous communication, telecommuting, and systematically managed access to masks, disinfectants, and sanitization, showing the relationship among these words.

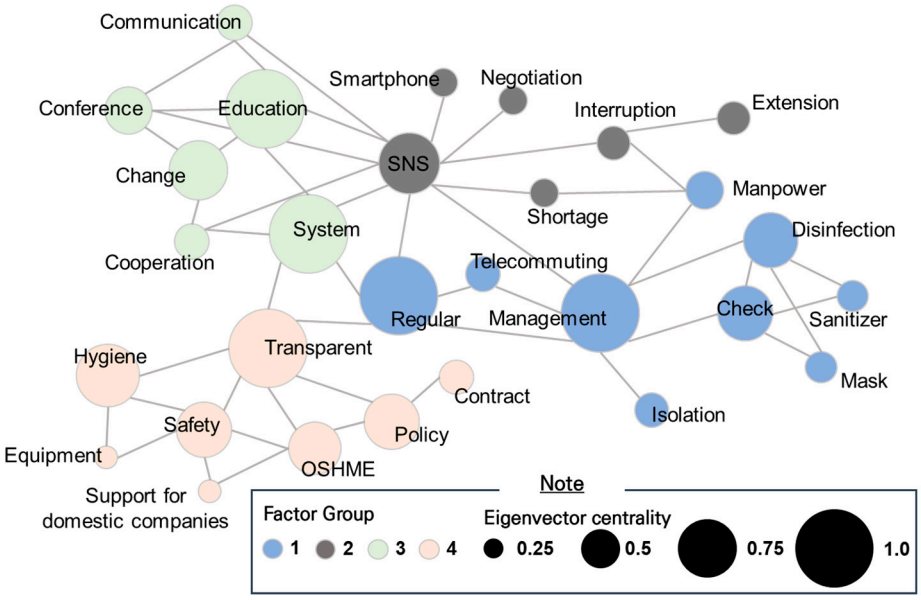

Figure 4. Network analysis results on construction site COVID-19 countermeasures in the ROK.

5. Discussion

5.1. Contribution of Research

According to the quantitative and qualitative results, the pandemic affected construction sites in the ROK, as shown in Figure 5. The effects most prevalent on Korean construction sites could be determined using the four large clusters revealed through a thorough literature analysis. The figure also shows the appropriate response method for each cluster.

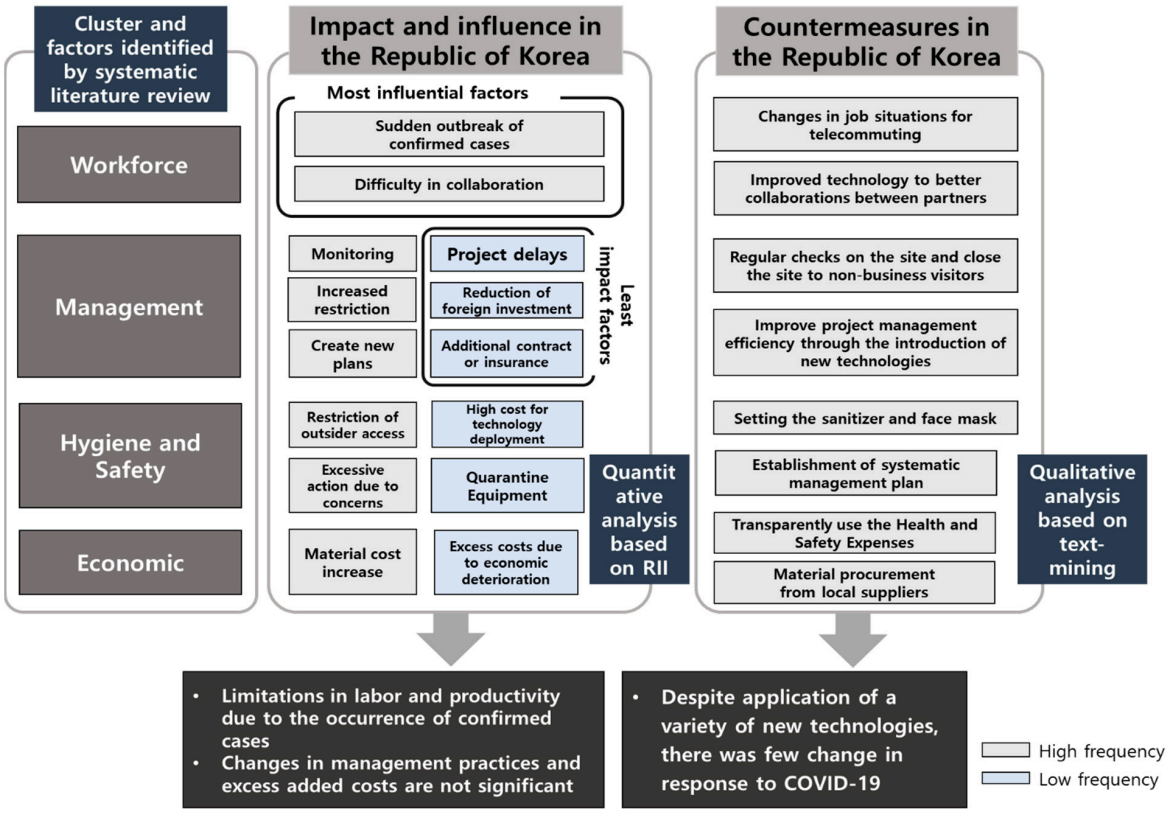

Figure 5. Schematic of integrated results based on quantitative and qualitative analysis.

During COVID-19, labor force issues were the most significant challenge at construction sites in the ROK, followed by productivity issues caused by sudden confirmed cases and collaboration difficulties. Moving a project forward was especially challenging due to the sudden onset of the pandemic, which delayed decision-making and made on-site work difficult. Because sites did not enforce compulsory lockdowns, less communication decreased work efficiency. Moreover, complications arose due to limited experience with telecommuting systems and difficulty dividing tasks. Additionally, the ever-changing regulations and standards regarding hygiene and safety created complications. Because of the emergence of several new protocols, proper guidance was required when implementing regulations [30]. In particular, determining who was granted access to sites and enforcing hygiene and safety was challenging. Consequently, decision-making and communication were restricted, necessitating additional time for negotiation and discussion. Furthermore, economic challenges existed due to increased market volatility. The impact of the pandemic on the ROK was essentially managed in the field, and numerous financial and project management challenges arose for those who performed traditional face-to-face tasks. Similarly, the Korean government has yet to develop an innovative method for field-based project management. The countermeasure analysis results among Korean construction sites imply that, despite various measures, such as social distancing and restricting business hours, no significant changes were observed, as the most frequently mentioned word was "none".

In contrast, as the pandemic burdened various industries, underdeveloped nations without self-sustenance have frequently developed local enterprises due to a lack of foreign investment [28]. For example, Iraq has been severely affected by the pandemic in terms of safety and risk management on construction sites [12]. Furthermore, a study conducted on construction sites in South Africa revealed that project delays and employment issues have long-term implications, with potential impacts such as loss in revenue, economic downturns, and business disruptions [11]. However, the interview results revealed that no significant changes had occurred in the ROK due to suspending or reducing overseas investments. This was a positive conclusion, considering the ROK, as an OECD member, could proceed with projects at its own expense. In addition, most developing countries implemented comprehensive entry and exit controls to contain the spread of the virus. Consequently, this led to a complete halt in business operations at construction sites and offices, resulting in significant economic losses [11,69]. The ROK had no enforced lockdown measures, and the construction sites and offices were consistently operated remotely. While there were issues such as decreased productivity, project disruptions due to the pandemic were rare.

Therefore, the keyword derived from the interviews was "none", indicating that although the Korean construction site's response plan was inadequate, there was no serious economic loss or health crisis due to COVID-19. This suggests that Korea responded effectively compared to countries that experienced severe economic crises owing to COVID-19. Korean construction sites demonstrated the ability to adapt to the pandemic through remote operations and changes in working methods without imposing full lockdowns. Additionally, pandemic management strategies helped in achieving a balance between maintaining economic activity and controlling the spread of the virus. Amidst a global decline in foreign investment, Korean construction sites demonstrated the resilience and self-sufficiency of the domestic economy with their ability to continue operating. Meanwhile, the response of Korean construction sites in the face of changing health and safety regulations can contribute to the development of more effective health and safety management practices. In addition, the Korean response during the COVID-19 pandemic has an important global reference value, suggesting that the Korean construction industry is resistant and resilient to risks. This study identified issues through the systematic investigation of Korean construction sites during the COVID-19 pandemic, which can provide effective references and ideas for the development of the construction industry not only in ROK but also globally in the post-pandemic period. Furthermore, given that construction sites are high-risk environments by nature [9], the Korean experience can provide a framework for

other countries to refer to when faced with similar public health crises, particularly on how to manage economic activity and health risks without imposing full-scale lockdowns.

5.2. Practical Analysis

The further analysis of the research findings revealed that compared to the current conventional management strategy, implementing telecommuting in the field can be greatly beneficial, even beyond the pandemic. However, practical restrictions still exist regarding collaboration, and the unexpected absence of managers may cause complications. Therefore, communication tools that facilitate collaboration must be designed. Because staffing challenges could be overwhelming if a similar pandemic occurs, the active introduction of 3D scanners and robotic technologies to replace humans must be considered to overcome a lack of access to external personnel and extreme measures in staffing input [5]. Because project meetings and management are conducted from home, efficiency must be enhanced by reviewing construction stages and identifying material supply and demand based on BIM beyond the nominal use of 3D models [9,32].

Additionally, a positive effect was observed after the pandemic. Construction site costs did not increase during the pandemic because projects were not halted. The OSHME fund, which had previously been utilized sparingly in the ROK, was now used intensely, and the ratio of calculations expanded in comparison with those of previous ones [47]. Safety education is vital to increase the utilization of these funds, and psychological care for infected individuals must be provided while maintaining patients' employment stability [42,47]. Moreover, from the perspective of construction site managers, policies were established to ease additional spending related to COVID-19.

The findings of this study were derived by methodically assessing a framework for analyzing the impact and countermeasures of COVID-19. Based on this framework, the COVID-19 construction site challenges were classified under workforce, management, hygiene and safety, and economic damage. Investigating the impacts on Korean construction sites based on the framework factors revealed workforce decline, collaboration difficulties, and site management issues due to increased material costs and excessive health and safety regulations. In contrast, project delays and a lack of foreign investment were minimal, and only a few objections to adopting modern management technology and hygiene equipment expenses were observed. Consequently, newly adopted smart technology, such as 3D scanners, drones, or 3D models, will likely increase digital collaboration and support the development of new systems for site management. Additionally, the transparent application of previously veiled health and safety-related expenditures can create an environment in which construction costs can be utilized more efficiently and practically. Despite similar viral diseases that may emerge, construction sites may be able to operate continuously by applying a developed framework without compulsory lockdowns. Moreover, by implementing a similar approach, conducting practical and versatile analysis by country to understand cultural differences and highlight countermeasures in labor-intensive industries is possible.

In the post-pandemic period, governments around the world have established a series of policies and projects to promote digital transformation to solve the problems caused by COVID-19 and promote recovery. Countries, such as the United States, China, Germany, Japan, and the United Kingdom, have established digital industrial transformation policies to transform economic structures, create jobs, and enhance industrial competitiveness, and the construction industry has been particularly targeted to benefit from Artificial Intelligence (AI) and digital transformation policies [13]. These policies are in line with the Sustainable Development Goal (SDG) 8, which is to achieve sustainable economic growth and decent work and employment security, as well as Goal 9, which is to build infrastructure and promote sustainable industrialization, and these are in line with the measures proposed to complement the problems identified in this study [70]. This study is significant not only for identifying the deficiencies in the construction industry during COVID-19 through a systematic framework but also for providing a reference for the

Korean government to facilitate the transition to smart construction sites by suggesting new development directions. The results of this study can help in providing government guidelines and countermeasures to prevent similar viral diseases that may occur in the future, as well as ensure that construction sites can be operated continuously without forced closure based on the developed framework [71]. In addition, the framework developed through a systematic theoretical review provides solutions that can be applied in developing countries to improve the safety and productivity of construction sites in these countries. Therefore, the methodology presented in this study can be adopted to conduct practical cross-country analysis, understand cultural differences, and develop customized responses for construction-intensive industries. This is important not only for situations, such as COVID-19, but also for addressing sudden health and safety risk situations.

6. Conclusions

The sudden onset of the pandemic caused global chaos and adverse effects, particularly in labor-intensive construction sites. As a result, pandemic prevention measures, such as self-isolation and site control, were implemented at these sites. These measures led to issues such as construction project delays, with such trends expected to continue for the foreseeable future. Furthermore, the pandemic's impacts and associated response strategies varied depending on each country's governance. Therefore, this study developed a framework through theoretical considerations by systematically examining these effects and the related response measures in different countries. This framework classified the factors affecting construction sites into four clusters: workforce, management, hygiene and safety, and economic. Within these clusters, 24 impact factors and 18 response measures were derived. Based on this study's framework, a quantitative and qualitative analysis was conducted by surveying and interviewing managers of construction sites during the pandemic. An RII analysis was used to assess the direct and potential impacts of the pandemic on construction sites, and a qualitative analysis based on text-mining was performed on the interview results to propose customized response measures for the ROK. As a result, the framework presented in this study was developed with the specific circumstances of each country in mind, allowing for its application across various situations beyond a single nation.

Construction sites in the ROK faced challenges such as sudden outbreaks of confirmed cases, decreased productivity due to collaboration difficulties, increased material costs, economic losses due to restrictions to external access, and the importance of hygiene management. Additionally, cases of investment reduction or business discontinuation were rare in the ROK, with damages primarily related to legal losses due to insufficient measures to address issues such as unsecured contracts and inadequate compensation systems. The interview results, which were conducted to understand the response to these circumstances, indicated no significant difference between the pre- and post-COVID-19 situations. In other words, although the industrial landscape changed due to COVID-19, the construction sites in the ROK largely adhered to their existing practices without major alterations. However, there was an increase in remote work, regular inspections, and education for workers. Additionally, an expanded response scope was observed regarding the transparent and accurate application of industrial safety and health management standards. In summary, the construction industry in the ROK, a labor-intensive sector with a conservative approach to adopting new technologies, was impacted in various ways during the pandemic. However, appropriate responses were lacking. Therefore, policies and institutional measures must be established to enhance sites' responses by addressing these issues.

This study established approaches to address similar future pandemic scenarios by evaluating the impacts and countermeasures in the ordinarily conservative construction industry, which had been slow to adopt new technologies and is labor-intensive; therefore, it offers a unique research opportunity [2,40]. Moreover, the study presents a novel framework for analyzing these scenarios. However, it should be noted that the proposed

framework may not directly apply to analyzing situations in other countries, and comparisons with situations in other countries were limited. As a result, this study presents an academic framework for establishing how to manage construction sites in the future. By addressing the limitations of this study, future studies can help develop national plans. Moreover, companies cannot take the initiative given that the nature of the issue lies within the scope of national governance management. Therefore, the results of this systematic and complex study are expected to extend the scope of the Korean construction industry and usher in a new paradigm.

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Appendix A

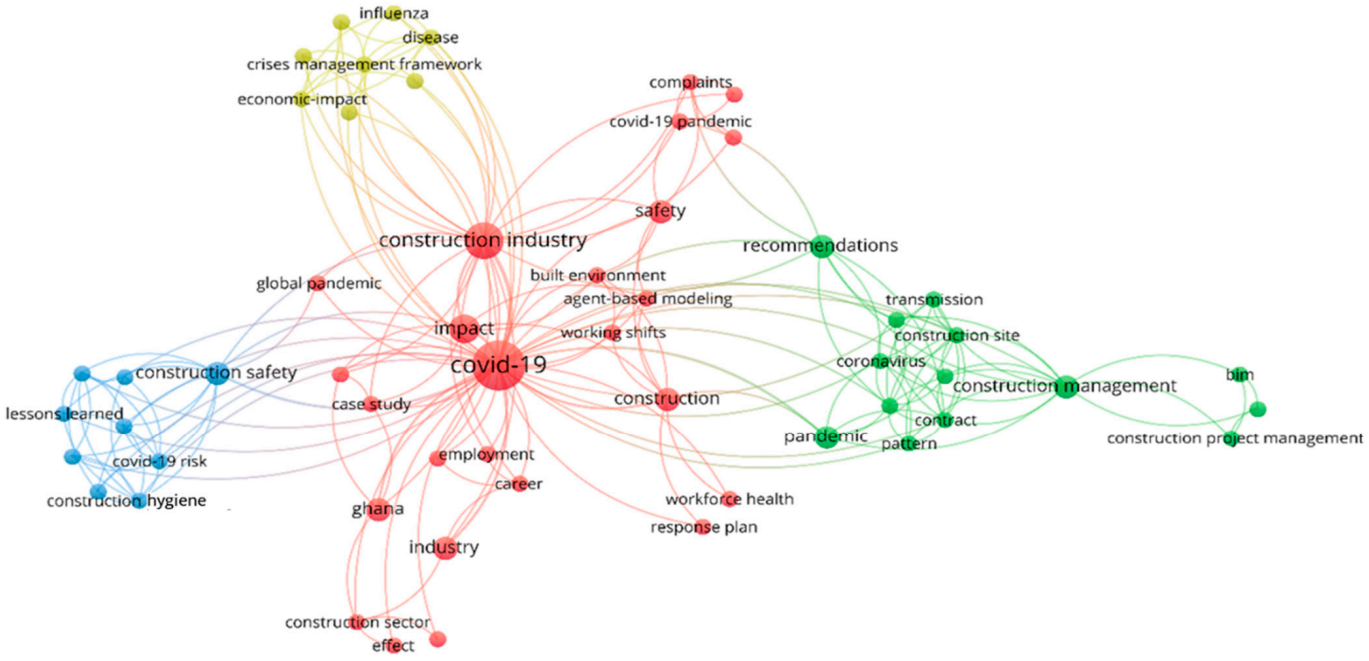

Figure A1. VOSviewer-based keyword analysis.

Table A1. Framework for identifying impacts on construction sites.

Impacts		Factors with Descriptions	Reference	Questionnaire (Closed Question)
Workforce	Workforce shortage	Decrease in work rates	Agyekum et al. [18]	Do you feel a substantial decrease in the work rate at the site?
		Workforce shortage due to suspended projects and the spreading of the virus	Bou Hatoum et al.; Assaad and El-adaway; Esa et al.; Bell et al.; Ekanayake et al.; Leontie et al. [21–23,28,29,32]	How often have you experienced a program being interrupted or understaffed due to the pandemic?
		The sudden outbreak of confirmed cases	Amoah et al. [8]	How often have you experienced difficulties due to the sudden occurrence of confirmed cases?
	Low worker productivity	Infected workers' self-quarantine	King et al.; Esa et al.; Bou Hatoum et al. [23,29,31]	How often have you experienced difficulties of managing sites due to self-isolation?
		Supervising telecommuting	Amoah et al.; Alsharef et al. [8,14]	Have you experienced inconveniences due to managing telecommuters?
		Collaboration difficulties	Alsharef et al.; Amoah et al.; Orzel and Wolniak [8,14,36]	Have you experienced a decrease in the efficiency and productivity ratio at the construction site due to collaboration difficulties?
Management	Site management	Site monitoring	Amoah et al. [8]	Have you experienced increased monitoring difficulties while supervising sites?
		Lack of client support for presenting new technology	Yang et al. [43]	Have you experienced considerable difficulties communicating with clients due to a lack of familiarity with new technologies?
		Creating new plans as the situation changes	Salami et al. [40]	Have you experienced setting up a new progress schedule due to the number of confirmed cases or social distancing?
	Project suspensions	Increased government rules and restrictions	Bell et al.; Onubi et al.; Cheshmehzangi; Leontie et al.; Stride et al.; Bsisu; Esa et al. [1,3,22,24,25,29,32]	How often have you experienced difficulties with limited management practices in your country? (Social distancing, etc.)
		Project delays due to orders from headquarters	Bou Hatoum et al. [23]	Have you had difficulties starting a project because it was interrupted or postponed by an order from the head office?
		Delays in inspections and securing permits	Alsharef et al.; Al-Mhdawi et al. [12,14]	How many times have you experienced business interruptions or delays caused by commands from headquarters?
		Reduced public projects and foreign investment	Alsharef et al.; King et al.; Ogunnusi et al. [14,31,34]	Have you experienced difficulties due to a lack of foreign investment or orders?
	Contractual and legal	Additional contractual, legal, and insurance aspects	Assaad and El-adaway; Orzeł and Wolniak [21,36]	How difficult is it to conduct business due to the additional laws and insurance regulations?
		Unable to secure contracts	Amoah et al. [8]	Do you often struggle to obtain additional contracts?

Table A1. *Cont.*

Impacts		Factors with Descriptions	Reference	Questionnaire (Closed Question)
Hygiene and safety	Site safety	Excessive action due to virus concerns	Bou Hatoum et al. [23]	How often have you experienced work inconveniences due to concerns regarding the spread of the virus while conducting on-site management?
		Restriction of outsider access	Raoufi and Fayey [37]	Have you ever felt uncomfortable with prohibiting outsiders from accessing the site?
	Hygiene	Disinfection measures	Raoufi and Fayey; Assaad and El-adaway [21,37]	Have you experienced difficulties implementing quarantine measures like machine and on-site disinfection?
		Quarantine equipment	Agyekum et al. [18]	Have you experienced difficulties due to the installation of quarantine facilities like heat detection cameras?
Economic	Added technology deployment costs	High technology costs	Yang et al. [43]	How many new quarantine-related technologies have you used that resulted in additional costs?
	Disrupted supply chains	Increase in material costs	Agyekum et al.; Al-Mhdawi et al.; Esa et al. [12,18,29]	How difficult is the rising cost of materials due to closed borders or trade challenges?
		Supply chain suspension due to subcontractors and material shortages	Agyekim et al.; Assaad and El-adaway; King et al.; Esa et al.; Ling et al.; Alsharef et al.; Bou Hatoum et al. [7,14,18,21,23,29,31]	How often have you experienced a business interruption due to a lack of material supplies caused by interruptions in the supply chain of subcontractors and materials on site?
	Revenue loss	The short-term impact of revenue loss	Aigbavboa et al. [11]	Have you experienced a significant loss of revenue on-site?
		Excess costs due to economic deterioration and project suspension	Bou Hatoum et al. [23]	Have you experienced economic downturns, cost overruns to recover from project disruption, or financial impacts?
		Payment delays, additional cost payments	Alsharef et al.; Agyekum et al. [14,18]	Have you experienced material price increases, payment delays, and additional payments?

Table A2. Framework to identify countermeasures at construction sites.

Countermeasures		Factors with Description	Related Impact Factors from Table A1	Reference	Interview Questions (Open Questions)
Workforce	Education	Educating the workforce to deal with the virus	Workforce shortages due to project suspensions; the spreading of the virus; the sudden outbreak of confirmed cases	Agyekum et al.; Jones et al.; Araya [10,18,19]	How have safety education methods for workers changed?
	Working from home	Changes in job situations due to telecommuting	Supervising telecommuting	Oo and Lim; Chih et al.; Orzeł and Wolniak; Ogunnusi et al. [26,34–36]	How are you responding to the changing environment, such as telecommuting?
		Improved technology to better collaborate between partners (innovative ways to communicate remotely)	Collaboration difficulties; decreased work rates	Alsharef et al.; Raoufi and Fayek [14,37]	What improved infrastructure have you provided to facilitate collaboration between telecommuters and the construction site? What are the challenges pertaining to site management?
	Self-quarantine care	Self-quarantine for workers who fall ill	Infected workers' self-quarantine	Salami et al.; Chih et al.; Orzeł and Wolniak; Ogunnusi et al. [26,34,36,40]	How do you manage the site when a worker is suddenly absent?
		Inform employees of possible virus exposure so they can quarantine	The sudden outbreak of confirmed cases; Infected workers' self-quarantine	Bou Hatoum et al. [23]	How do you manage self-quarantined workers?
		Management and progression of psychological care for workers	Infected workers' self-quarantine	Tong et al. [42]	How do you provide psychological care for full-time workers?
Management	Site management	Regular checks on the site and closing of the site to non-business visitors	Increased government rules and restrictions; site monitoring; restricting outsider access	Agyekum et al.; Stiles et al.; Yang et al.; Orzeł and Wolniak; [3,18,36,42]	How are you conducting on-site inspections and managing access?
		Cleaning spaces for common use	Restriction of outsider access	Pamidimukkala and Kermanshachi [44]	How are you inspecting on-site access?
		Regular monitoring of public health and government announcements	Delays in inspections and securing permits; additional contractual, legal and insurance aspects	Raoufi and Fayek; Onubi et al. [1,37]	How do you conduct regular hygiene and safety inspections in adherence to government guidelines?

Table A2. *Cont.*

Countermeasures		Factors with Description	Related Impact Factors from Table A1	Reference	Interview Questions (Open Questions)
Management	Innovation in Project Management	Managing other project risks	Unable to secure contracts, project delays due to orders from headquarters; the short-term impact of revenue loss	Aigbavboa et al. [11]	In addition to on-site health and hygiene, what risks were perceived after COVID-19?
		Plan rescheduling to reflect the impacts of COVID-19	Create new plans as the situation changes	Salami et al. [40]	If your project site is shut down unexpectedly, how would you handle situations like on-site labor costs and process changes?
		Improved project management efficiency through the introduction of new technologies (BIM, virtualization, simulation, AI)	Lack of client support for presenting new technology	Ling et al.; Baraibar et al.; Ebekozien and Aigbavboa; Ogunnusi et al.; Araya; Araya and Sierra; Nnaji et al.; [7,9,11,19,20,27,34]	What new technologies have you introduced to manage and increase efficiency?
Hygiene and safety	Hygiene protocols	Face shields, sanitizers, disinfectants, gloves, face masks, etc.	Quarantine equipment	Agyekum et al.; Salami et al. [18,40]	How do you install and manage hygiene protocols to improve hygiene?
		Introduction of new hygiene protocols, including site cleaning	Excessive action due to virus concerns	Salami et al.; Jagun et al.; Stride et al. [3,30,40]	How do things like cleaning change because of the new social distancing and sanitation laws?
	Establishment of new safety policies	New safety policies adopted in the construction industry	Excessive action due to virus concerns; additional contractual, legal, and insurance aspects	Aigbavboa et al. [11]	Were any new safety measures introduced?
Economic	Delivery of materials	Use of local suppliers rather than higher-risk international suppliers	Reduced number of public projects and foreign investment; supply chain suspension due to subcontractors and material shortages; increase in material costs	Raoufi and Fayek [37]	How are you handling project delays caused by delayed material delivery from overseas suppliers? Have you increased your contracts with domestic companies?

Table A2. *Cont.*

Countermeasures		Factors with Description	Related Impact Factors from Table A1	Reference	Interview Questions (Open Questions)
Economic	Contracts and insurance	Establish additional contractual, legal, and insurance aspects	Excess costs due to economic deterioration and project suspension; payment delays and additional cost payments	Assaad and El-adaway [21]	How are additional contracts, insurance-related items, or compensation negotiated?
	Additional costs due to installing new technology	Introduction of new technologies for hygiene and management, such as sensing devices and environmental sensors	High technology costs	Leontie et al.; Orzeł and Wolniak; Nnaji et al. (2022) [9,32,36]	How do you deal with the additional cost of introducing sensors?

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