Modelling the critical challenges of quality assurance of cross-border construction logistics and supply chain during the COVID-19 pandemic

Abstract
Purpose: The COVID-19 pandemic has impacted the construction industry, yet still, it is unclear from existing studies about the critical challenges imposed on quality assurance (QA), particularly Cross-border Construction Logistics and Supply Chain (Cb-CLSC). Thus, this study aims to identify and examine the critical challenges of QA of Cb-CLSC during the COVID-19 pandemic.

Methodology: The aim is achieved via an embedded mixed-method approach pragmatically involving a desk literature review and engaging 150 experts across the globe using expert surveys, and results confirmed by semi-structured interviews. The approach is based on Interpretive Structural Modelling (ISM) as its foundation.

Findings: The study revealed ten critical challenges of QA, with the top four including "the shortage of raw construction material (C7)", "design changes (C6)", "collaboration and communication difficulties (C1)" and "changes in work practices (C10)". However, examining the interrelationships among the critical challenges using ISM confirmed C7 and C10 as the most critical challenges. The study again revealed that the critical challenges are sensitive and capable of affecting themselves due to the nature of their interrelationship based on MICMAC analysis. Hence, being consistent with why all the challenges were considered critical amid the pandemic. Sentiment analysis revealed that the critical challenges have not been entirely negative but also positive by creating three areas of opportunities for improvement: technology adoption, worker management, and work process management. However, four areas of challenges in the QA include cost, raw material, time, and work process, including inspection, testing, auditing, communication, etc.

Practical implication: The finding provides a convenient point of reference to researchers, policymakers, practitioners, and decision-makers on formulating policies to enhance the effectiveness of construction QA during the pandemic through to the post-pandemic era.

Originality: The study enriches the extant literature on QA, Cb-CLSC, and the COVID-19 pandemic in the construction industry by identifying the critical challenges and examining the interrelationships among them. This provides a better understanding of how the construction QA has been affected by the pandemic and the opportunities created.

Keywords: COVID-19, Construction Quality Management, Critical challenges, Cross-border Construction Logistics and Supply Chain, Quality assurance

1 Introduction

Cross-border Construction Logistics and Supply Chain (Cb-CLSC) comprises interrelated activities and processes engaging contractors, suppliers, or vendors between economies where one performs construction services in the other economy (Mawhinney, 2008). Assuring the quality of projects, termed quality assurance (QA), is a critical tool for the success of projects under Cb-CLSC as it guarantees confidence in the projects to meet pre-stated quality standards and perform satisfactorily during the entire service life (International Organisation for Standardisation [ISO], 1994). This distinguishes QA from quality control, though the terms are occasionally used in tandem. QA is process-oriented and focuses on improving processes and methodologies to develop a quality project by engaging every member of an organisation toward defect avoidance. In contrast, quality control is product-oriented and focuses on improving end products by identifying and fixing defects, involving specific teams that test the products (ReQtest, 2016). Quality control may be an important aspect of

QA processes, where individual finished sub-works are examined and tested to verify quality before proceeding to the next sub-works (ASQ, 2015). However, by the very nature of involving two or more economies in Cb-CLSC, specific challenges do occur especially in the case of QA.

QA facilitates the improvements of quality processes and tailors the processes to ensure the client's requirements are met along with statutory and organisational requirements. With QA integrated fully into the construction processes in Cb-CLSC, it regulates the conduct of different processes and prevents side-stepping (Chung, 2002). Suppose any certain process is found deviating or with an error from the established procedure; the untoward event is reviewed by management, and a loophole is plugged in to prevent a recurrence. This depends on effective collaboration and communication with multiple stakeholders across all borders; hence, making QA a complex practice with concerns of being time-consuming; laborious, and prone to numerous human errors/mistakes.

The complexity of performing QA has worsened due to the coronavirus (COVID-19), which was introduced as a pandemic in March 2020 (World Health Organisation [WHO], 2020). Though COVID-19 mitigation measures have helped achieve steady recovery (Office for National Statistics [ONS], 2021), they have also impeded the movement between economies during QA, disrupting the construction supply chain. This is due to stringent mitigation measures, including social distancing, lockdown, travelling restrictions, and workplace limited capacity (Organization for Economic Co-operation and Development [OECD], 2020; Ghansah and Lu, 2023). This has affected the quality of work performed on construction sites toward the overall project quality. For example, relating the quality of construction products to construction output, the ONS (2021) recorded a fall of 12.5% in construction output in 2020 compared with 2019.

Academia, in partnership with the industry, has reported on the impact of COVID-19 on the construction industry from various perspectives, such as the general construction industry (Ogunnusi et al., 2020), the health and safety of the construction workforce (Pamidimukkala et al., 2021), and the use and adoption of digital technologies (Leontie et al., 2022). Other varied studies have been conducted in areas including health and safety management (Kum et al., 2023; Sadeh et al., 2023), construction performance (Gumusburun Ayalp and Civici, 2023), and construction supply chain management (Sutterby et al., 2023). Considering the challenges, how the pandemic and the associated mitigation measures have affected QA is still unclear. As such, Ghansah et al. (2023) explored the critical areas of QA and examined their sentiments amid the pandemic, considering Cb-CLSC. However, the unique critical challenges of the QA amid the pandemic have not been clearly identified, and this may be different across economies. Meanwhile, identifying these critical challenges can contribute to developing a resilience framework to adequately position the QA for the post-pandemic era and endure the risks of future pandemics.

This study, thus, aims to investigate the critical challenges of QA of Cb-CLSC amid the COVID-19 pandemic. The specific objectives are (1) to empirically identify the unique critical challenges of QA amid the pandemic, (2) to examine the complex interrelationships among the critical challenges and prioritise them, and (3) to understand the sentiment levels of the critical challenges. These are achieved by engaging experts across the globe via an embedded mixed-method approach using expert online surveys and semi-structured interviews. The approach is integrated with Interpretive Structural Modelling (ISM) as the kernel. The finding contributes to knowledge by identifying the critical challenges of QA amid the pandemic, their associated interrelations, and their sentiment level. This may guide researchers to further the QA in the construction industry. It may also assist the practitioners and policymakers in developing a resilience framework capable of positioning the QA adequately for the post-pandemic era and enduring the risks of future pandemics.

2 Research Method

This study pragmatically adopted the embedded mixed-method approach to achieve the related objectives via a pragmatic worldview using expert online surveys and semi-structured interviews. With this approach, qualitative and quantitative data are collected and analysed with the traditional quantitative research design (Creswell and Clark, 2017). This implies using qualitative data to complement and validate the results of the quantitative data. However, its weakness lies in being biased because it gives a preconceived mind on what the researcher expects from the qualitative data. Hence, the researcher may miss discoveries from the qualitative data. This approach has been adopted for construction management and engineering research in specific fields, such as housing needs evaluation (Ijasan and Ahmed, 2016). Overall, the embedded mixed-method approach for this study follows four main steps, as illustrated in Figure 1.

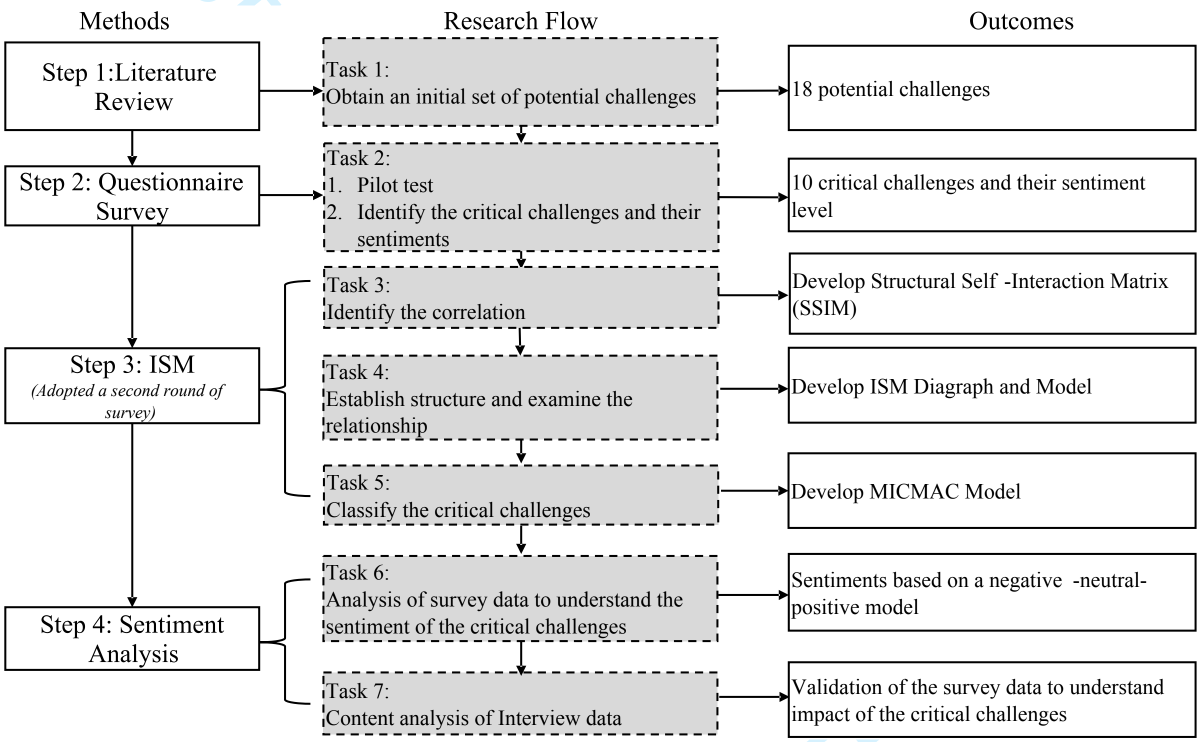

Figure 1: Research Flow (Source: Authors own work)

2.1 Preliminary Identification of Potential Challenges

A two-round literature search was conducted in this study. With the first round, specific keywords, such as “challenges”, “barriers”, “COVID-19”, “coronavirus*” (* denotes fuzzy search), “quality assurance”, “quality management”, “cross-border construction”, “logistics and supply chain” and other related terms were entered to find relevant literature in the Google Scholar database. However, only a limited number of studies were identified. In this preliminary research step, it is important to identify a list of potential challenges as possible. Thus, a second round of literature review was conducted to identify the possible challenges of QA during the COVID-19 pandemic. Keywords include “challenges”, “COVID-19*”, and “quality assurance in construction, logistics, and supply chain”. For a comprehensive literature search, in both rounds of literature search, the same keywords were used to collect relevant papers from different databases, including Web of Science, Scopus, Google Scholar, and Advanced Google. After the second round of literature search, the authors screened each of the collected papers and recorded the potential challenges described. This was also done through a critical evaluation of the challenges to align with the study’s context by taking inspiration from authentic and reliable web pages of organisations, such as the Centre for Disease Control and Prevention, International Labour Organisation, Occupation Safety and Health Act, etc. Based on frequency and factor diversification, 18 potential challenges of QA of Cb-CLSC during the COVID-19 pandemic were collected. Each is briefly described in Appendix A.

2.2 Identification of Critical Challenges

The list of potential challenges was filtered to identify the critical challenges before ISM was conducted. The reason is that twelve or fewer variables are usually considered for studies using ISM. This is because the increase in the number of variables increases the complexity of the methodology (Attri et al., 2013). The study first issued a questionnaire survey to filter the challenges to obtain experts' opinions across the globe. As a result, the Likert scale adopted includes level of agreement (1= Strongly disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly agree) and Level of Sentiment 1=Negative, 2=Neutral, 3= Positive). A pilot study was then conducted to check the comprehensiveness and relevance of the potential challenges by engaging valuable responses from five experts (three academicians [one from the UK, one from Australia and one from Hong Kong] and two quality inspectors [one from Hong Kong and the other from Mainland China]). The valuable comments helped modify by further filtering the 18 potential challenges to 10, as illustrated in Table 1, informing the final questionnaire (see Appendix D). The interview questions were also piloted to have well-refined questions to interest experts' participation (see Appendix E).

Table 1: Potential challenges of QA after piloting (Source: Authors own work)

Code	Potential Challenges	References #
C1	Collaboration and communication difficulties	1,2,3,4,5
C2	Long approval process and schedule delays	2,5,6,7,8,9,10,11,12,13
C3	Heavy workloads and shortage of construction workers	2,5,14,15,16,17,
C4	Legal issues due to a breach of contract terms and conditions.	5,18,19,20,21,22
C5	Working with masks difficulties.	2,23,28
C6	Design changes	2,5,29
C7	Shortage of raw construction material.	5,8,12,13,15,19,24,25
C8	Halting of operations and Site closure.	5,6,30
C9	Rising cost of construction materials.	13,26,31
C10	Changes in work practices.	2,5,27,29

For details of references #, see Appendix B.

An online survey was adopted to distribute the questionnaires using "Qualtrics XM" via personalised emails of experts to allow responses from LinkedIn, WeChat, and WhatsApp messenger. This was done by adopting purposive and snowball sampling targeting experts with knowledge and experience in construction QA. This helped direct the researcher to potential experts for the interview. The interview session was conducted via online platforms, such as Zoom and WeChat. Experts were considered if (1) they had extensive experience and were theoretically versed in the construction QA processes, (2) they had sufficient direct hands-on experience in construction QA, and (3) they had been involved in at least QA processes in their organisation. The duration of the data collection continued for five to six months. The experts were prompted with several reminders to remind the experts to respond to the survey and attend an interview session if available. Due to the snowball sampling technique adopted, the number of questionnaires distributed was not determined. However, an approximate value of 200 online questionnaires could be estimated for the distribution. Finally, 150 responses were collected from the experts. A limitation of this approach is the accurate estimation of the response rate, as the respondents forwarded the survey to potential experts. However, it is suggested that a minimum sample size of 30 is recommended as appropriate for analysis (Ott and Longnecker, 2015). Hence, 150 is relatively high for analysis in this study. Correspondingly, 13 interviews were conducted to derive insight to complement the survey findings, meeting the minimum requirements for a qualitative study: 5-50 participants (Dworkin, 2012).

The collected dataset was initially cleansed to remove uncompleted responses. The Statistical Package for the Social Sciences (IBM–SPSS), version 27, was adopted for data analysis. Figure 2 details the profile of the experts engaged in the survey, whereas Table 2 presents the profile of the interviewees. Overall, the experts highly constituted those from Ghana, Hong Kong, and Mainland China with 24.7%, 19.3%, and 15.3% respectively. The response rate of experts from the academia was 23.09%, a good survey response reflecting the consent of the academia (Cleave, 2020), while the industry was 76.92%, across economies with specialities, such as academics, quality auditing, and quality engineering. It also engaged authorised persons from the governments, client representatives, and others. The "others" included other team members deemed essential in the QA process, i.e., project managers, construction managers, and site supervisors. Most experts had years of work experience from 1–10 years either by research or industry experience, and few had work experience from 11–20 years. With the interviewees, experts were noted to be highly qualified with academic certificates and work experience from two to ten years.

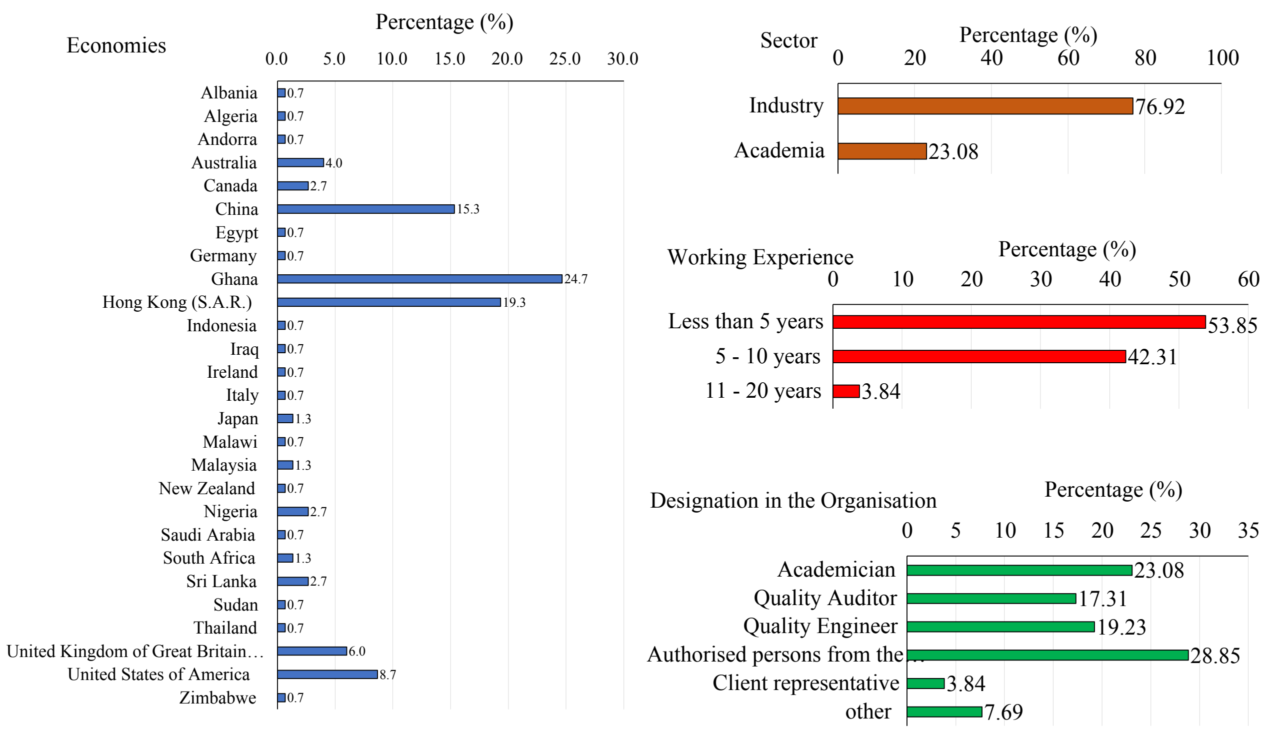

Figure 2: Experts' Profile (Source: Authors own work)

Table 2: Profile of Interviewees (Source: Authors own work)

Interviewee	Designation	Qualification	Years of Experience
A	Quality inspection officer	BSc	5
B	Quality inspection officer	MSc	2
C	Quality engineer	BSc	2
D	Quality inspection officer	MSc	5
E	Quality manager	MSc	4
F	Quality inspection officer	MSc	3

G	Onsite quality inspection officer	BSc	2
H	Quality manager	MSc	10
I	Director of Quality Management System Department	MSc	4
J	Quality officer (in charge of logistics)	BSc	2
K	Supply chain manager	MSc	6
L	Quality engineer	BSc	7
M	Quality engineer	MSc	3

2.2.1 Cronbach's Alpha (CA) test, Normality test, Descriptive test, and Normalisation score

The internal consistency in the related dataset was found to be excellent using the CA value, which was recorded as a level of agreement (0.925) and a level of sentiment (0.886) (Pallant, 2001). This then guaranteed the dataset for further analysis.

Adopting the Kolmogorov-Smirnov (K-S), test denoted that the dataset was not normally distributed for both data regarding the level of agreement and the sentiment level (see Appendix F). Using the means score, the central tendency of the experts on the challenges was relatively good, as well as the standard deviation. Checking the level of criticality, the normalisation score showed a high level of criticality compared to the threshold of ≥0.500 (Adabre et al., 2020). Hence, all the challenges are critical. For the results of the descriptive analysis and normalisation scores, see Appendix G.

2.2.2 Disparity Test

The Mann-Whitney U test was adopted due to the non-parametric nature of the dataset to assess the degree of association of experts' ranking on the level of agreement and the sentiment from the perspective of academia and industry experts. This commenced with a null hypothesis, H_0, stating that:

"there is no significant disparity vis-à-vis the level of agreement/sentiment on the challenges of the QA practices of Cb-CLSC among the two groups (academia and industry)".

The H_0 is retained if the P-value exceeds the significant level of 0.050. For the results of the disparity test between academia and the industry, see Appendix F.

2.2.3 Rank Agreement Analysis

Using the rank agreement analysis, the level of consensus between academia and the industry was estimated to understand the agreement rate on the critical challenges of QA amid the pandemic. This approach has been adopted in construction management literature for similar situations (Zhang, 2005). The rank agreement is a quantitative method that uses the "rank agreement factor" (RAF). The RAF shows "the absolute difference in the ranking of factors between two groups". Relating to the two groups of respondents: the academia (Group 1) and the industry practitioners (group 2). Let the rank of a critical challenge within group one be R_{i1} while the same critical challenge within group two be $R_{i2.}$ N is the number of critical challenges in each component, and the number of groups (which in this case is 2) is represented by k. Then, (R_{i1}-R_{i2}) of a critical challenge is the difference in ranks obtained from the two groups – academia and industry. R_i of a challenge is the sum of the ranks of the critical challenges from academia and the industry. The following equations could be used to determine the RAF (Okpala and Aniekwu, 1988):

$R_i = \sum_{i=1}^{N} Rij$ (1)

Where R_{ij} = sum of the ranks given to QA practice by the two different groups.

The mean value of the total ranks (R_{j2}) is given by

$R_{ij} = \frac{1}{N}\sum_{i=1}^{N} Rij$ (2)

$RAF = \frac{\sum_{i=1}^{n}|(Ri1 - Ri2)|}{N}$ (3)

The maximum rank agreement factor (RAF_{max}) is given by

$RAF_{max} = \frac{\sum_{i=1}^{n}|(Ri1 - Rj2)|}{N}$ (4)

The percentage disagreement (PD) is given by:

$PD = \frac{\sum_{i=1}^{n}|(Ri1 - Ri2)|}{\sum_{i=1}^{n}|(Ri1 - Rj2)|} \times 100$ (5)

The percentage agreement (PA) is given by:

PA = 100 – PD (6)

For this study,

$PD = \frac{21}{37.2} \times 100$ = 56.452% = 56%

Therefore, PA = 44%

For the detailed results of the rank agreement analysis on the critical challenges, see Appendix H. Overall, the PA on the challenges is 44%, showing a low agreement and at least a reasonable agreement between academia and the industry. The difference may be due to their differential perspectives on the challenges. However, there is no significant disparity vis-à-vis the level of agreement on the critical challenges among the two groups (academia and industry). Hence, the variables still reflect the critical challenges of QA amid the pandemic considering the study's context.

2.3 ISM Methodology

ISM, as developed by Warfield in 1974, mainly analyses the interrelationships among factors of a complex system, just like the Analytic Hierarchy Process (AHP). As AHP finds it difficult to obviate the potential interactions within a criteria cluster (Wu, 2008), ISM helps to study the direct and indirect interrelationships between various factors with ranking and direction (Attri et al., 2013). In the field of construction, ISM has been adopted to study the risks involved in the design stage of construction projects (Etemadinia and Tavakolan, 2018), barriers to off-site construction in China (Gan et al., 2018), and barriers to BIM implementation in China (Tan et al., 2019). This study draws a different perspective by studying the interrelationships between the critical challenges of the QA amid the COVID-19 pandemic. ISM is adopted in this research because of its strength in studying complex system dynamics and its dependence on expert experience and quality responses rather than quantity. This makes it suitable for this study's context, where the experts contacted to examine the interrelation among the critical challenges are few, and very difficult to have enough responses via an online expert survey. Also, the number of key challenges identified from the previous analysis is suitable for ISM since 12 or fewer factors are usually considered (Tan et al., 2019). Increasing the number of factors increases the complexity of the methodology. This follows the five essential steps of ISM methodology, as illustrated in Figure 3. MICMAC (*Matrice d'Impacts Croisés Multiplication Appliquée à un Classement*) is finally adopted to classify the challenges based on their driving and dependence power.

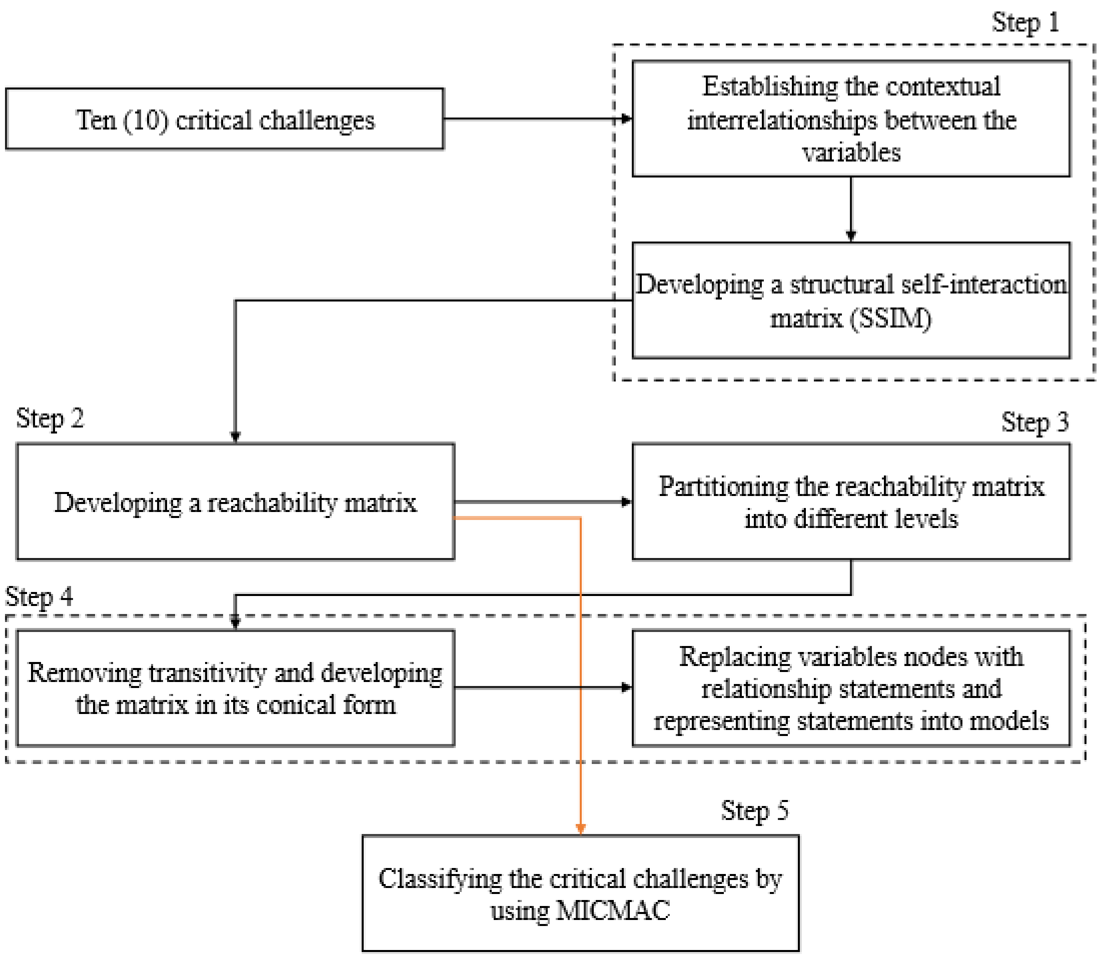

Figure 3: Processes of ISM in this Study (Source: Authors own work)

Step 1: Establishing the Contextual Interrelationship Among the Critical Challenges

After exploring the critical challenges, which have been agreed upon by the experts in academia and the industry, as denoted by the Mann-Whitney test, the study proceeded to check how the critical challenges interrelate among themselves. To achieve that, 20 experts were thoughtfully contacted via an online expert survey to respond to how the critical challenges interact. This was done based on their experience and designation. The surveys permitted the expect to provide their educational background, employer, position, and years of experience. The main questions were structured to allow the experts to respond using "yes" or "no" if there is a relation between two sets of critical challenges. The challenges were divided into sections and distributed among the experts to collect responses on the interrelationships (see Appendix I). This permitted convenience and allowed easiness in responding to the questions. Ultimately, 10 experts responded to the expert survey; their profiles are shown in Table 6. The dataset was interpreted to find contextual interrelationships among the critical challenges and input the results into the Structural Self-Interaction Matrix (SSIM). For this study, the interrelations between the critical challenges *i* and *j* were represented by four symbols: "V = challenge *i* influences challenge *j*"; "A = Challenge *j* influences challenge *I*"; "X = challenges *i* and *j* influence each other"; and "O = challenge *i* and *j* do not influence each other since they are unrelated". The "Minority gives way to the majority" principle is adopted to determine the interrelationship in a case when different experts made different judgements toward the relationship between two critical challenges.

Table 3: Profile of Experts Engaged in the Second Round of Survey (Source: Authors own work)

No.	**Qualification**	**Sector**	**Designation**	**Experience (Years)**
1	MSc	Industry	Client Representative	<5
2	BSc	Industry	Quality Engineer	5-10
3	BSc	Industry	Client Representative	<5
4	MSc	Industry	Client Representative	<5
5	BSc	Industry	Quality Auditor	<5
6	PhD	Academia	Academician	5-10
7	PhD	Academia	Academician	5-10
8	BSc	Industry	Quality Engineer	<5
9	MSc	Industry	Quality Control Officer	5-10
10	BSc	Industry	Quality Auditor	<5

Based on the results of the second round of expert surveys on the interrelationships among the critical challenges, a contextual relationship matrix is established, as illustrated in Table 4.

Table 4: Developed SSIM (Source: Authors own work)

Code	**C10**	**C9**	**C8**	**C7**	**C6**	**C5**	**C4**	**C3**	**C2**	**C1**
C1	X	A	X	O	X	X	X	A	V	
C2	X	X	X	X	A	X	A	A		
C3	X	V	A	V	A	X	V			
C4	X	A	X	X	X	0				
C5	V	V	V	V	X					
C6	X	V	V	X						
C7	X	X	X							
C8	X	X								
C9	V									
C10										

Step 2: Reachability Matrix

The four symbols, V, A, X, and O, are substituted by 1 and 0 to transform the SSIM into a binary matrix for further analysis per the ISM methodology. Table 5 depicts the adopted substitution rule. When the direction of the correlation between the challenges is V, A, X, and O, the (i, j) and the (j, i) of the reachability matrix are filled accordingly, as illustrated in Table 6. For example, if (C1, C9) in the SSIM is A, the (C1, C9) in the reachability matrix will be 0, and the (C9, C1) will be 1.

Table 5: Substitution Rule (Source: Authors own work)

Entry	*i, j*	*j, i*
V	1	0
A	0	1
X	1	1
O	0	0

An initial reachability matrix is developed following the substitution rule, as shown in Table 6, which shows the relationships between the 10 critical challenges. Transitivity is checked to produce a final reachability matrix.

The transitivity followed a basic assumption that if challenge A is related to B and B is associated with C; then A is necessarily related to C (Mandal and Deshmukh, 1994). This study adopted a Python function, shown below, to check the transitivity (Xiang et al., 2013). Other studies have also adopted MATLAB to carry out this exercise (Liu et al., 2018). This was cross-checked to validate the accuracy of the Python function with an understanding of the literature. This also ensured logic with the transitivity. Manual checking of transitivity may be prone to error and time-consuming. Table 7 shows the final reachability matrix after the function was called with the initial matrix using Python 3.4. Figure 4 also shows the significant interrelationships between the challenges.

Table 6: Initial Reachability Matrix (Source: Authors own work)

Code	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	1	1	0	1	1	1	0	1	0	1
C2	0	1	0	0	1	0	1	1	1	1
C3	1	1	1	1	1	0	1	0	1	1
C4	1	1	0	1	0	1	1	1	0	1
C5	1	1	1	0	1	1	1	1	1	1
C6	1	1	1	1	1	1	1	1	1	1
C7	0	1	0	1	0	1	1	1	1	1
C8	1	1	1	1	0	0	1	1	1	1
C9	1	1	0	1	0	0	1	1	1	1
C10	1	1	1	1	0	1	1	1	0	1

```
def transitiveClosure (matrix):
  result = ""
  length = len(matrix)
  for k in range(0, length):
    for row in range(0, length):
      for col in range(0, length):
        matrix[row] [col] = matrix[row][col] or (matrix[row][k] and matrix[k][col])
    result += ("\n W" + str(k) +" is: \n" + str(matrix).replace("]," , "] \n") + "\n")
  result += ("\n Transitive closure is \n" + str(matrix).replace("]," , "]\n"))
  print result
  return result
```

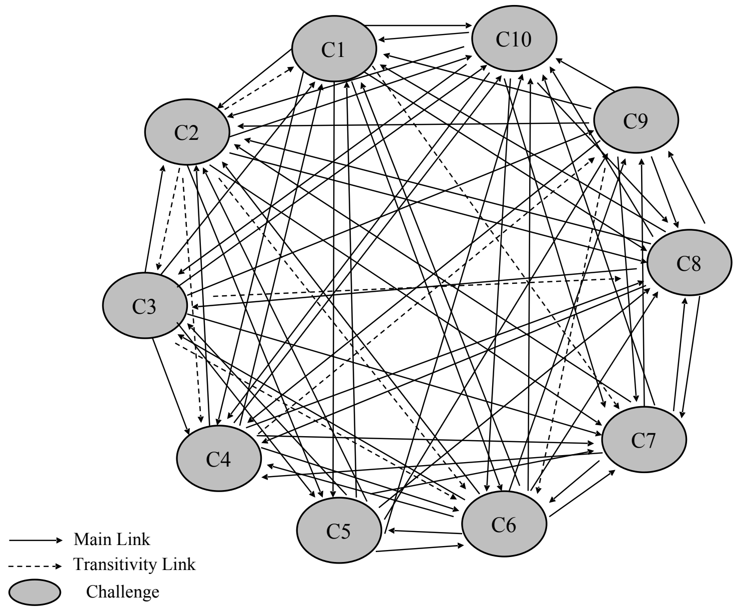

Figure 4: Significant Network Showing the Interrelationships Between the Critical Challenges (Source: Authors own work)

Table 7: Final Reachability Matrix (Source: Authors own work)

Code	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**Driving Power**
C1	1	1	0	1	1	1	1*	1	0	1	8
C2	1*	1	1*	1*	1	1*	1	1	1	1	10
C3	1	1	1	1	1	1*	1	1*	1	1	10
C4	1	1	0	1	0	1	1	1	1*	1	8
C5	1	1	1	0	1	1	1	1	1	1	9
C6	1	1	1	1	1	1	1	1	1	1	10
C7	0	1	0	1	0	1	1	1	1	1	7
C8	1	1	1	1	0	0	1	1	1	1	8
C9	1	1	0	1	0	1*	1	1	1	1	8
C10	1	1	1	1	0	1	1	1	0	1	8
Dependence Power	9	10	6	9	5	9	10	10	8	10	86

1* indicates the indirect influence relationship between challenges in considering transitivity

Step 3: Level Partitions

Table 7 was used to identify the reachability and antecedent sets of every challenge to produce partition levels. The reachability set includes a specific challenge and any other challenges it may lead to, while the antecedent set consists of a specific challenge and any other challenges that may result. The reachability set is those with a value of 1 in its row on the final reachability matrix. Similarly, the antecedent set has a value of 1 in its column on the final reachability matrix. The intersection of the reachability and antecedent sets is derived for all the challenges. The challenges for which the reachability set and the intersection set are the same occupy the top level of the ISM hierarchy, indicating that these challenges are likely to be influenced by other challenges. Once the challenge at the top level is identified, it is discarded from the other challenges' reachability and antecedent sets. This process is repeated to obtain challenges at the next level and continues until all the challenges are placed in the ISM hierarchy. Table 8 shows the results of the level partitions after a series of iterations.

Table 8: Partition Levels (Source: Authors own work)

Challenges	Reachability Set	Antecedent Set	Intersection Set	Level
Iteration 1				
C1	C1, C2, C4, C5, C6, C7, C8, C10	C1, C2, C3, C4, C5, C6, C8, C9, C10	C1, C2, C4, C5, C6, C8, C10	
C2	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10	I
C3	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10	C2, C3, C5, C6, C8, C10	C2, C3, C5, C6, C8, C10	
C4	C1, C2, C4, C6, C7, C8, C9, C10	C1, C2, C3, C4, C6, C7, C8, C9, C10	C1, C2, C4, C6, C7, C8, C9, C10	I
C5	C1, C2, C3, C5, C6, C7, C8, C9, C10	C1, C2, C3, C5, C6	C1, C2, C3, C5, C6	
C6	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10	C1, C2, C3, C4, C5, C6, C7, C9, C10	C1, C2, C3, C4, C5, C6, C7, C9, C10	
C7	C2, C4, C6, C7, C8, C9, C10	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10	C2, C4, C6, C7, C8, C9, C10	I
C8	C1, C2, C3, C4, C7, C8, C9, C10	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10	C1, C2, C3, C4, C7, C8, C9, C10	I
C9	C1, C3, C4, C6, C7, C8, C9, C10	C2, C3, C4, C5, C6, C7, C8, C9, C10	C3, C4, C6, C7, C8, C9, C10	
C10	C1, C2, C3, C4, C6, C7, C8, C10	C1, C2, C3, C4, C5, C6, C7, C8, C9, C10	C1, C2, C3, C4, C6, C7, C8, C10	I
Iteration 2				
C1	C1, C5, C6	C1, C3, C5, C6, C9	C1, C5, C6	II
C3	C1, C3, C5, C6 C9	C3, C5, C6	C3, C5	
C5	C1, C3, C5, C6, C9	C1, C3, C5, C6	C1, C3, C5, C6	
C6	C1, C3, C5, C6, C9	C1, C3, C5, C6, C9	C1, C3, C5, C6, C9	II
C9	C1, C3, C6, C9	C3, C5, C6, C9	C3, C6, C9	
Iteration 3				
C3	C3, C5, C9	C3, C5,	C3, C5	
C5	C3, C5, C9	C3, C5	C3, C5	
C9	C3, C9	C3, C5, C9	C3, C9	III
Iteration 4				
C3	C3, C5	C3, C5,	C3, C5	IV
C5	C3, C5	C3, C5	C3, C5	IV

Step 4: ISM Diagraph and Model

From Table 8, long approval process and schedule delays (C2), legal issues due to a breach of contract terms and conditions (C4), shortage of raw construction material (C7), halting of operations and Site closure (C8), and changes in work practices (C10) have the same reachability and intersection set after the first iteration. Following the ISM principles, these are partitioned to level I and are discarded from the sets to commence the next iteration.

C2, C4, C7, C8, and C10 were cancelled out of the next iteration (i.e., iteration 2) as they were partitioned to level I. Collaboration and communication difficulties (C1) and design changes (C6) had their reachability set, equalling the intersection set in iteration 2. Thus, they were partitioned to level II, as shown in Table 8.

Challenges partitioned to level I and II were discarded to start the next iteration (i.e., iteration 3). Only "rising cost of construction materials (C9)" had its reachability set equalling the intersection set, thus, partitioned to level III, as shown in Table 8.

A similar step was conducted to partition the remaining challenges. Heavy workloads and shortage of construction workers (C3) and working with masks difficulties (C5) were noted to be the last set of challenges, with the reachability set equalling the intersection set after the fourth iteration. Thus, C3 and C5 were partitioned to level IV, as shown in Table 8.

The identified levels of the challenges from Table 8 were used to develop the ISM hierarchical model of the 10 critical challenges, as shown in Figure 5.

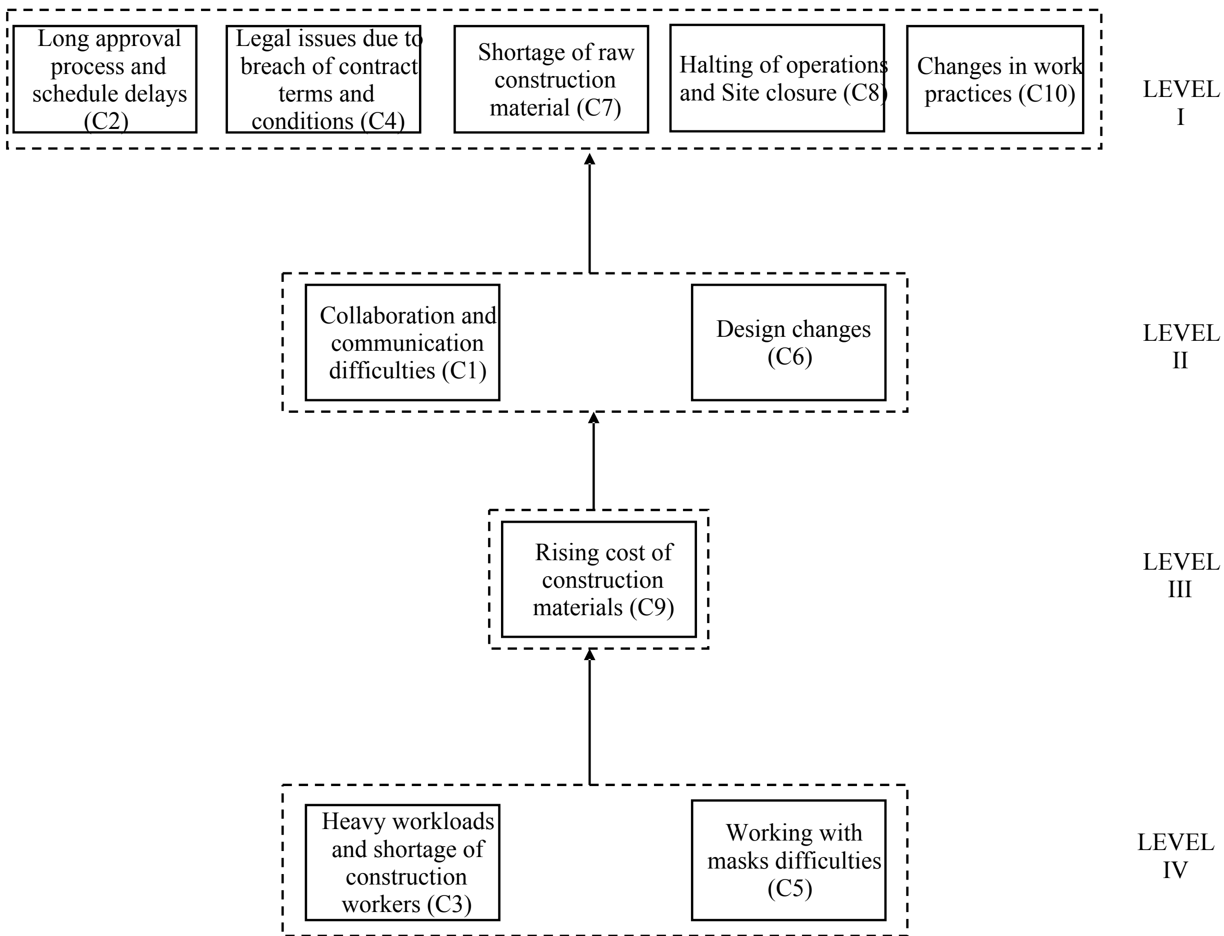

Figure 5: ISM Model of the Critical Challenges (Source: Authors own work)

Step 5: Classification of the Critical Challenges

The final reachability matrix is transformed into a MICMAC diagram depending on the dependence power and driving power of the critical challenges. The highest value in the dependence and driving power is 10 on the *x*-axis, and the minimum is 1. Thus, the axis ranges from 1 to 10 (9 units), and half is 4.5. This approach helps in partitioning the challenges into a two-dimensional diagram (diagraph) (Saka and Chan, 2020), as shown in Figure 6. A challenge with a higher dependence power denotes that several other challenges should be addressed before this challenge can be eliminated. A driver with higher driving power indicates that its elimination allows for solving several other challenges (Attri et al., 2013). Following the classification adopted by previous studies (Mandal and Deshmukh, 1994), the challenges can be divided into four categories: (1) autonomous variables, where the driving and the dependence power are both low; (2) dependent variables, where driving power is low, but dependence power is high; (3) driver variables, where driving power is high, but dependence power is low; and (4) linkage variables, where the driving and dependence power are both high.

Figure 6 shows the results of the MICMAC analysis of the 10 challenges. These were observed as follows:

1. None of the challenges was identified as an autonomous variable, indicating that all the challenges can hinder QA during the pandemic concerning the study's context.
2. None of the challenges was identified as dependent variables. Thus, all the challenges are highly dependent on themselves.
3. None of the challenges was revealed as a driver variable. This denotes that all the challenges have a high driving power.
4. All the challenges were identified as linkage variables. This indicates that each of the 10 variables can affect others and have a feedback influence on themselves.

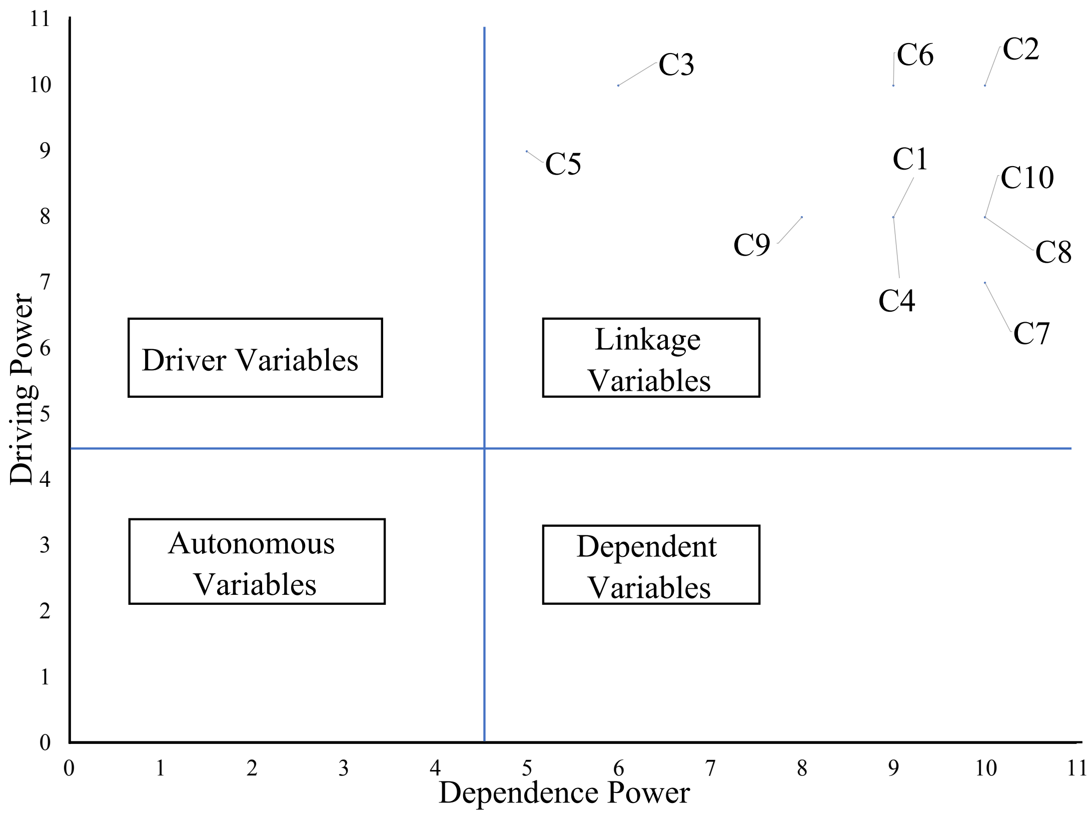

Figure 6: Results of the MICMAC Analysis (Source: Authors own work)

2.4 Sentiment Analysis

Finally, sentiments on the critical challenges are assessed using the negative-neutral positive model. Using the means score analysis, the sentiment scores are determined along with normalisation scores to understand how the challenges have affected the QA process based on the experts' views. This is also assisted with percentage and frequency. Table 9 shows the results of the sentiment analysis from the survey.

Content analysis is performed on the interview data to understand more from the real-life cases based on experts' responses. This is intended to complement the results of the expert survey. The experts' specific responses are evaluated based on the areas of challenges and opportunities across the QA process. The evaluation revealed the areas of challenges to include work processes, cost, time, and materials, while the areas of opportunities comprise technology adoption, work process management, and worker management. These are aligned with the specific responses of the interviewees (see Appendix J). Thus, the results can validate the assertion that the pandemic has been a challenge, pushing organisations to be innovative in managing workers and processes while adopting advanced technologies.

Table 9: Results of the Sentiment Analysis of the Survey (Source: Authors own work)

Code	Sentiments			Standard deviation	Sentiment score	Normalisation scores
	Negative	Neutral	Positive			
C1	28(53.84%)	19(36.54%)	5(9.62%)	0.669	1.56	0.280
C2	31(59.62%)	17(32.69%)	4(7.69%)	0.641	1.48	0.240
C3	24(46.15%)	24(46.15%)	4(7.69%)	0.631	1.62	0.310
C4	15(28.85%)	27(51.92%)	10(19.23%)	0.693	1.90	0.450
C5	19(36.54%)	27(51.92%)	6(11.54%)	0.653	1.75	0.375
C6	20(38.46%)	23(44.23%)	9(17.31%)	0.723	1.79	0.395
C7	20(38.46%)	12(23.08%)	20(38.46%)	0.886	2.00	0.500
C8	25(48.07%)	10(19.23%)	17(32.69%)	0.894	1.85	0.425
C9	23(44.23%)	21(40.38%)	8(15.38%)	0.723	1.71	0.355
C10	20(38.46%)	19(36.54%)	13(0.250)	0.793	1.87	0.435

3 Discussion

3.1 Criticality of the Challenges

Undeniably, the COVID-19 pandemic has imposed challenges on the QA, which emanates from the COVID-19 mitigation measures. Understanding from a central tendency point of view from the experts denoted the top three challenges to include halting of operations and site closure (C8), long approval process and schedule delays (C2), and the rising cost of construction materials (C9). However, the criticality level using normalisation scores showed inconsistency with the central tendency by revealing the top two critical challenges of QA amid the pandemic: the shortage of raw construction material (C7) and design changes (C6). Collaboration and communication difficulties (C1) and changes in work practices (C10) were considered third due to the equal level of criticality obtained. The inconsistency created by the central tendency and criticality levels may be due to the level of agreement on the challenges, which may not necessarily be highly critical compared with other challenges. Thus, this justifies the conclusion that different economies may experience homogenous challenges of QA amid the pandemic. However, the criticality of the challenges might be different due to contextual-specific features. Subsequently, all the challenges are revealed to be highly critical though the level of criticality differs. These critical challenges are traced throughout the QA process, threatening the ability to deliver a quality project on time and within budget (PlanRadar, 2022) amid the pandemic. Thus, organisations need to seriously tackle these challenges as a priority throughout the QA process to ensure adequate execution of QA tasks.

The study reveals that the COVID-19 pandemic has greatly impeded QA activities in the construction industry, and this emanates from the effects on labour, material, time, and cost. Overall, the inference that can be drawn in this context is that the adequacy of the QA process is affected as it involves material, labour, time, cost, and quality. For instance, immediately the supply chain of an organisation is disrupted, this causes a slow delivery of materials throughout the QA process. This may cause organisations to halt projects or probably look elsewhere to procure material. This also aligns with Mclnnes (2020), who discovered that 87% of construction businesses experience a reduced operation of suppliers, material shortages, labour shortages, and financial difficulties when impacted by the pandemic. Other critical challenges, including C1 and C2, are likely to emanate due to the difficulties created by the restricted movement of experts to conduct QA tasks, such as inspection, auditing, etc., on projects across borders (Oey and Lim, 2021). It is worth noting that, in the pandemic era, the identified challenges are highly critical. Therefore, organisations must be determined to strategise effectively and efficiently to minimise them by deploying innovative strategies that harness the opportunities created by the pandemic (Ghansah and Lu, 2024).

3.2 Interrelationships Between the Critical Challenges

The Mann-Whitney U test indicated no statistically significant differences between the two sectors (academia and the industry). This is due to the relatively close mean values among the two sectors, confirming the reliability dataset to achieve reliable results. Overall, the percentage agreement (PA) estimated for the 10 critical challenges is 44%, which depicts a low agreement but at least a reasonable agreement between experts from academia and the industry. The low agreement rate may be due to the different perspectives of academia and industry on each critical challenge based on the rankings. However, the result of the Mann-Whitney test balances the relatively low PA.

With the ISM approach, this study revealed that the critical challenges are highly related and would influence the QA in different ways. The critical challenges were partitioned into four levels. Level I suggest interesting results as it is the most critical that needs to be prioritised, including C2, C4, C7, C8, and C10. These challenges can be traced across the QA process along with time, material, and work processes. C7, as considered critical with the normalisation score, emerges from the disruptions in the supply chain of material throughout the QA process, considering the study's context. This is consistent with the findings reported by Mclnnes (2020) when the construction material shortage was identified among the few key challenges imposed by the COVID-19 pandemic. C2 stems from the restriction of movement of experts from location to location and observing quarantine days, which tend to affect QA tasks if not planned carefully. In other cases, it may be unethical to travel to other locations (Lu et al., 2022), depending on the COVID-19 situation of the location. This then has the potential to delay operations onsite or halt operations until inspections and auditing are performed. This may lead to the C8, a critical challenge partitioned to level I. With C4, many contracts do not address the scenario of a "*black swan*" event like the COVID-19 pandemic, and if projects are not shut down during lockdown, they put organisations in a difficult position with the ability to meet contract obligations, including pre-stated quality requirements (Mclnnes, 2020). Subsequently, changes in work practices (C10) might occur, and organisations would be challenged to be innovative in devising new strategies to adapt to new practices to ensure the continuity of QA tasks throughout the QA process. Thus, it would be the responsibility of organisations to orient experts and workers to the new ways of operation to attain adequacy in the QA processes.

Level II consists of Collaboration and communication difficulties (C1) and design changes (C6), which emanate from obtaining accurate information throughout the QA process. C1 depicts the difficulty of being physically present on the operation site to collaborate and seek information on the quality of cross-border projects. The collaboration process in QA has been impeded by the pandemic mitigation measures and the fear of getting infected (Oo et al., 2021; Rankohi et al., 2022; Yang et al., 2023). However, this stimulates organisations to devise innovative ways to collaborate and communicate with experts and workers and supervise and inspect works/services from remote locations. This can be achieved by deploying innovative digital technologies such as building information modelling technology, blockchain, augmented reality, digital twins, etc. (Lu et al., 2022; Leontie et al., 2022). The disruptions caused by the pandemic influence project and operation costs, leading to design changes. The design may continue to change if the project management process keeps changing due to the pandemic, and this may stem from the shortage and the rising cost of materials. Thus, this affects the adequacy of QA tasks conducted on a project, especially in the context of this study.

The rising cost of construction materials (C9) is partitioned to Level III, and this emanates from the disruptions in the supply chain of construction materials due to the pandemic effect. Heavy workloads and shortage of construction workers (C3) and working with masks difficulties (C5) were similarly partitioned to level IV, which considers workforce and personal protective equipment, such as face masks. A shortage of construction workers may occur due to the fear of getting infected, especially when the working environment is unsafe (Rankohi et al., 2022). This leads to heavy workloads on workers, which stresses workers on the sites, especially when they are to perform more for extra prize awards. This then also leads to low work efficiency, which may affect the quality of projects (Pamidimukkala et al., 2021; Oo et al., 2021). Working with face/nose masks may not always create a safe environment, as experts/workers may sometimes feel uncomfortable wearing the masks. It is important to know that, depending on the worker's health status, wearing the mask for a long time may cause fatigue and breathing issues. This contributes to a worker's low efficiency, which may affect the project quality. Despite these critical challenges, organisations can explore the opportunities created and harness them to position the QA to be adequate.

Based on the interrelationships among the critical challenges, the study categorised the critical challenges into autonomous, driver, dependent, and linkage variables using MICMAC analysis. The study revealed none of the critical challenges to be a driver variable, dependent variable, and autonomous variable, but all are linkage variables. This depicts that all the challenges are sensitive and can affect themselves. For instance, C8, which may result from C7, would affect C2 by causing delays or cancellations throughout the QA assurance process. With issues mounting, including heavy workloads and a shortage of construction workers, the pressure to complete projects on time would emerge. Often, it is impossible to complete projects according to the timelines, forcing construction firms to adjust, leading to C10. Similarly, the other critical challenges could influence other critical challenges, as the MICMAC analysis depicted. The result is consistent with the earlier results of the normalisation scores on the challenges, as all were noted to be highly critical. The result contradicts the conclusion of Nair and Suresh (2021) that legal issues, project delays, and financial loss are the only linkage challenges of the pandemic in construction. Focusing deeply on the QA, a critical construction area, all identified critical challenges are noted as linkage variables, and these highly influence themselves during pandemics. Thus, considering all the critical challenges as "linkages" throughout the QA process amid the pandemic helps to devise strategies to effectively minimise the critical challenges by harnessing the created opportunities.

3.3 Sentiments on the Critical Challenges

A sentiment analysis adopted by the study denoted that the critical challenges have not entirely been negative but also positive. The positivity stems from how organisations harness the opportunities created to ensure the continuity of QA tasks throughout the QA process. The study revealed that, among the critical challenges, C2 (59.62%) has the most negative influence on the QA, followed by C1 (53.84%) and C8 (48.07%). However, these are also associated with positive impacts that can be harnessed to position the QA to be adequate. In this study, the neutral and the positive levels depict the opportunities created amid the challenges caused by the pandemic. The result is consistent with Burczyk (2021), who reported that positive things have come out of the collective response to the difficulties created by the pandemic. This is obvious in the construction industry in revealing impressive resilience and adaptability to challenging circumstances. This implies that minimising the impacts of the challenges involves organisations developing innovative strategies to accelerate their responses to the pandemic throughout the QA process.

Evaluating the interview data on the experts' sentiments revealed two main themes of consideration throughout the QA process amid the pandemic: the area of the challenges and the area of opportunities. The area of challenges denotes the areas the pandemic has influenced throughout the QA process. The study revealed such areas to include the work process, time, costs, and materials. The pandemic has influenced the work process of QA by impeding the level of inspections, testing, and work auditing that may need a physical presence on site. This stems from the institution of the pandemic mitigation measures that restrict the movement of experts/workers (Kwok et al., 2021). For instance, the challenge with face-to-face communication and inspection has increased the inadequacy level of QA, which involves restricting the movement of experts from one border to the other, as in the case of Hong Kong – Mainland China links. This then causes changes in the QA processes, affirming the C10, which was partitioned to Level I. Costs have been incurred twofold. First, costs have skyrocketed thanks to the disruptions in the supply chain, shortage of construction materials, reworks from inadequate inspection, and procurement of health and safety equipment to provide a safe environment (Jeon et al., 2022). This supports the assertion reported by COR-Global (n.d) that the global demand for materials and the strained economy is driving construction costs up, which could continue even in the post-pandemic era. Thus, the cost increment affirms C9 as being noted as a critical challenge, though not partitioned to level I but rather level III. Second, additional costs due to the adoption of innovative strategies involving digital technologies, as emphasised by interviewee C, D, E, and H. Time has also been affected throughout the QA process, and this has caused delays, confirming the critical challenge, C2, which was partitioned to Level I. Lastly, material procurement is another area of concern that organisations experience problems across the QA process amid the pandemic due to its shortage. This stems from disruptions in the supply chain. Interviewee K emphasised this by relating to the untimely procurement of raw materials due to the pandemic and the increasing cost of construction materials. This also affirms C7 for being partitioned to level I. The other critical challenges not stated are also influencing challenges, though they were not specifically mentioned by the interviewees but were noted via an expert survey. Thus, organisations must consciously devise innovative strategies to minimise the impact of critical challenges.

The area of opportunities in the QA denotes the areas of improvement due to the pandemic by harnessing the created opportunities. The study revealed such areas as technology adoption, worker management, and work process management. The construction industry has slowly adopted digital technologies (Hart, 2022). However, there has been an increasing adoption rate of digital technologies for QA activities through the QA process amid the pandemic. This is purported to ensure the continuity of QA activities and services amid the pandemic. As interviewee A highlighted, the pandemic has stimulated the application of intelligent technologies for the quality management of construction projects. The opportunities include automation of quality monitoring, online monitoring of logistics movement, intelligent detection, online communication and collaboration systems, etc. These reduce the physical presence and interactions on construction sites, providing a safe environment for experts/workers throughout the QA process. Worker management has been an area of opportunity, and this involves how experts/workers are strategically managed to ensure the continuity of QA tasks. Such strategies tend to reduce the time for personnel to operate in the field and to improve the corresponding technical developments. This also demonstrates the importance of using skilled experts, as emphasised by interviewee G. This helps reduce the number of onsite workers (Araya, 2022), especially when the multi-skilled experts can assist with quality inspection and control. Lastly, the study revealed work process management as an area of opportunity in the QA process, and this involves means to improve the work to meet quality requirements throughout the process. This is directly related to using technologies that help improve existing platforms or develop new platforms to adapt to the new situation created by the pandemic. The pandemic has created an opportunity for flexibility in terms of time when performing QA, interviewee L emphasised. Thus, the areas of opportunities, if harnessed continuously and effectively, could position the QA to be adequate during and after pandemics.

4 Conclusions

There is a need to identify and evaluate the critical challenges of QA of Cb-CLSC during the COVID-19 pandemic towards the efforts to understand and develop a resilience framework to adequately position the QA systems for the post-pandemic era and endure the risks of future pandemics. This study pragmatically fills the gap by engaging experts from different economies via an embedded mixed-method using expert online surveys and semi-structured interviews. The method is integrated with ISM as the kernel.

The study revealed ten critical challenges of QA, with the top four challenges including "the shortage of raw construction material (C7)", "design changes (C6)", "collaboration and communication difficulties (C1)" and "changes in work practices (C10)". However, examining the interrelationships among the critical challenges confirmed C7 and C10 as the most critical challenges. The study again revealed that the critical challenges are sensitive and capable of affecting themselves due to the nature of their interrelationships among them based on the MICMAC analysis. Hence, being consistent with why all the challenges were considered critical amid the pandemic. Further analysis revealed that the critical challenges have not been entirely negative but also positive by creating three areas of opportunities for improvement: technology adoption, worker management, and work process management. However, four areas of challenges in the QA include cost, raw material, time, and work process, including inspection, testing, auditing, communication, etc.

Theoretically, the findings of this study enrich the extant literature on QA, Cb-CLSC, and the COVID-19 pandemic in the construction industry by identifying the critical challenges and examining the interrelationships among them. This provides a better understanding of how the construction QA has been affected by the pandemic and the opportunities created. The findings could also serve as a reference to direct researchers in devising innovative strategies to mitigate critical challenges and ensure adequate QA during pandemics. Practically, the findings deepen the understanding of the challenges of QA during the pandemic to the construction quality management front-liners and policymakers. This knowledge serves as a reference with valuable insights discovered on the critical challenges and their relationships, the negative and positive sentiments on the critical challenges, areas of challenges, and the opportunities to the decision-makers, policymakers, and quality management experts. This informs the players on the likely challenges of QA and creates policies to overcome the challenges when another pandemic occurs. Overall, the finding provides a convenient point of reference for researchers, policymakers, practitioners, and decision-makers on formulating policies to enhance the effectiveness of QA during the pandemic through to the post-pandemic era.

There are limitations to this study that need to be mentioned. The study adopted a 150-sample size to generate the results of this study due to the specific experts needed across the globe and the reachability difficulty in limited time. However, future research may expand the study to other economies not mentioned and use rigorous analytical tools to identify and examine the critical challenges of QA during the pandemic, taking lessons from this study. Also, most of the experts were predominantly located in Ghana, Hong Kong, and China, and this could be a potential limitation associated with regional concentration. A balanced number of experts from different regions around the world may enhance the generalisability of the findings. Hence, establishing specific criteria for expert selection including geographical diversity based on the specific situation of a country or ensuring equal representation from various parts of the world could significantly strengthen the study's robustness and the applicability of its conclusions across different global contexts. Nevertheless, the relevance and depth of this study's findings remain due to the candid and rigorous analytical tools employed via the embedded mixed-method approach, contacting experts from different economies.

References

Adabre, M.A., Chan, A.P., Darko, A., Osei-Kyei, R., Abidoye, R. and Adjei-Kumi, T. (2020). Critical barriers to sustainability attainment in affordable housing: International construction professionals' perspective. *Journal of Cleaner Production*, *253*, p.119995.

Araya, F. (2022). Modelling the influence of multi-skilled construction workers in the context of the covid-19 pandemic using an agent-based approach. *Journal of Construction*, *21*(1), pp.105-117.

Attri, R., Dev, N. and Sharma, V. (2013). Interpretive structural modelling (ISM) approach: an overview. *Research Journal of Management Sciences*, *2319*(2), p.1171.

Burczyk, D. (2021). *10 Positive Construction Trends to Come Out of COVID-19,* https://constructible.trimble.com/construction-industry/10-positive-construction-trends-to-come-out-of-covid-19.

Chung, H.W. (2002). *Understanding quality assurance in construction: a practical guide to ISO 9000 for contractors*. Routledge.

Cleave, P. (2020), *What Is a Good Survey Response Rate?* https://www.smartsurvey.co.uk/blog/what-is-a-good-survey-response-rate#:~:text=By%20contrast%2C%20a%20survey%20response,relationship%20between%20the%20business%20and.

COR-Global (n.d), *Challenges While Constructing During the Pandemic*, https://projectcor.com/blog/challenges-while-constructing-during-the-pandemic/.

Creswell, J. W., and Clark, V. L. P. (2017). *Designing and conducting mixed methods research*. Sage publications.

Dobrucali, E., Sadikoglu, E., Demirkesen, S., Zhang, C. and Tezel, A. (2022). Exploring the Impact of COVID-19 on the United States Construction Industry: Challenges and Opportunities. *IEEE Transactions on Engineering Management*.

Dworkin, S.L. (2012). Sample size policy for qualitative studies using in-depth interviews. *Archives of sexual behaviour*, 41(6), pp.1319-1320.

Etemadinia, H. and Tavakolan, M. (2021). Using a hybrid system dynamic and interpretive structural modeling for risk analysis of design phase of the construction projects. *International Journal of Construction Management*, *21*(1), pp.93-112.

Gan, X., Chang, R., Zuo, J., Wen, T. and Zillante, G. (2018). Barriers to the transition towards off-site construction in China: An Interpretive structural modelling approach. *Journal of cleaner production*, *197*, pp.8-18.

Ghansah, F.A. and Lu, W. (2024), "Managerial framework for quality assurance of cross-border construction logistics and supply chain during pandemic and post-pandemic: lessons from COVID-19 in the world's factory", *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-10-2023-1050.

Ghansah, F.A and Lu, W. (2023) Responses to the COVID-19 pandemic in the construction industry: a literature review of academic research, *Construction Management and Economics*, https://doi.org/10.1080/01446193.2023.2205159.

Ghansah, F.A., Lu, W. and Ababio, B.K., (2023). Quality assurance of cross-border construction logistics and supply chain during the COVID-19 pandemic: evidence from the Hong Kong–Mainland China links. *International Journal of Logistics Research and Applications*, pp.1-21.

Gumusburun Ayalp, G. and Çivici, T. (2023), "Factors affecting the performance of construction industry during the COVID-19 pandemic: a case study in Turkey", *Engineering, Construction and Architectural Management*, Vol. 30 No. 8, pp. 3160-3202. https://doi.org/10.1108/ECAM-10-2021-0890.

Hart, P. (2022). *Why are construction companies slow in adopting technology?* https://www.linkedin.com/pulse/why-construction-companies-slow-adopting-technology-phil-hart/.

ISO (1994) *Quality management and quality assurance—Vocabulary, International Organization for Standardization*.

Jeon, J., Padhye, S., Bhattacharyya, A., Cai, H. and Hastak, M. (2022). Impact of COVID-19 on the US Construction Industry as Revealed in the Purdue Index for Construction. *Journal of Management in Engineering*, *38*(1), p.04021082.

Kum, Y.T., Yap, J.B.H., Lew, Y.-L. and Lee, W.P. (2023), "Transforming construction health and safety management during COVID-19 pandemic using innovative technologies: PLS-SEM approach", *Engineering, Construction and Architectural Management*. https://doi.org/10.1108/ECAM-08-2022-0780.

Kwok, W.C., Wong, K.C., Ma, TF, Ho, KW, Fan, L.W.T., Chan, K.P.F., Chan, S.S.K., Tam, T.C.C. and Ho, P.L. (2021). Modelling the impact of travel restrictions on COVID-19 cases in Hong Kong in early 2020. *BMC public health*, *21*(1), pp.1-8.

Leontie, V., Maha, L.G. and Stoian, I.C. (2022). COVID-19 Pandemic and Its Effects on the Usage of Information Technologies in the Construction Industry: The Case of Romania. *Buildings*, 12(2), p.166.

Ling, F.Y., Zhang, Z. and Yew, A.Y. (2022). Impact of COVID-19 pandemic on demand, output, and outcomes of construction projects in Singapore. *Journal of Management in Engineering*, *38*(2), p.04021097.

Liu, P., Li, Q., Bian, J., Song, L., and Xiahou, X. (2018). Using interpretative structural modelling to identify critical success factors for safety management in subway construction: A China study. *International journal of environmental research and public health*, *15*(7), p.1359.

Lu, W., Wu, L., Xu, J., and Lou, J. (2022). Construction E-Inspection 2.0 in the COVID-19 Pandemic Era: A Blockchain-Based Technical Solution. *Journal of Management in Engineering*, *38*(4), p.04022032.

Mandal, A., SG. and Deshmukh (1994). *Vendor Selection Using Interpretive Structural Modelling*, *14*(6), pp.52-59.

Mawhinney, M. (2008). *International construction*. John Wiley & Sons.

Mclnnes, F. (2020). *Construction quality management in the era of COVID-19*, https://www.ideagen.com/thought-leadership/blog/construction-quality-management-in-the-era-of-covid-19.

OECD (2020), *The territorial impact of COVID-19: Managing the crisis across levels of government*, https://www.oecd.org/coronavirus/policy-responses/the-territorial-impact-of-covid-19-managing-the-crisis-across-levels-of-government-d3e314e1/.

Oey, E. and Lim, J. (2021), Challenges and action plans in construction sector owing to COVID-19 pandemic – a case in Indonesia real estates, *International Journal of Lean Six Sigma*, 12(4), pp. 835-858. https://doi.org/10.1108/IJLSS-09-2020-0149.

Ogunnusi, M., Hamma-Adama, M., Salman, H. and Kouider, T. (2020). COVID-19 pandemic: the effects and prospects in the construction industry. *International journal of real estate studies*, *14*(2).

Okpala, D.C. and Aniekwu, A.N. (1988). Causes of high costs of construction in Nigeria. *Journal of Construction Engineering and Management*, *114*(2), pp.233-244.

ONS (2021), *Construction output in Great Britain: December 2020, new orders and Construction Output Price Indices, October to December 2020: December 2020,* https://www.ons.gov.uk/businessindustryandtrade/constructionindustry/bulletins/constructionoutputingreatbritain/december2020#annual-construction-output-growth-in-2020.

Oo, B.L., Lim, T.H.B. and Zhang, Y. (2021). Women workforce in construction during the COVID-19 pandemic: Challenges and strategies. *Construction Economics and Building*, *21*(4), pp.38-59.

Ott, R. L., and M. T. Longnecker (2015). An introduction to statistical methods and data analysis. Toronto: Nelson Education.

Pallant, J. (2001). *SPSS survival manual: A step by step guide to data analysis using SPSS for Windows (versions 10 and 11): SPSS student version 11.0 for Windows*. Open University Press.

Pamidimukkala, A., Kermanshachi, S. and Jahan Nipa, T. (2021). Impacts of COVID-19 on health and safety of workforce in construction industry. In *International Conference on Transportation and Development 2021* (pp. 418-430).

PlanRadar (2022). *Construction quality assurance: Common challenges and how to solve them,* https://www.planradar.com/au/construction-quality-assurance-common-challenges/.

Rankohi, S., Bourgault, M. and Iordanova, I. (2022). The new-normal challenges and IPD solutions: a Canadian case study, *Built Environment Project and Asset Management*, 13(1), PP.20-35.

Sadeh, H., Mirarchi, C., Shahbodaghlou, F. and Pavan, A. (2023), "Predicting the trends and cost impact of COVID-19 OSHA citations on US construction contractors using machine learning and simulation", *Engineering, Construction and Architectural Management*, Vol. 30 No. 8, pp. 3461-3479. https://doi.org/10.1108/ECAM-10-2021-0953.

Saka, A.B. and Chan, D.W.M. (2020), Profound barriers to building information modelling(BIM) adoption in construction small and medium-sized enterprises (SMEs): An interpretive structural modelling approach, *Construction Innovation*, 20(2), pp. 261-284.

Sutterby, P., Wang, X., Li, H.X. and Ji, Y. (2023), "The impact of COVID-19 on construction supply chain management: an Australian case study", *Engineering, Construction and Architectural Management*, Vol. 30 No. 8, pp. 3098-3122. https://doi.org/10.1108/ECAM-10-2021-0942.

Tan, T., Chen, K., Xue, F. and Lu, W. (2019). Barriers to Building Information Modelling(BIM) implementation in China's prefabricated construction: An interpretive structural modelling(ISM) approach. *Journal of Cleaner Production*, *219*, pp.949-959.

WHO (2020). *Coronavirus disease(COVID-19).* https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/coronavirus-disease-covid-19.

Wu, W.W. (2008). Choosing knowledge management strategies by using a combined ANP and DEMATEL approach. *Expert systems with applications*, *35*(3), pp.828-835.

Xiang, R. (2013), *Warshall algorithm*, https://shorturl.at/cxHOX.

Yang, L., Lou, J., Zhou, J., Zhao, X. and Jiang, Z. (2023), "Complex network-based research on organization collaboration and cooperation governance responding to COVID-19", *Engineering, Construction and Architectural Management*, Vol. 30 No. 8, pp. 3749-3779. https://doi.org/10.1108/ECAM-08-2021-0731.

Zhang, X. (2005). Critical success factors for public-private partnerships in infrastructure development. *Journal of construction engineering and management*, *131*(1), pp.3-14.

Appendix A: Potential Challenges of QA of Cb-CLSC during the COVID-19 Pandemic (Source: Authors own work)

Code	Proposed Challenges	Description	Source
C1	Collaboration difficulty	Collaboration is essential in the QA processes regardless of whether the project is a local or a cross-border construction project; however, this has been challenged amid the COVID-19 pandemic. Amid the pandemic, effective physical collaboration on cross-border projects has been impeded, though the industry has devised innovative virtual means to ensure that. QA is adequate with effective collaboration, and this has faced challenges as experts find it difficult to travel between borders and physically be on sites to inspect and collaborate with workers. On-site workers find it challenging to collaborate due to fear of getting infected by the virus and going contrary to the set restriction by the government.	Oo et al. (2021), Rankohi et al. (2022), Oey and Lim (2021)
C2	Cost of quarantine	QA, in this study's context, requires experts travelling from one border to another to inspect the quality of projects. Amid the pandemic, quarantine has imposed difficulty on this activity by adding additional cost, which caters for the quarantine period. This replicates in affecting the cost of Cross-border construction projects as the cost of quarantine is added to the construction cost. Hence, experts must consider quarantine costs to ensure an adequate QA.	Elnagger and Elhegazy (2022), Al-Mhdawi et al. (2022a), Leontie et al. (2022), Ling et al. (2022), Briggs et al. (2022)
C3	Delays from travelling	QA has been impeded by delay due to the delay in travelling caused by the COVID-19 pandemic. The delay is due to the documentation and quarantines before and during travelling. Experts must produce necessary documents and proof of quarantine before travelling to different countries. Sometimes, the delay may be due to the scrutiny of the necessary documents at the airport. This has thrown many challenges. To handle that, experts need to be proactive in their actions towards conducting the QA amid the pandemic.	Aigbavboa et al. (2022), Dobrucali et al. (2022); Al-Mhdawi et al. (2022a), Leontie et al. (2022), Ling et al. (2022), Olatunde et al. (2022)
C4	Complexity with border arrangement	QA has experienced the complexities caused at the airport due to the travelling arrangements regarding the pandemic. This has caused delays and extra costs to ongoing cross-border construction projects, especially when the project continuation is highly dependent on quality auditors and inspectors. With this, experts are challenged to consider the complexities involved during project planning and design.	Aigbavboa et al. (2022), Dobrucali et al. (2022)
C5	Feasibility study difficulty due to lack of information	Getting information, which is essential in the feasibility study of cross-border projects, has been impeded due to a lack of collaboration and physical on-site activities. There is a lack of physical collaboration to share information among the experts properly. This has then impeded the retrieval of reliable information for the QA. Experts are now reluctant to travel to conduct feasibility studies due to the fear of getting infected.	Rankohi et al. (2022), Simpeh et al. (2022), Kukoyi et al. (2022)
C6	Long approval process and schedule delays	QA has been challenged in this pandemic era by long approval processes and schedule delays of construction projects. Due to the slowness in activities on project execution as well as collaboration among experts on sites, auditing of works has been delayed. And, in a case where the project relies on the results of the quality audits, it takes longer if the auditors do not collaborate effectively and physically on site. This activity has been heavily challenged.	Rankohi et al. (2022), Oey and Lim (2021), Olatunde et al. (2022), Rehman et al. (2022), Agyekum et al. (2022)
C7	New design requirements to address health and social distancing concerns	The pandemic has again challenged the QA, causing new design requirements to address site health and social distancing issues. In executing cross-border projects towards the quality required, it is important to ensure the health and safety of the workers involved. Thus, the QA has been challenged to include the workers' health and safety by ensuring a good and safe environment for executing cross-border projects according to requirements.	Simpeh et al. (2022), Rankohi et al. (2022), Oey and Lim (2021)
C8	Complexity in assessing construction work processes	Assessing projects is paramount to QA towards quality requirements. Amid the pandemic, it has become difficult for experts to audit the quality of projects by assessing the project. This difficulty is due to the lack of communication and collaboration amid the pandemic because workers fear being infected by the virus. As a result, experts will have to dwell on virtual means to assess projects if possible.	Yang et al. (2021b)
C9	Shortage of skilled construction labourers	The number of skilled workers on-site to execute projects has been influenced negatively by the pandemic due to the fear of getting infected by the virus. The volume of work to be executed for a project has been impacted, which also affects the quality of the project being satisfied by the client. As QA requires the construction labourer to perform their responsibilities, work environments must be safe to encourage labourers to attend to their respective work.	Stride et al. (2021), Rankohi et al. (2022), Oey and Lim (2021), Jeon et al. (2022), Ogunrinde et al. (2022), Niroshana et al. (2022)
C10	Legal issues due to the breach of contract terms and conditions	QA, in the pandemic era, has experienced legal issues due to the breach of contract terms and conditions. These are associated with the work responsibilities of experts and their ability to fulfilling their part. However, due to the fear of infection, the pandemic has affected some of the responsibilities, leading to a breach of contract on specific cross-border projects.	Rankohi et al. (2022), Bsisu (2020), Husien et al. (2021), Umar (2022), Amoah et al. (2022), Radzi et al. (2022)

C11	Heavy workloads	Heavy workloads stress the workers in performing their responsibilities towards the quality of the project. This manifests during the pandemic when there is a shortage of labourers on a specific project; hence, workers may be charged to perform more work. In one way or the other, this affects the QA processes if assigned tasks are not efficiently performed.	Pamidimukkala et al. (2021), Oo et al. (2021a)
C12	Increase project duration	This may be due to the delays caused by the pandemic; therefore, more time may be needed to complete the cross-border project. It then affects the actual project duration, which may also affect the quality in terms of cost and time. This then challenges the QA process, therefore, must be considered during planning.	Oey and Lim (2021b)
C13	Working with masks influences fatigue, productivity, and quality	Since QA is process oriented and depends on the responsibility of all workers, their attitude toward work execution is crucial. Working with masks on, on the part of workers feels uncomfortable, which may affect their behaviour in executing projects, regardless of whether it is a local or a cross-border construction project. It affects their health by causing fatigue and other breathing issues. If not performed efficiently during the pandemic, it may affect the quality of projects.	Oey and Lim (2021)
C14	Design changes	The pandemic has introduced the challenge of design changes due to a shortage of construction materials. When this happens, it disrupts the project schedule, as well as the project cost, hence, affecting the process of managing the quality. This also affects the ability to ensure that the required quality of a project is achieved, i.e., if the design keeps changing.	Rankohi et al. (2022), Oey and Lim (2021)
C15	Supply-chain disruptions	The pandemic has disrupted construction supply chain management. This is severe in a cross-border construction project, which requires experts to travel to inspect the quality of projects. When this happens, quality auditors and others find it difficult to inspect projects in other countries, impacting the adequacy of the QA. This affects the material supply and experts' movements, which are now restricted by border arrangements.	Rankohi et al. (2022), Jeon et al. (2022), Al-Mhdawi et al. (2022a), King et al. (2022), Rehman et al. (2022), Ogunnusi et al. (2021), Husien et al. (2021)
C16	Shortage of raw construction material	The pandemic has affected the QA process in the form of a shortage of raw construction materials, as much as disrupting the construction supply chain. This then challenges the continuation of project executions and causes design changes that affect the quality of the project.	Agyekum et al. (2022), Rankohi et al. (2022)
C17	Site closure due to virus outbreak	Due to the COVID-19 regulations in stabilising the spread of the virus, construction sites need to be closed. This affects the project continuation and may affect the project duration, regardless of being a local project or a cross-border project. As such, inspection and auditing of work quality cease, affecting the QA processes.	Rankohi et al. (2022)
C18	Halting of construction business operations	The stopping of construction works also challenges the QA, like C17. This affects the QA process in terms of cost and project duration.	Aigbavboa et al. (2022)
Keywords used for the literature search		"challenges of quality management", barriers to quality management", "challenges to construction activities", "barriers to construction activities", "COVID-19 pandemic", "challenges to quality assurance", "challenges to managing quality during COVID-19", and "coronavirus"	

Appendix B: Detailed References to Table 1 (Source: Authors own work)

Serial number	References	Detail Reference
1	Oo et al. (2021)	Oo, B.L., Lim, T.H.B. and Zhang, Y. (2021). Women workforce in construction during the COVID-19 pandemic: Challenges and strategies. Construction Economics and Building, 21(4), pp.38-59.
2	Oey and Lim (2021)	Oey, E. and Lim, J. 2021, Challenges and action plans in construction sector owing to COVID-19 pandemic – a case in Indonesia real estates, International Journal of Lean Six Sigma, 12(4), pp. 835-858.
3	Simpeh et al. (2022)	Simpeh, F., Bamfo-Agyei, E. and Amoah, C. (2022), Barriers to the implementation of COVID-19 safety regulations: insight from Ghanaian construction sites, Journal of Engineering, Design and Technology, 20(1), pp. 47-65.
4	Kukoyi et al. (2022)	Kukoyi, P.O., Simpeh, F., Adebowale, O.J. and Agumba, J.N. (2022), Managing the risk and challenges of COVID-19 on construction sites in Lagos, Nigeria, Journal of Engineering, Design and Technology, 20 (1), pp. 99-144.
5	Rankohi et al. (2022)	Rankohi, S., Bourgault, M. and Iordanova, I. (2022). The new-normal challenges and IPD solutions: a Canadian case study, Built Environment Project and Asset Management, 13(1), PP. 20-35.
6	Aigbavboa et al. (2022)	Aigbavboa, C.O., Aghimien, D.O., Thwala, W.D. and Ngozwana, M.N. (2022), Unprepared industry meet pandemic: COVID-19 and the South Africa construction industry, Journal of Engineering, Design and Technology, 20(1), pp. 183-200.
7	Dobrucali et al. (2022)	brucali, E., Sadikoglu, E., Demirkesen, S., Zhang, C. and Tezel, A. (2022). Exploring the Impact of COVID-19 on the United States Construction Industry: Challenges and Opportunities. IEEE Transactions on Engineering Management.
8	Al-Mhdawi et al. (2022)	Al-Mhdawi, M.K.S., Brito, M.P., Abdul Nabi, M., El-Adaway, I.H. and Onggo, B.S., (2022). Capturing the impact of COVID-19 on construction projects in developing countries: A case study of Iraq. Journal of Management in Engineering, 38(1).
9	Leontie et al. (2022)	Leontie, V., Maha, L.G. and Stoian, I.C. (2022). COVID-19 Pandemic and Its Effects on the Usage of Information Technologies in the Construction Industry: The Case of Romania. Buildings, 12(2), p.166.
10	Ling et al. (2022)	Ling, F.Y., Zhang, Z. and Yew, A.Y. (2022). Impact of COVID-19 pandemic on demand, output, and outcomes of construction projects in Singapore. Journal of Management in Engineering, 38(2), p.04021097.
11	Olatunde et al. (2022)	Olatunde, N.A., Awodele, I.A. and Adebayo, B.O. (2022), Impact of COVID-19 pandemic on indigenous contractors in a developing economy, Journal of Engineering, Design and Technology, 20(1), pp. 267-280.
12	Rehman et al. (2022)	Rehman S. U., M., Shafiq, M.T. and Afzal, M. (2022). Impact of COVID-19 on project performance in the UAE construction industry, Journal of Engineering, Design and Technology, 20(1), pp. 245-266.
13	Agyekum et al. (2022)	Agyekum, K., Kukah, A.S. and Amudjie, J. (2022), The impact of COVID-19 on the construction industry in Ghana: the case of some selected firms, Journal of Engineering, Design and Technology, 20(1), pp. 222-244.
14	Stride et al. (2021)	Stride, M., Renukappa, S., Suresh, S. and Egbu, C. (2021), The effects of COVID-19 pandemic on the UK construction industry and the process of future-proofing business, Construction Innovation, Vol. ahead-of-print No. ahead-of-print.
15	Jeon et al. (2022)	Jeon, J., Padhye, S., Bhattacharyya, A., Cai, H. and Hastak, M. (2022). Impact of COVID-19 on the US Construction Industry as Revealed in the Purdue Index for Construction. Journal of Management in Engineering, 38(1), p.04021082.
16	Ogunrinde et al. (2022)	Ogunrinde, O., Okpala, I.U., Hatamleh, M.T., Oyeyipo, O. and Ojelabi, R.A. (2022). The Impact of the Covid-19 Pandemic on Construction Labor Force and Performance Metrics: A Case for Automation. In Construction Research Congress 2022 (pp. 541-551).
17	Niroshana et al. (2022)	Niroshana, N., Siriwardana, C. and Jayasekara, R. (2022). The impact of COVID-19 on the construction industry and lessons learned: a case of Sri Lanka. International Journal of Construction Management, pp.1-18.
18	Bsisu (2020)	Bsisu, K.A.D. (2020). The impact of COVID-19 pandemic on Jordanian civil engineers and construction industry. International Journal of Engineering Research and Technology, 13(5), pp.828-830.
19	Husien et al. (2021)	Husien, I.A., Borisovich, Z. and Naji, A.A. (2021). COVID-19: Key global impacts on the construction industry and proposed coping strategies. In E3S Web of Conferences (Vol. 263, p. 05056). EDP Sciences.

20	Umar (2022)	Umar, T. (2022). The impact of COVID-19 on the GCC construction industry. International Journal of Service Science, Management, Engineering, and Technology (IJSSMET), 13(2), pp.1-17.
21	Amoah et al. (2022)	Amoah, C., Bamfo-Agyei, E. and Simpeh, F. (2022). The COVID-19 pandemic: the woes of small construction firms in Ghana. Smart and Sustainable Built Environment, 11(4), pp.1099-1115.
22	Radzi et al. (2022)	Radzi, A.R., Rahman, R.A. and Almutairi, S. (2022). Modelling COVID-19 Impacts and Response Strategies in the Construction Industry: PLS–SEM Approach. International Journal of Environmental Research and Public Health, 19(9), p.5326.
23	Yang et al. (2021)	Yang, Y., Chan, A.P., Shan, M., Gao, R., Bao, F., Lyu, S., Zhang, Q. and Guan, J. (2021). Opportunities and Challenges for Construction Health and Safety Technologies under the COVID-19 Pandemic in Chinese Construction Projects. International Journal of Environmental Research and Public Health, 18(24), p.13038.
24	King et al. (2022)	King, S.S., Rahman, R.A., Fauzi, M.A. and Haron, A.T. (2022), Critical analysis of pandemic impact on AEC organizations: the COVID-19 case, Journal of Engineering, Design and Technology, 20(1), pp. 358-383.
25	Ogunnusi et al. (2021)	Ogunnusi, M., Hamma-Adama, M., Salman, H. and Kouider, T. (2020). COVID-19 pandemic: the effects and prospects in the construction industry. International journal of real estate studies, 14(Special Issue 2).
26	Osuizugbo (2021)	Osuizugbo, I.C. (2021). The need for and benefits of buildability analysis: Nigeria as a case study. Journal of Engineering, Design and Technology, 19(5), pp.1207-1230.
27	Simpeh et al. (2022)	Simpeh, F., Bamfo-Agyei, E. and Amoah, C. (2022), Barriers to the implementation of COVID-19 safety regulations: insight from Ghanaian construction sites, Journal of Engineering, Design and Technology, 20(1), pp. 47-65.
28	Matusiak et al. (2020)	Matusiak, Ł., Szepietowska, M., Krajewski, P., Białynicki-Birula, R. and Szepietowski, J.C. (2020). Inconveniences due to the use of face masks during the COVID-19 pandemic: a survey study of 876 young people. *Dermatologic therapy*, *33*(4)
29	Jones et al. (2022)	Jones, W., Gibb, A.G. and Chow, V. (2022). Adapting to COVID-19 on construction sites: what are the lessons for long-term improvements in safety and worker effectiveness?. *Journal of Engineering, Design and Technology*, *20*(1), pp.66-85.
30	Alsharef et al. (2021)	Alsharef, A., Banerjee, S., Uddin, S.J., Albert, A. and Jaselskis, E. (2021). Early impacts of the COVID-19 pandemic on the United States construction industry. *International journal of environmental research and public health*, *18*(4), p.1559.
31	Al Amri et al. (2021)	Al Amri, T., 2021. The economic impact of COVID-19 on construction industry: Oman's case. *European Journal of Business and Management Research*, *6*(2), pp.146-152.

Appendix C: Informed Consent Form

Dear Sir/Madam,

Quality Assurance of Cross-border Construction Logistics and Supply Chain in the Covid-19 Pandemic Era

You are invited to participate in an ongoing study that forms part of a PhD research by XXXXXXXXXXXX in the Department of XXXXXX, the University of XXXXXXXXX.

I hope to collect data based on your knowledge and experience regarding the implications of COVID-19 on the quality assurance of construction projects. The survey/interview will only take you about 15-20 minutes to complete. I would like to stress that all information collected will remain strictly confidential. Individual details will not be disclosed or identifiable from this survey.

It is important for you to consider if you fall in the following criteria before responding to the questionnaire:

1. You have extensive experience and were theoretically versed in the construction QA processes;
2. You have sufficient direct hands-on experience in construction QA; and
3. You have been involved in at least QA processes in their organization.

If you have any questions about the research, please feel free to contact Mr. XXXXXXXXXXXXX. If you have questions about your rights as a research participant, please contact the Human Research Ethics Committee (HREC), XXXX.

HREC Reference Number: EA210435

I understand the procedures described above and agree to participate in this study (tick the box and proceed to Part II).

☐

Appendix D: Final Questionnaire

A. Demographic Data Section

Kindly respond to the questions by carefully ticking [√] the appropriate box OR typing in the appropriate space for each item based on your valuable knowledge and experience.

1. Please state your country of origin or economy?...

2. Which sector do you belong?
a. Industry [ ] b. Academia [ ]

3. What is your designation?
a. Academician [ ] b. Quality Auditor [ ] c. Quality Engineer [ ] d. Quality Assurance/Control Manager [ ] e. Authorised person from the government [ ] f. Client representative [ ] g. Other [ ] Please specify………………………………………………………….

4. How long have you been working in the organisation?
a. Less than 5 years [ ] b. 5-10 years [ ] c. 11-20 years [ ] d. 21-30 years [ ] e. More than 30 years

B. Main Questions

Kindly respond by carefully ticking [√] the appropriate section of the tables based on your valuable knowledge and experience.

a. What is your level of agreement on the following challenges to the quality assurance of cross-border construction logistics and supply chain amid the COVID-19 pandemic? Please, answer using the Five-point Likert Scales: **1= Strongly disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly agree.**

b. What have been the effects of the challenges? Please rate using **Negative, Neutral, or Positive.**

(Source: Authors own work)

No.	**Challenges**	**Level of Agreement**					**Effect/impact/sentiment**		
		1	**2**	**3**	**4**	**5**	**Negative**	**Neutral**	**Positive**
1	Collaboration and communication difficulties.								
2	Long approval process and schedule delays.								
3	Heavy workloads and shortage of construction workers.								
4	Legal issues due to breach of contract terms and conditions.								
5	Working with masks difficulties.								
6	Design changes								
7	Shortage of raw construction material.								
8	Halting of operations and Site closure.								
9	Rising cost of construction materials.								
10	Changes in work practices.								
	Other, please state clearly and rank								

Appendix E: Interview Questions

<u>A. Demographic Data Section</u>

1. What is your country of origin?
2. What is your designation?
3. What is your qualification?
4. How long have you been working in the firm?

<u>B. Main Question</u>

What have been the challenges and opportunities in checking the quality of your project amid the COVID-19 pandemic, considering cross-border construction logistics and supply chain?

Appendix F: Results of Normal Test and Disparity Test (Source: Authors own work)

Code	Kolmogorov-Smirnov[a]						Mann-Whitney test							
	Level of Agreement			Level of sentiment			Level of agreement				Level of sentiments			
	K S value	df	Sig., P-value	K S value	df	Sig., P-value	U stat	W	Z-score	Asymp. Sig. (2-tailed)	U stat	W	Z-score	Asymp. Sig. (2-tailed)
C1	0.324	52	0.000	0.336	52	0.000	205.500	1025.500	-0.813	0.416	190.000	268.000	-1.218	0.223
C2	0.275	52	0.000	0.369	52	0.000	206.500	1026.500	-0.779	0.436	186.000	264.000	-1.352	0.177
C3	0.258	52	0.000	0.297	52	0.000	223.000	301.000	-0.388	0.698	192.000	270.000	-1.163	0.245
C4	0.224	52	0.000	0.267	52	0.000	236.500	314.500	-0.079	0.937	217.500	1037.500	-0.537	0.592
C5	0.213	52	0.000	0.284	52	0.000	201.500	279.500	-0.868	0.385	221.000	1041.000	-0.459	0.647
C6	0.251	52	0.000	0.247	52	0.000	213.500	291.500	-0.609	0.543	193.000	271.000	-1.106	0.269
C7	0.294	52	0.000	0.255	52	0.000	172.500	250.500	-1.577	0.115	240.000	318.000	0.000	1.000
C8	0.259	52	0.000	0.309	52	0.000	235.500	1055.500	-0.107	0.915	188.500	266.500	-1.215	0.224
C9	0.233	52	0.000	0.280	52	0.000	206.000	284.000	-0.782	0.434	227.000	305.000	-0.307	0.756
C10	0.266	52	0.000	0.247	52	0.000	229.500	307.500	-0.241	0.810	224.500	1044.500	-0.359	0.720

W=Wilcoxon, df=degree of freedom=52, P-value significant at ≤0.050; "a" = significant disparity among the sectors

Appendix G: Results of Descriptive Analysis and the Normalisation Scores (Source: Authors own work)

Code	Overall					
	Mean	SD	Ns	Rank	95% Confidence level for mean	
					Lower bound	Upper bound
C1	3.90[a]	1.089	0.725	3	3.60	4.21
C2	4.13	0.971	0.710	6	3.86	4.40
C3	3.87	1.155	0.718	5	3.54	4.19
C4	3.25	1.100	0.563	9	2.94	3.56
C5	3.65	1.170	0.550	10	3.33	3.98
C6	3.98	1.075	0.745	2	3.68	4.28
C7	4.04	1.120	0.760	1	3.73	4.35
C8	4.27	0.689	0.635	8	4.08	4.46
C9	4.04	0.862	0.680	7	3.80	4.28
C10	3.90[a]	1.089	0.725	3	3.60	4.21

Note: Ns = Normalisation score = (actual mean–minimum mean) / (maximum mean-minimum mean), only normalisation scores ≥0.5 are deemed critical by the experts; SD=Standard deviation; W=Wilcoxon; Ranking based on the Ns; df=degree of freedom=52; [a]Equal mean, wherein challenges with equal SD are ranked the same; also challenges with low SD is ranked higher.

Appendix H: Results of Rank Agreement Analysis (Source: Authors own work)

Code	Academia			Industry			Agreement Analysis		
	Mean	SD	Rank	Mean	SD	Rank	R_i	$\lvert(R_{i1} - R_{i2})\rvert$	$\lvert R_i - R_{j2}\rvert$
C1	3.92	1.443	3	3.90	0.982	7	10	4	0.9
C2	4.25[a]	1.138	2	4.10	0.928	4	6	2	4.0
C3	3.83[a]	1.030[b]	4	3.88	1.202	8	12	4	1.1
C4	3.25	1.055	10	3.25	1.127	10	20	0	9.1
C5	3.42	1.165	8	3.73	1.176	9	17	1	6.1
C6	3.67	1.497	7	4.08	0.917	5	12	2	1.1
C7	3.42	1.505	9	4.22	0.920	2	11	7	0.1
C8	4.25[a]	0.866	1	4.28	0.640	1	2	0	8.9
C9	3.83[a]	1.030[b]	4	4.10	0.810	3	7	1	3.9
C10	3.75	1.357	6	3.95	1.011	6	12	0	1.1
Total							$\sum_{i=1}^{n}(Ri) = 109$ $R_j = \frac{108}{10} = 10.9$	$\sum_{i=1}^{n}\lvert(Ri1 - Ri2)\rvert = 21$	$\sum_{i=1}^{n}\lvert(Ri1 - Rj2)\rvert 37.2$

[a]Equal mean; [b]Equal SD, wherein challenges with equal SD are ranked the same.

Appendix I: Interrelationship between the Critical Challenges

A. Demographic Data Section

Kindly respond to the questions by carefully ticking [√] the appropriate box OR typing in the appropriate space for each item based on your valuable knowledge and experience.

1. Please state your country of origin?..
2. What is your qualification?
   a. BSc. [ ] b. MSc. [ ] c. PhD [ ] d. other [ ], please specify………………………………
3. Which sector do you belong?
   a. Industry [ ] b. Academia [ ]
4. What is your designation?
   a. Academician [ ] b. Quality Auditor [ ] c. Quality Engineer [ ] d. Quality Assurance/Control Manager [ ] e. Authorised person from the government [ ] f. Client representative [ ] g. Other [ ] Please specify……………………………………………………….
5. How long have you been working in the organisation?
   a. Less than 5 years [ ] b. 5-10 years [ ] c. 11-20 years [ ] d. 21-30 years [ ] e. More than 30 years

B. Main Questions

Kindly respond based on your valuable knowledge and experience. The following are critical challenges to the QA of cross-border construction logistics and supply chain amid the COVID-19 pandemic. How do they interact among themselves? Kindly respond by ticking (√) under 'Yes/No' on how the challenges influence one another.

(Source: Authors own work)

"Collaboration and communication difficulties" influences:		**Yes**	**No**
1	Long approval process and schedule delays.		
2	Heavy workloads and shortage of construction workers.		
3	Legal issues due to breach of contract terms and conditions.		
4	Working with masks difficulties.		
5	Design changes		
6	Shortage of raw construction material.		
7	Halting of operations and Site closure.		
8	Rising cost of construction materials.		
9	Changes in work practices.		

(Source: Authors own work)

"Long approval process and schedule delays" influences:		**Yes**	**No**
1	Collaboration and communication difficulties.		
2	Heavy workloads and shortage of construction workers.		
3	Legal issues due to breach of contract terms and conditions.		
4	Working with masks difficulties.		
5	Design changes		
6	Shortage of raw construction material.		
7	Halting of operations and Site closure.		
8	Rising cost of construction materials.		
9	Changes in work practices.		

(Source: Authors own work)

"Heavy workloads and shortage of construction workers" influences:		**Yes**	**No**
1	Collaboration and communication difficulties.		

2	Long approval process and schedule delays.		
3	Legal issues due to breach of contract terms and conditions.		
4	Working with masks difficulties.		
5	Design changes		
6	Shortage of raw construction material.		
7	Halting of operations and Site closure.		
8	Rising cost of construction materials.		
9	Changes in work practices.		

(Source: Authors own work)

"Legal issues due to breach of contract terms and conditions" influences:		**Yes**	**No**
1	Collaboration and communication difficulties.		
2	Long approval process and schedule delays.		
3	Heavy workloads and shortage of construction workers.		
4	Working with masks difficulties.		
5	Design changes		
6	Shortage of raw construction material.		
7	Halting of operations and Site closure.		
8	Rising cost of construction materials.		
9	Changes in work practices.		

(Source: Authors own work)

"Working with masks difficulties" influences:		**Yes**	**No**
1	Collaboration and communication difficulties.		
2	Long approval process and schedule delays.		
3	Heavy workloads and shortage of construction workers.		
4	Legal issues due to breach of contract terms and conditions.		
5	Design changes		
6	Shortage of raw construction material.		
7	Halting of operations and Site closure.		
8	Rising cost of construction materials.		
9	Changes in work practices.		

(Source: Authors own work)

"Design changes" influences:		**Yes**	**No**
1	Collaboration and communication difficulties.		
2	Long approval process and schedule delays.		
3	Heavy workloads and shortage of construction workers.		
4	Legal issues due to breach of contract terms and conditions.		
5	Working with masks difficulties.		
6	Shortage of raw construction material.		
7	Halting of operations and site closure.		
8	Rising cost of construction materials.		
9	Changes in work practices.		

(Source: Authors own work)

"Shortage of raw construction material" influences:		**Yes**	**No**
1	Collaboration and communication difficulties.		
2	Long approval process and schedule delays.		
3	Heavy workloads and shortage of construction workers.		
4	Legal issues due to breach of contract terms and conditions.		
5	Working with masks difficulties.		
6	Design changes		
7	Halting of operations and Site closure.		

8	Rising cost of construction materials.		
9	Changes in work practices.		

(Source: Authors own work)

"Halting of operations and Site closure" influences:		**Yes**	**No**
1	Collaboration and communication difficulties.		
2	Long approval process and schedule delays.		
3	Heavy workloads and shortage of construction workers.		
4	Legal issues due to breach of contract terms and conditions.		
5	Working with masks difficulties.		
6	Design changes		
7	Shortage of raw construction material.		
8	Rising cost of construction materials.		
9	Changes in work practices.		

(Source: Authors own work)

"Rising cost of construction materials" influences:		**Yes**	**No**
1	Collaboration and communication difficulties.		
2	Long approval process and schedule delays.		
3	Heavy workloads and shortage of construction workers.		
4	Legal issues due to breach of contract terms and conditions.		
5	Working with masks difficulties.		
6	Design changes		
7	Shortage of raw construction material.		
8	Halting of operations and Site closure.		
9	Changes in work practices.		

(Source: Authors own work)

"Changes in work practices" influences:		**Yes**	**No**
1	Collaboration and communication difficulties.		
2	Long approval process and schedule delays.		
3	Heavy workloads and shortage of construction workers.		
4	Legal issues due to breach of contract terms and conditions.		
5	Working with masks difficulties.		
6	Design changes		
7	Shortage of raw construction material.		
8	Halting of operations and Site closure.		
9	Rising cost of construction materials.		

Appendix J: Specific Interviewee Responses (Source: Authors own work)

Interviewee	Specific response		Area of the challenge in QA	Area of the opportunity in QA
	Challenge	Opportunity		
A	*"For construction project quality management, the biggest challenge is the usual face-to-face communication link of quality management."*	*"It stimulates the application of intelligent detection, Internet, Internet of things and other technologies in quality management, and promotes the development of construction project quality management."*	Work process, including inspection, testing, auditing, communication, etc.	Technology adoption
B	*"How to use information technology to monitor the quality of buildings in real-time, consider stakeholders, and coordinate the problems."*	*"The rise of prefabricated buildings will replace the traditional architectural model, which also puts forward higher requirements for the building quality, such as standing out in the same architectural environment."*	Work process, including inspection, testing, auditing, communication, etc.	Technology adoption
C	*"With the introduction of new technologies, employers' employment requirements have increased, on-the-job learning content has increased, and the risk of job-hopping and sunk costs have increased significantly."*	*"Development of new technologies. Employers are beginning to seriously explore the application of new technologies, rather than superficial."*	Cost	Technology adoption
D	*"Increased costs and longer timelines."*	*"Under an epidemic, there is a need to reduce the time for personnel to operate in the field and to improve the corresponding technical development."*	1. Cost 2. Time	Worker management
E	*"The centralised start of work after the end of the epidemic may increase the cost of rework."*	*"Using existing tools or developing new platforms and tools to adapt to new situations in the future plays a crucial role in project quality management, which is an opportunity for quality management."*	Cost	Work process management

F	*"The epidemic prevention and control measures led to increased construction costs and reduced profits."* *"The number of migrant workers decreased during the epidemic prevention and control period, resulting in higher labour costs."*	Not mentioned	Cost	-
G	*"The current policy of vaccination in China is strict and work is often suspended."*	*"The greatest opportunity would be to demonstrate the importance of skilled workers. Because of the frequent stoppages, many projects are now not allowed to be worked on by new people because they are slow. So, the importance of skilled workers increases, and it would definitely be good to have skills that can assist with quality control."*	Time	Worker management
H	*"Increased workloads, such as vaccination inspections, consuming more costs and time."*	*"The pandemic contributes to the digital transformation of the way quality management is carried out and improves the automation of quality monitoring."*	1. Cost 2. Time	Technology adoption
I	*"More challenges are caused by temporary epidemic control requirements; production workers and front-line managers may not be able to get to the factory on time because of temporary lockdown."*	*"Under the epidemic prevention and control policy, if the management personnel cannot be present, fully automated and digital quality management is very necessary."*	Time	Technology adoption
J	*"Due to different epidemic prevention and control policies in Mainland China and Hong Kong, higher epidemic prevention and control requirements cost us more energy and time, which in turn reduces our income."*	*"If the epidemic continues, online monitoring of logistics movement may be the future."*	1. Cost 2. Time	Technology adoption

K	*"The first is the impact on the production of prefabricated components. Due to the impact of the epidemic, the raw materials are not timely procured, including the delivery of prefabricated components under the impact of the epidemic, which are testing our supply chain capacity."*	*Not mentioned*	1. Raw materials 2. Time	-
L	*"Mainly goes to the quality supervision/checking using an "indirect" or "remote" method together with using visual aid."*	*"Mainly goes to the "flexibility" in terms of time when performing the quality inspection."*	Work process, including inspection, testing, auditing, communication, etc.	Work process management
M	*"The works are suspended due to a positive case."*	*Not mentioned*	Time	-