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Critical Construction Readiness Factors for Bridge Projects

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Abstract

Egyptian investment in infrastructure projects is considerable, especially in bridge construction projects that commonly face delays, cost overruns, rework, and poor productivity. A proper construction readiness (CR) assessment can enhance project performance. This study aims to identify the critical factors that impact the CR of bridge projects in Egypt. Through a literature review and a pilot study with ten highly experienced professionals, a list of 43 construction readiness factors (CRFs) was prepared. To quantitatively rank these CRFs and identify the critical ones, a questionnaire was administered through structured interviews with 92 project managers and engineers experienced in bridge construction projects in Egypt. The participants represented the perspectives of contractors, owners, and consultants. A CRF with a normalized mean score greater than or equal to 0.5 was classified as a critical construction readiness factor (CCRF). For these CCRFs, agreement analysis among contractors, owners, and consultants was conducted using the Kruskal-Wallis test. The correlation strength was also investigated using Spearman's correlation. In total, 16 CCRFs were identified, with the top five: verification of underground utility locations, completion of land surveying work, issuance of clear and sufficient construction drawings, adequate geotechnical investigations, and obtaining all necessary permits and approvals from local authorities. This study provides practitioners with critical factors necessary for assessing the CR of bridge projects in Egypt. From an academic standpoint, it enhances understanding of CR, which is rarely discussed.

Keywords: Construction Readiness; Critical Factors; Bridge Construction Projects; Structured Interview; Egypt.

1. Introduction

Infrastructure projects drive the growth of any developing country. Among these projects, bridges are crucial in maintaining uninterrupted traffic flow at road intersections and watercourse crossings, ensuring smooth and continuous transportation. In recent years, Egypt has witnessed a boom in bridge construction [1]. Between 2014 and 2024, the Egyptian government allocated 2 trillion EGP (approximately $41.71 billion) to transportation infrastructure projects, including constructing 1000 bridges and tunnels as a part of these initiatives [2]. Bridge construction projects are prone to risks that can lead to delays and cost overruns [3]. Unlike many other construction projects, bridges are frequently constructed in areas with continuous traffic, presenting significant challenges in maintaining traffic flow and ensuring the safety of both drivers and construction workers. They also include extensive interaction with various existing infrastructures, requiring information and permits from multiple authorities. Moreover, change orders often arise during construction due to varying soil conditions, leading to extended project timelines, increased costs, and disputes between

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contractors and owners [4]. Therefore, substantial preconstruction efforts should be exerted to enhance the project performance and ensure a smooth construction process without unintended interruptions.

Poor preconstruction practices are frequently recognized as significant contributors to delays [5], cost overruns [6], reworks [7], and productivity declines [8]. However, only a few studies have addressed preconstruction efforts as a single unit, reflecting the overall preconstruction maturity. This unit can be referred to as construction readiness (CR), which is defined by Ibrahim et al. [9] as "a series of activities and procedures that should be completed or substantially completed prior to construction to productively start and sustain construction operations." This definition may be refined for simplicity as a set of integrated preconstruction efforts enhancing construction performance. In this study, the term 'preconstruction phase' refers to the period between issuing the letter of award, or the letter of intent to award, and the actual commencement of construction. *Preconstruction activities* are the tasks that should be completed during this phase [10-12]. CR can be seen as a measure of the maturity of the preconstruction phase.

Before 2014, the transportation infrastructures in Egypt had deteriorated and were insufficient for smooth and safe traffic flow, posing a barrier to several developments. Consequently, the Egyptian government treats bridge and highway projects as urgent and necessary projects that must be constructed quickly. Therefore, for most current bridge construction projects, the direct order (direct awarding) method is employed for contractor selection instead of traditional competitive methods [13, 14], which take much longer. A significant portion of contract documents are completed after the contractor is selected and before the actual commencement of construction. This approach increases the importance of the preconstruction phase and highlights the significance of investigating CR before proceeding with the construction of bridge projects.

Almost all transport infrastructure projects experience significant cost escalations [15]. A field survey on road projects in Egypt, which face similar challenges to bridge projects, showed that all projects experienced time overruns and cost escalations, averaging 74% and 46%, respectively, with an average quality level of 71.76% [16]. This poor performance directly impacts GDP, as the primary contract type for infrastructure projects in Egypt is the unit price, where the risk is shared between the owner (public sector) and the contractor [17]. Consequently, proper management practices are essential to control risks and meet project requirements with cost-effective solutions [18, 19]. Project performance can be improved by ensuring the project is construction-ready, which can lead to approximately a 22% improvement in time, 20% in cost, a 7% reduction in rework, a 29% increase in productivity, and a 21% reduction in changes compared to projects that are not construction-ready [13]. Achieving this mandates a thorough construction readiness (CR) assessment, which requires identifying the critical factors that distinguish construction-ready projects from those that are not [9].

The Construction Industry Institute (CII) was the first to study CR as a standalone concept [20]. This effort was consolidated into a model for assessing the CR of industrial projects in the U.S. [9]. Following this, Radzi et al. [21] identified a list of critical factors required for assessing the CR of highway projects in Malaysia. Also, Abdul-Rahman et al. [22] identified the critical factors for abandoned housing projects. Radzi et al. [23] investigated the key challenges of CR when using BIM in housing projects.

The existing literature on CR focuses on project types other than bridges. It is limited to countries that do not necessarily share the characteristics of Egypt's construction industry, showing a gap that this research aims to address. This research aims to identify the critical factors affecting the CR of bridge projects in Egypt. A pilot study with ten highly experienced professionals was conducted, and a questionnaire survey was administered through structured interviews with 92 project managers and engineers experienced in bridge construction projects. The questionnaire responses were analyzed using mean score ranking, normalization, Cronbach's alpha reliability, agreement analysis using the Kruskal-Wallis and post-hoc Dunn's tests, and Spearman's correlation to measure the strength of the relationship between the different groups. The analysis resulted in the identification of 16 critical construction readiness factors (CCRFs). These factors will help project teams assess the CR of their bridge projects and avoid commencing construction prematurely. From an academic standpoint, this research deepens the comprehension of CR, a topic that is rarely discussed.

The remainder of this paper is structured as follows: The second section provides a literature review of prior studies related to CR and explains the rationale for conducting this research. The third section outlines the adopted methodology to address the research aim. The fourth section displays the results of the data analysis process. Finally, the fifth section delves into a discussion of each identified CCRF. It also includes a comparison with the findings of previous CR studies.

2. Literature Review

2.1. Premature Start to Construction

The CII funded the research team RT-323 to investigate the factors contributing to premature starts in construction to prevent the negative consequences and delays that can arise [24]. Through in-depth case studies, nine drivers, ten leading indicators, and thirteen impacts of premature starts were identified [11]. These findings were quantitatively assessed using a questionnaire survey [12]. As a result, the top three drivers were the owner's aggressive schedule, the owner's benefits from commencing construction, and the time-to-market considerations. The top three leading indicators were incomplete engineering documentation, delayed design deliverables, and unrealistic schedules. The top three impacts were cost overruns, delays, and rework. Building upon this, Leite & Griego [25] developed an Excel-based tool named premature start impact analysis (PSIA), which enables project team members to identify the possible impacts of user-reported drivers and leading indicators. PSIA encourages transparent communication among project parties about the negative consequences of commencing a construction project prematurely. While PSIA assists project teams in taking proactive measures, it does not offer any guidance on preconstruction activities that could prevent premature starts.

2.2. Readiness Assessment for Flash Tracking

Flash-track projects can be challenging to manage and require a different approach to project delivery [26]. As a result, the CII funded research team RT-311 to develop a tool for its members to assess their readiness to execute flash track projects [27]. Austin et al. [28] identified 47 critical practices for successfully implementing flash track projects. Pishdad-Bozorgi et al. [29] determined the relative weights of these practices using the analytical hierarchy process and incorporated them into a readiness assessment model. This model evaluates the capability of the executing company to adopt a particular type of project delivery instead of focusing on whether the project is ready for construction. In other words, it evaluates company readiness rather than project readiness.

2.3. Project-Level Readiness Assessment

The construction project typically progresses through multiple phases, from conception to completion, with each phase building upon the deliverables of the preceding ones. This progressive elaboration makes the project-level readiness assessment dependent on the timing at which the project is investigated. Therefore, this assessment can be conducted before commencing each phase based on the outputs of the previous phases. The CII developed the project definition rating index (PDRI) tool to evaluate how well a project's scope is defined [30]. PDRI is considered a project-level readiness assessment tool, as it is employed during an earlier stage to assess the design readiness of the project [21]. Several studies were conducted to customize PDRI to suit various types of construction projects [31-36]. Aligning with the same concept, assessing the CR is also a project-level readiness assessment conducted before the construction phase. The concept of CR is rarely discussed as a single topic in the available literature.

2.4. Construction Readiness

In 2017, the CII initiated a research project titled "*Construction Readiness Assessment for Productivity Improvement*" [20]. A list of 228 binary construction readiness factors (CRFs) spanning across 15 categories was developed by Ibrahim et al. [9]. The relative weights of these factors were determined using a mathematical model based on data from CII's projects in the U.S. These weights are compiled in an assessment model, expressing a project's CR as a percentage. This model is the first of its type in research and practice; however, it is limited to vertical industrial projects. Therefore, Ibrahim et al. [9] recommended further CR studies to include horizontal projects such as highways, bridges, and tunnels.

Following this recommendation, valuable research was conducted on highway construction projects in Malaysia. Radzi et al. [37] identified 31 CRFs through interviews with industry experts. Subsequently, Radzi et al. [38] investigated whether there are differences in these CRFs between the different types of highway projects (i.e., expressway and highway projects). Using a questionnaire survey, Radzi et al. [21] identified 18 critical factors for assessing the CR of highway projects. Abdul-Rahman et al. [39] investigated the CR of abandoned projects in Malaysia through interviews with contractors and project owners. Abdul-Rahman et al. [22] identified 45 CRFs for abandoned housing projects. Subsequently, they identified 21 critical factors for assessing CR using a questionnaire survey.

Radzi et al. [23] investigated the challenges of achieving sufficient CR for building information modeling (BIM)-based building projects in Malaysia. Through interviews with experts, they identified 12 themes of challenges facing CR when BIM is adopted. These findings are qualitative and were not quantitatively assessed.

2.5. Research Gap

Despite the significant impact of CR on project performance, only a few studies have focused on this topic. Existing research on CR can be consolidated into three primary efforts. Ibrahim et al. [9] developed a model for assessing CR, but it is limited to vertical industrial projects and does not apply to horizontal projects such as highways, bridges, and tunnels. Radzi et al. [21] identified the critical factors for assessing the CR of highway projects. Similarly, Abdul-Rahman et al. [22] identified the critical factors for abandoned housing projects. Both studies are limited to the Malaysian construction industry and specific project types, constraining their applicability to other project contexts and different construction environments. A research gap exists in capturing the characteristics of bridge projects or the Egyptian market. This research aims to address this gap by identifying the critical factors that impact the CR of bridge projects in Egypt and could be used for its assessment.

3. Research Methodology

The methodology of this research, shown in Figure 1, includes a literature review, an expert-based pilot study, data collection using a questionnaire survey, and data analysis.

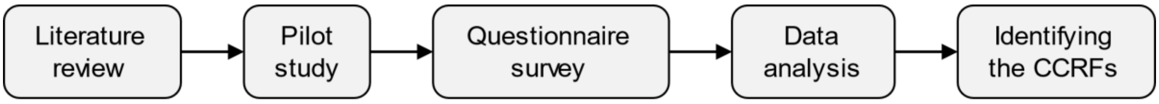

Figure 1. Research methodology

Based on reviewing the available literature on CR [9, 13, 21, 22] and the expert-based pilot study, a list of 43 CRFs (Table 1) for bridge projects was prepared. These factors were divided into six categories: engineering, planning, legal and contractual aspects, site preparation, project team, and resources. The pilot study involved ten highly experienced professionals, seven with more than 25 years of experience and three with more than 15 years. Additionally, two of them hold Ph.D. degrees. The pilot study aimed to extract the CRFs suitable for the bridge projects in Egypt from those identified in the literature and to include any potential CRFs if necessary. The final list of CRFs was then used to build the questionnaire survey, which is discussed in the following section.

3.1. Questionnaire Survey

The questionnaire is an effective data collection tool frequently used in construction management research [40-42]. It was used in this research to quantitatively rank the CRFs based on their importance, identify the critical ones among them, and investigate any disagreements among the contractor, owner, and consultant regarding these critical factors. The following subsections discuss the targeted population, the sampling method, the development of the questionnaire, and the data collection process.

3.1.1. Target Population

The targeted population consisted of project managers and engineers working on bridge construction projects in Egypt, encompassing members from contractors, owners (public sector), and consultants. Owner members included are individuals from the General Authority for Roads and Bridges (GARB), the principal owner of bridges in Egypt.. Three criteria were established for the participants to ensure the quality of the data: a minimum of four years of experience, involvement in at least two bridge construction projects in Egypt, and engagement in an ongoing one. These criteria guarantee their experience and representativeness.

3.1.2. Sampling Method

In the absence of a sampling frame for this research, non-probability sampling methods were utilized [43]. Non-probability sampling occurs when it is not possible to specify the probability that any person within the survey's population will be included in the sample [44]. Purposive and snowball techniques were employed. In purposive sampling, the researchers select participants based on defined criteria that fit the research purpose [45], while snowball sampling is used to expand the participant group through referrals [46]. In snowball sampling, initial participants are asked to suggest more contacts from their networks who meet the research criteria and are willing to participate; these suggested contacts, in turn, recommend additional potential participants, creating a chain [47]. It is typically used when it is challenging to find suitable participants, especially in studies focused on specific issues [48]. Using the snowball approach in this research was also justified by its frequent use in construction management research [49-51].

3.1.3. Questionnaire Development

The questionnaire was divided into four sections. The first section collected demographic information about the participant, including name, position, years of experience, company name and type (owner, consultant, or contractor), the number of bridge projects participated in, the name of the current project engaged in, and contact information. The second section consisted of the 43 CRFs shown in Table 1. Participants were asked to evaluate the importance of each factor regarding the CR of bridge projects. A five-point Likert scale (1 = not important, 2 = less important, 3 = moderately important, 4 = important, and 5 = very important) was used for this purpose. The third section comprised two questions: the first inquired whether the absence or inadequate addressing of any of the 43 CRFs impacted the performance of the participant's ongoing project, and the second invited participants to suggest additional CRFs. In the fourth section, participants were asked to recommend other experienced individuals who could complete the questionnaire.

Before collecting the data, the questionnaire was validated by four practitioners with more than ten years of experience. The recommendation was to translate the questionnaire into Arabic. The translated version ensures clarity in data collection, as the primary language in Egypt is Arabic. Participants were free to choose either the English version or the Arabic one.

Table 1. List of CRFs for bridge projects

Category	Code	Description of the CRF	Source
Engineering	CRF01	Clear and sufficient construction drawings have been issued to support construction activities (issued for construction drawings).	[9, 21, 22]
	CRF02	Specifications, standards, and bill of quantities (BOQ) have been clearly published to support construction activities.	[13]
	CRF03	Design coordination and clash detection have been completed.	[9, 21, 22]
	CRF04	A well-defined process for requests for information (RFIs) and engineering support has been established.	[9, 21, 22]
	CRF05	The process for submittal and approval of shop drawings, items, and vendor information has been clearly defined.	[13, 22]
Planning	CRF06	The construction schedule has been developed.	[13, 21, 22]
	CRF07	A well-defined construction execution plan has been developed, including method statements for each activity.	[13]
	CRF08	The critical path has been identified.	[13]
	CRF09	Planned activities' durations and production rates are realistic and in line with project conditions.	[9, 21, 22]
	CRF10	A proper site layout plan has been developed.	Pilot study
	CRF11	The HSSE (Health, Safety, Security, and Environmental) plan has been developed.	[13]
	CRF12	The project quality plan has been developed.	[13]
	CRF13	A plan to ensure communication and coordination among project participants has been developed.	[13]
	CRF14	The mobilization plan has been developed.	[13]
	CRF15	A cost control system is ready for the project.	[13]
	CRF16	A document control system is ready for the project.	[13]
Legal and contractual aspects	CRF17	All necessary permits and approvals from local authorities have been obtained.	[13, 21, 22]
	CRF18	The land acquisition has been completed.	[21, 22]
	CRF19	The notice of award has been issued.	[21, 22]
	CRF20	The scope and completeness criteria have been well-defined in the contract.	[13]
	CRF21	The down payment procedures have been agreed upon.	Pilot study
	CRF22	The necessary insurance for the project has been obtained.	[21, 22]
Site preparation	CRF23	Adequate geotechnical investigations of the project site have been completed.	[13]
	CRF24	All necessary utilities are available on site (e.g., electricity, drainage, communication tools, etc.).	[13, 21, 22]
	CRF25	The locations of underground utilities at the construction site have been verified.	[21]
	CRF26	The site condition has been verified to be the same as the contract.	[21, 22]
	CRF27	The traffic control plan has been developed, approved by authorities, and implemented.	[21, 22]
	CRF28	The relocation of underground utilities that will be interrupted by the project has been completed.	[21]
	CRF29	On-site safety communication (safety signage and safety board locations) is in place.	[13, 21, 22]
	CRF30	The site security control procedures have been established.	[13]
	CRF31	Land surveying work has been completed.	Pilot study
Project team	CRF32	The project team members have the skills, capacity, and qualifications to take on the project.	[9]
	CRF33	A responsibility assignment matrix has been developed for the project.	[13]
	CRF34	An organizational chart for the construction team has been developed and communicated to assign roles and functions.	[13]
	CRF35	The communication methods among the project team have been well-defined (reports, e-mails, meetings, etc.).	[13]
Resources	CRF36	Funding for the project has been acquired.	[21, 22]
	CRF37	The relevant contracts have been signed to support the construction schedule (e.g., subcontracts, supply contracts, and purchase orders).	[9]
	CRF38	A proposed list of subcontractors has been prepared.	Pilot study
	CRF39	A clear procurement process and supporting systems for ordering, delivering, installing, and storing materials have been established.	[9, 21, 22]
	CRF40	A tool and equipment management plan has been developed, including acquisition, mobilization, placement, storage, movement, and maintenance.	[13]
	CRF41	All equipment operators are certified.	[13]
	CRF42	All pieces of equipment have been inspected and certified.	[13]
	CRF43	The resources (people, tools, and systems) needed to perform the quality control plan are in place.	[13]

Note: Some CRFs in the table were subjected to minor or major edits (merges and/or additions) from their original versions in the sources

3.1.4. Data Collection Process

The data was collected via structured interviews because of the poor response rates in most construction management studies conducted in Egypt when collecting data through questionnaires with practitioners [52]. In this method, data is acquired using a questionnaire sheet containing pre-established questions presented in a structured format [53]. The interviewer's role is to provide the interviewee with any necessary clarifications. This approach offers several advantages, including reaching difficult-to-reach populations, achieving higher response rates, and ensuring that data collection procedures are correctly followed [54]. Additionally, it guarantees the highest level of data accuracy [55]. The data collection process included scheduled visits to bridge construction sites, meetings at offices, and private meetings. In total, 92 questionnaires were collected. This sample size appears adequate, considering the research focuses on a specific field—bridge construction—which includes a relatively small number of engineers involved. It is also worth noting that the sample size used is sufficient when compared with other published studies that utilized snowball sampling along with structured interviews; Darko et al. [56], Ahmadabadi & Heravi [57], and El-Razek et al. [58] used sample sizes of 43, 48, and 88, respectively.

3.2. Data Analysis

Figure 2 illustrates the algorithm used to identify the CCRFs and confirm the agreement among the study groups. Initially, the CRFs were ranked based on their statistical mean scores. Subsequently, the mean scores were normalized, resulting in each CRF receiving a normalized value ranging from 0 to 1. A CRF with a normalized value of 0.5 or more was considered a CCRF. Several published studies adopted this approach of ranking and normalization to identify critical factors [21, 22, 59]. Cronbach's alpha coefficient was then calculated for the identified CCRFs as a reliability measure. Afterward, an agreement analysis was conducted among the perspectives of study groups (contractors, consultants, and owners) regarding each CCRF to ensure its criticality among the different groups. The Kruskal-Wallis test was employed for agreement analysis, which is frequently used for this purpose [21, 60, 61]. For the CCRFs that showed disagreement, the post-hoc Dunn's test was applied to investigate which study groups differed. Finally, Spearman's rank correlation coefficients were utilized to quantitatively measure the strength of relationships between each pair of study groups regarding the total identified CCRFs. This approach was adopted in several studies [60, 62, 63]. The following subsections discuss each of these steps in detail.

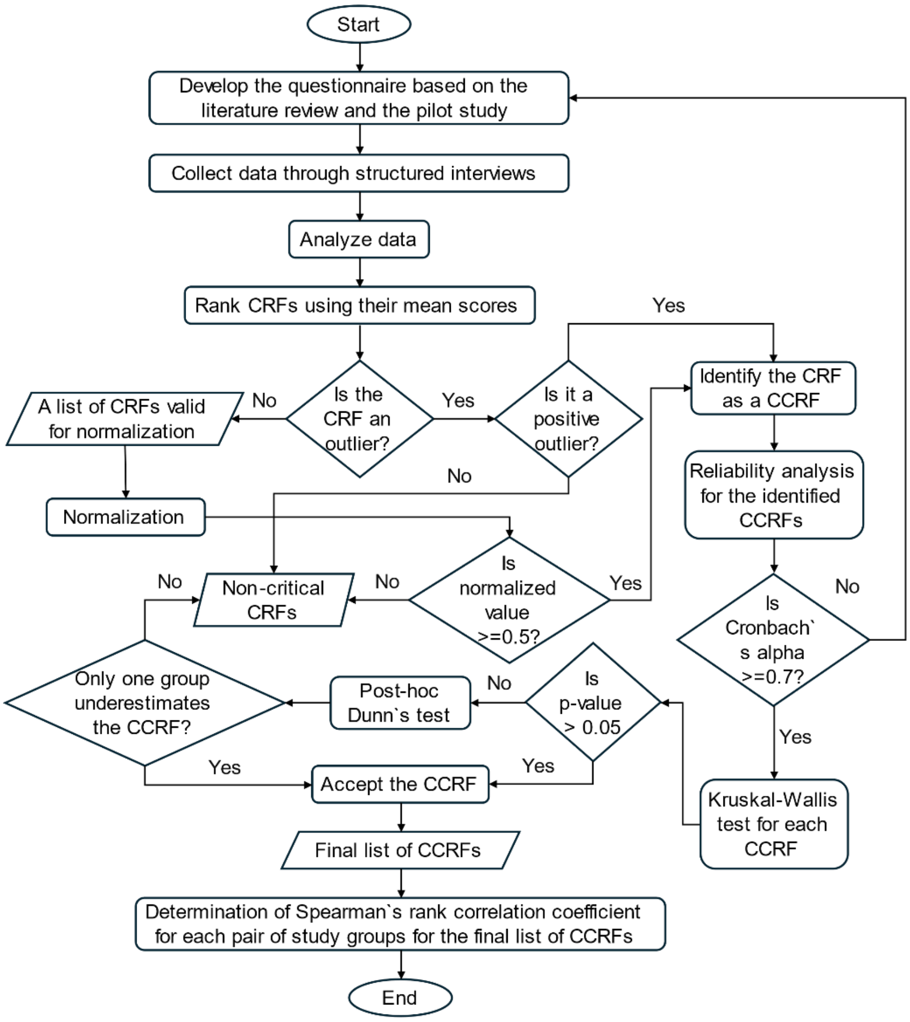

Figure 2. Steps followed to identify the CCRFs

3.2.1. Ranking CRFs Based on the Mean Score

The statistical mean scores were used to rank the CRFs based on their importance for CR. The mean score for each CRF is calculated by adding the Likert scores obtained from all participants for this CRF and then dividing the sum by the total number of participants. It provides a summary measure of the responses ' central tendency, indicating the average level of importance assigned to each CRF. For the CRFs with the same mean score, the CRF with a lower standard deviation was ranked first [64]. A mean score with a small standard deviation is more representative of the data than the mean score with a large standard deviation [65].

3.2.2. Normalization

After ranking the CRFs, normalization of the mean scores was performed. Normalization is a technique for scaling the data to a specified range [66]. It requires a data set without outliers [67]. Therefore, outliers must be investigated and excluded, if any. The box and whisker plot was employed for this purpose, as it is a tool not sensitive to extreme values [68]. Subsequently, Equation 1 was used for mapping the mean scores to normalized values in the range of [0, 1] [67].

$$Value\ after\ Normalization = \frac{Value\ before\ Normalization - Minimum\ Value}{Maximum\ Value - Minimum\ Value} \tag{1}$$

The analysis utilized these normalized values to identify the CCRFs. A cutoff value of 0.5 was established to distinguish between critical and non-critical factors. Therefore, CRFs with a normalized mean score of 0.5 or higher were classified as CCRFs. Positive outliers exceeding the normal range's upper limit were also considered CCRFs. These identified CCRFs underwent further analysis to confirm their reliability and ensure agreement among the study groups.

3.2.3. Reliability Analysis

Reliability means the degree to which measurement values can be reproduced under the same conditions [69]. It shows the ability of an instrument to measure consistently [70]. There are different forms of reliability; one of the most prominent is internal consistency [71], which describes the extent to which the items in a questionnaire measure the same concept [70]. Internal consistency can be measured using Cronbach's alpha coefficient [72], one of the most widely used measures of reliability in several sciences [73]. The value of alpha (α) is given by Equation 2 and expressed as a number between 0 and 1 [72]. It was calculated for the list of CCRFs that resulted from the previous step. The value of 0.7 for alpha provides satisfactory reliability [74, 75]. Therefore, it was adopted as a minimum acceptable value.

$$\alpha = \frac{n}{n-1}\left(1 - \frac{\sum_{i=1}^{n} \sigma_i^2}{\sigma_t^2}\right) \tag{2}$$

where n is the number of items (i.e., the number of CCRFs), σ_i^2 is the variance of item i, and σ_t^2 is the variance of the total score (summation of all items).

3.2.4. Agreement Analysis

Given the diverse perspectives of the study groups (contractors, owners, and consultants), it was necessary to conduct an agreement analysis among them regarding the CCRFs. For three or more groups, the one-way analysis of variance (ANOVA) is usually used for this purpose [76]. ANOVA is a parametric test with the limitation of requiring that all the involved groups have normal distributions [77]. The non-parametric alternative to ANOVA is the Kruskal-Wallis test [78], which was valid in our case as it does not require the normal distributions of each study group [79].

The Kruskal-Wallis test [80] is a hypothesis test that uses the ranks of combined samples from three or more independent groups. The null hypothesis states that the groups have the same median (i.e., no significant difference among study groups). In the Kruskal-Wallis test, the test statistic H is calculated using Equation 3 [81], a general Equation that is valid also when ties occur, i.e., when two or more observations share the same rank. The existence of ties is a common scenario when the Likert scale is employed. The test statistic H approximately follows the chi-square distribution, provided that each group contains at least five observations [82]. This research employed a confidence level of 95% (i.e., alpha = 0.05). The test was conducted separately for each CCRF. If the p-value corresponding to the statistic (H) exceeded alpha, the null hypothesis was retained, indicating no significant difference among the groups regarding the CCRF under consideration. Otherwise, the null hypothesis was rejected, suggesting disagreement among the groups.

$$H = (N-1)\frac{\sum_{i=1}^{k} n_i(\bar{R}_i - \bar{R})^2}{\sum_{i=1}^{k}\sum_{j=1}^{n_i}(R_{ij} - \bar{R})^2}, \tag{3}$$

where N is the total number of observations, k is the number of groups, n_i is the number of observations in group i, $\bar{R}_i$ is the mean rank of observations in group i, R_{ij} is the rank of observation j in group i among all observations, and $\bar{R}$ is the mean of all the R_{ij}, which is equal to 0.5 $(N+1)$.

The Kruskal-Wallis test determines whether there is a significant difference among the groups, but it does not specify which group(s) differ from the others. To identify pairwise differences between groups, other types of tests known as post-hoc tests should be utilized, which examine each pair of groups separately [65]. There are several post-hoc tests; the post-hoc Dunn's test [83] was used in this study. It employs the sum of ranks from the combined sample to identify the differing groups, meaning that the test is applied separately to each pair using the ranks from the sample that encompass all groups. For each CCRF that showed a significant disagreement, the test was conducted. If the test revealed that only one group underestimates the CCRF concerning the other group(s), the CCRF was critical. Otherwise, it was rejected and classified as an ordinary CRF, not a CCRF. This process resulted in a final list of CCRFs.

3.2.5. Spearman's Rank Correlation Coefficients

Spearman's rank correlation coefficient is a non-parametric statistic for assessing the degree of the association between two variables [84]. Spearman's correlation is based on the ranks of the values rather than the actual numerical values. It was used herein to measure the correlation between the perceptions of contractors and owners, contractors and consultants, and owners and consultants regarding the final list of CCRFs. The coefficient was calculated using Equation 4 [60] for each pair of groups. The value of Spearman's rank correlation coefficient ranges from -1 to 1, indicating the strength and direction of the relationship. In order to interpret its value, the ranges defined by Mukaka [85] were adopted.

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)}, \tag{4}$$

where d_i is the difference in ranks for each CCRF between the pair of groups, and n represents the number of data pairs (i.e., the number of CCRFs).

4. Results

The data collected from the 92 participants was analyzed using IBM SPSS Statistics (Version 27). This section displays the results of the analysis process.

4.1. Demographic Profile of the Participants

Among the 92 participants were 48 contractors, 23 owners (GARB members), and 21 consultants. As shown in Figure 3, 48 (52%) participants had ten or more years of experience. Figure 4 illustrates how many bridge project participants were involved. 46 (50%) participants engaged in six or more bridge projects. Table 2 illustrates the distribution of the participants based on their professions.

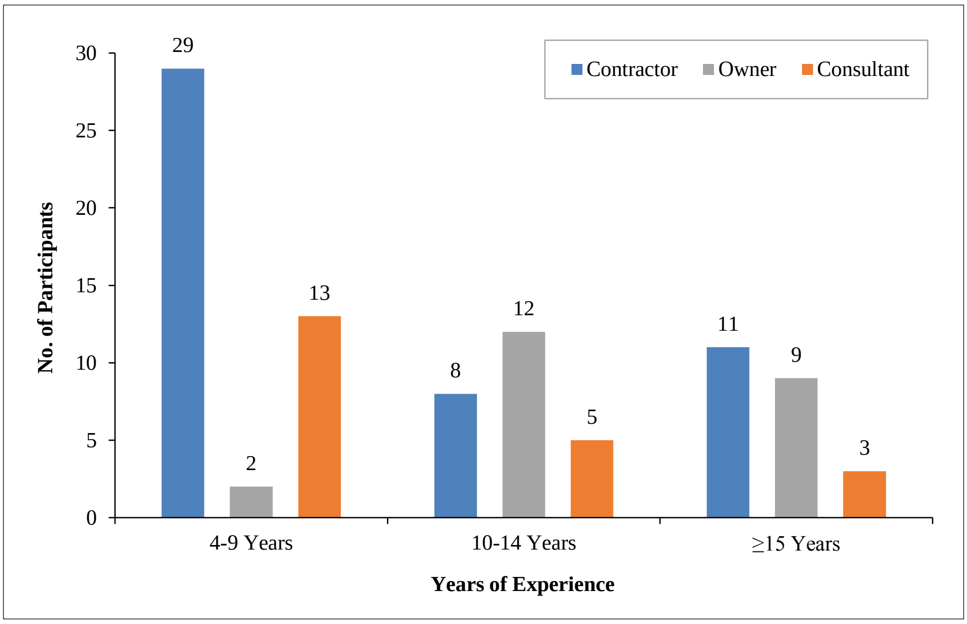

Figure 3. Distribution of participants based on years of experience

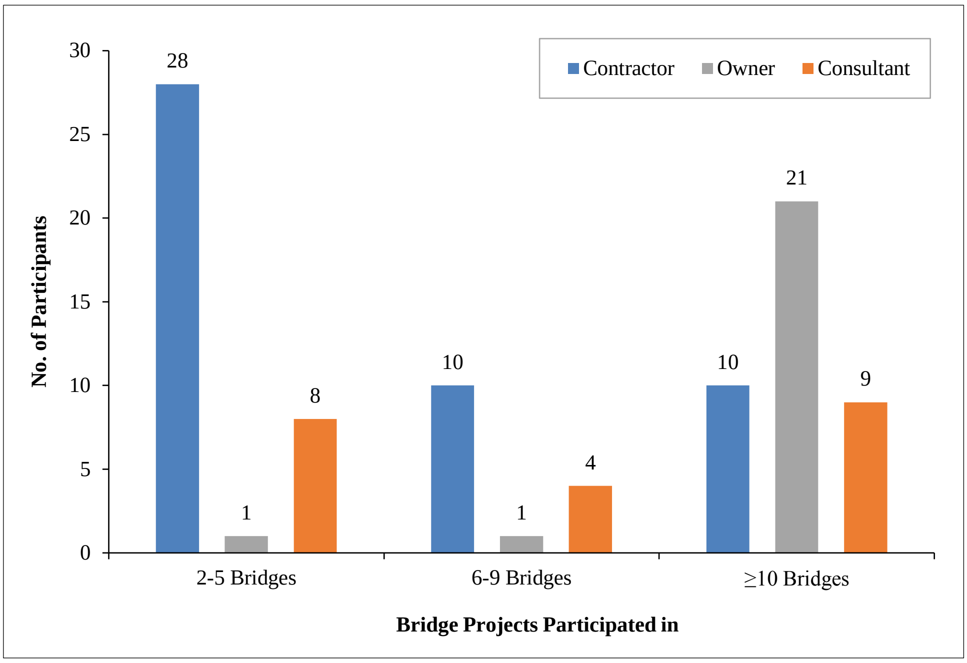

Figure 4. Distribution of participants based on the number of bridge projects involved

Table 2. Distribution of participants based on profession

Profession	Frequency
Head of Sector	2
Project Manager	27
Construction Manager	6
Technical Office Manager	3
Surveying Manager	5
Senior Site/Supervision Engineer	12
Senior Design Engineer	4
Site/Supervision Engineer	21
Technical Office Engineer	6
Others	6

4.2. Ranking of CRFs

For the 43 CRFs, ranking was conducted for each group separately and for the overall participants. Table 3 shows the ranked CRFs, mean scores, and standard deviations. The maximum and minimum overall mean scores are 4.717 and 3.304, respectively. The five CRFs with the highest overall mean scores are verification of underground utility locations, completion of land surveying work, issuance of clear and sufficient construction drawings, adequate geotechnical investigations, and obtaining all necessary permits and approvals from local authorities. The five CRFs with the lowest overall mean scores are ensuring that the resources needed to perform the quality control plan are in place, establishing a clear procurement process and supporting systems for ordering, delivering, installing, and storing materials; ensuring that activities` durations and production rates are realistic and in line with project conditions; ensuring that all equipment operators are certified; and preparation of a proposed list of subcontractors.

Table 3. Ranking of CRFs based on their mean scores

Code	Contractor (N=48)			Owner (N=23)			Consultant (N=21)			Overall (N=92)			
	Mean	Std. dev.	Rank	Mean	Std. dev.	Rank	Mean	Std. dev.	Rank	Mean	Std. dev.	Rank	Normalization
CRF25	4.750	0.438	1	4.826	0.388	1	4.524	0.873	4	4.717	0.561	1	1.000[c]
CRF31	4.688	0.552	2	4.696	0.470	3	4.667	0.577	2	4.685	0.533	2	0.977[c]
CRF01	4.563	0.616	4	4.696	0.559	4	4.714	0.463	1	4.630	0.569	3	0.938[c]
CRF23	4.583	0.577	3	4.739	0.689	2	4.571	0.746	3	4.620	0.644	4	0.931[c]
CRF17	4.542	0.651	5	4.565	0.590	5	4.238	0.889	6	4.478	0.703	5	0.831[c]
CRF18	4.521	0.618	6	4.522	0.730	6	4.048	1.203	9	4.413	0.827	6	0.785[c]
CRF03	4.375	0.672	8	4.435	0.662	7	4.381	0.865	5	4.391	0.710	7	0.769[c]
CRF10	4.271	0.644	10	4.348	0.647	11	4.143	0.727	7	4.261	0.661	8	0.677[c]
CRF32	4.313	0.689	9	4.435	0.728	8	3.857	0.793	12	4.239	0.747	9	0.662[c]
CRF19	4.396	0.792	7	4.391	0.722	9	3.381	1.284	28	4.163	0.998	10	0.608[c]
CRF27	4.271	0.676	11	4.174	0.717	14	3.619	1.203	22	4.098	0.865	11	0.562[c]
CRF02	4.104	0.881	16	4.391	0.783	10	3.762	1.179	16	4.098	0.950	12	0.562[c]
CRF06	4.083	1.028	17	4.261	0.752	13	3.905	1.411	11	4.087	1.065	13	0.554[c]
CRF36	4.208	0.743	12	4.087	0.668	16	3.714	0.902	18	4.065	0.782	14	0.538[c]
CRF30	4.146	0.825	13	3.957	0.706	19	3.952	0.805	10	4.054	0.790	15	0.531[c]
CRF12	3.979	0.838	20	4.043	0.706	18	4.095	0.944	8	4.022	0.825	16	0.508[c]
CRF04	4.104	0.831	15	3.913	0.900	22	3.762	1.044	15	3.978	0.902	17	0.477
CRF07	4.125	0.672	14	3.739	0.810	28	3.762	0.768	14	3.946	0.747	18	0.454
CRF24	3.979	0.785	19	4.261	0.689	12	3.429	1.121	26	3.924	0.905	19	0.438
CRF28	3.917	0.871	25	4.174	0.834	15	3.571	1.121	23	3.902	0.938	20	0.423
CRF14	3.958	0.713	21	3.957	0.767	20	3.667	0.730	19	3.891	0.733	21	0.415
CRF26	3.917	0.846	24	3.913	0.848	21	3.667	1.017	20	3.859	0.884	22	0.392
CRF13	3.917	0.767	23	3.783	0.671	25	3.714	0.784	17	3.837	0.760	23	0.377
CRF08	3.771	0.973	34	3.870	0.757	23	3.667	1.111	21	3.772	0.950	24	0.331
CRF34	3.854	0.850	28	3.826	0.717	24	3.381	0.973	27	3.739	0.863	25	0.308
CRF42	3.938	0.885	22	3.783	0.795	27	3.238	1.221	32	3.739	0.982	26	0.308
CRF11	4.000	0.968	18	3.000	0.953	43	3.810	1.209	13	3.707	1.095	27	0.285
CRF05	3.854	0.772	27	3.565	0.843	34	3.476	0.928	25	3.696	0.835	28	0.277
CRF33	3.771	0.951	33	4.043	0.638	17	3.095	0.944	37	3.685	0.948	29	0.269
CRF16	3.833	0.834	29	3.696	1.020	30	3.238	0.995	31	3.663	0.917	30	0.254
CRF40	3.875	0.789	26	3.652	0.935	32	3.143	1.236	36	3.652	0.977	31	0.246
CRF29	3.833	0.930	31	3.783	0.736	26	2.905	1.179	42	3.609	1.016	32	0.215
CRF15	3.813	0.938	32	3.435	0.843	41	3.286	1.007	30	3.598	0.950	33	0.208
CRF37	3.833	0.907	30	3.565	1.037	35	3.048	1.117	38	3.587	1.029	34	0.200
CRF35	3.521	0.825	41	3.652	0.832	31	3.524	0.750	24	3.554	0.803	35	0.177
CRF22	3.688	0.854	35	3.522	0.898	36	3.190	0.873	33	3.533	0.883	36	0.162
CRF21	3.583	1.048	40	3.565	0.662	33	3.333	0.796	29	3.522	0.908	37	0.154
CRF20	3.646	0.838	37	3.478	0.898	37	3.190	1.250	34	3.500	0.966	38	0.138
CRF43	3.646	0.863	38	3.478	1.123	41	3.143	1.195	35	3.489	1.022	39	0.131
CRF39	3.667	0.834	36	3.478	0.994	40	2.952	0.865	41	3.457	0.919	40	0.108
CRF09	3.521	0.945	42	3.696	0.926	29	2.952	0.740	40	3.435	0.929	41	0.092
CRF41	3.604	0.962	39	3.261	0.964	42	3.000	1.449	39	3.380	1.108	42	0.054
CRF38	3.438	0.712	43	3.478	0.947	39	2.810	0.981	43	3.304	0.874	43	0.000

[c] Critical construction readiness factor

Rankings for the categories were also conducted. Table 4 shows mean scores, standard deviations, and the ranking. The categories with the highest and lowest mean scores are site preparation and resources, respectively.

Table 4. Ranking of categories based on their mean scores

Code	Contractor (N=48)			Owner (N=23)			Consultant (N=21)			Overall (N=92)		
	Mean	Std. dev.	Rank	Mean	Std. dev.	Rank	Mean	Std. dev.	Rank	Mean	Std. dev.	Rank
Site preparation	4.231	0.807	1	4.280	0.769	1	3.878	1.116	2	4.163	0.891	1
Engineering	4.200	0.793	2	4.200	0.850	2	4.019	1.019	1	4.159	0.865	2
Legal and contractual aspects	4.063	0.912	3	4.007	0.892	3	3.563	1.128	4	3.935	0.980	3
Planning	3.934	0.870	4	3.802	0.873	5	3.658	1.013	3	3.838	0.911	4
Project Team	3.865	0.876	5	3.989	0.777	4	3.464	0.898	5	3.804	0.876	5
Resources	3.776	0.862	6	3.598	0.953	6	3.131	1.140	6	3.584	0.988	6

4.3. Normalization

The box plot analysis revealed no outlier CRFs in the dataset, as shown in Figure 5. Therefore, normalization was conducted for all 43 CRFs without any exclusions. The normalized values for the CRFs are shown in Table 3. In total, 16 CRFs were classified as CCRFs. The normalized values of these critical factors are marked with a superscript (c) in Table 3. It is important to note that the critical factors were recoded from (01) to (16) with a prefix of "CCRF" instead of "CRF." For instance, "CCRF01" replaces "CRF25," and "CCRF02" replaces "CRF31," etc. These updated codes are utilized throughout the rest of the paper, particularly in the discussion section.

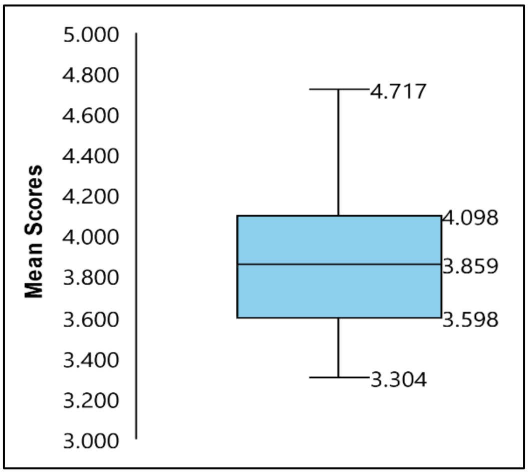

Figure 5. Box plot for outlier detection

These 16 CCRFs include the top ten ranked CRFs for contractors, owners, and consultants, as shown in Figure 6. This indicates that the identified CCRFs encompass the most critical factors for all groups, highlighting their comprehensiveness.

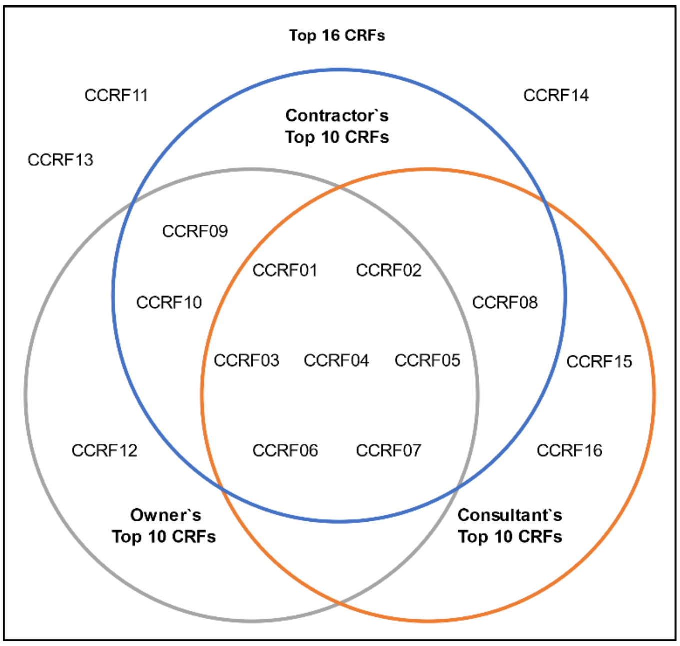

Figure 6. The top ten CRFs for contractors, owners, and consultants, along with the 16 CCRFs

Figure 7 shows the distribution of the CCRFs across the categories. The category with the highest participation is "site preparation," which includes five CCRFs. The categories with the lowest participation are "project team" and "resources," each including one CCRF.

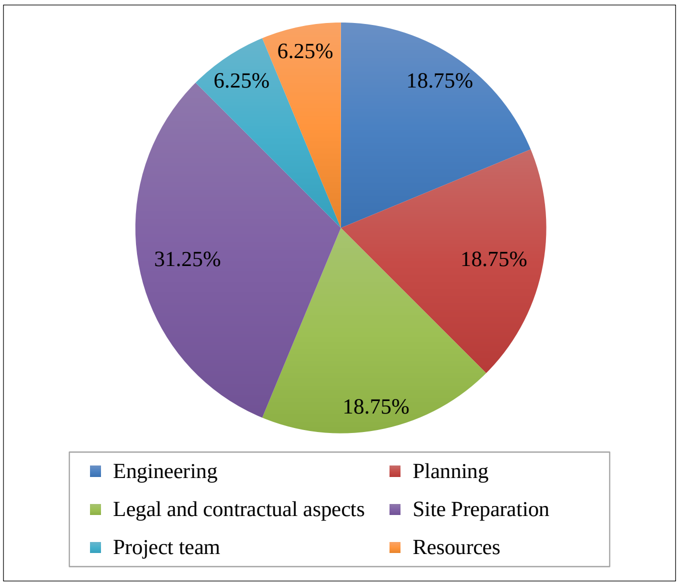

Figure 7. Distribution of the CCRFs across the categories

4.4. Reliability Analysis

The calculated alpha (α) for the 16 CCRFs is 0.807. This value satisfies the reliability requirement, as it is greater than 0.7. Generally, a value of 0.8 or higher indicates high reliability [86].

4.5. Agreement Analysis

Table 5 presents the results of the agreement analysis for the 16 CCRFs. The Kruskal-Wallis test indicated no significant difference in 14 of the 16 CCRFs. The two CCRFs that demonstrated disagreement are CCRF09 and CCRF10, which respectively ensure that the project team members have the skills, capacity, and qualifications to take on the project and the issuance of the notice of award. For these two CCRFs, the post-hoc Dunn's test revealed that the consultant's perspective differs from that of the contractor and owner. However, there is no significant difference between the contractor and the owner. The consultant group only underestimates the importance of these two CCRFs. However, the other two groups considered them of high importance. These results illustrate the overall agreement among the contractor, owner, and consultant for the 16 CCRFs, with the consultant only deviating from the contractor and owner for two CCRFs. Figure 8 also shows the convergence and divergence of perceptions among the contractor, owner, and consultant.

Table 5. Results of the Kruskal-Wallis and post-hoc Dunn's tests for the CCRFs

Code	Description	Mean Rank of			Statistic (H)	p-Value	Accept H0 if p-Value > 0.05	Different Pairs
		Contractor	Owner	Consultant				
CCRF01	The locations of underground utilities at the construction site have been verified.	46.38	49.76	43.21	1.202	0.548	Accepted	
CCRF02	Land surveying work has been completed.	46.91	45.96	46.17	0.039	0.981	Accepted	
CCRF03	Clear and sufficient construction drawings have been issued to support construction activities (issued for construction drawings).	44.06	49.37	48.93	1.250	0.535	Accepted	
CCRF04	Adequate geotechnical investigations of the project site have been completed.	43.81	52.30	46.29	2.424	0.298	Accepted	
CCRF05	All necessary permits and approvals from local authorities have been obtained.	48.40	48.46	40.02	2.090	0.352	Accepted	
CCRF06	The land acquisition has been completed.	48.00	49.57	39.71	2.321	0.313	Accepted	
CCRF07	Design coordination and clash detection have been completed.	45.29	47.50	48.17	0.264	0.876	Accepted	
CCRF08	A proper site layout plan has been developed.	46.70	49.50	42.76	0.911	0.634	Accepted	
CCRF09	The project team members have the skills, capacity, and qualifications to take on the project.	48.53	53.30	34.40	7.154	0.028	Rejected	Consultant-Contractor & Consultant-Owner
CCRF10	The notice of award has been issued.	51.86	50.91	29.40	12.957	0.002	Rejected	Consultant-Contractor & Consultant-Owner

CCRF11	The traffic control plan has been developed, approved by authorities, and implemented.	50.48	47.26	36.57	4.733	0.094	Accepted
CCRF12	Specifications, standards, and bill of quantities (BOQ) have been clearly published to support construction activities.	46.05	53.87	39.45	3.669	0.160	Accepted
CCRF13	The construction schedule has been developed.	45.98	48.46	45.55	0.193	0.908	Accepted
CCRF14	Funding for the project has been acquired.	50.73	46.87	36.43	4.939	0.085	Accepted
CCRF15	The site security control procedures have been established.	49.78	42.09	43.83	1.865	0.394	Accepted
CCRF16	The project quality plan has been developed.	45.42	46.11	49.40	0.382	0.826	Accepted

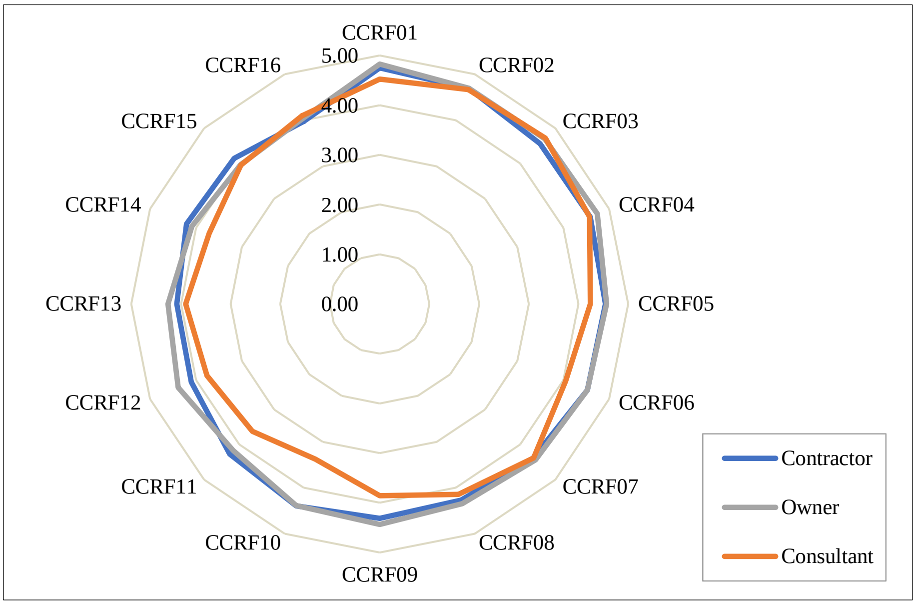

Figure 8. Contractor, owner, and consultant perceptions regarding the CCRFs

4.6. Spearman's Rank Correlation Coefficients

Table 6 shows the values of Spearman's rank correlation coefficients regarding the 16 CCRFs for each pair of groups, along with their interpretation according to Mukaka [85]. The results reveal varying levels of correlation among the stakeholders. The contractor-owner pair shows a high correlation coefficient of 0.909, indicating strong alignment in assessing these CCRFs. In contrast, the owner-consultant pair exhibits a correlation of 0.682, suggesting moderate agreement between the two parties. Similarly, the contractor-consultant pair shows a moderate correlation of 0.627, reflecting a somewhat lower, but still notable, degree of agreement. These coefficient values indicate the level of agreement on the rankings among the groups and do not suggest that one party underestimates the importance of the CCRFs relative to the other, mainly since the 16 CCRFs include the top ten CRFs for each group.

Table 6. Spearman's rank correlation coefficient for each pair of groups

The Pair of Groups	Value of Spearman`s Rank Correlation Coefficient	Strength of correlation
Contractor-Owner	0.909	Very High
Contractor-Consultant	0.627	Moderate
Owner-Consultant	0.682	Moderate

5. Discussion

This section compares the results with the previous CR studies and discusses each identified CCRF for bridge projects.

5.1. Comparison with Prior CR Studies

Previous studies examined the CR for different types of projects rather than specifically for bridge projects. Radzi et al. [21] identified 18 CCRFs for highway projects using the same approach adopted in this research. Similarly, Abdul-Rahman et al. [22] identified 21 CCRFs for abandoned housing projects. Ibrahim et al. [9] did not distinguish between critical and non-critical factors for industrial projects. Therefore, Radzi et al. [38] normalized the factors for industrial projects and highlighted 11 of them as CCRFs. This research identified 16 CCRFs for bridge projects. Table 7 displays which CCRFs were also considered critical in prior studies.

Table 7. Comparison with prior CR studies

Code	Description	Industrial [9]	Highway [21]	Abandoned housing [22]
CCRF01	The locations of underground utilities at the construction site have been verified.	×	✓	×
CCRF02	Land surveying work has been completed.	×	×	×
CCRF03	Clear and sufficient construction drawings have been issued to support construction activities (issued for construction drawings).	✓	✓	✓
CCRF04	Adequate geotechnical investigations of the project site have been completed.	×	×	×
CCRF05	All necessary permits and approvals from local authorities have been obtained.	×	✓	✓
CCRF06	The land acquisition has been completed.	×	✓	✓
CCRF07	Design coordination and clash detection have been completed.	✓	×	×
CCRF08	A proper site layout plan has been developed.	×	×	×
CCRF09	The project team members have the skills, capacity, and qualifications to take on the project.	×	×	×
CCRF10	The notice of award has been issued.	×	✓	✓
CCRF11	The traffic control plan has been developed, approved by authorities, and implemented.	×	✓	×
CCRF12	Specifications, standards, and bill of quantities (BOQ) have been clearly published to support construction activities.	×	×	×
CCRF13	The construction schedule has been developed.	×	✓	✓
CCRF14	Funding for the project has been acquired.	×	✓	×
CCRF15	The site security control procedures have been established.	×	×	×
CCRF16	The project quality plan has been developed.	×	×	×

Eight common CCRFs are shared between bridge and highway projects due to their similarity as horizontal transportation infrastructures with many similar characteristics. In contrast, only two CCRFs are shared between the bridge and industrial projects, and five are shared between the bridge and abandoned housing projects. Both industrial and abandoned housing projects are vertical, with relatively small areas and minimal interaction with existing facilities, unlike bridge and highway projects. This disparity indicates that the critical factors affecting CCRFs are highly dependent on the type of project and cannot be generalized across all project types. The issuance of clear and sufficient construction drawings is the only common critical factor across all CR studies, highlighting its significant impact on CR overall, regardless of project type

5.2. Discussion of the CCRFs for Bridge Projects

This subsection discusses the identified CCRFs for bridge projects revealed from the survey, shown in Table 7.

- ***Underground Utility Locations (CCRF01)***

Underground utilities include electrical cables, information transfer/television cables, pressurized water pipelines, pressurized gas or fluid pipelines, sewer or drainage pipelines, and other auxiliary lines used for various purposes [87]. Most underground utility damages are caused by construction practices [88], representing one of the major dilemmas for the construction industry [89]. This is due to the wide range of impacts of these damages, such as construction delays, high repair costs, environmental harm, and both fatal and nonfatal casualties [90]. Damage to underground utilities significantly affects national and local development and citizens' quality of life [91]. The American Institute of Constructors highlighted it as the third major crisis for contractors [92]. The damages occur when the locations of these utilities are not verified before excavation begins [93]. Preventing these damages requires these utilities to be precisely located before the commencement of construction, i.e., during the preconstruction phase. This need is increased in bridge construction projects due to the extensive piling work frequently required in substructure work. The survey revealed that verification of underground utility locations is the most critical factor for CR in bridge projects. It was also identified as the sixth critical factor for highway projects. In contrast to industrial and abandoned housing projects, it was not identified as a critical factor. Industrial projects are often developed in designated industrial zones planned and coordinated by authorities, resulting in a much lower probability of striking underground utilities during construction than horizontal infrastructure. For abandoned projects, the primary concerns are often structural integrity, site accessibility, and financial feasibility rather than the location of underground utilities, which might already be well documented and thus less likely to pose a significant risk during construction revival.

- ***Land Surveying Work (CCRF02)***

Land surveying is a crucial prerequisite activity for the construction process of any project [94]. It represents the cornerstone of any physical development [95]. Surveying work continues throughout the entire construction phase. However, the focus here is on preconstruction detailed land surveying, which typically includes mapping the existing features of the construction site, such as the terrain, vegetation, and structures already in place. It also encompasses establishing horizontal and vertical stations and other reference points on the site that will guide construction activities. In bridge construction, close coordination with existing facilities is imperative, and the bridge's functionality relies heavily on accurate positioning, levels, and slopes. This highlights the importance of land surveying for bridge construction. Completing land surveying work was identified as the second critical factor for bridge projects. Despite the substantial need for land surveying work in highway construction projects [96], it was not identified as a critical factor. This could be attributed to the fact that highway construction typically spans considerable lengths, making it time-consuming to conduct land surveying for the entire project at once. Instead, land surveying work will progress in tandem with the construction phases. It also was not identified as a critical factor for industrial and abandoned housing projects, as they are often of limited area, and the required land surveying work is generally more compact and straightforward than those required for bridge construction projects.

- ***Construction Drawings (CCRF03)***

Construction drawings are typically issued to the contractor after the contract is awarded. These drawings, also known as working drawings or Issued for Construction (IFC) drawings, serve as a reference for shop drawings throughout the construction process. They include any issued addenda and provide more detailed information than tender drawings. Incomplete or unclear construction drawings significantly cause the contractor's lack of comprehension of the work [97], leading to delays and subsequent claims and disputes [98]. Issuing clear and sufficient construction drawings was identified as the third critical factor for bridge projects, as they are necessary to provide precise dimensions and levels of the bridge elements and structural details required for developing the shop drawings. It was also identified as the most critical factor for industrial projects, seventeenth for highway projects, and nineteenth for abandoned housing projects. It is the only common CCRF across all CR studies, highlighting its significant impact on CR generally.

- ***Geotechnical Investigation (CCRF04)***

Generally, the more effort spent on geotechnical investigation, the lower the construction cost of the project [99]. In bridge construction, the actual quantities are typically greater than the estimates, primarily due to variations in the subsurface structure encountered during construction [100]. Without a detailed geotechnical investigation for bridge construction projects, there is a significant risk of facing change orders, claims, cost overruns, and delays [4]. Site visits during the data collection process revealed that the following practice is commonly followed in several current bridge projects in Egypt: A preliminary geotechnical investigation is conducted before design. Following this, the design is developed with an initial substructure design. Subsequently, the contractor is selected. During the preconstruction phase, the contractor is obligated to perform a detailed geotechnical investigation needed for the substructure's final design. This practice makes the contractor's geotechnical investigation during the preconstruction phase extremely important. It must be done appropriately, as any omissions in its execution or inaccurate assumptions regarding soil conditions may lead to severe consequences. Adequate geotechnical investigation was identified as the fourth critical factor for bridge projects. However, it was not identified as a critical factor in any previous CR study. This disparity may be attributed to the extensive substructure work involved in bridge construction. Current Egyptian practice also increases the significance of geotechnical investigation after the contract has been awarded to the contractor (i.e., the phase where CR is investigated) rather than during the initial design stages.

- ***Permits and Approvals (CCRF05)***

The construction of transportation infrastructure facilities requires various statutory permits and approvals [101]. The allocation of responsibility for securing them can vary based on the specific project and the contractual agreements between the involved parties. Whether the responsibility lies with the contractor or the owner or is shared between them, these permits and approvals are essential for commencing construction. While these regulations are in place to safeguard the public, the extended and costly procedures may lead the project team to commence construction without obtaining the necessary permits [102]. Constructing without required permits and approvals may result in legal actions by local authorities, which include issuing stop-work orders and halting construction until all permits are secured. These interruptions often lead to delays and cost overruns, negatively impacting project outcomes. Moreover, the contractor might be subject to financial penalties for non-compliance with regulations. To avoid these consequences, adhering to all regulatory requirements and obtaining the necessary permits and approvals before entering the construction phase is crucial. This ensures legal compliance, minimizes risks, and contributes to the project's success. Obtaining all necessary permits and approvals from local authorities was identified as the fifth critical factor for bridge projects. Approval from local authorities was identified as the most critical factor for abandoned housing projects. It was also identified as the second critical factor for highway projects. However, it was not identified as a critical factor in industrial projects. Industrial projects typically have environmental and social impacts, often raising public concerns. This mandates, by default, that every step during their development undergoes a stringent permitting and approval process [21]. Therefore, the construction of an industrial project cannot commence without the necessary permits and approvals.

- ***Land Acquisition (CCRF06)***

Governments primarily employ land acquisition, which involves transferring ownership from the private sector to the state, to address the growing demand for land spurred on by fast urban and economic growth [103]. The process may involve negotiations, compensation, legal procedures, and addressing intricate coordination issues to facilitate the transfer of control over the land from private landowners to the government. This compulsory land acquisition for development, while potentially benefiting society, creates tension and disrupts the lives of those facing dispossession, displacing families, farmers, and businesses [104]. As a result, public resistance or community opposition poses a significant risk to the land acquisition process, making it more complicated. Thus, commencing construction before completing land acquisition can lead to interruptions and subsequent declines in performance. Infrastructure projects that require large amounts of land, such as transportation networks, often encounter challenges with land acquisition. According to Elawi et al. [105], land acquisition is the primary cause of delays in road and bridge projects. These delays are owner-related, typically resulting in contractor claims and often becoming a significant source of disputes. Completing land acquisition is identified as the sixth critical factor for bridge projects. It was also recognized as the second critical factor for abandoned housing projects and the fourth for highway projects. However, it was not included in industrial construction projects, as the owners typically control the selection of the project's location and often own the land before construction is procured. Conversely, in transportation infrastructure, demand usually dictates a location, whether privately owned or not, making land acquisition more critical for highway and bridge projects than industrial projects.

- ***Design Coordination and Clash Detection (CCRF07)***

Design coordination issues, such as contradictions, mismatches, errors, and discrepancies in drawings, often lead to construction problems, necessitating late changes for correction [106]. Effective coordination is a critical success factor for construction projects [107]. Although design coordination and clash detection primarily occur during the design phase (i.e., pre-award), the contractor should also dedicate effort to revising and ensuring their completion during the preconstruction phase. Completing design coordination and clash detection was identified as the seventh critical factor for bridge projects. Design coordination was also identified as the tenth critical factor for industrial projects. However, it was not recognized as a critical factor for highway or abandoned housing projects.

- ***Site Layout Plan (CCRF08)***

The site layout plan is a crucial plan that should be developed before the commencement of construction [108], as it significantly influences the safety and productivity of the operations [109]. It includes the temporary facilities required for construction, their sizes and shapes, and their locations within the construction site [110]. An effective site layout plan significantly increases construction efficiency [111] and reduces construction costs [112]. Although the optimal time for developing a site layout plan is before mobilization, site engineers frequently overlook it, and instead, the site planning is done as the work progresses [113]. This practice often negatively impacts construction performance, especially at congested construction sites. According to Sambasivan & Soon [114], delays related to the movement of equipment within the construction site, which are caused by poor site layout planning, are one of the critical factors disrupting the progress of work. Developing a proper site layout plan was identified as the eighth critical factor for bridge projects. However, it was not identified as a critical factor in any previous CR study.

- ***Skills, Capacity, and Qualifications of the Project Team Members (CCRF09)***

The success of a construction project depends on the effectiveness of its project team [115]. This encompasses various aspects, including the members' skills, capacity, and qualifications to undertake the required tasks and achieve the project objectives efficiently. Having a competent project team is essential for bridge construction projects where intricate engineering tasks and specialized construction methods are often involved. The project team for a bridge construction project in Egypt typically consists of members from GARB, the consultant assigned by GARB, the contractor, and occasionally the consultant assigned by the contractor. This includes project managers, construction managers, technical office engineers, site engineers, surveyors, supervisors, and laborers. GARB members mostly have extensive experience in bridge construction, especially as they undergo career progression based on years of experience and usually undergo technical training courses. However, contractors and consultants, given the expansion of bridge construction in Egypt, may sometimes need to employ personnel with little experience and inadequate training to meet the workforce demand. Consequently, a team with fewer competencies may be formed, resulting in poor construction performance. Ensuring the project team members have the skills, capacity, and qualifications to take on the project was identified as the ninth critical factor for bridge projects. However, it was not identified as a critical factor for any prior CR study.

The agreement analysis regarding CCRF09 revealed discrepancies between the perspectives of consultants and contractors and between consultants and owners. However, there is a consensus between contractors and owners. Unlike consultants, contractors and owners agree that this factor significantly affects CR. Consultants, contractors, and owners in construction projects have distinct roles that shape their perspectives on the importance of project team skills, capacity, and qualifications. Consultants, typically serving as technical advisors, focus on ensuring design compliance, making them less directly involved in managing the on-site workforce. As a result, they may place less emphasis on CCRF09 as a critical factor. Conversely, contractors are responsible for executing the work and managing labor, so they are acutely aware of how CCRF09 affects project timeline, cost, and quality. Owners share the contractor's concern since they are directly affected by poor performance and are interested in the overall project's success. This difference in roles explains why consultants may perceive the importance of CCRF09 differently from contractors and owners, who face the direct impact of workforce inadequacies.

- ***Notice of Award (CCRF10)***

The contractual relationship between the owner and the selected contractor begins with issuing a notice of award. This notice typically signifies the owner's intent to enter into a contract with the contractor and generally includes the essential terms and conditions of the agreement. It forms the legal foundation upon which the contractor's procurement is triggered, as it constitutes credit for the contractor to award subcontracts, issue major purchase orders, and develop the required preconstruction submittals. Without notice of award, the project faces one of two potential issues: the first is waiting until the formal contracting process is completed to start the preconstruction phase, which is time-consuming and often does not satisfy the owner's desire for early commencement; the second is entering the preconstruction phase without establishing any contractual relationship, thereby exposing the contractor to numerous risks. The issuance of the notice of award was identified as the tenth critical factor for bridge projects. It was also identified as the most critical factor for highway projects and the third critical factor for abandoned housing projects. However, it was not recognized as a critical factor for industrial projects.

The agreement analysis regarding CCRF10 uncovered discrepancies between the perspectives of consultants and owners and between consultants and contractors. However, there is no disparity between contractors and owners. Contractors and owners tend to recognize the notice of award as a critical factor because it directly impacts their ability to proceed with project activities legally. It represents the green light for contractors to begin operations and engage with subcontractors, manufacturers, and suppliers. At the same time, it assures owners that the project is moving forward according to the agreed terms. In contrast, consultants are typically less involved in the contractual formation between the owner and contractor. Their focus is on design, technical specifications, and oversight rather than the contractual mechanics enabling the project to commence. As a result, consultants may not fully appreciate the operational and legal implications of the notice of award, leading to a divergence in viewpoints.

- ***Traffic Control Plan (CCRF11)***

The construction sites of bridges impact the general surrounding environment and, more specifically, the flow of traffic [116, 117]. This traffic impact represents a significant risk for workers and the public, necessitating a proper traffic control plan (TCP). This plan outlines measures to minimize disruptions, manage detours, control access points, and implement temporary traffic signals or signage. The principal goal of the TCP is to allow the construction of a bridge to proceed while ensuring a steady and safe flow of traffic [118]. During the preconstruction phase, the TCP undergoes several steps, including traffic impact analysis, design, regulatory compliance, coordination with emergency services, stakeholder communication, and establishing necessary road diversions. TCP development, approval, and implementation were identified as the eleventh critical factor for bridge projects. For highway projects, diverting the roads interrupted by the project, which is part of TCP implementation, was recognized as the eighteenth critical factor. The TCP was not considered a critical factor for industrial and abandoned housing projects, as they are typically located in areas away from traffic flow, resulting in no interrupted roads or required diversions.

- ***Specification, Standards, and BOQ (CCRF12)***

The specifications complement the role of drawings by specifying the materials, workmanship, and required construction procedures [119]. They form the foundational framework for developing the quality plan, providing essential requirements to ensure the desired level of quality throughout the project's execution. Inadequate or incomplete specifications are one of the common causes of disputes within the construction industry [120]. Several standards may be referenced in specifications or adopted entirely in specific aspects, a common practice in bridge construction. The construction standards cover various areas such as safety, materials, methods, or codes. When a standard is adopted, it becomes an integral part of the specifications. These referenced standards should be well-revised for any inconsistencies with other contract documents. The bill of quantities (BOQ) is not only a pre-contract tool but also has a vital post-contract role, serving as the foundation for evaluating progress payments and providing a consistent basis for evaluating variations [121]. Inconsistencies within the BOQ, specifications, and drawings, as well as errors in the BOQ itself, create ambiguities in contract documents, leading to frequent construction disputes [122]. Therefore, the BOQ should be clear and aligned with the other contract documents.

Specifications and BOQ are commonly included in tender documents for competitive bidding, as they are necessary for contractors to prepare their bids. However, in the direct award method, they may be issued after the contract is awarded; this is often the case in current Egyptian bridge construction projects. Therefore, it is crucial to ensure they are clearly published before construction commences, highlighting this as the twelfth critical factor for bridge projects. However, it was not identified as a critical factor in any previous CR study.

- ***Construction Schedule (CCRF13)***

Upon the contract being awarded, the contractor often starts to develop a detailed construction schedule, which, after the owner's approval, will be the baseline that is essential for project execution, tracking, and progress reporting and will serve as the legal foundation for administering construction disputes and claims [123]. Developing a precise construction schedule is one of the most crucial preconstruction tasks undertaken by the contractor [10]. It outlines the activities to be performed along with their sequence, timing, and required resources. Developing the construction schedule was identified as the thirteenth critical factor for bridge projects. For highway projects, verification and approval of the work plan from the owner were identified as the eighth and fifteenth critical factors, respectively. They also were identified as the twenty-first and twentieth critical factors for abandoned housing projects. The work plan is a broader term that primarily includes the construction schedule. For industrial construction projects, it was not identified as a critical factor.

- ***Funding for the Project (CCRF14)***

The contractor's financial problems are one of the main reasons for delays in construction projects [58, 124, 125]. Therefore, adequate funding is necessary to ensure that the project can be carried out from start to finish without any financial constraints [126]. Acquiring funding for contractors is about determining how to fill the time gap between incurring expenditures and securing revenues, including the timely payment of material suppliers and subcontractors. This process is optimally established during the preconstruction phase after assigning the contractor's project budget and developing the construction cash flow. The nature of bridge construction, especially the substructures, demands accelerated cash flow. Therefore, in scenarios where advanced payment does not exist, as is often the case in current Egyptian practices, rapid financial support is crucial to meet the expenses associated with construction activities. Acquiring funding for the construction of a bridge was identified as the fourteenth critical factor. It was identified as the third critical factor for highway projects. However, it was not identified as a critical factor for industrial or abandoned housing projects.

- ***Site Security Control Procedures (CCRF15)***

One of every four construction sites has experienced theft or burglary at some point [127]. Such incidents include pilfering construction materials, tools, equipment, and other items. Theft and burglary disrupt construction progress [128] and erode the profit margin [129]. Therefore, it is crucial to proactively address these challenges by implementing robust security measures and procedures during the preconstruction phase. Establishing site security control procedures was identified as the tenth critical factor for bridge projects for consultants, the thirteenth for contractors, and the nineteenth for owners. However, it was not identified as a critical factor in any previous CR study.

- ***Project Quality Plan (CCRF16)***

Quality planning is a critical step that should be done appropriately prior to the commencement of construction [130]. It involves planning activities to identify and address deviations from project requirements before and during execution, as well as ensuring the work meets requirements after completion. Developing the project quality plan ensures thorough consideration and preparation for the specific project requirements while providing the owner with a clear demonstration of how these requirements will be fulfilled [130]. It also helps the contractor's team to realize the contract documents with less rework [131]. The contractor is required frequently to develop and submit the project quality plan for the owner's approval, along with the other preconstruction submittals. The development of the quality plan is identified as the sixteenth critical factor for bridge projects. However, it was not identified as a critical factor in any previous CR study.

6. Conclusion

To enhance the performance of bridge construction projects in Egypt and avoid premature construction starts with their subsequent disruption, it is imperative to ensure that the bridge projects are construction-ready, necessitating a thorough CR assessment. A questionnaire was administered through structured interviews with project managers and engineers experienced in bridge construction in Egypt. As a result, 16 CCRFs were quantitatively identified. These factors define what constitutes a construction-ready bridge project and are essential for assessing the CR. The top five factors are verification of underground utility locations, land surveying works, issuance of clear and sufficient construction drawings, adequate geotechnical investigations, and acquisition of all necessary permits and approvals for construction. For each identified CCRF, agreement analysis was conducted using the Kruskal-Wallis test to uncover any disagreement among the perspectives of contractors, owners, and consultants. The test revealed that 14 of the 16 CCRFs showed no significant disagreement among the study groups. The only two CCRFs that showed disagreement are CCRF09 and CCRF10, which respectively ensure that the project team members have the skills, capacity, and qualifications to take on the project and the issuance of the notice of award. For these two CCRFs, the post-hoc Dunn's test indicated that the perspective of consultants only deviates from that of contractors and owners. Spearman's rank correlation coefficient is used to measure the strength of the correlation between each pair of study groups regarding the 16 CCRFs. Contractors and owners showed a very high correlation. However, the correlation is moderate between consultants and the two other groups.

The identified CCRFs can be integrated into a construction readiness assessment index, enabling practitioners involved in bridge construction to assess the project's maturity to begin construction effectively. This index will allow them to take proactive measures during the preconstruction phase to ensure the project is construction-ready. Additionally, these CCRFs can serve as a vital checklist for the project team to determine the commencement date optimally. It should also be noted that some of the identified CCRFs are not exclusive to bridges; they are also relevant to other transportation infrastructure projects in Egypt, such as highways and tunnels, which face similar challenges. This study also contributes to the academic understanding of CR, as it is one of the few efforts dedicated to this subject.

This study is limited to bridge construction projects in Egypt, especially for the era after 2014. Additionally, the study only highlighted the critical factors without providing any method for assessing their fulfillment in the project under consideration. The recommendation for further research is to examine the validity of the identified CCRFs for other infrastructure projects in Egypt, investigate CR for various types of construction, and develop tools for objectively assessing the completion level of each CCRF.

7. Declarations

7.1. Author Contributions

Conceptualization, H.A.E.M. and A.M.E.; methodology, H.A.E.M.; software, A.G.H.; validation, H.A.E.M. and A.M.E.; formal analysis, A.G.H.; investigation, H.A.E.M.; resources, A.G.H.; data curation, H.A.E.M.; writing—original draft preparation, A.G.H.; writing—review and editing, H.A.E.M. and A.M.E.; supervision, H.A.E.M. and A.M.E. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data generated in this research is available from the corresponding author upon reasonable request.

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7.4. Conflicts of Interest

The authors declare no conflict of interest.

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Appendix I: Questionnaire Survey Form

Introduction

Dear Participant,

The data you provide in this questionnaire is required for MS thesis (academic) research titled "Assessing the construction readiness of bridge projects in Egypt."

This research aims to assess the construction readiness of bridge projects in Egypt. *Construction readiness* is "a series of activities and procedures that should be completed or substantially completed prior to construction to productively start and sustain construction operations."

Some Notes on Construction Readiness:

- The process of assessing construction readiness takes place after the contract is awarded and before the mobilization to determine the degree of preconstruction maturity.
- The construction readiness assessment is performed by the project team, and based on this assessment, major decisions are taken, such as construction commencement, sacrificing more efforts to critical preconstruction activities for enhanced construction readiness, or negotiating for a delayed commencement date.

Aim of the Questionnaire

A total of 43 construction readiness factors have been identified. The purpose of this questionnaire is to assess the importance of each factor.

Confidentiality of the Responses

Rest assured that your personal information will be kept confidential and used solely for research.

First Part

Participant information

Name: ____

Position or title: ____

Number of years of experience: ____

Number of bridge construction projects involved in: ______________________

Name of the current bridge construction project you work on:_________________

Organization name: ____

Organization type: ____

Phone No.: ____

Email address: ____

Second part

This part aims to assess the importance of each construction readiness factor according to the bridge construction projects in Egypt. A 5-point Likert scale is used to determine the degree of importance; the scale is as follows:

Likert Scale	
1	Not Important
2	Less Important
3	Moderately Important
4	Important
5	Very Important

Please answer the following question based on your experience.

How important is this factor in affecting the construction readiness of bridge projects in Egypt?

Category	Construction Readiness Factor	1	2	3	4	5
Engineering	1. Clear and sufficient construction drawings have been issued to support construction activities (issued for construction drawings).					
	2. Specifications, standards, and bill of quantities (BOQ) have been clearly published to support construction activities.					
	3. Design coordination and clash detection have been completed.					
	4. A well-defined process for requests for information (RFIs) and engineering support has been established.					
	5. The process for submittal and approval of shop drawings, items, and vendor information has been clearly defined.					
Planning	6. The construction schedule has been developed.					
	7. A well-defined construction execution plan has been developed, including method statements for each activity.					
	8. The critical path has been identified.					
	9. Planned activities' durations and production rates are realistic and in line with project conditions.					
	10. A proper site layout plan has been developed.					
	11. The HSSE (Health, Safety, Security, and Environmental) plan has been developed.					
	12. The project quality plan has been developed.					
	13. A plan to ensure communication and coordination among project participants has been developed.					
	14. The mobilization plan has been developed.					
	15. A cost control system is ready for the project.					
	16. A document control system is ready for the project.					
Legal and contractual aspects	17. All necessary permits and approvals from local authorities have been obtained.					
	18. The land acquisition has been completed.					
	19. The notice of award has been issued.					
	20. The scope and completeness criteria have been well-defined in the contract.					
	21. The down payment procedures have been agreed upon.					
	22. The necessary insurance for the project has been obtained.					
Site preparation	23. Adequate geotechnical investigations of the project site have been completed.					
	24. All necessary utilities are available on site (e.g., electricity, drainage, communication tools, etc.).					
	25. The locations of underground utilities at the construction site have been verified.					
	26. The site condition has been verified to be the same as the contract.					
	27. The traffic control plan has been developed, approved by authorities, and implemented.					
	28. The relocation of underground utilities that will be interrupted by the project has been completed.					
	29. On-site safety communication (safety signage and safety board locations) is in place.					
	30. The site security control procedures have been established.					
	31. Land surveying work has been completed.					
Project team	32. The project team members have the skills, capacity, and qualifications to take on the project.					
	33. A responsibility assignment matrix has been developed for the project.					
	34. An organizational chart for the construction team has been developed and communicated to assign roles and functions.					
	35. The communication methods among the project team have been well-defined (reports, e-mails, meetings, etc.).					
Resources	36. Funding for the project has been acquired.					
	37. The relevant contracts have been signed to support the construction schedule (e.g., subcontracts, supply contracts, and purchase orders).					
	38. A proposed list of subcontractors has been prepared.					
	39. A clear procurement process and supporting systems for ordering, delivering, installing, and storing materials have been established.					
	40. A tool and equipment management plan has been developed, including acquisition, mobilization, placement, storage, movement, and maintenance.					
	41. All equipment operators are certified.					
	42. All pieces of equipment have been inspected and certified.					
	43. The resources (people, tools, and systems) needed to perform the quality control plan are in place.					

Third Part (Optional)

Please answer the following questions.

Q1: Based on your current project, if any of the construction readiness factors mentioned earlier in the questionnaire were absent or inadequately addressed and impacted the project performance?

If any, please mention their numbers.

____
____
____

Q2: In your experience, are there other readiness factors that should be added?

____
____
____

Fourth Part (Optional)

Please recommend participant(s) who may participate in this questionnaire.

Name	Phone No. or e-mail