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An Investigation of Construction Project Efficiency: Perception Gaps and the Interrelationships of Critical Factors

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Abstract: Construction projects are complex as various project entities involve and collaborate with each other. This complexity not only causes issues such as project delays but also makes it difficult to manage projects. Previous research has often used productivity and efficiency interchangeably, but they are not the same. The field of construction efficiency has not been fully studied to understand its entire potential in a practical context. Toward this end, this research aims to support efficient construction project management by exploring the inefficiency factors as well as identifying the perception gaps between different occupations and the interrelationships between the factors. Twenty inefficiency factors were identified through a comprehensive literature review; then, the importance of the factors and the perception gaps among stakeholders were studied by analyzing online survey data using RII (relative importance index), Welch's *t*-test, and factor analysis. In addition, interviews with field engineers and managers allowed us to explore cause-and-effect relationships among the factors and determine triggering and critical factors based on their chain reactions. This research found that a major perception gap among project stakeholders was in the factor of unrealistic scheduled dates. The research contributes to project risk management and strategic planning for construction project efficiency.

Keywords: construction efficiency; risk management; inefficiency factors; perception gaps; interrelated inefficiency; chain reactions; construction management

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1. Introduction

The construction industry has served as a driver of economic growth by improving the capacity and the efficiency of the economy in most countries [1]. Continuous progress in construction productivity has remained a primary emphasis area for both governments and the industry, as productivity reflects efficiency. However, in comparison with services and other industries such as manufacturing, the construction industry's productivity remains relatively low. Many sectors of the construction industry have been plagued by issues such as poor management, dangerous and unpleasant working conditions, and poor quality; in turn, many studies have recognized these issues as elements that affect construction productivity [2].

A construction project consists of various entities and stakeholders, and its complexities and uncertainties can be potential reasons for time and cost overruns. According to the Associated General Contractors of America, around 60% of construction projects are delayed or canceled, with one of the major reasons being the labor shortage, which affects the productivity in construction projects [3]. Extensive study has been conducted to investigate construction productivity over the last few decades. The issue of low construction productivity has remained a major concern in both developed and developing countries' building industries [4,5]. Increased construction productivity would not only increase revenues and earnings for businesses but also save the industry costs. As a result, there is a pressing need to develop new approaches for increasing construction productivity [4]. Previous studies have encompassed a wide variety of productivity issues in various geographical areas and different types of construction activity [4].

However, the field of construction efficiency remains an area in which much more research is needed to fully understand its entire potential in a practical industry context [4,6]. Although productivity and efficiency have often been used interchangeably, they are not the same [7]. Productivity is often the relationship between man-hours and work performed [8]. On the other hand, efficiency can be defined as the best possible output per unit of time. Efficiency indicates "doing things right" [9,10]. Thus, efficiency considers factors that can cause different productivity [11]. Efficiency can provide a broader, holistic approach to how things could be done the best and the right way. Therefore, this research studies efficiency factors that have direct or indirect links with project outcomes.

The current state of the art in the domain of construction productivity has been in one of two streams: One focuses on the characteristics and reasons that cause project delays, while the other focuses on delay analysis [12]. There have been many studies related to a specific area, such as labor productivity and factors affecting it. Given that project inefficiency is a holistic approach to understanding projects' success or failure, this research will explore inefficiency factors including factors affecting productivity and project delay.

Although inefficiency factors are investigated in some of the studies, few studies have investigated how inefficiency factors are perceived by different people. Understanding perception gaps between different groups and stakeholders will help to improve multi-organizational coordination, risk communication, and quality control [13,14]. Toward this end, this research elucidates perception gaps related to construction project inefficiencies among stakeholders who have different occupations, project types, and years of experience. The perception gaps can be discussed in scope review meetings, charter meetings, or at any other major milestones to make sure that all the project entities understand each other's perceptions about factors and that those tasks are thus planned accordingly.

In addition, this research studies interrelationships among inefficiency factors. There is a lack of understanding of how one inefficiency factor affects the others and how those factors finally affect the project outcome. Without knowing the attributes that need to be controlled, it is difficult to develop practical strategies for achieving construction project efficiency. By presenting potential relationships among the factors, this research will propose viable and impactful mitigation strategies for construction project efficiency.

This research intends to support efficient construction project management based on a holistic understanding of construction inefficiency. This research (a) investigates factors affecting construction inefficiency, (b) identifies perception gaps in the inefficiency in the industry, and (c) broadens the understanding of how the factors' interrelationships have an impact on the overall project. Construction inefficiency factors were detected through a comprehensive literature review, and their relative importance was collected in an online survey for analysis by calculating a relative importance index (RII) [15] and conducting factor analysis [12]. The perception gaps across different occupations, project types, and years of experience are explored through statistical analysis, specifically Welch's t-test [16]. The interrelationships among the factors were observed qualitatively by consolidating causes and effects collected from onsite interviews. Inefficiency mitigation strategies are suggested in addressing cascading inefficiency chain effects by stopping critical factors. This study contributes to the body of knowledge on project risk management by enabling industry professionals to communicate the gaps in inefficiency identified among project entities as well as understand which are the most triggering inefficiency factors and come up with a strategy to minimize or avoid those for minimizing productivity losses and achieving project completion within time and budget.

2. Research Background

Although extensive research has been conducted to identify factors affecting construction productivity and inefficiency, a general agreement that can fill gaps in research and practices in the industry has not been reached [4]. For example, performance factors affecting construction projects in the Gaza Strip in Palestine were investigated considering only three types of respondent groups, i.e., owners, consultants, and contractors [5], which can restrict a thorough understanding of performance factors in the industry. Doloi et al. (2012) identified 7 critical factors of construction delay, lack of commitment, inefficient site management, poor site coordination, improper planning, lack of clarity in project scope, lack of communication, and substandard contract, out of 45 attributed affecting delay [12]. There is still a lack of in-depth discussions with industry experts for better understanding of the inefficiency factors.

Meanwhile, an understanding of how all stakeholders perceive certain criteria has the potential to have a significant impact on project outcomes. For example, [17] explored safety and risks on construction projects and stated that stakeholders can usually identify the critical safety risks but that they have different estimates of risk likelihood, thereby creating some disparity. The literature in this domain states that many researchers have noted the disparity in risk perceptions among key stakeholders in safe construction work [18], but few have offered empirical data to back up their claims [17]. Thus, understanding gaps in stakeholders' perceptions is important for facilitating smooth communications and the progress of construction projects [19]. To achieve this purpose, a study compared rankings of 42 delay factors perceived by respondents, and 8 comparisons were conducted: owner and contractors, owner and consultants, contractors and consultants, contractors and subcontractors, experts with less than 10 years of safety experience and those with more than 10 years of experience, owners and project managers, project managers and site superintendents, and finally companies with fewer than 250 employees and more than 250 [19]. Another study identified 30 different causes of delay in the Hong Kong construction industry based on literature review, then classified those into 7 delay categories: client-related, engineer-related, contractor-related, human behavior-related, project-related, external factor-related, and resource-related [20]. The research conducted rank agreement factors (RAF), percentage agreement (PA), and percentage disagreement (PD) to understand the differences in perception between respondent groups.

Although many studies have focused on improving individual efficiency factors that affect construction projects, there is not much study available that gives an overall picture of the impacts of inefficiencies on construction projects as a whole. Additionally, identifying the interrelations between factors is critical to understanding how one inefficiency factor triggers others. Recognizing the root causes of major inefficiencies in projects and taking measures to control them will be helpful to industry practitioners. For example, 44 factors resulting in delays in construction projects in Nigerian industry were identified from questionnaires distributed to construction managers and literature reviews [21]. A pareto analysis was applied and discovered that around 88% of the factors were responsible for 90% of overall delays, leading to the conclusion that there is not much difference between the factors: none stood out as a major contributing factor. An integrated approach of studying both the causes and effects of delays to an entire project in the Malaysian construction industry was presented [22]. Qualitative research revealed 10 major reasons for delays in construction projects from a list of 28 factors. The relationship between cause and effect was studied using the relative importance index (RII) and Spearman's rank correlation. Through a comprehensive literature review, 15 independent root causes of construction project cost overruns among a pool of 146 potential causes were identified [23]. The top three root causes for cost overruns were (a) premature tender documents, (b) too many changes in owners' requirements or definitions, and (c) unrealistically low tender winning prices. Nasirzadeh and Nojedehi stated that identification of root causes will help to improve productivity by implementing appropriate solutions [24].

3. Materials and Methods

Figure 1 shows the overall research workflow. This methodology consists of the data collection stage and the analysis stage. After identifying construction inefficiency factors through a comprehensive literature review, an online Likert-scale survey was conducted to collect data indicating the importance of the factors. In addition, onsite interviews were conducted to explore in-depth knowledge on the jobsites.

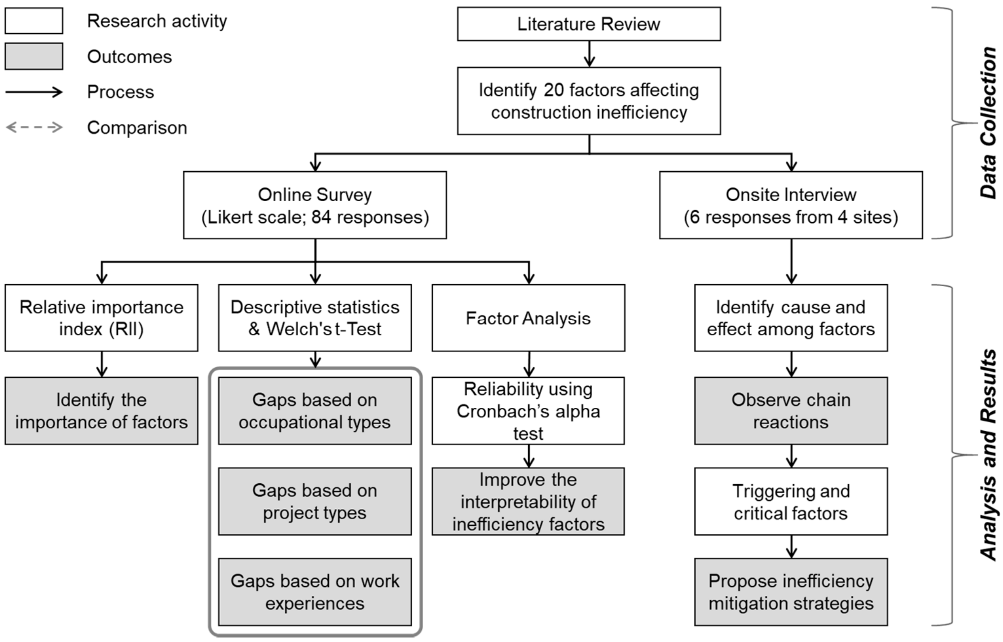


Figure 1. Overall Research Workflow.

In the data analysis stage, using online survey data, three analyses were conducted: (1) we measured relative importance index (RII) to assess the overall rankings among the factors [15]; (2) Welch's *t*-test was then conducted to identify perceived gaps in the importance of factors by occupation, project type, and years of work experience because the samples had unequal variances [16]; and (3) factor analysis was employed to enhance the factors' interpretability [25] by grouping inefficiency factors within the same category. By calculating Cronbach's alpha, we could ensure internal consistency within a group of inefficiency factors [26]. In addition, qualitative onsite interviews were conducted to identify the causes and effects among the factors.

4. Data Collection

4.1. Factors Identification through Literature Review

A comprehensive literature review was conducted to identify factors affecting construction project inefficiency. The authors found literature describing multiple factors: project delays, cost overruns, poor labor productivity, poor design and planning, communication issues, contract documents, construction execution phases, and inventory and logistic issues. Then the duplicated factors were removed, along with removing redundancies among factors by merging several factors into one representative factor. The 20 inefficiency factors shortlisted from several literature reviews and previous research are presented in Table 1.

Table 1. Summary of extracted construction inefficiency factors.

#	Factors	Descriptions in References	Ref.
1	Lack of coordination between project entities	Unclear information coordination between owner and project parties; no proper platform for coordinating with each other	[27]
2	Communication barriers resulting in lack of trust and disputes	Slow information flow between parties	[28]
3	Ambiguity in contract documents	No conformance to specifications	[29,30]
4	Noninvolvement of all stakeholders in early phase of project	Development of poor designs; Lack of creative solutions and intensive exchange of ideas	[31,32]
5	Improper resource allocation	Not enough room for changes; much idle time for resources, thereby decreasing efficiency	[33,34]
6	Irregular documentation and tracking of reworks and change orders	Unclear bid documents; owner-directed changes; scope additions	[35–37]
7	Unrealistic scheduled dates	Improper understanding of scope of project; improper scheduling and sequencing of work; inaccurate estimation of work	[38,39]
8	Lack of skill and experience of workforce	Not enough training given to unskilled labor; lack of awareness	[40–43]
9	Less emphasis on safety and environmental factors	Reportable accident rates on project; no specific safety personnel/department and/or resources	[44,45]
10	Supervision and inspection delays	Incompetent supervisors	[15,46]
11	Inventory and logistics issues	Lack of proper tools and equipment	[47,48]
12	Lack of automation and integration of technologies	Lack of using techniques or advanced software	[49]
13	Lack of motivation and attitude of workforce	No incentives to workers; long working hours and unpaid/less overtime payments; absenteeism	[50–53]
14	Inadequate risk identifications and prioritization	Time and cost overruns because of uncertainties; poor decision-making pertaining to risk factors	[54,55]
15	Improper project delivery system and contract type	Improper identification of stakeholders; Improper drafting of scope contractual responsibilities for all entities	[56–58]
16	Interoperability issues with software	Loss of design data; lack of using design data	[59–61]
17	Lack of considering modular or prefabricated construction	Not prefabricating standardized elements, inefficient methods of constructing work	[62,63]
18	Ignorance of building performance aspects in early stages	Poor planning because of increased life cycle costs; Changes in design later because poor decisions	[64]
19	External factors (force majeure, political)	Pandemic situation; political interference; inclement weather	[65,66]
20	Overcrowded work areas	Improper onsite resource planning; Interference between crews	[47,67,68]

Factor #1 "Lack of coordination between project entities", one of the key risks in construction projects, might result in anarchy in the administration of construction teams and programs [27]. Enhancing the quality and efficiency of construction requires strengthening participants' perceptions of collaboration and communication. Communication barriers can occur due to lack of trust and disputes [69]. According to a study by Doloi, partnerships for successful construction projects are based on communication, trust, confidence, and joint risk management. The research showed that trust and confidence explain the most variance in partnering success. The trust and confidence factor was measured by trust, confidence, and dispute resolution [70]. Thus, this research derived the inefficiency of "Communication barriers resulting in lack of trust and disputes" (#2).

"Ambiguous contract documents" (#3) can cause disagreement between project parties and result in many legal battles in the construction industry [30,71]. Although the main goals of contract drafting processes are to ensure clarity in obligations, responsibilities, and rights, as well as to support coordination, project parties frequently fail to indicate their approvals, resulting in ambiguous contract provisions in order to speed up the contract signature process. The primary causes of confusion and different interpretations include complex linguistic structure, legal and technical terminology, and ambiguity in contractual terms. Divergent interpretations of construction contracts owing to ambiguous language may result in disagreements, claims, and disputes, jeopardizing the effective completion of project objectives [29].

All the relevant stakeholders should be brought in during the early phase/conceptual stages because all parties can influence the decisions made and have impacts on the desired outcome [31,32] "Early involvement of all stakeholders" will improve construction efficiency by allowing for value engineering and constructability studies [72]. Its counterfactor "Noninvolvement of all stakeholders in early phase of project" was then derived (#4) [31,32].

The type of project delivery system will change the responsibilities of project stakeholders, the owner's willingness to be involved, the owner's in-house technical capability, risk allocation, and the owner's willingness to control over design [56–58,73]. Thus, different types of "project delivery system and contract type" will influence construction projects' success (#15). According to a survey conducted by Durdyev et al., a project management team must devote time and effort to accurately estimating the cost of a building project; otherwise, resource allocation will be erroneous. Gaps in understanding the proper optimization of resources between the stakeholders result in "improper resource allocation" (#5), leading to time and cost overruns in the project [33,34,74]. Given that construction waste can be one of the inefficiency measures of construction projects [37], this research considered factors engendering construction waste as inefficiency factors. Reworks or variation works were one of the contributing factors to construction waste [37]. According to [35], "lack of documentation of accidents and reworks" may cause serious inefficiency (#6).

Aggressive scheduling can worsen the efficiency of the construction operation [75]. The "Unrealistic schedule" (#7) was one of the highest contributing causes of time and cost overruns in the UAE construction industry [76]. Unrealistic contract duration causes inefficiency during the construction phase by project managers, taking time in reviewing initial expected completion time and amending where necessary [39]. In a survey conducted in Nairobi County in Kenya by Munyoki, around 98% of the respondents observed that project completion was delayed because of "supervision and inspection delays" (#10). Supervision and inspection are one of the major causes for declining productivity in construction projects [46]. Supervision and inspection delays were revealed as one of the contributing factors for the productivity decline in the UAE construction industry [15]. On construction sites, congested work areas will affect productivity [47] as well as inefficient work. Congestion of work areas causes not only schedule compression but also several other contributing factors [68]. According to one study, congestion of work areas accounted for a total of 422 inefficient work hours for the construction of the fifth and sixth floors of a building, which accounted for an additional cost of USD 8440 [68]. Construction logistics should also be measured and monitored continuously in order to avoid the issue of longer lead times [47,48]. Thus, "inventory and logistics issues" (#11) were explored in this research. Jarkas and Bitar (2012) stated that the efficiency of workers is significantly impacted by restricted site access and confined working space, owing to a loss of flexibility in labor, materials, equipment, and plant movement in and out of sites [77]. Given this, "overcrowded work areas" (#20) were presented as one of the inefficiency factors.

Ngundo (2014) identified the importance of risk anticipation by studying Kibera slum upgrading schemes in Nairobi [78]. The study suggested having guidelines in place for the selection of appropriate project entities and that the project team should have a good balance of both technical skills and administrative skills. It was also suggested that all those participating in building projects receive project risk planning training in order to improve their ability to identify, prioritize, and filter project risks in order to manage them in a structured and methodical manner. Time and cost overruns can be caused by uncertainties and poor decision-making pertaining to risk factors [54,55]. In this respect, "adequate risk identifications" will affect construction efficiency (#14).

The most important contributing factors affecting labor productivity in several construction industries were found to be "skill and experience of labor" (#8) [79] and "lack of motivation and attitude of workforce" (#13) [46,50,51,53]. Having a highly motivated and competent workforce is one of the major drivers of increased efficiency, and hence those factors are considered in this study.

Jiang et al. studied the management of construction safety as a system and came up with a system dynamic model whose results revealed that compromising on safety jeopardizes efficiency and that only by prioritizing safety will a project have both a solid safety record and consistent production (#9) [45]. For having an effective environmental realization, the identification of possible impacts of building construction projects is essential, which will help improve uncertainties, thereby improving efficiency [80]. Hence, it is advisable that an environmental protection plan be prepared for each of the construction stages.

The automation of construction processes is one of the most promising approaches to improving efficiency [49]. Construction automation can improve collaboration among stakeholders, reduce the time to perform construction activities on site, and therefore aid in improving construction efficiency. Furthermore, according to a study evaluating the influence of automating the identification and localization of designed components on craft efficiency on industrial projects [81], the amount of labor time spent on the identification of a component on yard was reduced by a ratio of 8 to 1, and the number of components not easily found reduced by a ratio of 18 to 1, and this led to an improvement in overall efficiency of 4.2%. This research considered the "lack of automation and integration of technologies" (#12) as one of the construction inefficiency factors. In the construction industry, building information modeling (BIM) has been applied for improving the efficiency of sharing, managing, and controlling project information [60]. Still, given that the multidisciplinary nature of construction project development requires transferring data to different platforms, loss of design data can lead to delays and rework [59,82]. Here, "lack of software compatibility" and "inefficient data interoperability" (#16) can constrain the effective implementation of BIM in construction projects

Tsz Wai et al. (2021) stated that since off-site production predominates, modular construction provides a higher quality of work because rework is lower (#17) [83]. Fixing the modules' design early on reduces the amount of rework that occurs as a result of design modifications. Modules are also constructed in the factory, which increases the likelihood of getting the design correct the first time and makes quality control easier [84]. It has been suggested that off-site building can improve product quality by decreasing rework to 1% [85]. Building performance aspects (#18) are very important in architecture, building systems, and regulations, which include factors such as energy efficiency, thermal comfort, indoor air quality, and daylighting. It is essential to consider all these aspects early in the design phase, not only to conform with the thresholds required by laws but also to prevent remedial actions such as design changes, reconstruction, replacement, and repairs during the construction, which involves a significant cost, time, and resources [86]. External variables such as force majeure and political risks (#19) are also factors affecting project inefficiency through political interferences as well as unforeseen circumstances related to inclement weather or pandemic situations that might have a severe impact on the project timeline and budget [65,66].

4.2. Online Survey

An online survey was conducted among industry practitioners to measure attitudes and opinions about 20 construction inefficiency factors while protecting anonymity. The questionnaire was divided into two parts: (1) the respondents' occupational information including professional position in the construction industry, the type of projects they have been a part of, and lastly, the number of years of experience they have (3 questions) and (2) their perceptions of the impacts of the inefficiency factors on a Likert scale of 1 to 5 [87] (20 questions). This survey was approved by the Institutional Review Board (IRB) at Purdue (# 2021-864). Data from the experiments were anonymously collected, and informed consent was obtained for each participant.

- 1 = Not Important (issue need not be addressed)
- 2 = Slightly Important
- 3 = Moderately Important
- 4 = Important
- 5 = Extremely Important (issue needs to be addressed).

The survey was electronically created in Qualtrics and distributed via multiple channels such as LinkedIn and emails to Construction Advisory Council (CAC) members in the School of Construction Management Technology at Purdue. The survey data were collected from June to September 2021. A total of 84 responses were received and analyzed.

4.3. Site Visits and Interviews

Expert interviews on construction sites were conducted to explore in-depth knowledge on the jobsites about the causes and effects of the inefficiency factors. Four construction projects located within the authors' physically reachable areas were visited, which included an academic building, an orchestra building, a historical building renovation project, and a vet hospital on a university campus. Observations were made on the site on topics pertaining to efficiency, and interviews were conducted with project team members.

In addition to the impacts of the 20 inefficiency factors, in the site interview, the experts were asked to share their heuristic knowledge about the main causes of each factor from those 20 factors. In asking this, we intended to identify the relationships between the factors, how these interconnections influence the project as a whole, and the root causes of inefficiencies.

5. Results

5.1. Relative Importance Index (Rii)

Previous research has applied a relative importance index (RII) to measure the relative importance of the factors [15] using Equation (1) [88,89]:

$$\text{RII} = \sum W \div A \times N \tag{1}$$

where W is the weight given to each attribute by a respondent, A is the highest weight, and N is the total number of respondents. RII indicates the importance of a factor influencing construction inefficiency.

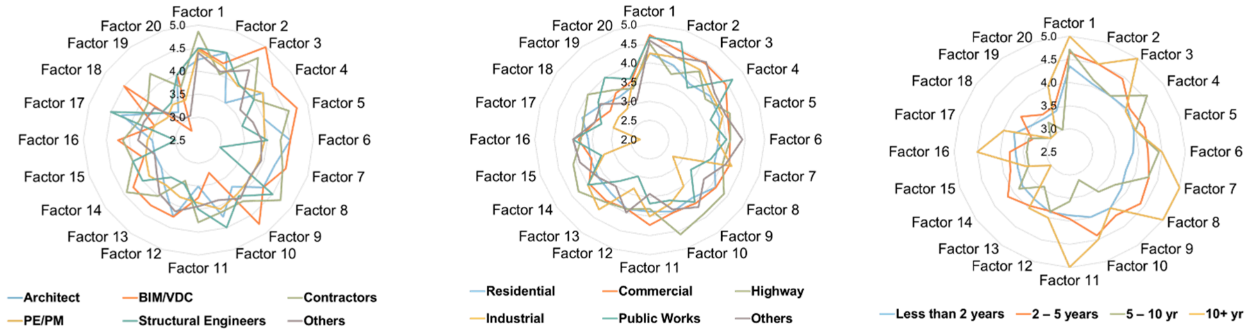
Table 2 shows the relative importance of the 20 factors. The highest ranking was lack of coordination between project entities, which was considered an extremely influential factor in project inefficiency. Fragmented communications and information had a higher impact than other factors on construction inefficiency.

Table 2. Relative importance of construction inefficiency factors.

Rank	Factors	Mean	RII
1	Lack of coordination between project entities	4.41	0.892857
2	Communication barriers resulting in lack of trust and disputes	4.18	0.835714
3	Ambiguity in contract documents	4.13	0.82619
4	Noninvolvement of all stakeholders in early phase of project	4.11	0.821429
5	Improper resource allocation	4.02	0.804762
6	Supervision and Inspection delays	4.02	0.804762
7	Irregular documentation and tracking of reworks and change orders	4.01	0.802381
8	Lack of skill and experience of workforce	4.01	0.802381
9	Less emphasis on safety and environmental factors	4.01	0.802381
10	Unrealistic scheduled dates	3.98	0.795238
11	Inventory and logistics issues	3.89	0.778571
12	Lack of automation and integration of technologies	3.87	0.77381
13	Inadequate risk identifications and prioritization	3.85	0.769048
14	Lack of motivation and attitude of workforce	3.8	0.759524
15	Interoperability issues with software's	3.7	0.740476
16	Improper project delivery system and contract type	3.69	0.738095
17	Lack of considering modular or prefabricated construction	3.64	0.728571
18	Ignorance of building performance aspects in early stages	3.51	0.702381
19	Overcrowded work areas	3.44	0.688095
20	External factors (force majeure, political)	3.4	0.680952

5.2. Different Perceptions by Occupation, Project Type, and Work Experience

Understanding the perception gaps between multiple stakeholders will help to improve coordination, communication, and quality control. This research thus endeavored to identify perception gaps for the impacts of inefficiency factors among industry professionals in different occupations, project types, and work experience. Figure 2 shows the impacts of inefficiency factors averaged by industry professionals' occupation, project type, and work experience from online survey responses. The architects ranked "communication barriers resulting in lack of trust and disputes" (factor 2) the highest, while contractors and project engineers/managers ranked "lack of coordination between project entities" (factor 1) the highest. In contrast, BIM/VDC and other occupation types ranked "ambiguity in contract documents (Factor 3)" the highest; ambiguous terms, clauses, and contracts exist for BIM works. The structural engineers ranked the "lack of considering modular or prefabricated construction" (Factor 17) as the highest, which makes sense as conventional onsite construction takes time to develop detailed shop drawings and fabricated materials. One of the lowest-rated inefficiencies was "external factors (force majeure, political)" (factor 19), commonly selected by architects, BIM/VDC, and others. On the other hand, contractors ranked "lack of integration of automation and technologies" (factor 12) the lowest, and project engineers/managers ranked "ignorance of building performance aspects in early stages" (Factor 18) the lowest. This shows that a mental shift is still needed toward considering project planning from a holistic approach and not as an individual activity.



(**a**) (**b**) (**c**)

Figure 2. Perception gaps of the impacts of construction inefficiency factors averaged by (**a**) occupation, (**b**) project types, and (**c**) work experience (Factor numbers are based on Table 1).

When it comes to project types, professionals in commercial and public work projects ranked the inefficiencies related to communication in and between project entities the highest (factor 1, factor 4). Professionals working on highway projects ranked supervision and inspection delays (factor 10) the highest, and ranked "overcrowded work areas (factor 20)" as the least important factor. Figure 2 shows the perception gaps of the impacts of inefficiency factors by industry professionals' occupation, project type, and work experience.

Considering that the sample sizes and Likert scale ratings differed by occupation, project type, and work experience, Welch's *t*-test was conducted [90] using R programming language to identify significant perception gaps. This would test the null hypothesis that the two groups' means were identical (H_0) (the alternative hypothesis: the two groups' means are different (H_a). The adjusted p values (<0.05) can be used to reject of retain the null hypothesis. According to the test results shown in Table 3, the perceived importance of factors 2, 4, 6, 9~10, 12~13, 15, and 17 was the same (there is no statistically significant difference) regardless of participants' positions, project types, or years of experiences. Major perception gaps were observed in factor 7, unrealistic scheduled dates. Perception gaps in professionals in the residential and commercial sectors were statistically significant for factor 3, ambiguity in contract documents and factor 5, improper resource allocation. Professionals in the commercial sector consider factor 3 and factor 5 more important than professionals in the residential sector do. Perception gaps often occurred between those who were in the construction industry less than 2 years and those whose experience was over 10 years. Professionals who had longer experience tend to perceive factor 7 as important.

Table 3. Inefficiency factors which present perception gaps by Occupation, Project Type, and Work Experience (Adjusted p values).

Comparison Groups	Factors	Factor 1	Factor 3	Factor 5	Factor 7	Factor 8	Factor 11	Factor 14	Factor 16	Factor 18	Factor 19	Factor 20
Contractor	Structural Engineer	NS *	NS	NS	**0.04**	NS	NS	NS	NS	NS	NS	NS
Other	Structural Engineer	NS	NS	NS	NS	NS	NS	NS	**0.04**	NS	NS	NS
Project Engineer/Manager	Structural Engineer	NS	NS	NS	**0.00**	NS	NS	NS	**0.00**	NS	NS	**0.01**
Commercial	Residential	NS	**0.04**	**0.04**	NS	NS	NS	NS	NS	NS	NS	NS
Less than 2 years	2–5 years	NS	NS	NS	NS	**0.02**	NS	NS	NS	NS	NS	NS
Less than 2 years	Over 10 years	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	NS	**0.01**	**0.02**	**0.00**
2–5 years	5–10 years	NS	**0.01**	**0.01**	**0.01**	**0.00**	**0.00**	**0.00**	NS	**0.01**	NS	NS
2–5 years	Over 10 years	NS	NS	NS	NS	**0.04**	NS	NS	NS	NS	NS	NS
5–10 years	Over 10 years	NS	NS	NS	**0.04**	NS	NS	NS	NS	NS	NS	NS

* "NS": Not Significant; Significant adjusted p values.

5.3. Factor Analysis

Factor analysis can distill a large number of seemingly unrelated but associated variables into a smaller number of underlying factors [12]. Factor analysis condenses a large number of variables into the fewest feasible entire or holistic impacts. Given that it does not tolerate arbitrary decisions as to what are relevant variables in any field, factor analysis is a more drastic break from statistics associated with experimental tradition. It provides a comprehensive and sensitive way to describe quantitative relationships between variables based on co-variable observation [91].

The Kaiser–Meyer–Olkin (KMO) test and Bartlett's test of sphericity were used to assess the survey data's suitability for the factor analysis [88]. The ratio of the squared correlation between variables to the squared partial correlation between variables is represented by the KMO statistic. It ranges between 0 and 1. A score around 1 suggests that the pattern of correlations is generally tight, implying that factor analysis should produce distinct and dependable conclusions [88]. A minimum value of 0.5 has been suggested [88]. The KMO value for the selected variables was 0.711, which we deemed suitable for the factor analysis of the response dataset. Principal component analysis was performed, and a total of six principal factors were extracted. These 6 factors explained 61.8% of total variance among 19 of the 20 inefficiency factors (excluding supervision and inspection delays" (#10). The calculations were performed on Minitab software. Table 4 shows the factors loading and the variables extracted and the total variance.

Cronbach's alpha was calculated for reliability analysis, which is essential to validating a model over time (i.e., consistency of measured attributes and scale) in Table 5. Cronbach's alpha can range from 0 to 1, with a higher value indicating stronger internal consistency. Cα is inflated by a large number of variables, so there is no set interpretation as to what an acceptable limit is [88]. As stated in [92], Cronbach's alphas more than 0.9 show very high reliability, 0.70 to 0.90 still presents high reliability, 0.50 to 0.70 shows moderate reliability, and less than 0.5 indicates low reliability. Cα for all 20 attributes was 0.849, which is considered high reliability.

Category A, planning, explained 15.90% of the total variance and consisted of three inefficiency attributes. The first attribute is "Less emphasis on safety and environmental factors", which are often overlooked and not given much-needed time during early planning stages. In the construction industry, around 29% of the total number of industrial workers account for around 40% of workplace accidents [93]. It is essential that an environmental protection plan be prepared for each of the construction stages [80]. In addition, risks occur in all construction phases and change during the project life cycle, and thus, the identification of risks is essential and is an iterative process [94]. As stated by Mortazavi et al., one of the neglected aspects of risk management is the internal impacts of risks, i.e., how one risk affects the other and thereby amplifies [95]. Here, the author advises looking out for such risk combinations and synergies as well. For the risk analysis, two methods, i.e., quantitative and qualitative methods are suggested.

Table 4. Factor Analysis Components Extracted.

Factor ID	Reason Description/Factor Name	Factor Loading	% Variance Explained
Category A	**Planning**		**15.90%**
Factor 9	Less emphasis on safety and environmental factors	0.741	
Factor 18	Ignorance of building performance aspects in early stages	0.67	
Factor 14	Inadequate risk identifications and prioritization	0.66	
Category B	**Contract Documentation**		**11.40%**
Factor 7	Unrealistic scheduled dates	0.783	
Factor 3	Ambiguity in contract documents	0.768	
Factor 4	Non-involvement of all stakeholders in early phase of project	0.632	
Factor 6	Irregular documentation and tracking of reworks and change orders	0.513	
Category C	**Communication**		**10%**
Factor 2	Communication barriers resulting in lack of trust and disputes	0.781	
Factor 1	Lack of coordination between project entities	0.758	
Category D	**Execution**		**9.50%**
Factor 11	Inventory and Logistics issues	0.746	
Factor 20	Overcrowded work areas	0.682	
Factor 13	Lack of motivation and attitude of workforce	0.581	
Factor 19	External factors (Force Majeure, Political)	0.425	
Category E	**Technology**		**8.40%**
Factor 12	Lack of automation and integration of technologies	0.787	
Factor 16	Interoperability issues with software's	0.642	
Category F	**Onsite performance aspects**		**6.60%**
Factor 17	Lack of considering modular or prefabricated construction	0.852	
Factor 8	Lack of skill and experience of workforce	0.411	
Factor 5	Improper resource allocation	0.234	
Factor 15	Improper project delivery system and contract type	0.188	
	Total Variance Explained		**61.80%**

Table 5. Reliability test for attributes using Cronbach's alpha.

Attributes	Cronbach's Alpha ($C\alpha$)
Attributes in Category A	0.75
Attributes in Category B	0.71
Attributes in Category C	0.64
Attributes in Category D	0.61
Attributes in Category E	0.586
Attributes in Category F	0.56
All attributes (20 factors)	0.849

The second category is contract documentation, which explained 11.40% of the total variance and consisted of four attributes. As we observed in the factor analysis, previous studies have also shown that construction failure can occur due to unrealistic scheduled dates [22,38,39]. In addition, there are a variety of types of ambiguity affecting the efficiency in the industry: ambiguity due to numerous variations in the bill of quantities, incomplete clauses and those that do not define the scope of anticipated work, ambiguities due to numerous changes in scope of work, excessive demands and uncertain enforceability, and ambiguous goal and performance requirements [71]. The major causes of misunderstanding and diverse interpretations are complex language structure [71], legalese and technical words, and ambiguity in contractual terms [71]. Divergent interpretations of construction contracts due to ambiguous phrases may result in disagreements, claims, disputes, and jeopardizing the proper completion of project objectives [29,71]. The influential attributes in this category are followed by "noninvolvement of all stakeholders in early phase of project" and "irregular documentation and tracking of reworks and change orders".

Category C, communication, explained 10% of the total variance and consisted of two attributes. The observations confirm the results from previous studies. Communication willingness and successfully improving formal communication among various project teams can contribute to preventing time and cost overruns [96–98]. The coordination process is often executed to increase efficiency and provide value to project delivery by addressing dependencies between project tasks and participants, or in other words, "managing dependencies between activities" [64]. The components that contribute to a good coordination process have been researched and categorized into three categories: mandates, systems, and behaviors: If the factors in these three groups are given sufficient weight and implemented throughout time, the activities will be more likely to succeed and will occur sooner [64].

Category D, execution, explained 9.50% of the total variance and consisted of four attributes. "Inventory and logistics issues" were identified as an important challenge to meeting the expectations and schedules set by new project management methods [99,100]. Category E, technology, explained 8.40% of the total variance and consisted of two attributes: "lack of automation and integration of technologies" and "interoperability issues between software". Category F, onsite performance explained 6.60% of the total variance and consisted of four attributes. Under this category, the impact of modular construction on efficiency was also observed in a previous study [101]. "Lack of skill and experience of workforce" is recognized as the main labor-related factor that contributes to the loss of efficiency in projects encountering craft shortages. Over the last few decades, skilled labor shortages have pervaded the North American construction sector, making recruiting and keeping competent labor a serious difficulty that can negatively impact overall project performance [102]. In addition, the appropriateness of the project delivery system (PDS) chosen for a project has a significant impact on project implementation efficiency [103]. The type of construction contract and clearly defined stakeholder relationships from various viewpoints are important success criteria and performance indicators for infrastructure projects [103]. Construction costs, disagreements, and project hazards rise as a result of poor contract selection and writing [103].

5.4. Interrelationships of the Factors for Identifying Root Causes

We explored the relationships between the various attributes based on the onsite interviews. Specifically, 6 experts on site were asked the causes and effects among the 20 inefficiency factors.

As the inefficiency factors are interrelated, cumulating inefficiency from one trigger to a chain reaction can be observed as shown in Figure 3. The main aim of this chain reaction diagram is to identify the factors that need to be controlled in order to reduce inefficiencies on projects. If any inefficiency factor occurs among factors 1~7, 10~11, 15, or 18, the factors will keep being caused due to the reinforcing chain effects. Among the factors, three factors: irregular documentation and tracking of reworks and change orders (factor 6), inventory and logistics issues (factor 11), and improper project delivery system and contract type (factor 15), can expand and aggravate inefficiency. At the same time, the figure also indicates that construction project efficiency can be controlled and improved by managing those three factors. In addition, lack of skill and experience of workforce (factor 8) and external factors (factor 19) are triggers of the majority of inefficiency factors. Given that external factors such as political reasons cannot be managed at the project level, root causes that initiate the chain effects of construction project inefficiency will be factor 8.

Based on the chain reactions in Figure 3, we explored triggering and critical factors. Triggering factors were defined as the factors that triggering a number of consequential inefficiency factors. Critical factors were defined as the factors stemming from the triggering factors and thereby resulting into inefficiency loops. Table 6 shows the critical factors and the chain reactions. We observed that factors 5, 7, 11, and 14 are critical factors causing chain reactions of construction inefficiency. Factor 5, improper resource allocation, causes factors 1, 4, and 15, and Factor 15 causes diverse inefficiency factors such as factors 3, 4, and 17.

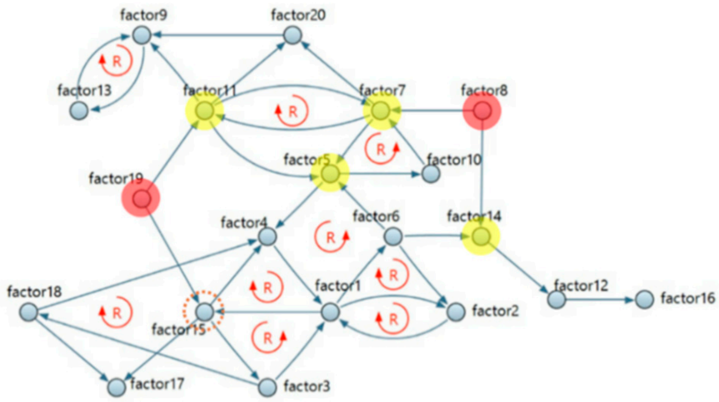


Figure 3. Chain reactions of construction inefficiencies ("R" denotes a loop reinforcing the inefficiency).

Table 6. Critical Factors and Chain Reaction.

Critical Factors	Chain Reactions
Factor 14 Inadequate risk identifications and prioritization	**14**→12→16
Factor 5 Improper resource allocation	**5**→4→1⇆2 **5**→4→1→**15**→4→1⇆2 **5**→4→1→**15**→3→18→4 **5**→4→1→**15**→3→1→**15** **5**→4→1→**15**→17 **5**→4→1→6⇆5
Factor 7 Unrealistic scheduled dates	**7**→**5**→10
Factor 11 Improper project delivery system and contract type	**7**⇆**11**→20→9⇆13

Given that chain reactions can reinforce inefficiency factors, managing triggering and critical factors may resolve the overall construction inefficiencies. To address the triggering factor 8, "lack of skill and experience of workforce", we can consider several mitigation strategies suggested by [104]: (a) hiring qualified contractors, subcontractors, and vendors, (b) devising skill development programs for the workforce, (c) investing in labor wages to get qualified personnel, (d) extending the retirement age, (e) attracting the young generation, and (f) training apprenticeships and experiences. To address another triggering factor, factor 19, "external factors (force majeure, political)", PESTEL analysis, analyzing political, economic, social, technological, environmental and legal factors of projects, can be adopted in the construction industry. The PESTEL analysis of construction projects can identify uncontrollable, external factors and prepare project team members [105].

Critical factor 5, "improper resource allocation", which results from triggering factor 8, can consider mitigation strategies such as (a) tracking resource availability, (b) managing workload allocation to track hour-by-hour availability, (c) monitoring resource productivity on project dashboards, (d) proactive resource planning to avoid last-minute firefighting [106], (e) analyzing schedule risks using a quantitative schedule risk analysis (QSRA) on the project at an early stage [107] and (f) leveraging cost-effective global resources across the matrix boundaries [108]. To avoid the critical factor 7, "unrealistic scheduled dates", which also results from triggering factor 8, we can explore mitigation strategies suggested by [109]: (a) training project planners, (b) conducting a process mapping to validate the time schedule with the site management/production team, (c) educating and advising the client on alternatives when an unachievable or unrealistic project timescale is stipulated, and (d) assigning time implications to risks. Critical factor 11, "improper project delivery system and contract type", which results from triggering factor 19, can be addressed by making proper decisions regarding the project delivery method.

Addressing certain aspects such as regulations and unique protocols, time and budget constraints, complexity of the project, and the owner's expertise will help to determine the most suitable project delivery method. Critical factor 6, "irregular documentation and tracking of reworks and change orders", which results from triggering factor 8, can be addressed with mitigation strategies such as (a) encouraging collaboration between the contractor and the design team [110], (b) enhancing interdisciplinary coordination during design [110], (c) ensuring clarity in contract documents [111], and (d) applying project documentation and management software tools such as Procore [112].

Factor 15, "inventory and logistics issues", results from triggering factor 19 as well as being caused by chain reactions that start from factor 5 and cause the diverse inefficiency factors 3, 4, and 17. To address factor 15, we can consider mitigation strategies such as (a) proactive analyses of project procurement, materials, and supply chains [113], (b) an inventory management system using new technology such as IoT or blockchain to guide inventory management [114], or (c) adopting vendor-managed inventory of optimizing inventory and routing simultaneously [115].

6. Conclusions

This research intends to support efficient construction project management by providing a holistic understanding of inefficiency factors, perception gaps among stakeholders, and interrelationships among the factors. Both quantitative and qualitative data were collected from an online survey and onsite interviews. To analyze the multifaceted aspects of inefficiency factors, statistical analyses using RII, Welch's *t*-test, and factor analysis were conducted for the online survey data. Onsite interviews were interpreted as qualitative to consolidate causes and effects among the factors and observe chain reactions of project inefficiency.

First, this research identified common inefficiency factors in the construction industry by conducting a comprehensive literature review. A total of 20 inefficiency factors were shortlisted, and an online survey based on Likert scale was conducted. A total of 84 responses were obtained and analyzed. A relative importance index (RII) was used to determine the ranking of factors, and "lack of coordination between project entities" was the highest-rated inefficiency with a RII of 4.41; "external factors (force majeure, political)" was rated the lowest with a RII of 3.4 on a scale of 5. A factor analysis was then performed to understand the relationships between variables based on co-variable observation. The factors were merged and condensed into six main categories, namely, planning, contract documentation, communication, execution, technology, and onsite performance, explaining a total variance of 61.80%. A Cronbach's alpha test was conducted for reliability analysis, which is essential for validating the build of the model over time, and the value ranged from 0.56 to 0.75 for the 6 categories; the value was 0.849 for all the 20 factors. The higher the value, the stronger the internal consistency between factors.

Perception gaps in inefficiency among different stakeholders were observed in this research using Welch's *t*-test. The background was divided into three major category: occupation, type of project, and years of experience. Major perception gaps were observed in factor 7, unrealistic scheduled dates. Perception gaps among professionals in the residential and commercial sectors were statistically significant in factor 3, ambiguity in contract documents, and factor 5, improper resource allocation. Professionals in the commercial sector considered factor 3 and factor 5 to be more important than professionals in the residential sector. Perception gaps occurred often between those who in the construction industry less than 2 years and those who had experience over 10 years. Professionals who had longer experience tended to perceive factor 7 as important.

The high Cronbach's alpha between all the factors indicates that there is a strong relationship between them, and hence, it was essential to understand how one factor affected the others. In order to determine this, onsite interviews with experts from four different types of construction projects were conducted. Based on the responses, the chain reactions of the factors were explored and showed the triggering and critical factors in overall construction inefficiency. The information related to interrelated factors can be used in the industry to understand which factors need to be prioritized and controlled first. Moreover, if, hypothetically, that factor is not able to be controlled for any reason, the chain reactions can be used to determine the upcoming inefficiency factors and mitigation strategies can be thought of beforehand, which would help to keep the project timeline and budget as planned.

The triggering factors of consecutive inefficiency factors were found to be “lack of skill and experience of workforce” and “external factors (force majeure, political)”. The critical factors were identified as “inadequate risk identification and prioritization”, “improper resource allocation”, “unrealistic scheduled dates”, and “improper project delivery system and contract type”. Several mitigation strategies to control and manage these triggering and critical factors are also mentioned.

This research mainly contributes on understanding the perceptions of efficiency among construction professionals with respect to occupation, type of project, and years of experience. This understanding will help the project team to collaborate effectively by taking into consideration everyone’s perspective and thereby preparing a plan of action. For example, on a corporate level, we can expect projects whose participants are mainly young professionals (less than 2 years) might be planned too ambitiously without regard for the severity of unrealistic schedule impacts. In addition, the interrelated factors can be implemented on site at any stage of the project in order to predict the upcoming barriers in the project that could lead to inefficiencies. We can then determine the next potential problem that might arrive and hence start taking precautions or have a prevention plan in place to address it. It is advised to use this chain reaction from the initial phase of construction planning and execution so as to optimize the efficiency of tasks. In addition, by developing appropriate interventions for chain reactions, we can improve overall efficiency. For instance, training the workforce (intervention for reducing factor 8) can moderate the corresponding inefficiency factors 7 and 14, enhancing the overall efficiency of construction projects.

Although best efforts were made to make a significant contribution to the industry, this paper has some limitations. The sample size for responses and interviews conducted is on the smaller side for statistical analysis. Next, the respondents were not evenly distributed among different occupations and project types, which might have induced some bias. This study followed an exploratory approach to providing new insights related to construction efficiency. In a future study, the sample size should be increased, and the factor relationships can be statistically tested by collecting more data and by being examined across different organizations in the construction industry. With sufficient data collection and for quantitative efficiency modeling, data validation should be conducted in the future. In addition, tangible scenarios for improving project efficiencies should be tested with empirical observations.

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