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Modeling Critical Rework Factors in the Construction Industry: Insights and Solutions

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Abstract: Construction professionals recognize rework's negative impact on project performance, yet a comprehensive understanding of its critical factors still needs to be provided. Consequently, this study sought to inquire deeply into the causes of construction rework. A systematic framework was employed to achieve the research objectives. Initially, potential causes of rework were identified through a systematic literature review. Subsequently, a survey was developed and emailed to the sample group. Exploratory factor analysis was used to extract critical rework factors (CRFs) and normalized mean value analysis was used to evaluate the criticality of the obtained causes. Structural equation modeling was used to quantify and simulate the effect sizes of the components that were collected. Out of 43 possible causes, this study found 21 critical causes why rework occurs in the Turkish construction sector. Additionally, it uncovered four original CRFs, namely "management and planning deficiencies", "design and time constraints", "labor quality and compliance issues", and "project dynamics and communication challenges". While numerous studies have explored rework causes using different approaches and methodologies, there remains a lack of insight into the key factors leading to rework. Unlike earlier research, this study offers a thorough and quantitative identification of four distinct critical rework factors in Turkey.

Keywords: rework; critical rework factors; structural equation modeling; normalized mean value; construction industry

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1. Introduction

Rework in engineering and construction contexts refers to the unnecessary effort involved in redoing a process or activity incorrectly implemented the first time. This phenomenon is particularly prevalent in construction projects, where it can lead to significant cost overruns and delays. For instance, Love et al. [1] define rework as "the unnecessary effort of redoing a process or activity that was incorrectly implemented the first time" [1]. This definition underscores the inefficiencies that can arise from poor initial execution, a critical concern for engineering goals focused on efficiency, cost-effectiveness, and timely project delivery. The relationship between rework and engineering goals is multifaceted. Rework not only increases project costs—contributing to an average of 52% of total cost growth in construction projects [2]—but also adversely affects project schedules, often leading to overruns of up to 22% [2]. Such impacts directly contradict engineering objectives, which prioritize adherence to budgets and timelines. Moreover, the causes of rework are often linked to deficiencies in project management practices, such as ineffective communication, lack of clear procedures, and insufficient quality control measures [3,4].

These factors highlight the need for robust project management frameworks that align with engineering goals to minimize rework.

Given these challenges, it is essential to understand the broader implications of rework on project performance in the construction industry. Rework is not merely a technical inefficiency but a systemic issue that affects multiple facets of project execution, from financial viability to workforce productivity. Addressing rework requires a holistic approach that integrates effective risk management, advanced construction methodologies, and continuous performance monitoring to ensure projects meet their intended objectives.

The construction industry encounters considerable risks related to rework, where project performance is frequently scrutinized, and outcomes are often criticized [5]. Key factors influencing project performance include cost [6,7], schedule [6,8], quality [9], productivity [10], and safety [11], which have been extensively examined [8]. Research indicates that cost overruns, delays, and diminished project performance can stem from various issues, with rework being a significant factor [12,13]. Construction rework, identified as a critical factor affecting project outcomes, has been highlighted by Asadi et al. [14].

According to Love and Smith [15], rework involves repeating or correcting tasks, leading to inefficiencies and disruptions. In the construction industry, rework [14] refers to non-value-adding activities, including correcting errors, fixing defects, modifying project scopes, and addressing non-compliance issues [16]. This process often involves reassembling tasks, speeding up schedules, generating waste, and results in value loss [17]. Kakitahi et al. [18] stated that project costs and schedules were influenced by construction rework by about 4.53% and 8.42%, respectively. In addition, rework costs represented 4.4% of the total construction value and consumed 7.1% of the overall work time [19]. In addition, Eze et al. [20] emphasized that rework can significantly decrease profits, lead to more disputes, and cause dissatisfaction among both owners and contractors.

Rework also leads to considerable inefficiencies in productivity. Thomas and Napolitan [21] observed that necessary modifications could reduce daily labor productivity by 25–50%, mainly due to the inaccessibility of construction materials needed for rework. Industry professionals recognize the considerable effect of rework on the poor performance of construction projects as well [22]. Therefore, identifying the origins of rework is crucial to prevent it from escalating into significant management challenges [12,23].

Extensive research has explored the causes of rework and its effects on project budgets and timelines across various construction sectors and countries. Rework is recognized as a major worldwide challenge within the construction industry, as demonstrated by studies conducted in different nations and industries [24,25]. Significant strides in understanding rework causes have been made by researchers in developed countries like Australia [7,26], the USA [27,28], and the UK [29]. Additionally, researchers from developing countries, including China [23,30,31], New Zealand [14], Spain [2], Uganda [18], Malaysia [5,32,33], Palestine [24], Indonesia [34], and Ukraine [35], where construction plays a crucial economic role, have increasingly focused on examining the causes of rework. Ye et al. [23] also pointed out the gap in knowledge concerning rework causes in developing nations.

In Turkey, the construction industry is vital for national economic growth, providing essential investment opportunities and boosting national revenue [35,36]. The Turkish construction sector develops critical infrastructure such as roads, power systems, bridges, and airports [37]. The Turkish Contractors Association report (2016) shows that the construction sector contributes to the Turkish economy by up to 30%, making it a cornerstone of the national economy [38]. Given this prominent role within the national economy, the construction sector serves as the driving force for Turkey. Therefore, highlighting the critical construction rework factors adversely affecting the construction industry's productivity is vital.

While several scholars have explored construction rework causes [20,24,28,39], there is a significant literature gap regarding the critical factors causing rework, particularly those most influential in developing countries' construction industries. This gap complicates developing strategic plans for mitigating rework incidences.

For the above reasons, this research seeks to clarify the key rework factors hindering project performance, leading to cost and schedule overruns, and affecting productivity in the Turkish construction industry. The study has four primary aims: (1) to emphasize the possible causes of construction rework, (2) to assess the significance of these identified causes, (3) to highlight the critical rework factors, and (4) to model the impact of obtained critical rework factors.

2. Construction Rework Causes and Literature Gap

A considerable body of research has sought to identify the causes of construction rework to mitigate its negative impact on the industry. Several factors contributing to construction rework have been identified, including labor productivity issues [40], safety performance [41], supply chain inefficiencies [16,42], and schedule delays [8,43]. Additionally, design changes [44–46], productivity setbacks [10], increased project costs [22,30,47], and overall project performance declines [24,39,48] have been noted.

Moreover, material waste generation has been linked to rework [49], as has organizational culture [3]. Effective rework management strategies have also been explored [50]. The interplay between contractual claims and rework has been another area of focus [14,51–54].

In reviewing studies from developed countries, Safapour and Kermanshachi [27] explored manageable rework causes in early phases through a case study in the USA. Shahparvari [29] focused on subcontractors' impacts on rework in the UK, revealing four leading causes. In Australia, 42 different rework factors, along with financial implications, were unveiled.

Construction rework causes have also attracted scholars' attention in developing countries. In China, Ye et al. [23] conducted a survey highlighting construction rework causes, determining 39 causes. Jarkas [55] pinpointed 36 construction rework causes, classified as client, designer, contractor-related, and external factors in Qatar. Hwang and Yang [8] pointed out seven client-related rework factors in the construction industry in Singapore. Enshassi et al. [24] revealed 57 construction rework causes in the Gaza Strip and grouped them into seven categories. Eze et al. [20] examined rework causes in Nigeria.

While the findings of previous studies on construction rework are valuable, they often focus on qualitative or quantitative analyses, relying predominantly on a single methodology, such as frequency and severity index [24,28,39,51], case study [22], content analysis [14], state of science [56], qualitative literature review [57,58], mixed approach [59], and scientometric analysis [60].

Although previous studies provide valuable insights, the literature must be thoroughly examined to identify the critical factors of construction rework. Recognizing these factors is essential for developing an effective strategic plan for mitigating rework.

This study addresses this gap by focusing on the critical construction rework factors with implications that can be extended to other developing countries. To achieve this, a systematic literature review (SLR) was carried out to determine possible causes of construction rework. A normalized mean value (NMV) analysis was used to identify the most important causes. The critical rework factors were then identified by exploratory factor analysis. Lastly, the effect magnitude of these components was measured by modeling them with structural equation modeling.

In contrast to previous studies, this research integrates multiple methodologies to provide a more comprehensive understanding. An online questionnaire, commonly used in earlier studies, was also utilized here. However, unlike most prior research, the survey questions were derived from a SLR, enhancing their objectivity. Additionally, the study uniquely investigates the criticality of the construction rework factor, a step not taken in earlier research. These differences represent a notable distinction from former studies.

3. Methodology

This study examines the critical rework factors in the Turkish construction industry quantitatively. A thorough multistage analytical approach was employed, primarily emphasizing the evaluation of potential causes in this field. Figure 1 illustrates the detailed methodological approach of this research.

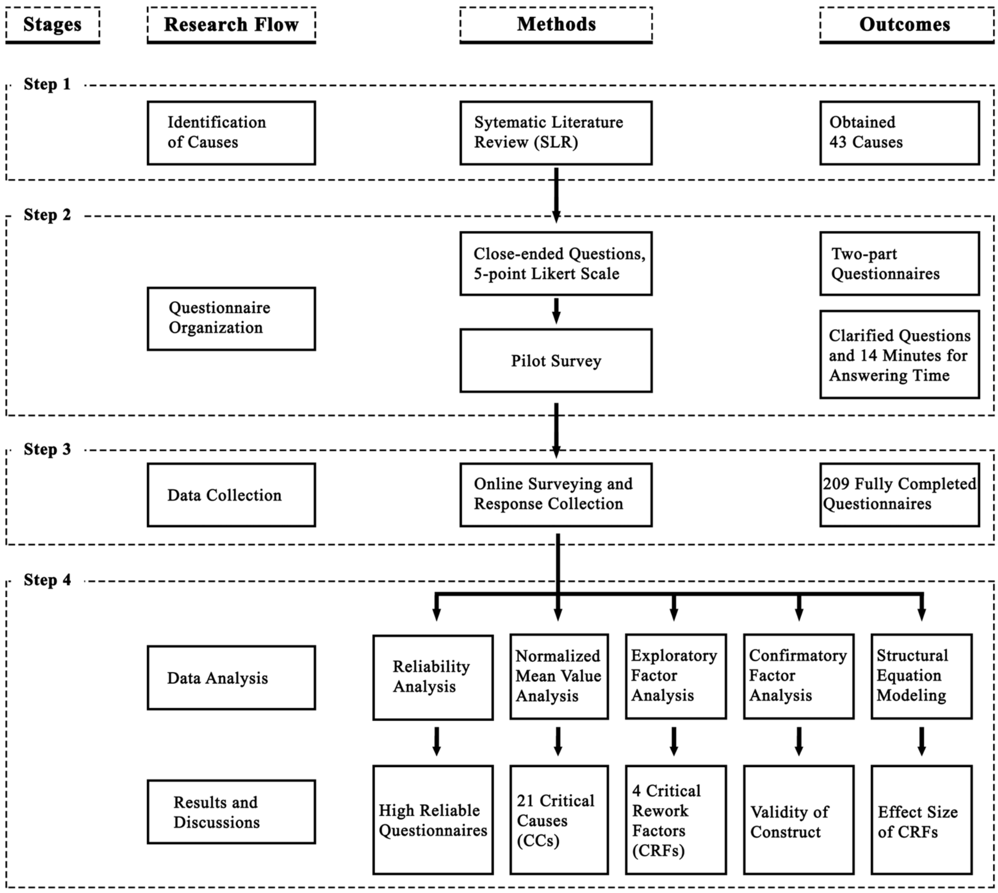

Figure 1. Framework of research.

The research began with a Systematic Literature Review (SLR) to pinpoint possible causes of construction rework. Following this, a questionnaire was designed, and data were collected by conducting the designed questionnaire online. After ensuring the internal consistency of the questionnaire by reliability analysis, NMV analysis was carried out, unveiling critical causes (CCs). Furthermore, to highlight the critical rework factors (CRFs), exploratory factor analysis was performed. Lastly, structural equation modeling was employed to model the obtained factors and reveal the impact size of each CRF on the occurrence of construction rework.

3.1. *Defining Potential Causes of Rework with a SLR*

The first stage of the study was defining the possible causes of rework. Possible causes of rework were obtained by a SLR, systematically, transparently, impartially, and reproducibly gathering data from the literature. Many researchers recognize this method as an objective approach [61].

A SLR is a comprehensive methodological approach for systematically evaluating, analyzing, and synthesizing all research concerning a particular topic, subject, or phenomenon within a scientific field [62]. In this study, a SLR was employed to conduct an in-depth review of the research domain.

A three-stage methodology was developed to pinpoint possible rework causes, including the 'planning', 'execution', and 'documentation' phases (Figure 2). The research questions were defined as follows:

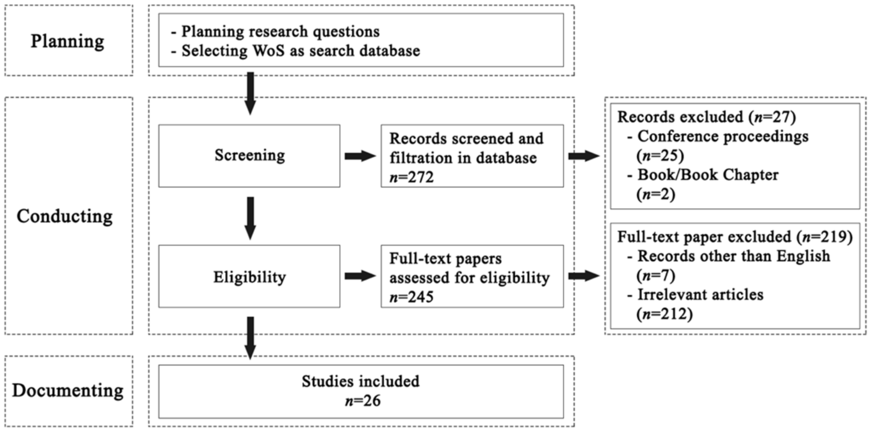

Figure 2. Phases of SLR.

RQ1: What are the possible causes of rework?
RQ2: What are the CCs of rework?
RQ3: What are the CRFs?
RQ4: What are the CRFs' effect size?

We reviewed the literature using Web of Science (WoS) to look into the construction rework domain [63]. WoS was selected due to its extensive and robust coverage of publications [64].

During the research process, in WoS, the search term that was utilized was the following: (ALL FIELDS) "rework" AND "construction" AND "causes". The search covered the period from 2000 to 2023 (September), resulting in 272 records. This timespan comprehensively reviews the causes of construction rework over the past two decades.

Since 2000, the construction industry has seen significant technological advancements, including adopting Building Information Modeling (BIM), advanced project management tools, and automation. These technologies have substantially impacted the causes and management of rework. This study assures the findings remain timely and relevant, addressing emerging obstacles in construction rework. This approach facilitates a more comprehensive understanding of current causes and potential strategies for improvement.

Filtering the gathered research publications required a specific definition of inclusion and exclusion criteria. The inclusion criteria for this search were (1) studies that address the causes of construction rework and (2) studies that have been published in publications with peer review. In their study, Shi et al. [65] noted that books, conference papers, and book chapters were not included because of frequent complaints about their lack of thorough peer review. Research published in languages other than English was one of the exclusion criteria. Applying these criteria resulted in the retention of 26 articles.

Through comprehensive analysis, 43 potential rework causes were determined and are presented in Table 1.

Table 1. Rework causes.

Code of Cause	Definition of Rework Causes	Relevant Literature
C1	Client-directed changes	[19,22,23,34,35,39,66,67]
C2	Poor communication with clients	[24,25,39]
C3	Client-directed plan and scope extensions	[25,39,68]
C4	Insufficient client involvement	[35,39,66]
C5	Inadequate or weak feasibility study	[25,39,66]
C6	Incomplete design	[24,25,66]
C7	Errors and omissions in design	[23,39,68]
C8	Design changes	[25,35,39]
C9	Insufficient experience	[22,54,66]
C10	Lack of understanding of the user	[23,39,69]
C11	Poor contract execution	[15,39,69]
C12	Design management failure	[25,40,68]
C13	Fixed time for a task	[22,66,69]
C14	Lack of using modern technology and software	[35,66,68]
C15	Lack of experience as a project manager	[24,25,34,39]
C16	Failure to perform adequate document control	[69–71]
C17	Poor planning and coordination	[23–25,39,66]
C18	Poor workload planning	[41,66,72]
C19	Ineffective management	[22,66,69]
C20	Lack of labor skills	[24,25,39,41]
C21	Time pressure	[25,39,66]
C22	Poor craft	[39,66,68]
C23	Non-compliance with specifications	[25,32,35]
C24	Shortage of skilled laborers required to complete work tasks	[34,39,66,68]
C25	Lack of motivation	[22,25,69]
C26	Poor site condition	[17,41,68]
C27	Complexity of design	[17,25,66]
C28	Inaccurate or lack of site investigation	[22,25,39,66]
C29	Increase in project changes as the number of project stakeholders grows	[19,35,73]
C30	Lack of safety considerations on the site	[34,39,66]
C31	Schedule pressures	[39,41,66]
C32	Poor communication among project teams	[24,66,68]
C33	Poor information flow	[23,24,41]
C34	Changes in project scope	[23,25,35,39]
C35	Inadequacies in contract documentation	[66,69,73]
C36	Use of poor-quality materials	[22,23,66]

Table 1. *Cont.*

Code of Cause	Definition of Rework Causes	Relevant Literature
C37	Shortage of construction materials in the market	[23,34,39]
C38	Wrong initial budget	[23,24,34]
C39	Lack of technological equipment and ineffective use of technology	[23,24,39,41,66]
C40	Change of laws	[24,68,69]
C41	The economic situation of the country	[24,39,55]
C42	Natural disasters	[23,34,39]
C43	Changes in construction method to improve constructability	[23,25,34,39,41,66,68]

3.2. The Questionnaire Design

The first section of the questionnaire evaluates 43 potential rework causes (Table 1). A five-point Likert-type scale, with one denoting "very low" and five denoting "very high", was used on the sample group to rate the importance of each cause.

Sociodemographic data, such as occupation type, construction industry experience, educational attainment, and the frequency of reworks encountered by participants, were collected in the second portion.

3.3. Data Gathering

A structured survey was administered to architects, engineers, and construction managers working within the Turkish construction sector. To enhance clarity and address any ambiguities, a pilot test was performed to clarify the questionnaire and resolve any potentially confusing statements. Twelve participants, four professionals from each field with more than five years of expertise, participated in the pilot study.

The finalized questionnaire was emailed to 984 participants on 26 December 2023. Responses were accepted until 6 March 2024, resulting in 249 returned questionnaires. Out of these, we received 209 valid responses, representing a 21.23% response rate. According to Akintoye [74], 20% and 30% response rates are acceptable for construction research. Furthermore, Molwus et al. [75] pointed out that between 100 and 400 participants are acceptable and adequate for performing structural equation modeling.

Random sampling methods were employed in this study, a commonly applied approach in construction research. This technique ensures that every individual in the population has a chance of being selected [76,77]. This approach aids in generating a sample that fairly represents the population while reducing the likelihood of voluntary response bias. The sample size was calculated using Equation (1), which was adapted from [76].

$$SS = \frac{Z^2 \times P(1-P)}{C^2} \quad (1)$$

where:

SS = sample size;
Z = Z value (1.96 for 95 percent confidence level);
P = percentage picking a choice, expressed as a decimal (0.5 used for sample size needed);
C = margin of error (9 percent), the maximum estimation error, which can be 9 or 8 percent.

$$SS = \frac{1.96^2 \times 0.5(1-0.5)}{0.09^2} = 118.57 \approx 119\ (as\ the\ minimum\ sample\ size)$$

Therefore, the sample size of 209 is considered sufficient.

Among the 209 participants, 44.5% were architects, 32.5% were construction managers, and 23.0% were engineers. Regarding experience in the construction industry, 53.6% had 1–5 years, 13.9% had 6–10 years, 11.5% had 11–15 years, 7.7% had 16–20 years, and 13.4% had more than 20 years of experience, indicating a highly acceptable level of experience. In terms of educational qualifications, 66.0% of participants held bachelor's degrees, 27.8% had master's degrees, and 6.2% possessed doctorates. Additionally, 73.2% of participants reported frequently or always encountering construction reworks within the industry.

3.4. Data Analysis

Using IBM SPSS Statistics v.26.0 and LISREL v.8.7, several types of statistical analyses were performed on the questionnaire data. First, reliability measurement in surveys employing a Likert scale is crucial for evaluating internal consistency among the questions [78]. To assess the internal consistency of the questions, a reliability study was first conducted using Cronbach's alpha (α) coefficient, which ranges from 0 to 1. A α of 0.7 or higher, by generally recognized standards, denotes an acceptable level of reliability. [79,80].

To identify the most critical causes of construction rework, this study employed Normalized Mean Value (NMV) analysis as a ranking method. The NMV technique is commonly used in construction research to determine the significance of various factors by normalizing their mean values within a predefined range. The threshold for classifying a cause as critical was set at NMV > 0.5, ensuring that only causes with relatively high perceived importance were selected for further analysis.

The NMV of each rework cause was calculated using the following Equation (2):

$$Normalized\ mean\ value = \frac{(mean\ of\ rework\ cause - lowest\ ranked\ mean)}{(highest\ ranked\ mean - lowest\ ranked\ mean)} \quad (2)$$

Causes with NMV values above 0.5 were considered significant contributors to construction rework and classified as critical causes (CCs). This threshold aligns with previous construction management research methodologies that employ ranking techniques to determine key influencing factors. Several scholars, such as Liao and Teo [81], Xu et al. [82], and Zhao et al. [83], have used this ranking analysis method to categorize critical causes; however, this approach has not previously been applied to evaluate CCs for construction rework.

Understanding the structure of factors is essential for achieving one of this study's main objectives. Therefore, an Exploratory Factor Analysis (EFA) was conducted on the CCs to identify critical rework factors (CRFs) that cause rework. EFA is a powerful statistical technique primarily employed to uncover the underlying structure of a dataset by identifying latent variables that explain the observed correlations among measured variables. The research process of EFA typically encompasses several critical steps, including data preparation, factor extraction, rotation, and the interpretation of results. Initially, the data must be prepared, which involves assessing the suitability of the dataset for factor analysis. This is often performed using the Kaiser–Meyer–Olkin (KMO) measure and Bartlett's Test of Sphericity. A KMO value above 0.5 and a significant Bartlett's Test indicate that the data is appropriate for EFA, allowing researchers to proceed with the analysis [84,85]. Once the data are deemed suitable, the next step is factor extraction, where various methods such as Principal Component Analysis (PCA) can be employed to identify the number of factors that best represent the data [86].

Following factor extraction, the rotation of factors is performed to achieve a clearer and more interpretable structure. Common rotation methods include Varimax rotation, which help in maximizing the variance of factor loadings and simplifying the factor structure [87].

After rotation, researchers must interpret the factor loadings, which indicate the strength and direction of the relationship between the observed variables and the latent factors. A common threshold for factor loadings is 0.4 or higher, which suggests a strong relationship between the variable and the factor [88]. The interpretation process also involves examining the eigenvalues, where factors with eigenvalues greater than 1 are typically retained, as they explain more variance than a single observed variable [89].

Finally, researchers often validate the findings through confirmatory factor analysis (CFA) to ensure the robustness of the identified factor structure. This step is crucial as it provides evidence for the construct validity of the factors derived from EFA [90].

In this study, the CRFs acquired by EFA were subjected to CFA to evaluate their validity using LISREL. The degree to which a test captures the idea it is meant to capture is known as its validity. High-validity survey questions are better at assessing the qualities they are intended to gauge. A number of indices, including the comparative fit index (CFI), the root mean square error of approximation (RMSEA), and the chi-square (χ^2) test statistic, were used to assess the model fit. In CFA, path coefficients show how strongly variables are related to one another; values less than 0.1 suggest modest impacts and values around 0.3 indicate moderate effects, while values 0.5 or higher indicate substantial effects [91]. At a 99% significance level, path coefficients of 0.5 or higher and *t*-values greater than 2.58 were deemed statistically significant.

At the last stage, SEM was performed to assess the impact size of each CRFs' contribution to rework. SEM was chosen for this study due to its ability to model latent variables, allowing for a more accurate representation of CRFs than traditional multivariate regression. Unlike regression, SEM enables the simultaneous analysis of measurement and structural models, providing a more comprehensive understanding of rework causation. Additionally, SEM allows for model fit evaluation using indices such as CFI, RMSEA, and GFI, ensuring the robustness of the results. It also captures complex interrelationships between multiple dependent and independent variables, quantifying the relative impact of each CRF. Furthermore, SEM evaluates the model's fit concerning the relationships between measurement paths and latent variables. Although there are differing views regarding the suitability of path coefficients over the 0.1 cutoff, a coefficient of 0.2 is usually advised [92]. At a 99.0% confidence level, *t*-values greater than 2.58 and path coefficients of 0.5 or greater were deemed significant for this investigation [93]. Finally, SEM effectively addresses measurement error and multicollinearity, enhancing the validity and reliability of findings, making it the most suitable analytical approach for this research.

4. Results

4.1. Reliability Analysis

Cronbach's α coefficient of the identified 43 rework causes was determined as 0.953, which exceeds the minimum acceptable threshold of 0.7 [80], which explains the excellent internal consistency of the questionnaire.

4.2. Identifying and Ranking the Critical Rework Causes

The means, standard deviations, and normalized mean values of 43 rework causes were calculated and are represented in Table 2.

Table 2. Defining and ranking CCs (n = 209).

Cause	Mean	Standard Deviation	NMV	Order
C1	4.038	0.999	0.905 *	5
C2	3.651	1.175	0.540 *	19
C3	4.014	0.973	0.882 *	9
C4	3.282	1.173	0.193	39
C5	3.598	1.225	0.491	22
C6	3.746	1.212	0.630 *	16
C7	3.866	1.156	0.743 *	13
C8	4.124	1.080	0.986 *	2
C9	3.593	1.205	0.486	23
C10	3.340	1.218	0.248	36
C11	3.464	1.267	0.364	31
C12	3.392	1.315	0.297	34
C13	3.804	1.214	0.685 *	15
C14	3.077	1.363	0.000	43
C15	3.641	1.244	0.531 *	20
C16	3.474	1.168	0.374	29
C17	3.962	1.180	0.833 *	10
C18	3.689	1.214	0.576 *	17
C19	3.823	1.201	0.702 *	14
C20	3.871	1.117	0.748 *	12
C21	3.536	1.143	0.432	26
C22	4.019	1.113	0.887 *	7
C23	3.651	1.155	0.540 *	18
C24	4.019	1.117	0.887 *	8
C25	3.206	1.217	0.121	42
C26	3.244	1.202	0.157	41
C27	3.502	1.135	0.400	27
C28	3.450	1.180	0.351	32
C29	3.474	1.315	0.374	30
C30	3.276	1.202	0.187	40
C31	3.952	1.050	0.824 *	11
C32	4.081	0.934	0.945 *	4
C33	4.019	0.970	0.887 *	6
C34	4.139	0.948	1.000 *	1
C35	3.474	1.156	0.374	28
C36	3.560	1.200	0.455	24
C37	3.340	1.257	0.248	37
C38	3.560	1.325	0.455	25
C39	3.316	1.215	0.225	38
C40	3.435	1.284	0.337	33
C41	4.124	1.178	0.986 *	3
C42	3.344	1.357	0.251	35
C43	3.618	1.035	0.509 *	21

* Refers to critical causes (CCs).

The NMV analysis revealed that 21 out of 43 potential causes of construction rework exceeded the criticality threshold (NMV > 0.5), classifying them as CCs. The cause with the highest NMV was C34 "Changes in project scope" (NMV = 1.000), while the lowest-ranked cause, C14 "Lack of using modern technology and software" (NMV = 0.000), did not meet the threshold (Table 2).

4.3. Revealing Critical Rework Factors: Exploratory Factor Analysis

Exploratory Factor Analysis (EFA) was conducted to identify the underlying structures of the 21 critical causes (CCs) and determine the critical rework factors (CRFs) in the Turkish construction industry (Table 3).

Table 3. Exploratory and confirmatory factor analysis results.

Factors	Code of CCs	EFA			CFA	
		Eigenvalue	Loads of Causes	% of Variance	Standardized Coefficients	
Factor 1	C32 C33 C31 C3 C1 C2 C34 C41	3.889	0.758 0.736 0.710 0.665 0.643 0.621 0.594 0.521	18.521	0.83 0.81 0.75 0.50 0.57 0.56 0.66 0.57	
Factor 2	C17 C18 C19 C15 C43	3.357	0.861 0.854 0.741 0.691 0.590	15.984	0.80 0.67 0.89 0.81 0.62	
Factor 3	C22 C24 C20 C23	3.020	0.817 0.792 0.787 0.706	14.381	0.82 0.85 0.80 0.65	
Factor 4	C7 C6 C8 C13	2.824	0.805 0.799 0.758 0.434	13.446	0.86 0.84 0.81 0.59	
Total Explained Variance				62.332	χ^2/df	2.155
Kaiser–Meyer–Olkin (KMO) value:				0.859	RMSEA	0.045
Barlett's Test of Sphericity	Approx. Chi-square:			2514.593	CFI	0.960
	df:			210	GFI	0.950
	p:			0.000	AGFI	0.810

Before performing EFA, the suitability of the dataset was assessed using the KMO measure and Bartlett's Test of Sphericity. The KMO value was 0.859, exceeding the 0.5 threshold, confirming that the dataset was appropriate for factor analysis [94]. Additionally, Bartlett's Test of Sphericity was significant ($p < 0.001$), indicating that the correlation matrix was not an identity matrix, further supporting the feasibility of factor analysis.

Principal Component Analysis (PCA) was employed for factor extraction to determine the optimal number of factors. The selection of factors was guided by eigenvalues greater than 1, ensuring that each retained factor accounted for more variance than an individual observed variable. The analysis revealed four distinct factors, explaining 62.33% of the total variance, which were subsequently identified as CRFs.

Varimax rotation was applied to improve the interpretability of the factor structure. Varimax rotation is a widely used orthogonal rotation method that maximizes the variance of factor loadings, leading to a more distinct and meaningful grouping of variables. Factor loadings greater than 0.4 were considered significant, aligning with best practices in factor analysis. All CCs exhibited factor loadings greater than 0.4; the findings are summarized in Table 3.

Along with their associated factor loadings the four extracted CRFs are named below:

Factor 1: project dynamics and communication challenges (PDCC).
Factor 2: management and planning deficiencies (MPD).
Factor 3: labor quality and compliance issues (LQCI).
Factor 4: design and time constraints (DTC).

4.4. Validation Through Confirmatory Factor Analysis (CFA)

The results of the CFA are shown in Table 3, which shows that all factor loadings are more than 0.5. With a χ^2/df ratio of 2.155, a comparative fit index (CFI) of 0.96, a root mean square error of approximation (RMSEA) of 0.045, and a Goodness-of-Fit Index (GFI) of 0.95, the model meets the necessary goodness-of-fit (GOF) requirements. When taken as a whole, these indicators show a strong model. This evaluation indicates that the CFA model fits well and is suitable for assessing the reliability of the measurement scales.

4.5. Evaluation of the Measurement Model

The SEM evaluates how the four CRFs influence construction rework. Figure 3 illustrates the hypothesized structural relationships between four CRFs and their impact on construction rework. The pathways in Figure 3 represent hypothesized causal relationships supported by CFA and reliability tests. After the CFA checked the validity of the measurement scale, a hypothetical model was constructed, and four hypotheses were developed (Figure 3). The model comprises four latent constructs, each representing a significant contributor to rework and their direct paths to the dependent variable, "Construction Rework." Each pathway in the hypothetical model represented a conceptual connection between two constructs and symbolized a hypothesis (H_1–H_4).

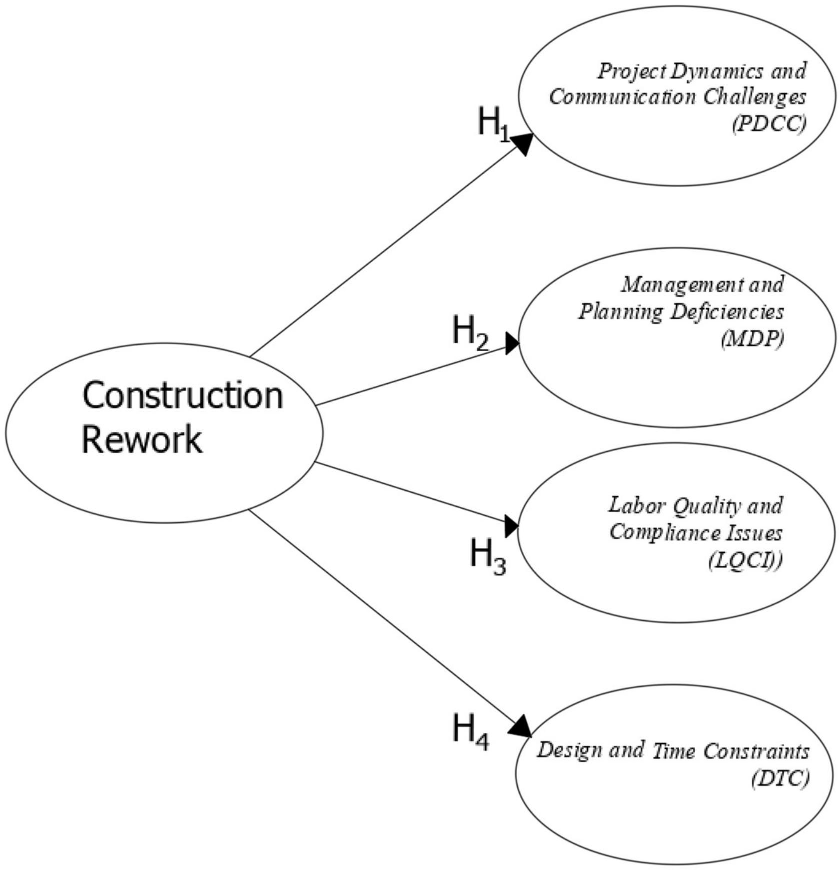

Figure 3. Hypothetical model.

Considering the four latent factors (Factor 1, Factor 2, Factor 3, and Factor 4) as critical rework factors, hypotheses were formulated as follows, and paths are shown in Figure 3:

H_1. *PDCC impacts on construction rework.*

H_2. *MPD impacts on construction rework.*

H_3. *LQCI impacts on construction rework.*

H_4. *DTC impacts on construction rework.*

4.6. Model Reliability and Validity

Two reliability metrics, Cronbach's alpha (α) and composite reliability (CR), were used to assess the validity and reliability of individual items [86]. The study's latent variables all showed CR values between 0.86 and 0.87, which are higher than the suggested minimum of 0.70. Cronbach's alpha values, likewise, go beyond the recommended cutoff of 0.70, ranging from 0.80 to 0.88, as indicated in Table 4. Additionally, to evaluate internal consistency, the Average Variance Extracted (AVE) was computed; ideal values are greater than 0.50 [95]. As shown in Table 4, the study's AVE values, which varied from 0.54 to 0.61, exceeded the minimum threshold and validated the sufficiency of every component.

Table 4. Reliability and validity test results.

Latent Variables	CR	CA	AVE
PDCC	0.86	0.84	0.54
MPD	0.87	0.88	0.58
LQCI	0.86	0.86	0.61
DTC	0.86	0.80	0.61

Regarding the model presented in Figure 3, a definitive SEM was developed, as shown in Figure 4. The parameters (GOF measures and *t*-value) used to validate the model are detailed in Tables 5 and 6.

Table 5 shows that the constructed SEM has a good degree of fit. Consequently, the model satisfies the established GOF requirements. The expected effects, R^2 values, and the postulated routes are detailed in Table 6.

Table 5. Model statistics.

Fit Index	Suggested Values	Structural Equation Results	Evaluation
X^2/df	$0 \leq X^2/df \leq 3$	2.16	Good Fit
GFI	$0.95 \leq GFI \leq 1.00$	0.95	Good Fit
AGFI	$0.95 \leq AGFI \leq 1.00$	0.96	Good Fit
RMSEA	$0 \leq RMSEA \leq 0.05$	0.04	Good Fit
CFI	$0.95 \leq CFI \leq 1.00$	0.97	Good Fit
NFI	$0.95 \leq NFI \leq 1.00$	0.96	Good Fit

Table 6. Estimates of the structural equation model's path coefficients.

Hypothetical Paths and Expected Influences	Path Coefficient *	*t*-Value (1-Tail)	Interpretation	R^2
H_1: PDCC $\rightarrow$ RWRK	0.65	7.79	Supported	0.43
H_2: MPD $\rightarrow$ RWRK	0.76	8.91	Supported	0.57
H_3: LQCI $\rightarrow$ RWRK	0.68	8.22	Supported	0.47
H_4: DTC $\rightarrow$ RWRK	0.72	8.87	Supported	0.52

Note: * All standardized path coefficient estimates are expected to be significant at $p < 0.01$.

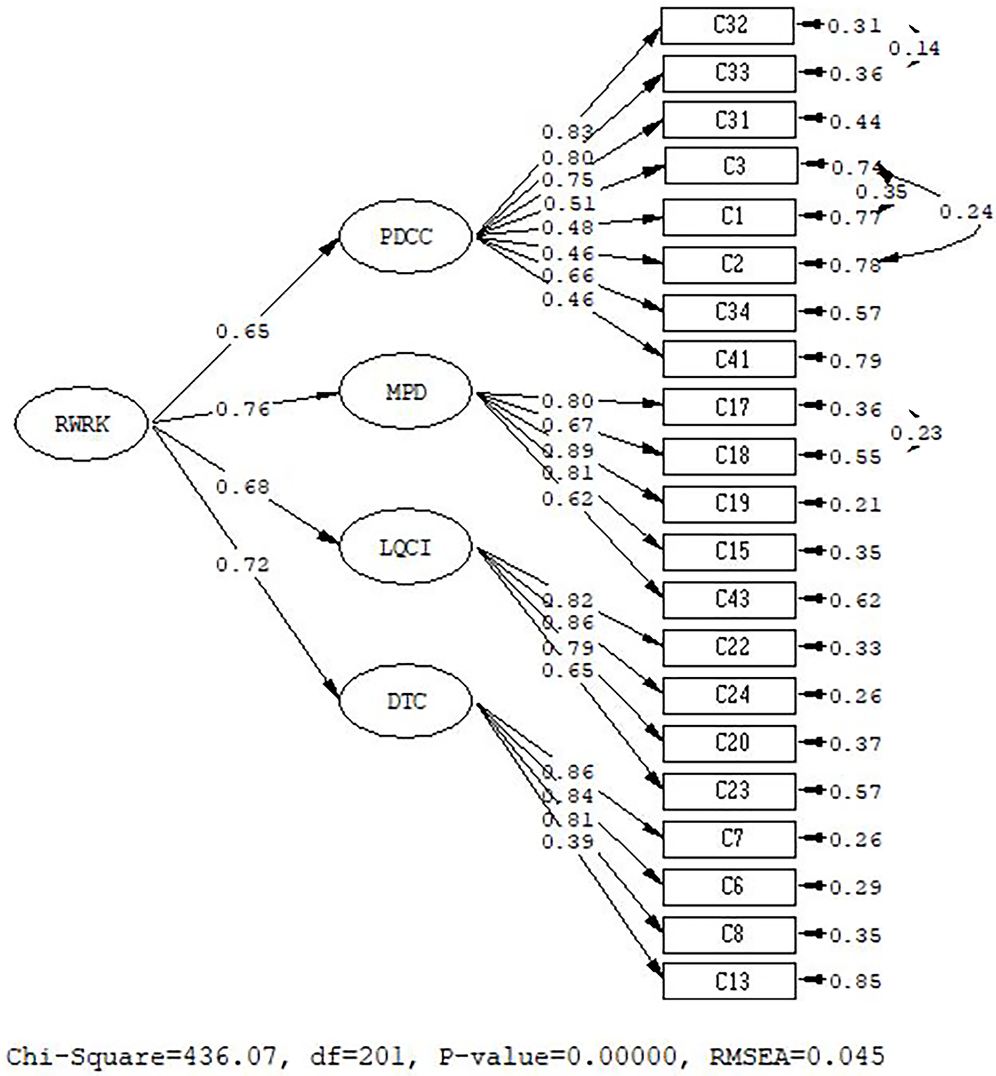

Figure 4. Final SEM of CRFs.

All hypotheses surpassed the critical one-tailed *t*-value of 2.58 at a 0.01 significance level (Table 6). According to Table 6, MPD (0.76) and DTC (0.72) exert the most significant impact on construction rework, followed by LQCI (0.68) and PDCC (0.65), respectively.

4.7. Transmission Mechanisms of Hypotheses

H$_1$. *Management and Planning Deficiencies (MPD) → Construction Rework.*

PDCC encompasses inefficiencies in project communication, coordination failures, and poor management of project dynamics. Miscommunication between stakeholders often results in incorrect work execution, requiring modifications and rework. The SEM analysis confirms a direct relationship between PDCC and rework, with a path coefficient of 0.65, indicating a substantial influence on rework occurrences.

H$_2$. *Management and Planning Deficiencies (MPD) → Construction Rework.*

MPD includes inadequate planning, poor scheduling, and ineffective risk management strategies. When management fails to allocate resources properly or foresee potential risks, rework becomes inevitable due to errors and project inefficiencies. The SEM model confirms that MPD has the strongest impact on construction rework, with a path coefficient of 0.76, highlighting its critical role in rework prevention.

H$_3$. *Labor Quality and Compliance Issues (LQCI) → Construction Rework.*

LQCI pertains to workforce skill deficiencies, non-compliance with building codes, and improper execution of construction activities. A lack of skilled labor and failure to meet regulatory standards result in defects that require costly corrections. The SEM model supports this relationship, assigning LQCI a path coefficient of 0.68, reinforcing its substantial effect on construction rework.

H$_4$. *Design and Time Constraints (DTC) → Construction Rework.*

DTC represents incomplete designs, frequent design changes, and unrealistic project timelines. These constraints lead to rushed construction activities, increasing the likelihood of defects and necessary corrections. The model demonstrates that DTC significantly contributes to construction rework, with a path coefficient of 0.72, confirming its substantial influence.

The structural equation modeling results, summarized in Table 6, validate these hypothesized relationships, with all path coefficients exceeding 0.5 and *t*-values surpassing the 2.58 threshold at a 99% confidence level. The findings highlight MPD and DTC as the most influential CRFs, followed by LQCI and PDCC, emphasizing the need for targeted interventions in project management, workforce training, and design optimization to minimize rework occurrences.

5. Discussion

The SEM analysis supported all four hypotheses, as illustrated in Figure 4 and detailed in Table 6. Path coefficients close to one signify a strong correlation, while those approaching zero indicate weaker relationships, aligning with the findings of Hair et al. [96]. CRFs are classified into three impact levels: coefficients ranging from 1 to 0.71 are deemed highly significant with a substantial effect, those between 0.70 and 0.51 reflect a high impact, and coefficients between 0.50 and 0.20 indicate a moderate effect [91].The analysis in Figure 4 and Table 6 reveals that two of the four factors are highly critical for construction rework, while the remaining two factors have a significant impact on construction rework.

5.1. Management and Planning Deficiencies (MDP)

Management and planning deficiencies (MPD) is a major factor in construction rework, with a 0.76 path coefficient. While management's role in rework is widely recognized, few studies have evaluated MPD as a distinct latent factor. MPD significantly affects the industry's ability to adopt sustainable practices. Poor project planning often leads to unrealistic timelines, budgets, and resources, resulting in rework when expectations fall short [32]. Rework is commonly linked to poor-quality management, ineffective techniques, and poor subcontractor management [51,97]. Issues such as inadequate stakeholder engagement, insufficient supervision, and non-compliant materials also contribute to rework [17]. Effective design management, stakeholder coordination, and project oversight can help reduce rework and improve project outcomes.

5.2. Regarding Design and Time Constraints (DTC)

DTC is the second unique and phenomenally effective CRF, with a path coefficient of 0.72. Design errors, omissions during construction, failures of constructed parts, changes initiated by clients, poor communication, and coordination issues are significant contributors to construction project rework [3]. Design rework often arises from client-driven changes in scope and specifications, design errors, and procurement mistakes. In contrast, construction rework is linked to a need for implemented techniques and better construction management policies [51]. Variations in project cost and time due to rework are often a result of errors in design, poor communication, and coordination issues [3]. Rework in construction projects can lead to undesired loss of effort, cost overruns, and schedule delays, affecting project performance at both the design and construction phases [20]. Design-induced rework has been shown to contribute to over 70% of the total rework in construction and engineering projects, underscoring the substantial effect of design errors on the incidence of rework [15].

Furthermore, rework adds to project time and cost overruns and contributes to waste and delays in project completion schedules [98]. In construction projects, rework is a leading factor affecting schedule performance, substantially contributing to construction schedule growth [4]. Rework harms the performance and productivity of design and construction organizations, leading to cost and time overruns [20]. Construction companies must implement quality management practices and emphasize coordinating project documentation during the design development to reduce rework instances [25]. Addressing design errors, improving communication, and ensuring effective coordination are essential to mitigate rework in construction projects. By focusing on design quality, the timely identification of errors, and efficient project management, construction rework can be minimized, leading to improved project performance and reduced costs.

5.3. Regarding Labor Quality and Compliance Issues (LQCI)

Labor quality and compliance issues (LQCI) constitute a significant CRF with a 0.68 path coefficient. Factors influencing rework include a lack of skilled labor, non-compliance with specifications, poor planning, and inadequate coordination [40]. Labor skill deficiencies and improper subcontractor selection significantly contribute to rework [25]. Internal factors like workforce skill levels, construction methods, and buildability also affect labor productivity and rework [99]. Rework is often driven by quality deviations, technical non-compliance, and poor craftsmanship [50,100]. Addressing LQCI through skilled labor, specification adherence, and effective coordination is essential for reducing rework and enhancing project outcomes.

5.4. Regarding Project Dynamics and Communication Challenges (PDCC)

Project dynamics and communication challenges (PDCC) is a significant construction rework factor (CRF) with a 0.65 path coefficient. Poor communication, coordination, and integration during the design phase are primary contributors to rework [20]. Rework can also arise from inadequate design information, non-compliant materials, and a lack of supervision from early project stages [52]. Poor project definition, ineffective pre-project planning, and constructability issues also exacerbate rework [101]. In dynamic project environments, frequent interactions and complex activity interrelations often exceed traditional management methods, increasing rework risks [102]. Addressing PDCC through improved communication and coordination is essential for minimizing rework and enhancing project performance.

To comprehensively understand the impact of CRFs on construction rework, it is essential to integrate both statistical insights from SEM and industry perceptions reflected in NMV rankings. The path coefficients from SEM indicate the relative contribution of each CRF to rework, whereas the NMV ranking represents the perceived importance of individual causal factors based on survey responses. The correlation between impact values (from SEM) and importance degree (NMV ranking) confirms that the most impactful CRFs (MPD and DTC) also align with some of the highest-ranked CCs, such as design errors, scope changes, and poor management. However, variations exist due to the subjective nature of importance ratings and the quantitative relationships modeled in SEM. This finding highlights the need to integrate both statistical impact analysis and industry perception when prioritizing interventions to reduce rework.

6. Conclusions

A comprehensive methodological framework was conducted in this study to highlight the critical factors contributing to construction rework and assess their impacts. By conducting a systematic literature review (SLR), we identified 43 rework causes. These causes were subsequently used to design a questionnaire for data collection. Finally, 209 responses were statistically analyzed and a normalized mean value (NMV) analysis identified 21 out of the 43 causes as critical contributors (CCs).

An exploratory factor analysis was conducted to reveal CRFs further, identifying four critical factors. SEM was employed to model the impact of these CRFs. The SEM analysis revealed that the most significant CRFs were management and planning deficiencies (MPD), design, and time constraints (DTC), with path coefficients of 0.76 and 0.72, respectively. Labor quality and compliance issues (LQCI) and project dynamics and communication challenges (PDCC) were also identified as significant factors, with path coefficients of 0.68 and 0.65.

Our findings align with previous studies on construction rework but extend the discourse by integrating multiple methodologies. Studies such as those conducted by Ye et al. [23] in China and Jarkas [55] in Qatar identified a wide range of rework causes, focusing on client-, designer-, and contractor-related factors and external factors. Similarly, Enshassi et al. [24], in the Gaza Strip, categorized 57 rework causes into seven groups. However, these studies primarily utilized qualitative analyses or single-method approaches, such as frequency and severity indices, case studies, and content analyses. In contrast, our study systematically quantified rework causes and examined their interrelationships using SEM, offering a more comprehensive and predictive framework.

The role of management and planning deficiencies (MPD) in construction rework has been widely recognized in the literature. Love et al. [22] found that poor project planning and ineffective subcontractor management were key drivers of rework in Australian projects. Our findings confirm these insights, showing that MPD exerts the most substantial influence on construction rework (path coefficient = 0.76), emphasizing its critical role in rework prevention. This suggests that proactive planning strategies and enhanced risk management protocols are essential to reducing rework instances.

Design and time constraints (DTC) emerged as another dominant factor in our study (path coefficient = 0.72). Previous research, such as that by Yap and Skitmore [32], highlighted design errors and frequent design changes as major contributors to rework in Malaysian construction projects. Similarly, Arashpour et al. [103] analyzed rework disruptions in residential projects, emphasizing the negative impact of last-minute design modifications. Our study supports these conclusions while providing additional empirical validation through SEM analysis.

Labor quality and compliance issues (LQCI) was also identified as a major rework driver (path coefficient = 0.68). Studies by Mahamid [49] found that poor workmanship and non-compliance with building codes significantly increase the likelihood of rework. Our results reinforce these findings, demonstrating that investing in skilled labor training and quality control measures is crucial for mitigating rework.

Lastly, project dynamics and communication challenges (PDCC) had a notable effect on rework (path coefficient = 0.65). Prior studies, including those by Trach et al. [73], emphasized the role of ineffective communication in project failures. Our research builds upon this by showing how structured communication protocols and collaborative tools can help reduce rework in construction projects.

Finding the CRFs impeding the development of construction methods is the specific focus of this work. This research offers important insights for scholars, stakeholders, and policymakers in the building industry by identifying these aspects. By reducing construction reworks in projects, it helps them to comprehend and address the problems that impact time, cost, and quality.

Moreover, this study is among the few that strive to create a thorough framework for measuring the impact and significance of these CRFs. Policymakers and business executives in the Turkish construction sector can use this model as a resource, and it may also be used in similar circumstances in other developing nations. The quantified framework aims to support the formulation of customized strategies and frameworks to encourage mitigating rework within the construction industry.

For architectural, engineering, and construction (AEC) firms, this study's findings are important. In this regard, this study has management and empirical ramifications, which are explained below.

6.1. Conceptual and Empirical Implications

The proposed model highlights the critical need to address the CRFs that impede project performance within the AEC sectors of developing countries. The goal of this research is to close the gap between theoretical understanding and real-world application by outlining causes to mitigate the rework. Notably, it addresses a significant gap in the literature by analyzing CRFs in Turkey's AEC industry.

This research identifies and quantifies the CRFs through a rigorous approach utilizing SLR and SEM. The conceptual framework developed extends existing models by adding new elements, such as the impact of CRFs on the project's cost and schedule performance, thus enhancing our theoretical comprehension of the topic.

Conceptually, understanding these factors provides insights into rework incidences, which can lead to developing proactive strategies to prevent rework in construction projects. By analyzing and categorizing the factors contributing to rework, construction industry stakeholders can better understand the underlying issues that lead to rework occurrences.

Empirically, identifying critical rework factors in the Turkish construction industry can have practical implications for project performance and success. Construction professionals can implement targeted interventions to address these issues and minimize rework instances by pinpointing the specific factors contributing to rework. This can improve productivity, cost savings, and timely project delivery.

The empirical implications extend to the broader context of the construction industry in Turkey. By recognizing and addressing critical rework factors, construction companies can enhance their competitiveness, reputation, and overall project outcomes. This can contribute to the sustainable growth and development of the construction sector in Turkey.

It is particularly noteworthy that a robust prediction tool using SEM has been developed to assess the impact of critical rework factors on the AEC industry. This study contributes empirically to the discourse on construction rework, illuminating the complex dynamics involved and suggesting targeted interventions to address these factors effectively.

Four novel and unique factors (MDP, DTC, LQCI, and PDCC) specific to architects, civil engineers, and construction managers were included in the established model; these factors can be applied to the construction sector as a whole.

6.2. Practical Implications

Construction practitioners, policymakers, and researchers can use subsequent practical insights to better comprehend and mitigate the effects of CRFs that obstruct project success.

Accordingly, "management and planning deficiencies (MPD)" is the most critical rework factor and deserves attention. The following practical recommendations are proposed for policymakers, practitioners, and researchers to reduce its negative impacts:

- Construction practitioners may enhance project planning by developing detailed plans with clear milestones, resource allocation, and risk management strategies. Furthermore, standard operating procedures (SOPs) may be another aspect for practitioners. Implementing and adhering to SOPs for common project management tasks may reduce the likelihood of reworks.
- Policymakers may develop regulatory frameworks to enforce regulations mandating comprehensive project planning and risk management protocols. They may also provide incentives for using advanced planning and project management tools and facilitate access to technology to improve planning accuracy and efficiency.
- Researchers may research to identify and evaluate effective planning and management practices that minimize rework. They may also create and validate frameworks for improved project planning and management. Furthermore, scholars may research the impact of emerging technologies on project management and planning and assess how tools like AI, machine learning, and BIM (Building Information Modeling) can address management deficiencies to minimize rework.

The second most critical rework factor is "design and time constraints (DTC)", which cause rework, and may be mitigated by the following measures:

- Construction practitioners may conduct thorough reviews of design documents before construction begins to ensure that all design details are finalized and verified to prevent changes during construction. In addition, they may develop realistic and flexible project schedules that account for potential design changes and construction rework. Furthermore, they may adopt an integrated design–build approach where the design and construction teams work together from the start, which can help identify and resolve design issues early.
- Policymakers may establish regulations that require thorough design validation and planning before construction begins and implement standards that ensure design consistency and reliability. In addition, policymakers may promote collaborative project delivery methods, such as Integrated Project Delivery (IPD), that align the interests of design and construction teams, reducing the likelihood of construction rework.
- Scholars may study the benefits and challenges of integrated design and construction approaches and identify best practices for collaboration between design and construction teams. Moreover, they may investigate effective time management techniques and tools that can help mitigate the impact of design constraints and assess how these techniques can be applied in various project contexts.

The third CRF is "labor quality and compliance issues (LQCI)". To decrease adverse effects, we might make the following suggestions:

- Construction practitioners may invest in training and certification programs to enhance the labor force's skills and ensure workers are proficient in the latest construction techniques and safety protocols. They might also put strong quality control measures in place, such as frequent audits and inspections, to make sure that the work satisfies the necessary requirements. Additionally, practitioners may provide continuous training on compliance with building codes, safety regulations, and industry standards. On the other hand, practitioners may adopt rigorous hiring practices to ensure that only qualified and experienced workers are employed; they may verify credentials and conduct background checks to confirm expertise and reliability.

- Policymakers may strengthen the enforcement of building codes and standards and implement penalties for non-compliance to ensure that construction practices adhere to required quality and safety standards. Furthermore, they may ensure that labor laws protect the rights of construction workers and promote fair working conditions. This can help attract and retain skilled labor in the industry.
- Scholars may conduct research on effective methods for assessing labor quality in construction, identify key indicators of high-quality craft, and develop tools for monitoring these indicators. In addition, they may evaluate the effectiveness of different training programs in improving labor quality and compliance. Researchers may explore the potential use of technological advancements, like virtual reality (VR) and augmented reality (AR), for construction training and quality control.

The last and fourth critical rework factor is "project dynamics and communication challenges (PDCC)", and practical solutions can be offered:

- Construction practitioners may establish clear communication protocols and channels and use collaboration tools to ensure all stakeholders are informed and can easily share updates. They may also conduct regular meetings with all project stakeholders, including designers, contractors, and clients, to discuss progress, issues, and changes. In addition, practitioners may utilize project management software that integrates scheduling, budgeting, and communication tools. This helps with the real-time tracking and sharing of information. Another suggestion is implementing conflict resolution mechanisms to address disagreements quickly and effectively.
- Policymakers may develop and promote industry-wide standards for communication practices in construction projects and encourage the use of standardized forms, templates, and reporting formats. In addition, providing incentives for projects that demonstrate effective collaboration and communication among stakeholders, which could include tax breaks, grants, or recognition awards, is another suggestion.
- Researchers may investigate effective communication practices in construction projects. They may identify which methods and tools most successfully minimize misunderstandings and errors. They may also study the impact of different communication strategies on project success and rework rates. Another strategy could be creating frameworks and models that construction teams can use to improve communication and collaboration.

6.3. Limitations and Future Research Directions

Even if this study's considerable efforts have greatly helped identify important rework variables, there remains room for improvement. These limitations may be addressed in future studies. First, the WoS database was used for the SLR of this investigation. To identify potential reasons for construction rework more thoroughly, future research could benefit from combining several databases, such as SCOPUS and Google Scholar.

Future studies should broaden the focus to include contractors, subcontractors, supercontractors, and other associated professions in order to provide a more thorough study. Even if Turkey is a representative example of a developing country, the results may be more broadly applicable if it were compared to other similar countries. This would be further expanded by using the same measurement scale in cross-national comparison research.

While this study employs SEM to analyze the relationships between CRFs and construction rework, future research could explore the use of multivariate regression as a complementary analytical approach. Multivariate regression would allow researchers to control for differences among respondent groups, such as architects, engineers, and construction managers, as well as examine variations across firm sizes and industry sectors. This approach could provide additional insights into how different professional backgrounds and organizational characteristics influence rework factors. By integrating both SEM and multivariate regression in future studies, researchers could further validate findings, compare model performances, and refine predictive frameworks for minimizing construction rework.

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