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A Roadmap for Reducing Construction Waste for Developing Countries

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Abstract: With the rapid development of the construction industry, construction waste (CW) has recently attracted much attention in many developing countries such as Türkiye. As a result, the effective management of construction waste has emerged as a critical concern at the global level. Reducing and managing CW is imperative to promote sustainable urban development. Although several scholars have made many valuable attempts to develop strategies to minimize CW, one of the most effective ways is to propose a road map for CW minimization, which is a method that has never been applied before, neither in this domain nor in the construction management and architectural domain. Unlike former studies, a roadmap was developed for reducing CW in this study. To create a roadmap, three steps were followed in this study. Firstly, CW causes were identified with a systematic literature review. Then, surveys were conducted with the construction stakeholders to obtain their perceptions of these causes. A normalized mean value analysis was conducted, and the importance and criticality of the CW causes were determined. Secondly, a timeline was developed, and it overlapped with the importance of the causes. Finally, roadmap strategies were created, and solutions were proposed to solve the causes of CW in the short, medium, and long term. The roadmap method, which is often used to develop new technologies, has not been used in this way to solve a problem before. Therefore, the study is unique and offers strategies that can be integrated into other studies.

Keywords: construction waste; road mapping; construction waste management; normalized mean value (NMV) analysis

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1. Introduction

Türkiye has been developing extremely rapidly in the building and construction sector in recent years, along with economic growth. TUIK (Turkish Statistical Institute) [1] reports that the growth rate in the construction sector is 5.9% per year. With this increase, inevitably, the amount of construction waste (CW) in the construction sector has also increased. Waste is a type of loss that occurs during construction and adds no value to the project while incurring direct and indirect expenditures [2]. This loss is not only monetary but also increases resource consumption and environmental pollution, burdening the environment and negatively affecting people's living conditions [3]. The amount of CW has dramatically increased, which has disastrous effects on urban survival and sustainability regarding economic values and environmental safety [4]. For these reasons, construction waste management has become essential for developed and developing countries.

In 2015, leaders from 193 countries developed the ambitious Sustainable Development Goals (SDGs), a set of 169 targets that aim to address 17 of the most pressing challenges facing humanity by 2030 (UNDP 2015). Goal 11 of the Sustainable Development Goals, under the heading "Sustainable cities and communities", has ten targets. Target 11.6 aims to "reduce the negative per capita environmental impacts of cities by 2030, with special attention to air quality and municipal waste management and other waste management" [5].

The activities carried out in this target can be listed as smart cities [6], smart transportation [7], energy-efficient buildings [8], green buildings [9], certification systems [10], and waste management in the construction sector [11,12]. Within the framework of these factors, construction waste must be reduced and managed [13].

When the former studies in the literature are examined, many studies aim to recycle the waste generated during construction [14,15]. CW strategies vary in different countries, depending on the existing potentials and challenges of the construction industry and the local market [16]. This situation is related to the development of countries in the construction sector, socio-economic structure, construction culture, awareness, educational status, and economic structure. This study analyses CW management in Türkiye, a developing country. Although it does not fully represent the problems of other developing countries due to the difference in construction dynamics, it is an example of the solution to the waste problem.

Within the scope of this study, the causes of CW have been identified using the systematic literature review (SLR) method. These identified factors have been surveyed by the stakeholders in the process using a 5-point Likert scale. The survey results were analyzed using statistical methods, and the importance levels of the causes were determined. Then, the articles used in SLR were examined in detail. A matrix was prepared in which the causes and publication years have been overlapped to determine the years in which the factors entered the literature. This stage aims to identify the impacts of the causes during the timeline. In this way, solutions can be offered more easily, and it can be determined how the period's social, economic, and social characteristics are reflected in these factors. Finally, a road map for reducing CW has been proposed in the study.

2. Existing Studies on CW and Gaps in the Literature

Scholars from around the world have made great efforts to concentrate on a wide range of CW topics and issues, including the circular economy [17–19], an environmental management plan [16], waste management approaches [20–22], quantifying and qualifying CW [23–26], the causes of CW [3,27–34], and waste reduction [35].

The causes of CW in the construction industry have been examined worldwide; notably, the subject has attracted the attention of scholars in the construction industries of developing countries. Nawaz et al. [36] conducted a survey in Pakistan to uncover the critical management practices factors for CW and identified 27 factors classified into five major categories. Their findings revealed waste segregation, contract management, materials logistics management, materials reuse, and ancillary procedures, which were strongly correlated and helped reduce CW. A survey conducted in Egypt by Daoud et al. [33] identified 33 distinct causes for CW, classified them into six factors, and modeled them using structural equation modeling. The established model unveiled that "green building practices" have the highest impact on CW in Egypt, while "legislation", "material procurement measures", and "material procurement models" have the most negligible impact. Hasan et al. [31] examined the barriers to improving CW management in Bangladesh using data interviewing owners, engineers, and project managers. They revealed the four most significant challenges as "inadequate supervision", "inadequate labor", "negligence and careless attitude of workers", and "lack of space for storage on-site" [31]. Khoshand et al. [37] assessed different CW management alternatives in Iran using the Fuzzy Analytic Hierarchy Process. The findings indicated that economic factors were the most significant factors. Jin et al. [38] examined the perceptions toward CW recycling by conducting a survey in China. Researchers identified 20 difficulties in CW recycling and analyzed their perceptions, conducting index of relative importance (IRI) and one-way ANOVA analyses. Sivashanmugam et al. [34] analyzed the CW reduction barriers in the UK with semi-structured interviews and identified 22 barriers.

Table 1 provides an overview of the studies mentioned above on CW causes and highlights their contributions. As seen in Table 1, most of the former studies in this domain conducted statistical analysis. Statistical analysis is essential in comprehensively assessing and addressing the causes of construction waste. By utilizing methods like the

Relative Importance Index (RII), researchers can identify significant factors contributing to waste generation in construction projects [26]. Furthermore, statistical models have been developed to evaluate the impact of variables on construction waste generation [19].

Table 1. A summary of the former causes of CW studies.

Reference	Research Methods	Factors	Findings	Country	Research Gaps
[36]	Confirmatory Factor Analysis (CFA)	27	Waste segregation, contract management, materials logistics management, materials reuse, and onside procedures strongly correlate and help reduce waste on building sites.	Pakistan	Factors for the causes of CW have been identified in the study. The relationships between the factors have been determined. However, the importance levels of the factors have been excluded from the scope of the study.
[33]	Structural Equation Modeling (SEM)	6	The parameter with the highest impact on CW in Egypt is "green building practices", while "legislation", "materials procurement measures", and "materials procurement models" have the most negligible impact.	Egypt	The study determined the importance of 6 parameters affecting CW for Egypt's 2030 vision. The parameters identified in the study are for the 2030 vision, and the current situation factors are excluded. In the study, the factors are evaluated in 6 broad scopes. Examining the sub-headings of these comprehensive headings is also effective for future studies.
[31]	Qualitative, quantitative, and mixed methodologies Purposive Sampling Methods (Interview)	19	The four most significant challenges are "poor supervision," "inadequate worker workmanship," "negligence and carefree attitude of workers," and "lack of space for storage on site."	Bangladesh	In the study, 19 factors gathered under six categories have been identified. Determining the relationship of these parameters with each other and their importance will inspire future studies in reducing CW.
[34]	Thematic analyses	22	The study concluded that digital technologies such as BIM can potentially reduce CW.	UK	It is open to study to determine numerical data on how many digital technologies such as BIM reduce CW.
[39]	Practical measurement method	-	Awareness should be raised at the design stage to reduce CW in the construction industry. Waste should be evaluated with other design criteria at the design stage.	Thailand	A guide has been created with the method used in the study. The study is limited only to the design phase. Using a similar method in the construction phase of this study will be effective for the literature.
[40]	Direct observation in-depth case study	11	It has been determined that efficient material management in building projects would minimize waste production, enhance construction standards, and maximize building contractors' profits.	Nigeria	The 11 factors identified in this study were evaluated through 10 case studies. In this study, the factors identified through case studies can be evaluated with various statistical methods.

Table 1. *Cont.*

Reference	Research Methods	Factors	Findings	Country	Research Gaps
[37]	Fuzzy Analytic Hierarchy Process	16	The findings indicated that economic factors were the most significant factors for each criterion. The most successful sub-criteria in terms of the primary goal have been determined to be the investment cost in terms of economic criteria, public acceptability in terms of social criteria, water pollution in terms of environmental criteria, and final quality in terms of technical criteria.	Iran	The study determined the significance levels of 16 factors within the scope of economic, social, environmental, and technical criteria. In the literature review, many studies show that CW increases are experienced due to human resources. These factors are excluded from the scope of this study. However, these factors are open to being investigated with a similar method used in the study.
[41]	Mean and ranking analyses.	34	According to the study results, the lean construction model can reduce the amount of waste. In transitioning to this process, institutions should be involved in the change through policy practices that encourage lean methods. External pressures from the government and/or company owners may accelerate the transition to lean construction processes.	Dubai	As stated in the study, it has been determined that the respondents needed more understanding of lean principles. Lack of participation has led to uncertain results by the study's authors. For this reason, a similar study can be conducted again for the factors identified in the study.
[38]	Relative Important Index (RII) Analysis of Variance (ANOVA)	36	Government control has a significant impact on reducing CW. It is concluded that R&D studies in China have become the dominant factor in the waste diversion business.	China	As the study notes, future research could focus on tracking the assessment of construction and development waste diversion performance against relevant legislation, benchmarks, or government regulations, encouraging investments in recycling and reuse of C&D waste through case studies, and examining the impacts of the project delivery method.

While earlier studies have been insightful, they predominantly concentrated on only unveiling the causes of CW or barriers to CW management by quantitative or qualitative analyses using methodologies such as questionnaires, case studies, interviews, or structural equation modeling. The originality value of the current study emerged at this point by identifying the causes of CW and developing short-, medium-, and long-term solutions to minimize these causes with the roadmap method developed by authors as an innovative method to minimize these causes.

In other words, the differences and unique values of this study compared to former studies are listed as follows:

- ✓ Although earlier studies identified several CW causes in different ways (e.g., semi-structured interviews, random literature review), the causes of CW were determined by SLR in this study, which provides a comprehensive, unbiased, and reproducible synthesis of existing research on a specific topic, ensuring a high level of methodological rigor and reliability of findings.

✓ Former research generally proposed future research directions to minimize CW by reviewing the literature. Unlike previous studies, in order to highlight the effects of environmental and social aspects on the emergence of CW causes, the time interval in which the identified causes were used in the literature was determined.

✓ Another original issue, not addressed in previous studies on this subject, is the overlapping of the importance of CW causes with the determined time parameter, and all data could be analyzed holistically on a time scale.

✓ The fact that the roadmap method, which is generally used in industrial engineering, has not been used before in the construction and architecture sector, neither to solve a problem nor to develop a new technology,

✓ CW management varies from country to country, depending on its economic and sociocultural situation, culture, and many other parameters. The data and analysis results of such studies may give different results due to the country's construction dynamics. Therefore, even if the results of this study cannot be generalized to developing countries, it is thought that it can serve as an example of the solution to the waste problem.

✓ The study is original in terms of determining criteria for reducing the factors affecting CW and classifying the solution proposals in the short, medium, and long term and contributes to filling the gaps in the literature.

3. Research Methodology

This study aims to determine the root causes of waste in the construction industry and offer comprehensive solution recommendations that take a holistic approach to the analysis and integration of time. The general framework of the study consists of three stages. Figure 1 provides an overview of the process proposed for this study.

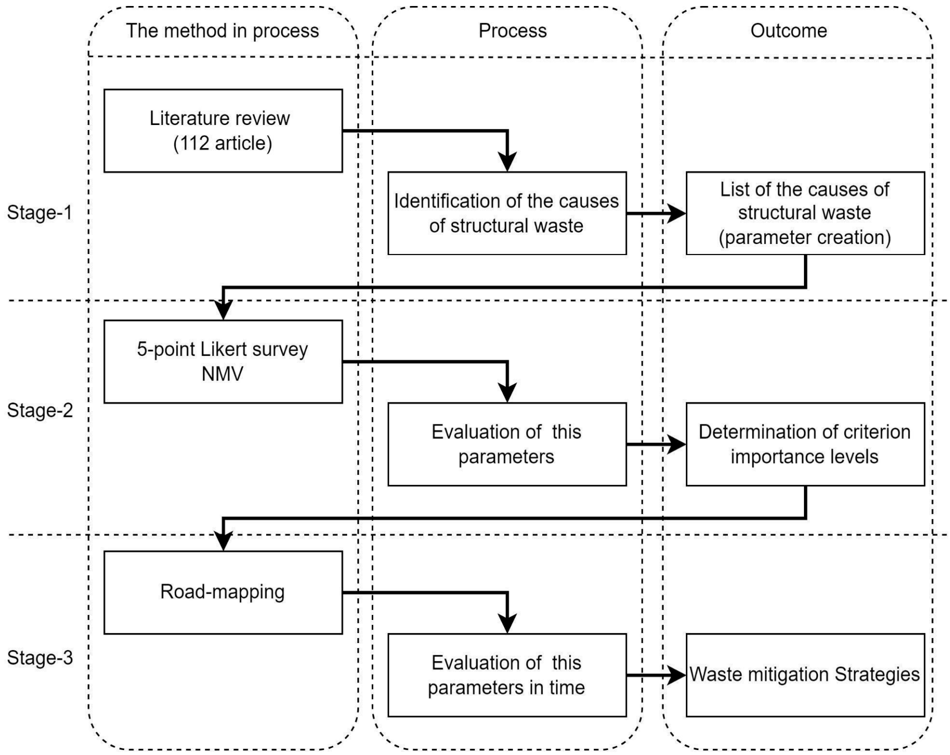

Figure 1. Methodology Framework.

In stage 1, the causes of CW were determined with SLR in the construction sector. Determining the causes of CW waste is significant to make a roadmap. Instead of limiting the scope of the study to specific journals, Web of Science (WoS) was selected to examine the research area to identify databases that would comprehensively cover relevant studies. WoS is a relevant data source for our study since it includes nearly all key publications, has built-in analytical tools to build representative counts [42], and employs better citation-matching algorithms than Scopus [43]. Although many studies in the WoS database are related to the subject, 112 articles containing direct causes of CW have been identified. By utilizing these studies, causes of CW in the construction sector have been identified under seven main categories: design, supply chain, transportation of material, planning and management, material storage, construction, workers-human resources, and external.

In the 2nd stage of the study, questionnaire questions have been organized on a 5-point Likert scale based on causes identified by SLR. This is a critical stage because universal causes of CW (determined by SLR) were evaluated in the scale of the Turkish construction industry, which will be a vital outcome for a road map for minimizing the CW. Data were collected through an online survey of the participants, and the obtained data were analyzed statistically using Statistical Package for the Social Sciences (SPSS) 22.0. Reliability and normalized mean value (NMV) analyses were performed.

The 3rd stage of the study consists of composing a road map. The roadmap provides a key role in integration (of tools and processes) [44]. A road map shows different technological "roads" that might be followed to achieve particular performance goals. One may decide on a specific course of action and create a plan with this method. Several options can be chosen and followed simultaneously if there is a lot of risk or ambiguity [36]. This study aims to draw a short-, medium-, and long-term road map for CW mitigation. In the study, a CW mitigation plan has been prepared by matching the highlighted causes identified as necessary for Türkiye with the years of validity in the literature. Although this method is used in business, engineering, and management, it is a very original study since it has yet to be used in construction and architectural management.

3.1. Identifying the Causes of Construction Waste with SLR

The current investigation commenced by identifying the origins of CW. To gather data systematically and transparently from the literature, potential causes were extracted through an SLR, a widely acknowledged objective methodology by numerous researchers [45].

The SLR, recognized as a robust methodological approach, was employed to systematically assess, analyze, and comprehend all CW-related research in the scientific field [46]. In this study, the relevant literature was comprehensively reviewed using this approach.

A three-stage methodology was implemented in this study to identify CW causes, encompassing the "planning", "execution", and "documentation" phases.

To explore the research domain, we chose the Web of Science (WoS), acknowledged as the premier database for literature review [47]. WoS was chosen for its comprehensive coverage and analytical capabilities, surpassing Scopus [43], making it the primary data source for this investigation.

3.2. Organizing the Questionnaire

The questionnaire consisted of two main sections. In the initial part, participants assessed the significance of CW causes (Cs). Respondents were required to rate the importance of these Cs on a five-point Likert-type scale, where a score of one represented "very low" and five signified "very high" impact. Five-point Likert scales were utilized to evaluate current forecasting methodologies and formulate optimal construction management strategies, as suggested by [48].

The second part of the questionnaire focused on gathering personal and sociodemographic information, including occupation type, experience in the construction industry, education level, and the participant's level of knowledge about CW.

3.3. Data Collection

The structured questionnaire was distributed to three leading professional groups: architects, engineers, and contractors with diverse roles, including project design and construction contracting, within public institutions, construction companies, and building inspection institutions in the Turkish construction industry. A pilot study was conducted to ensure clarity and identify potential confusion, involving 15 participants with over five years of experience, comprising five individuals from each profession. The final questionnaire was refined based on the feedback received during the pilot study.

On 9 April 2023, the final questionnaire was emailed to 1015 participants, and responses were accepted until 6 September 2023. A total of 325 responses were received, and after analysis, 246 valid surveys were considered, representing a response rate of 20.88%. Akintoye (2000) suggests that response rates falling between 20% and 30% are acceptable in construction research, indicating that the achieved rate is within acceptable bounds [49]. In the context of this study, a sample size of 246 can be considered adequate within this framework.

3.4. Data Analysis

The data obtained from the questionnaire were analyzed using the Statistical Package for the Social Sciences (IBM SPSS) v.26.0. Specifically, reliability analysis and normalized mean value analysis (NMV) were used.

Assessing the validity and reliability of a measurement instrument is crucial in research to ensure that the measuring instrument can consistently measure what it is intended to measure. One widely used method to evaluate reliability is Cronbach's alpha coefficient (α). Cronbach's alpha is a measure of internal consistency, indicating how closely related a set of items are as a group. It ranges from 0 to 1, with higher values suggesting greater reliability [50]. When using Cronbach's alpha to assess reliability, values between 0.7 and 1.0 are generally considered acceptable, indicating good reliability, while values below 0.7 indicate poor homogeneity within the scale [51,52].

After the reliability test, NMV analysis was employed for each of the Cs to identify critical ones, utilizing Equation (1):

$$Normalized\ Mean\ Value\ (NMV) = \frac{(mean\ of\ cause - lowest\ ranked\ mean)}{(highest\ ranked\ mean - lowest\ ranked\ mean)} \quad (1)$$

Any cause with an NMV exceeding 0.5 is considered a critical cause (CC). Various researchers have commonly employed this method of ranking analysis to categorize critical factors, as demonstrated in studies by Liao et al., Xu et al., and Zhao et al. [53–55] however, this method has not been used as a tool for creating a road map.

3.5. Road Mapping

Roadmapping is often used to develop new technologies in the field of industrial engineering [44,56,57]. Roadmapping aims to create a comprehensive technology roadmap process that can predict future technologies in terms of content and time [58]. However, there is no study in the field of architecture and construction that utilizes the "roadmapping" method. In addition, unlike previous studies in this domain, roadmapping is used for the first time in this study not to develop technology but to solve a problem.

The term "Roadmap" used in this study describes the modeling of the path to be followed in solving CW problems. Some criteria are needed when preparing a roadmap. It has been decided that there is no fixed criterion in the literature for creating a roadmap and that the mapping criteria will change according to the study's scope, purpose, and method. In this study, the time factor and the importance of the factors causing the problem are accepted as criteria for determining the path to be followed in solving the problem.

The concept of time is fundamental in solving a problem. In this study, determining the time period in which the causes determined by the SLR are evaluated in the literature and showing it on a table will create a pattern in the timetable to reveal the reasons for the occurrence of the problem. The created pattern is an important datum to evaluate the cause of the problem since it will reveal the time interval in which the problem is evaluated in the study.

Although many studies have been carried out in the literature to solve the criteria causing CW, the roadmap method has never been used in this field before. Mapping is necessary to determine various criteria to make short-, medium- and long-term plans for the solution. According to the former studies in the literature, the construction sector has been highly affected after the COVID-19 pandemic, and new findings have emerged in CW causes after COVID-19 [59]. Solving these emerging criteria as a priority and preventing the spread of these causes that cause CW are seen as the first parameters to be solved for CW reduction in this study. It is then considered that parameters of high importance and parameters that have been analyzed in the literature should be solved in the long term. Finally, the time-dependent parameters to be solved must be highlighted.

4. Findings and Discussion

4.1. Demographic Information

This sub-section presents the demographics of participants. Of the 246 participants, 49.2% were architects, 28.5% were engineers, and 22.3% were contractors. Of these participants, 33.7% have 1–5 years, 20.7% have 6–10 years, 7.7% have 11–15 years, 6.9% have 16–20 years, and 30.9% have 20–30 years of experience in the construction industry. Hence, a satisfactory level of experience was attained. Regarding educational level, 64.2% of participants had bachelor's degrees, and 35.8% had master's degrees and doctorates. Finally, among the sample group, 77.6% of participants indicated adequate knowledge of construction waste and its management, which was significant for the main subject of this study.

4.2. Identifying the Causes of CW

Causes of CW were obtained by SLR. During the SLR, primary studies were identified, systematically selected, extracted, analyzed, and synthesized. The search queries used in WoS were as follows: (ALL FIELDS) "construction" AND "construction waste" AND "causes" OR "reasons." The search timeframe was from 200 to 2023 (March), resulting in 834 records.

Establishing well-defined inclusion and exclusion criteria was crucial for efficiently filtering the collected research publications. Specific inclusion criteria were formulated: (1) research explicitly addressing causes of CW in construction projects and (2) studies published in peer-reviewed journals. This discerning approach toward academic journals is strategic, as such articles typically maintain higher quality standards [60]. Exclusion criteria were as follows: (1) research published in languages other than English and (2) studies lacking readily available full-text resources. After applying these criteria, 39 articles were retained—a detailed analysis of 39 articles identified and listed 54 causes of CW (Cs) in Table 2.

Table 2. Causes of CW.

Main Category	Codes of Causes	Definition of Causes	Sources	Main Category	Codes of Causes	Definition of Causes	Sources
Design (D)	D.01	Frequent Design Changes	[2,34,36,61–63]	Planning and Management (PaM)	PaM.01	Lack of a Management Plan for Wastes Generated During Construction at the Site	[29,64–69]
	D.02	Lack of Knowledge of the Designer	[31,40,70–72]		PaM.02	Incorrect Planning for Required Material Quantities	[28,39,40,66,73–76]

Table 2. *Cont.*

Main Category	Codes of Causes	Definition of Causes	Sources	Main Category	Codes of Causes	Definition of Causes	Sources
Design (D)	D.03	Low Quality of Design	[69,71,77]	Planning and Management (PaM)	PaM.03	Lack of Information about Material Dimensions	[66,68,78,79]
	D.04	Failure to observe the standard specified in legal regulations	[28,30,59,80]		PaM.04	Increased Reconstruction Works (lack of Control)	[2,4,18,19,31,81]
	D.05	Poor Coordination and Communication	[40,62,82,83]		PaM.05	Lack of control of the material brought to the construction site	[2,80,82]
	D.06	Lack of Experience as a Designer	[36,82,84,85]	Material Storage (MS)	MS.01	Unsuitable Field Storage Area Causing Damage or Deterioration	[32,40,74,79]
	D.07	Lack of Material Knowledge of the Designer	[26,28,30,31,71,76,86]		MS.02	Incorrect Storage Methods	[3,40,79]
	D.08	Deficiencies/Confusion in Agreement Documents	[28,30,59,72,80,82]		MS.03	Storage away from the site	[3,17,18,63]
	D.09	Changes in Customer Demands at the Last Moment	[62,82,87,88]		MS.04	Unnecessary Amount of Wasteful Products in the Field	[31,40,79]
	D.10	Deficiency in Design-Related Construction Details and Incompatibility between Projects in Details	[2,34,39,72,82]		MS.05	Loosely Packaged Materials Supplied	[31,78,89]
	D.11	Manufacturing in the field is contrary to the project and its annexes	[31,36,81,84]		MS.06	Incorrect Transport Methods from the Storage Point to the construction site	[17,40,84]
	D.12	Design and Detail Errors due to lack of information	[40,71,72,82]	Construction (C)	C.01	Mistakes due to carelessness	[36,83,90]
Supply Chain (SC)	SC.01	Material Order Errors due to lack of coordination between stakeholders	[31,34,38,40,66,74,91,92]		C.02	Unused Materials and Products	[28,32,36,40,76,93]
	SC.02	Incorrect estimation of the required amount of material	[28,39,40,75,76]		C.03	Equipment Failure	[36,63,83,94]
	SC.03	Poor material supply	[39,65,76,95]		C.04	Poor Workmanship	[36,38,40,79,83,90]
	SC.04	Supplier Errors	[34,40,59,75,76]		C.05	Time Pressure	[2,40,94]
	SC.05	Changes in Material Costs	[59,62,66,88]	Workers-Human Resources (W-HR)	W-HR.01	Lack of experienced employee	[31,38,69,96]
	SC.06	Ordering more than required	[62,97,98]		W-HR.02	Unethical Behavior of Workers	[79,90,99]
	SC.07	Frequent Order Changes	[62,76,79,95]		W-HR.03	Lack of education of Workers	[2,40,63,83]

Table 2. *Cont.*

Main Category	Codes of Causes	Definition of Causes	Sources	Main Category	Codes of Causes	Definition of Causes	Sources
Transportation of material (ToM)	ToM.01	Damage to material during transport	[36,39,40,79]	Workers-Human Resources (W-HR)	W-HR.04	Lack of Qualified Workers	[31,63,69,99]
	ToM.02	Problems in Entrance of Delivery Vehicles to the Site	[40,91,98]		W-HR.05	Inappropriate Over/Misuse of Materials	[22,68,93,94]
	ToM.03	Challenges Experienced in Transportation	[40,92,95,99,100]		W-HR.06	Lack of Worker's Willingness to Work	[2,90,96,99]
	ToM.04	Unsuitable Inefficient Material Discharge Method	[36,40,84,99]		W-HR.07	Abnormal Abrasion of Materials	[17,31,38,40,84]
	ToM.05	Careless behavior during material unloading	[36,40,68,74,79, 95]		W-HR.08	Lack of communication among stakeholders	[31,40,83,90,99]
	ToM.06	Inadequate Protection During Material Unloading	[36,40,78,99]		W-HR.09	Labor overtime work	[90,94,99]
External (E)	E.01	Weather Conditions	[16,86,94,101]		W-HR.10	Cutting of material Uneconomical Shapes	[99,102,103]
	E.02	Vandalistic Behavior of Workers	[36,40,86,101]				
	E.03	Damages Caused by 3rd Parties	[36,86,93]				

4.3. Reliability and Validity of the Questionnaire

To assess the internal consistency of the questionnaire, which was used as a measurement instrument, a reliability analysis was conducted using Cronbach's Alpha coefficient. The Cronbach's Alpha coefficient of the dataset for the 54 CW causes was determined to be 0.987. With a value of 0.987, it surpasses the commonly accepted threshold of 0.7 [51,52] and is well above it. This suggests that the questions assessing the 54 CW causes in the dataset indicate excellent internal consistency of the responses.

4.4. Determination of Critical Causes of CW (Normalized Mean Value analysis) and Ranking Analysis

The means and standard deviations for the entire set of 54 causes were computed and presented in Table 3. Upon conducting normalized mean value analyses, it was identified that 36 out of the 54 causes were deemed critical causes (CCs). Notably, cause W-HR.03 "Lack of education of workers" attained the highest mean value of 4.07, securing the top rank, while cause ToM.02 "Problems in Entrance of Delivery Vehicles to the Site", with the lowest mean value of 3.19, was assigned the 54th rank (refer to Table 3). The ranking analysis further disclosed that 36 of the 54 causes exhibited normalized mean values surpassing 0.5, indicating their significance as critical causes (CCs) for CW.

Table 3. Ranking and identification of critical causes.

Main Category	Code of Causes	Means and Ranking of Causes			
		Mean	Standard Deviation (SD)	Normalized Mean Value (MNV)	Rank
Design (D)	D.01	3.62	1.163	0.49	37
	D.02	3.69	1.143	0.57 *	30
	D.03	3.5	1.281	0.35	45
	D.04	3.61	1.216	0.48	39
	D.05	3.97	1.197	0.89 *	7
	D.06	3.79	1.17	0.68 *	18
	D.07	3.95	1.191	0.86 *	8
	D.08	3.62	1.153	0.49	38
	D.09	3.9	1.266	0.81 *	10
	D.10	3.91	1.257	0.82 *	9
	D.11	3.88	1.174	0.78 *	12
	D.12	3.88	1.158	0.78 *	13
Supply Chain (SC)	SC.01	3.79	1.226	0.68 *	19
	SC.02	3.7	1.27	0.58 *	27
	SC.03	3.78	1.206	0.67 *	22
	SC.04	3.57	1.235	0.43	41
	SC.05	3.19	1.258	0.00	53
	SC.06	3.66	1.188	0.53 *	33
	SC.07	3.45	1.241	0.30	48
Transportation of Material (ToM)	ToM.01	3.53	1.231	0.39	44
	ToM.02	3.19	1.217	0.00	54
	ToM.03	3.67	1.219	0.55 *	31
	ToM.04	3.76	1.212	0.65 *	24
	ToM.05	3.77	1.191	0.66 *	23
	ToM.06	4.06	1.196	0.99 *	2
Planning and Management (PaM)	PaM.01	3.83	1.169	0.73 *	15
	PaM.02	3.67	1.170	0.55 *	32
	PaM.03	4.02	1.209	0.94 *	4
	PaM.04	3.55	1.158	0.41	42
	PaM.05	3.8	1.156	0.69 *	17
Material Storage (MS)	MS.01	3.85	1.149	0.75 *	14
	MS.02	3.54	1.207	0.40	43
	MS.03	3.7	1.192	0.58 *	28
	MS.04	3.73	1.182	0.61 *	25
	MS.05	3.73	1.131	0.61 *	26
	MS.06	3.79	1.136	0.68 *	20
Construction (C)	C.01	3.63	1.185	0.50 *	36
	C.02	3.27	1.132	0.09	51

Table 3. *Cont.*

Main Category	Code of Causes	Means and Ranking of Causes			
		Mean	Standard Deviation (SD)	Normalized Mean Value (MNV)	Rank
Construction (C)	C.03	4.05	1.196	0.98 *	3
	C.04	3.81	1.206	0.70 *	16
	C.05	4.02	1.143	0.94 *	5
Workers-Human Resources (W-HR)	W-HR.01	3.79	1.168	0.68 *	21
	W-HR.02	3.89	1.189	0.80 *	11
	W-HR.03	4.07	1.149	1.00 *	1
	W-HR.04	3.98	1.142	0.90 *	6
	W-HR.05	3.65	1.176	0.52 *	34
	W-HR.06	3.43	1.184	0.27	49
	W-HR.07	3.7	1.107	0.58 *	29
	W-HR.08	3.25	1.264	0.07	52
	W-HR.09	3.65	1.155	0.52 *	35
	W-HR.10	3.36	1.242	0.19	50
External (E)	E.01	3.58	1.144	0.44	40
	E.02	3.49	1.167	0.34	46
	E.03	3.48	1.155	0.33	47

* denotes critical causes (CCs).

4.5. Overlapping of Critical Causes on the Timeline

The causes of CW vary over time due to environmental, social, and global effects. Identifying which causes have emerged in the literature and when will enable us to create a strategic plan for solving these causes. For this reason, a timeline was created to determine in which years the critical causes (CCs) identified in Table 3, which were obtained through NMV analysis, emerged and were evaluated in the literature. In this table, a pattern was obtained according to the cause's occurrence time in the literature. For example, D.02. "Lack of Knowledge of the Designer" is one of the CCs as identified in Table 3. When the source of D.02 is examined, the years in which D.02 exists in the literature are 2015 [70], 2018 [71], 2021 [40], and 2022 [31,72]. For this reason, the years 2015–2022 are marked in Table 4. In addition, the NMV value of the D.02 (NMV = 0.57) is also processed based on the value in Table 3.

Table 4. Overlapping of critical causes on the timeline.

		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Design	D.02								NMV = 0.57								
	D.05						NMV = 0.89										
	D.06	NMV = 0.68															
	D.07							NMV=0.86									
	D.09						NMV = 0.81										
	D.10															NMV = 0.82	
	D.11	NMV = 0.78															
	D.12											NMV = 0.78					
Supply Chain	SC.01						NMV = 0.68										
	SC.02						NMV = 0.58										
	SC.03														NMV = 0.67		
	SC.06						NMV = 0.53										

Table 4. *Cont.*

		2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Transportation	ToM.03		NMV = 0.55														
	ToM.04	NMV = 0.65															
	ToM.05				NMV = 0.66												
	ToM.06		NMV = 0.99														
Planning and Management	PaM.01		NMV = 0.73														
	PaM.02						NMV = 0.55										
	PaM.03					NMV = 0.94											
	PaM.05															NMV = 0.69	
Material Storage	MS.01				NMV = 0.75												
	MS.03									NMV = 0.58							
	MS.04				NMV = 0.61												
	MS.05				NMV = 0.61												
	MS.06	NMV = 0.68															
Construction	C.01														NMV = 0.50		
	C.03									NMV = 0.98							
	C.04				NMV = 0.70												
	C.05														NMV = 0.94		
Workers-Human Resources	W-HR.01		NMV = 0.68														
	W-HR.02		NMV = 0.80														
	W-HR.03		NMV = 1.00														
	W-HR.04		NMV = 0.90														
	W-HR.05			NMV = 0.52													
	W-HR.07	NMV = 0.58															
	W-HR.09		NMV = 0.52														

This pattern shows that new factors have emerged in the construction waste generation after 2020. However, more than creating a timeline based on the literature study is needed to create a roadmap for solving the problem. The causes of CW vary from country to country, depending on the policies of local governments and their perspectives on CW. Because of this, a comprehensive understanding of the causes of CW has been developed by overlaying the outcomes of the statistical analysis carried out on this study's data on the timeline, as shown in Table 4.

✓ CW causes on the timeline regarding the design process.

There are twelve causes of CW regarding the design phase, as seen in Table 3. Within the scope of overlapping CCs on the timeline, only critical causes whose NMV value exceeds 0.5 are considered and presented in Table 4.

Many studies investigate the effects of the design process on CW [69,79]. Many causes affecting the design process have been identified with four causes: D.01 "Frequent Design Changes" with NMV: 0.49, D.03 "Low Quality of Design" with NMV:0.35, D.04 "Failure to observe the standard specified in legal regulations" with NMV:0.48, D.08 "Deficiencies/Confusion in Agreement Documents" with NMV:0.49. However, these are not critical for developing countries. Therefore, they are not shown on the map.

The D.05 "Poor Coordination and Communication," which has gained awareness in the literature since 2013, is the most critical cause for Türkiye. The importance of communication between stakeholders in waste management was emphasized with NMV:0,89 during the design process. This situation can be explained by the need for practices enabling stakeholders to collaborate. The literature shows that Building Information Modeling (BIM) is one of the leading studies to prevent communication, misunderstanding, and many mistakes between stakeholders [104]. As seen in the literature, many obstacles exist in the transition phase to BIM processes in developing countries [105,106]. With the transition to BIM processes, there will likely be an improvement in parameter D.05.

D.07 “Lack of Material Knowledge of Designer” is the second important cause with NMV:0.86 value. Significantly, this cause appeared approximately in 2014, but it is still a subject open to research [107]. New materials are produced using developing technologies, and these materials’ use, construction technique, advantages, and disadvantages vary. Insufficient knowledge of the application of the new material leads to incorrect applications, resulting in reconstruction works and, ultimately, CW. Designers should constantly update their knowledge according to the technical properties of current materials. Considering that new materials are constantly being developed due to the rapid development of technology, it is evident that this parameter will remain important for many years. Providing designers and practitioners with technical details of the new materials entering the market and an information brochure if a particular detail is required in the application can minimize the generation of structural waste due to the mentioned factor.

It is seen that the D.10 “Deficiency in Design-Related Construction Details and Incompatibility between Projects in Details” has been examined in the literature since 2022, which is a new subject for CW management. This situation may be associated with COVID-19 [59]. Remote working during the COVID-19 period reveals the idea that there is an incompatibility in project details due to restrictions in stakeholders’ communication. This cause is the third most crucial cause in this process, with a value of NMV:082.

Although the cause that has been evaluated for the longest time in the literature that affects waste generation is the D.11 “Manufacturing in the field is contrary to the project and its annexes (Manufacturing defects),” this cause with the NMV:078 value is found to be less important relative to other cause in Türkiye. This is to work with the “package project” system in project planning. In this system, all static electrical and mechanical projects for the designed building are received from a single company. It also confirms that the cause of D.12, “Design and Detail Errors due to lack of information,” and D.11 are equally important within the scope of the package project [108].

The D.02 “Lack of Knowledge of the Designer” NMV:0.57 and D.06 “Lack of Experience of Designer” NMV:0.68 have been examined in the literature since 2008, and their importance levels for Türkiye are close to each other. The fact that these two causes were examined in a similar time interval and their importance levels are close to each other can be associated with the perception of similarity among the surveyed participants. These two parameters have been evaluated as interrelated in the literature [108]. These causes are in a cause-and-effect relationship.

✓ CW causes issues on the timeline regarding the supply chain process.

As waste management has gained importance since 2013, awareness of the supply chain’s relationship with CW has increased. For developing countries such as Türkiye, the SC.01 “Manufacturing in the field is contrary to the project and its annexes (Manufacturing defects)” is the most critical cause with NMV:0.68. Like in the design process, lack of coordination between stakeholders is an essential cause in the supply chain process.

The SC.06 “Ordering more than required” cause is the least essential cause with NMV:0.53. This can be attributed to the fact that the excess material arriving at the site can be used in another site or that waste is not created by selling the material arriving at the site to another user. In addition, the SC.02 “Incorrect estimation of the required amount of material” cause is not a very important parameter with NMV:0.58 due to the possibility of reordering when the material is perceived as incomplete supply.

When the timeline is examined in Table 4, although SC.01, “Material order errors due to lack of coordination between stakeholders”, SC.02, “Incorrect estimation of the required amount of material”, SC.06, “Ordering more than required”, parameters have not examined in the literature at similar times, the SC.03 “Purchase of product contrary to specification/poor material supply” NMV:0.68 cause is noteworthy in the literature after 2021. This condition is associated with COVID-19. As mentioned during the design process, stakeholders experienced difficulties in product selection due to mandatory restrictions during COVID-19. It is also seen in the literature that ordering the product based solely on verbal declaration without seeing it causes faulty and wrong material supply. Türkiye was also affected by the second most important parameter in this case.

✓ CW causes on the timeline regarding the transportation of material process.

The generation of construction waste due to the transportation of materials has been studied in the literature for many years and is still up to date. This situation is proof that this problem still needs to be solved. The most crucial cause under this heading for Türkiye is the ToM.06 "Inadequate protection during material unloading" with NMV:0.99. This situation can be solved by clearly defining the protection methods used in unloading contracts and specifications between transportation and construction companies [32].

As a cause definition, the ToM.04 "Unsuitable inefficient material discharge method" and ToM.05 "Careless behavior during material unloading" causes are interrelated causes [109] with NMV:0.65 and NMV:0.66, respectively. This is why their importance levels are close [15]. The solution to this situation can be solved by planning the unloading process and training the employees during the unloading process.

The cause ToM.03 "Challenges experienced in transportation" is the least essential parameter with NMV:0.55 under this heading. This situation is solved by developing emergency solution methods for problems that occur during discharge. However, it should be remembered that planning before discharge and specifications between companies can avoid all these causes.

✓ CW needs to work on the timeline regarding the planning and management process.

The cause PaM.01, "Lack of a management plan for wastes generated during construction at the site," has been the longest-studied cause for waste management in the literature. Many countries have researched planning for waste solutions [2,61,69]. This cause, which has been examined in the literature for a long time, is relatively less critical with NMV:0.73 in Türkiye and is explained by the need for more awareness when other parameters are considered.

The most crucial cause for Türkiye is parameter PaM.03, "Lack of information about material dimensions", with NMV: 0.94. This situation is related to the increase in material production companies, the production of various sizes with technological advancements, the need for pre-sales information by the companies, and the incomplete presentation of technical specifications. This explains the reasons for the lack of information.

The PaM.05 cause, with 0.69 NMV, has appeared since 2022 in the literature. This condition is associated with COVID-19. Due to various bans imposed during the COVID-19 period, access to the site was limited, and therefore, waste generation occurred due to problems in the control of materials entering the site.

For Türkiye, cause PaM.02, "Incorrect planning for required material quantities", is the least essential cause with NMN: 0.55 under this heading. As mentioned before, the problem can be solved by reordering the missing material coming to the field. In an over-order, the excess material can be stored, reused in another construction site, or sold.

CW causes on the timeline regarding the material storage process.

The longest studied cause under this heading in the literature is MS.06 "Incorrect transport methods from the storage point to the construction site" NMV: 0.68. The most critical cause for Türkiye is MS.01, "Unsuitable field storage area causing damage or deterioration," with NMV:0.75. It is known that Türkiye's construction sector is experiencing various problems in the storage area due to the rapid progress of construction and the shrinkage of the parcels to be used. This explains the high importance of inappropriate storage methods in Türkiye. Similarly, the limited field area explains the cause with MS.03 "Storage away from the site" NMV: 0.58.

✓ CW causes on the timeline regarding the construction process.

The cause of C.03, "Equipment failure", is the most critical cause in this process with NMV:0.98. Hiring construction equipment in the Turkish construction sector [110] is one of the most important reasons for this situation [57]. This cause has become very important due to the carelessness in the maintenance and use of this hired equipment. The cause C.05 "Time pressure" is the second important cause under this heading with NMV: 0.94. When this cause is examined, it is seen that it is processed in the literature after 2021, that is, after COVID-19. The fact that C.05 is a critical cause after COVID-19 can be explained by the intense time pressure in the construction sector due to the urgent shelter, care, and hospital needs during the epidemic [59]. This is the reason why the C.01 "Mistakes due to carelessness" cause is one of the issues investigated after COVID-19, which may be associated with the reflection of the pandemic effects on the construction sector. The pandemic has caused psychological and physiological damage to people. The studies carried out in the literature in this process prove that research on physiology, psychology, attention, and consciousness has begun to be carried out [59].

✓ CW causes on the timeline regarding the workers-human resources process.

When the "Workers-Human Resources Parameters" affecting the emergence of CW are analyzed, it is seen that all causes have very high importance in the Turkish construction sector and consist of causes that have been examined for many years. The covariate for all processes of "design, supply chain, transport, planning and management, materials and storage, and construction" is "Workers-Human Resources". The evaluation of this covariate in the literature was recognized much earlier than other categories, and all its parameters have been evaluated for many years.

4.6. Solution Suggestions with a Road Map

The roadmap phases for the solution to CW can be listed as follows:

1. The CW factors and the concept of time are integrated; it is seen that new factors have formed due to COVID-19 in the pattern formed. Mitigation and eliminating the adverse impacts of COVID-19 is the first possible solution, which should take place in the **short term**: It has been decided to evaluate the causes affecting the CW that occurred in the construction sector during the pandemic period as causes that need to be solved as a priority in order to be able to quickly adapt to the normalization process so that these causes do not spread over the long term. These reasons should not become a culture in the construction industry.
2. The elimination of the causes with high values of the NMV coefficient is the next solution, which should take place in the **medium term**: After the effects of the COVID-19 outbreak are resolved, it is thought that the causes, whose importance levels are highly determined by statistical methods, should be resolved in the medium term. These causes should be solved in the medium term to avoid spreading to the long term.

The elimination of the causes that appeared in the literature in the long term should take place in the **medium term**: When the spread of the causes in the literature over time is examined, it is predicted that the causes evaluated in the long term should be solved in the medium term in order to prevent further continuation of the causes evaluated in the long term.

3. Time-dependent causes should take place in the **long-term**: Since the causes whose solution depends on time cannot be solved in the short term and medium term, these causes are evaluated as factors that need to be solved in the long term.

The most necessary work for reducing CW occurring in the construction sector is to create a solution plan and roadmap as described above. In Figure 2, a periodic management plan has been created to reduce CW. As mentioned before, the effects of the COVID-19 pandemic have also been seen globally in the construction industry. These effects need to be resolved as soon as possible to reduce them, prevent their spread, and prevent these effects from becoming a part of the construction culture. For this reason, this parameter was thought to be solved first when creating a solution map.

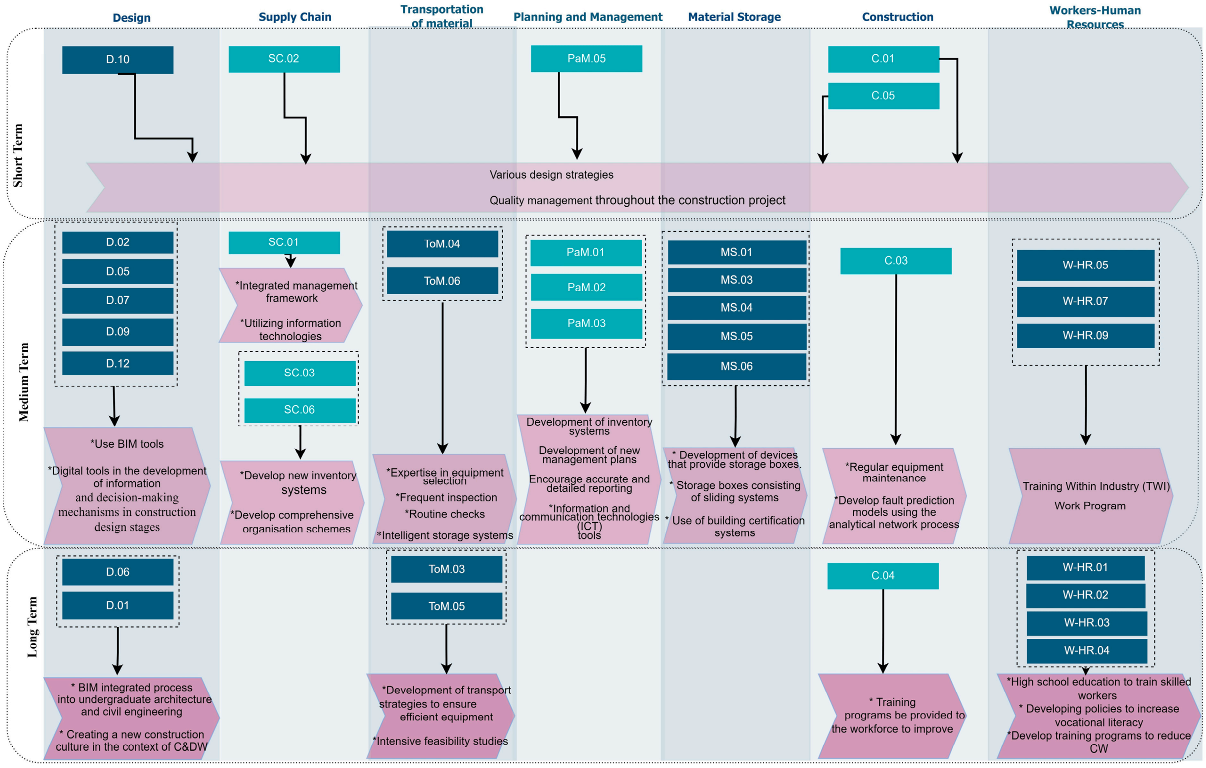

Figure 2. Roadmap to CW reduction. (* This sign refers to items of solution).

According to Figure 2, the causes that need to be resolved in the short term are listed as follows:

- ✓ D.10 "Deficiency in design-related construction details and incompatibility between projects in details" under the design process, SC.02 "Incorrect estimation of the required amount of material" under the supply chain process, PaM.05 "Lack of control of the material brought to the construction site" under the planning and management process, and C.01 "Mistakes due to carelessness" and C.05 "Time Pressure" under the construction process. Given that the COVID-19 pandemic is over, implementing regular design review meetings with all stakeholders to ensure alignment may be one of the short-term solutions for D.10. Adopting BIM may improve the accuracy and integration of design details for D.10. Developing and enforcing standard design templates and checklists may be another short-term solution for D.10. These strategies can help improve design team composition and increase awareness of the technical implications of managerial decisions [111,112].
- ✓ Regarding SC.02, utilizing advanced estimation software to enhance the accuracy of material quantity predictions may be a short-term solution. Another short-term key may be implementing a verification step where estimates are cross-checked by a second estimator.
- ✓ PaM.05 is another CC that needs to be addressed in the short term. Implementing strict inventory management practices to track material deliveries and usage may be a solution. Negotiating agreements with suppliers for quality assurance and timely delivery may be another method for the short term.
- ✓ C.01 is another critical concern that requires immediate attention. Using checklists and Standard Operating Procedures (SOPs) to minimize human errors may be a method. Finally, regarding C.05, developing realistic project schedules that allow adequate time for each phase of the construction process may be implemented. Ensuring adequate resources are allocated to critical tasks to prevent bottlenecks and rush work may be another short-term solution.

According to Figure 2, the parameters that need to be resolved in the medium term are listed as follows:

- ✓ Within the scope of the design process, cause D.02 "Lack of knowledge of the designer", D.07 "Lack of material knowledge of the designer", and D.12 "Design and detail errors due to lack of information" operations should continue in the medium term. Notably, these items are generally related to a lack of knowledge. Therefore, using digital tools may help minimize this cause's effect. Ho et al. [113] recommended that BIM tools be used to solve such deficiencies [113]. Hare et al. [114] also recommend using digital tools to develop information and decision-making mechanisms in the construction design stages [114]. The studies intensively emphasize that BIM systems can be used to fill information gaps [115,116].
- ✓ Within the scope of the supply chain process, SC.01, "Material order errors due to lack of coordination between stakeholders", and SC.03, "Poor material supply", SC.06, "Ordering more than required", must be resolved. Research on the solution of SC.01 generally recommends developing an integrated management framework and utilizing information technologies [117]. For SC.03 and SC.06, it is recommended to develop new inventory systems and to do this in digital environments [118]. Developing comprehensive organization schemes to meet the needs [119].
- ✓ Within the scope of the transportation process, causes ToM.04 "Unsuitable Inefficient Material Discharge Method" and ToM.06 "Inadequate Protection During Material Unloading" operations should continue in the medium term. To overcome these causes, Tafesse [120] suggests the development of specialized transport strategies as well as expertise in equipment selection, inspection, and routine checks [120]. In addition, Wang et al. suggest that intelligent storage systems can be developed [121].
- ✓ Within the scope of the "Planning and management" process, causes PaM.01 "Lack of a management plan for wastes generated during construction at the site," PaM.02 "Incorrect planning for required material quantities", and PaM.03 "Lack of information about material dimensions" operations should continue in the medium term. To tackle these causes, Joshi [118] and Wang et al. [121] suggest developing inventory systems [118] and developing management plans to address deficiencies in material and information sharing, encouraging accurate and detailed reporting in planning and allocation processes [122]. In addition, there are recommendations for the selection of "information and communication technologies" (ICT) tools for construction professionals [123].
- ✓ Within the scope of the "Material storage" process, causes MS.01 "Unsuitable field storage area causing damage or deterioration", MS.03 "Storage away from the site," MS.04 "Unnecessary amount of wasteful products in the field", MS.05 "Loosely Packaged materials supplied" and MS.06 "Incorrect transport methods from the storage point to the construction site" operations should continue in the medium term. One of the innovative methods developed in the literature for solving problems arising from storage is the development of devices that provide storage boxes [124]. Storage boxes consisting of sliding systems with the help of pipes are also one of these innovative methods. In addition to all these, building certification systems will also affect storage standards, as these certification systems will also affect these factors [125].
- ✓ Within the scope of the "Construction" process, cause C.03 "Equipment failure" operations should continue in the medium term. One of the studies to be carried out to solve this fault is to improve regular equipment maintenance practices. It is also recommended in the literature that fault prediction models be developed using the analytical network process [126].
- ✓ Within the scope of the "Workers-Human Resource" process, causes W-HR.05 "Inappropriate over/misuse of materials", W-HR.07 "Abnormal abrasion of materials", and W-HR.09 "Labor overtime work" operations should continue in the medium term. Implementing training programs such as the Training Within Industry (TWI) Work

Program can help improve construction workers' skills and reduce human errors that can contribute to equipment failures [127].

The solution to some of the causes of CW in the construction sector can be realized in a time-dependent manner. According to Figure 2, the parameters that need to be resolved in the long term are listed as follows:

- ✓ Literature searches for the solution of causes in design processes D.06 "Lack of experience of designer" and D.11 "Manufacturing in the field is contrary to the project and its annexes (Manufacturing defects)" emphasize that BIM integrated courses can be integrated into undergraduate architecture and civil engineering degree programs [106]. The integration and development of technology and design concepts will create a new construction culture. Even if this takes time, it will make a contribution that must be addressed in order to solve many problems.
- ✓ Within the scope of the "Transportation" process, causes ToM.03 "Challenges experienced in transportation" and ToM.05 "Careless behavior during material unloading" operations should continue in the long term. The amount of CO_2 emissions from CW caused by transportation processes in the construction sector has increased considerably [19]. To reduce CW, intensive feasibility studies should be carried out for the selection of vehicles, including the negotiation of the conditions of the vehicles, intensive feasibility studies for the selection of vehicles, and the development of transport strategies to ensure efficient equipment in the context of the transport parameter.
- ✓ Within the scope of the "Construction" process, cause C.04 "Poor workmanship" operations should continue in the long term. During the construction process, it was suggested that training programs be provided to the workforce to improve their knowledge and skills in correctly using materials to solve the problem of a poor workforce [127].
- ✓ Within the scope of the "Workers-Human Resource" process, causes W-HR.01 "Lack of experience employee", W-HR.02 "Unethical behavior of workers", W-HR.03 "Lack of education of workers", and W-HR.04 "Lack of qualified workers" operations should continue in the long term. One approach to addressing human error in the construction industry is to consider the potential of human factors such as safety orientation, workplace spirituality, work engagement, and worker agility to improve workplace well-being on construction sites [128]. Many of the former studies discuss the problems of low occupational literacy among workers in the construction sector [83,95]. To solve these problems, it is necessary to improve the occupational quality of workers, including their occupational skills, knowledge, and work attitudes [129]. In addition, the behavior of construction workers plays a vital role in waste generation, so training programs and appropriate working methodologies should be implemented to reduce waste [130].

5. Conclusions

In this study, a roadmap has been developed to reduce CW, which will be beneficial environmentally, economically, and in terms of health. The roadmap method is generally used in developing new technology in the literature. Unlike former research, the roadmap is used for the first time in solving a problem in this study, which constitutes its originality.

In this study, first of all, the causes affecting CW have been determined by the SLR method. Then, a survey was conducted with these causes, and the criticality of the factors was determined using statistical methods. In order to determine the environmental, social, and global characteristics of the causes, a chart was prepared to evaluate the factors by years, inspired by the "Temporal Trends of Keyword" analysis of bibliometric analyses. Then, within the scope of this criterion, the importance levels of the factors and the evaluation years in the literature have been compared. According to the results from Table 4, four strategies have been determined to create a roadmap. The first of the strategies is to determine the factors that arise due to the COVID-19 effect as factors that need to be solved in the short term to prevent them from becoming widespread and a part of the construction culture. Secondly, the degree of importance is considered, and the causes evaluated in the long term in the literature are resolved in the medium term. The last strategy is the causes that require time to solve, and it was decided to solve these factors in the long term. Considering all these strategies, "Various design strategies and Quality management throughout the construction project" have been proposed to eliminate the factors within the scope of the "design, supply chain, planning and management, construction" parameter in the short term to reduce CW.

In the medium term, "using BIM tools" and "digital tools in developing information and decision-making mechanisms in construction design stages" have been suggested to solve the causes under the design parameter. Within the scope of the supply chain, "Integrated management framework" and "utilizing information technologies" are recommended. Within the scope of the transportation parameter, "expertise in equipment selection", "frequent inspection", "routine checks," and "Intelligent storage systems" are recommended. Within the scope of planning and management, "Development of inventory systems", "Development of new management plans", "Encouragement of accurate and detailed reporting", and "Information and communication technologies (ICT) tools" are recommended. Within the scope of the material storage parameter, "Development of devices that provide storage boxes", "Storage boxes consisting of sliding systems", and "use of building certification systems" are recommended. Within the scope of the construction, "regular equipment maintenance" and "Develop fault prediction models using the analytical network process" are recommended. "Training Within Industry (TWI) Work Program" has been recommended within the scope of the workers-human resource process.

In the long term, under the design process, "BIM integrated process into undergraduate architecture and civil engineering" and "Creating a new construction culture in the context of CW" are recommended. Within the scope of the transportation process, "Development of transport strategies to ensure efficient equipment" and "Intensive feasibility studies" are recommended. Within the scope of the construction process, "training programs be provided to the workforce to improve" is recommended. Within the scope of the workers-human resource process, "Training skilled workers", "Developing policies to increase professional literacy", and "Developing training programs to reduce CW" are recommended.

Limitations and Future Research

This study is the first to use the roadmap method to reduce CW. It offers an innovative approach to using the roadmap method to develop technology to solve problems. There are some limitations in this study. The method can be developed within the framework of these limitations for future studies. The constraints can be listed as follows:

In the study, CW causes have been restricted according to the search made from the WoS database. In future studies, it can be tried with data from Scopus, Scholar, and similar databases, and the results can be compared with this study.

This study was conducted on the sample of Türkiye, one of the developing countries. The validity of the study results includes developing countries. The study can be repeated and compared in the future, or developed country data can be compared with developing country data.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

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