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Identification and analysis of barriers for construction and demolition waste reduction on commercial construction sites

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Authors' notes'

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Abstract

Objective: This study identifies and assesses the barriers to reducing construction and demolition waste (CDW) in medium-sized commercial construction sites in Brazil.

Methodology: A systematic literature review was conducted to identify and classify the main barriers to CDW reduction. Subsequently, the Fuzzy Dematel technique was applied to analyze the barriers based on managers' knowledge.

Originality: Synthesizing insights from existing research on CDW reduction challenges, the study classifies these barriers into technical, economic, and legal dimensions within the Brazilian civil construction sector. Through the analysis of these barriers from professionals' viewpoints, the research makes a distinctive contribution by providing a novel, focused examination within this specific context.

Results: The research revealed key economic, environmental, and technical factors. Results highlight the influence of legislation and government incentives on other barriers. The lack of financial resources emerged as a significant barrier to CDW reduction, according to managers' opinions.

Contributions: This study contributes to advancing the circular economy by identifying key barriers to reducing CDW in medium-sized commercial works. It provides practical recommendations to overcome these barriers, offering valuable insights for both theoretical development and practical applications.

Keywords: construction waste reduction, barriers, Fuzzy Dematel, systematic literature review, commercial construction sites

Identificação e análise de barreiras para a redução de resíduos de construção e demolição em canteiros de obras comerciais

Resumo

Objetivo: Este estudo identifica e avalia as barreiras para a redução de resíduos de construção e demolição (RCD) em canteiros de obras comerciais de médio porte no Brasil.

Metodologia: Foi realizada uma revisão sistemática da literatura para identificar e classificar as principais barreiras à redução de RCD. Posteriormente, foi aplicada a técnica Fuzzy Dematel para analisar as barreiras com base no conhecimento dos gestores.

Originalidade: Sintetizando os insights de pesquisas existentes sobre os desafios da redução de RCD, o estudo classifica essas barreiras em dimensões técnicas, econômicas e legais no setor da construção civil brasileira. Por meio da análise dessas barreiras sob a ótica dos profissionais, a pesquisa contribui de forma diferenciada ao fornecer um exame novo e focado dentro desse contexto específico.

Resultados: A pesquisa revelou os principais fatores econômicos, ambientais e técnicos. Os resultados destacam a influência da legislação e dos incentivos governamentais noutros obstáculos. A falta de recursos financeiros surgiu como uma barreira significativa à redução dos RCD, de acordo com as opiniões dos gestores.

Contribuições: Este estudo contribui para o avanço da economia circular ao identificar as principais barreiras à redução dos RCD em obras comerciais de média dimensão. Fornece recomendações práticas para ultrapassar estas barreiras, oferecendo conhecimentos valiosos para o desenvolvimento teórico.

Palavras-chave: redução de resíduos de construção, barreiras, Fuzzy Dematel, revisão sistemática da literatura, canteiros de obras comerciais

Identificación y análisis de barreras para la reducción de residuos de construcción y demolición en obras comerciales

Resumen

Objetivo: Este estudio identifica y evalúa las barreras para la reducción de residuos de construcción y demolición (RCD) en obras comerciales de tamaño medio en Brasil.

Metodología: Se realizó una revisión sistemática de la literatura para identificar y clasificar las principales barreras para la reducción de RCD. Posteriormente, se aplicó la técnica Fuzzy Dematel para analizar las barreras a partir del conocimiento de los gestores.

Originalidad: Sintetizando los conocimientos de las investigaciones existentes sobre los desafíos de la reducción de RCD, el estudio clasifica estas barreras en las dimensiones técnica, económica y legal dentro del sector brasileño de la construcción civil. A través del análisis de estas barreras desde el punto de vista de los profesionales, la investigación hace una contribución distintiva al proporcionar un examen novedoso y enfocado dentro de este contexto específico.

Resultados: La investigación reveló factores económicos, ambientales y técnicos clave. Los resultados destacan la influencia de la legislación y los incentivos gubernamentales en otras barreras. La falta de recursos financieros se reveló como un obstáculo importante para la reducción de los RCD, según la opinión de los gestores.

Contribuciones: Este estudio contribuye al avance de la economía circular mediante la identificación de barreras clave para la reducción de RCD en obras comerciales de tamaño medio. Proporciona recomendaciones prácticas para superar estas barreras, ofreciendo valiosas perspectivas tanto para el desarrollo teórico.

Palabras clave: reducción de residuos de la construcción, barreras, Fuzzy Dematel, revisión sistemática de la literatura, obras de construcción comercial

Introduction

According to Bao, Lee, and Lu (2020), civil construction activities account for approximately 25% of solid waste deposited in landfills in large cities. Meanwhile, Liu, Yi, and Wang (2020) indicate that this sector is responsible for generating 35% of solid urban waste worldwide. Therefore, reducing construction and demolition waste (CDW) is crucial to mitigating the negative impacts of human activity on the planet. CDW can stem from various sources, such as new constructions, demolitions, renovations, and expansions (Röhm, Marques Neto & Röhm, 2013). Pellegrini et al. (2020) define CDW as any surplus material, excluding earth materials, that must be removed from the construction site and sent to a landfill.

According to Peng, Scorpio, and Kibert (1997) and Huang et al. (2018), the management of construction and demolition waste (CDW) should be guided by the principles of the 3Rs (Reduce, Reuse, and Recycle). Among these principles, waste reduction should be given the highest priority, as it has the least impact on the environment. Reuse refers to the practice of using materials again for their original purpose (conventional reuse) or for a different function (creative reuse or repurposing). Recycling involves reducing items to create new materials or objects.

The Circular Economy model aligns with the principles of the 3Rs directly. By actively promoting waste reduction, material reuse, and recycling, the Circular Economy model seeks to break out of the linear "take-make-dispose" pattern of resource consumption and adopt a closed-loop system. This approach highlights the importance of maximizing the use of materials and products, extracting their maximum value throughout their life cycle, and diligently minimizing waste production, thereby contributing to the sustainable development of society (Shooshtarian, Maqsood, Caldera, & Ryley, 2022; Arantes, Zanon, Calache, Bertassini, & Carpinetti, 2022). Furthermore, this model emphasizes that two undesirable options for waste disposal are combustion and, particularly, landfill dumping (Korhonen, Honkasalo, & Seppälä, 2018). Thus, the focus of this study is on reducing the amount of CDW generated by construction sites that may end up being incinerated or dumped in landfills.

Liu, Yi, and Wang (2020) identify various barriers that construction managers must evaluate and monitor to reduce the generation of CDW at all stages of the physical construction schedule. However, Abarca-Guerrero, Maas, and Twillert (2017), who examined the barriers and motivations that lead to the reduction of CDW, argue that few authors have researched the barriers that prevent waste reduction in construction.

Given the cultural, economic, and legal differences across countries, construction managers face distinct challenges in reducing CDW (Bao, Lee, & Lu, 2020; Negash, Hassan, Tseng, Wu, & Ali, 2021). The relationships and levels of importance of these barriers in countries with consolidated legislation and stricter inspection differ from those in countries with less structured processes in these matters. Moreover, the organization of the civil construction sector varies across countries.

In Brazil, the commercial construction industry has significant economic relevance, with the presence of the 50 largest construction companies (CBIC, 2018). This sector, as defined by the National Classification of Economic Activities, version 2.0 (CNAE 2.0), involves the construction of commercial buildings, restaurants, schools, hospitals, shopping centers, among others, that are essential for the activities of the service sector. In developing countries like Brazil, this sector has increased its participation in the Gross domestic product (GDP) (de Souza Campos et al., 2013; Roth & Garcias, 2009). Therefore, studying commercial construction allows for a better understanding of its impact on the Brazilian economy and the identification of opportunities and challenges faced by this sector. Knowledge about commercial construction can assist in formulating efficient public policies, developing successful business strategies, and creating jobs and business opportunities (Menegaki & Damigos, 2018). Furthermore, understanding the growth and trends in commercial construction can provide valuable insights for investors, entrepreneurs, and industry professionals, enabling them to make informed decisions and maximize their potential for success.

In order to handle the issues discussed in the previous paragraphs, this study aims to identify and analyse the importance of different barriers to reducing CDW on commercial construction sites in Brazil, based on the knowledge and experience of their responsible managers, using a systematic literature review (SLR) to identify these barriers. The analysis and assessment of the importance of barriers to reducing CDW used the frequency of citations in the SLR and the fuzzy Dematel, which was used similarly to studies by Negash et al. (2021) and Mavi and Standing (2018). This multi-criteria technique enables the analysis of dependency relationships between the barriers and identifies those most relevant to the problem addressed. Using fuzzy representation in the experts' assessments allows for better handling of uncertainties and inaccuracies in judgments (Rodrigues et al., 2023).

In the existing literature, numerous studies have attempted to propose various categories of barriers concerning Construction and Demolition Waste (CDW). However, this present study aims to consolidate the barriers associated with CDW reduction that have been identified in previous research and categorize them into technical, economic, and legal dimensions. It is worth noting that previous works have predominantly analysed these barriers from a generic standpoint, failing to consider the unique characteristics and intricacies of individual nations. As a result, this study takes a focused approach by analysing the barriers through the lens of professionals within the Brazilian civil construction industry. Notably, no prior study, to the authors' knowledge, has endeavoured to incorporate this specific contextual perspective, making this research a novel contribution to the field.

The remainder of this article is structured as follows. Section 2 presents a brief theoretical foundation. Section 3 describes the research method, including the SLR and fuzzy Dematel techniques. Section 4 presents the results and discussions, including a list of barriers to reducing CDW identified in the literature and an analysis and evaluation of barriers in commercial works in Brazil. Section 5 provides the conclusions of this study.

Conceptual background

Civil construction is a highly significant sector that contributes to the economic growth of countries by generating employment opportunities and income. However, the sector's activities consume vast amounts of raw materials and energy, exploit natural resources to acquire materials, and negatively impact the environment through the generation of construction waste (Azevedo, Kiperstok, & Moraes, 2006).

CDW is a surplus resource on construction sites, representing between 10% and 15% of the materials used (Olanrewaju & Ogunmakinde, 2020). Souza et al. (1999) stresses the importance of identifying the type of loss being analyzed in construction work. Built-in loss, such as hardware dimensioned above the minimum design coefficients or plaster with thickness above the recommended level, exists as well as waste that comes out of the work. This work will focus on the second case, and the scope of the study will not include losses incorporated into the building during its construction. Identifying and quantifying this kind of loss is challenging and involves the analysis of projects and construction practices. This definition aligns with Pellegrini et al. (2020), who consider CDW to be any surplus material, except earth, that must be removed from the construction site for disposal.

Various government agencies, researchers, and companies have studied and developed actions to reduce, reuse, and recycle (3R) CDWs, thereby reducing their release into landfills

(Huang et al., 2018). However, numerous barriers make it difficult or unfeasible to implement these actions, making the reduction of CDWs a significant challenge for managers seeking circularity in their civil construction operations.

To structure the analysis, these numerous barriers have been grouped according to their characteristics. Negash et al. (2021) categorized the barriers into five categories: technical, economic, social, regulatory, and environmental. Subsequently, the authors defined the criteria within this grouping. Mahpour (2018) surveyed potential barriers to reducing construction waste based on the circular economy, grouping the criteria into behavioral, technical, and legal barriers.

In the present study, based on the division of Negash et al. (2021) and Mahpour (2018), we decided to condense the social (behavioral) and environmental barriers with the technical barrier. This decision was taken because the social theme also analyzes the operational behavior, and some of the environmental criteria are incorporated into current legislation. As a result, the barriers in this study were grouped into three categories described below:

- Technical: This category includes concepts directly linked to the execution techniques of the works, such as planning, transportation, and storage methods, training and education (including environmental) of actors that have a direct impact on the reduction of CDW, mainly involving the management and team experience (Abarca-Guerrero et al., 2017; Agamuthu, 2008).
- Economic: This category refers to the financial and economic obstacles that influence and hinder the management of CDW on construction sites (Abarca-Guerrero et al., 2017).
- Legal: This category involves issues related to laws and regulations that impact CDW management at construction sites, involving the roles of different actors such as inspection bodies, government, and managers. (Abarca-Guerrero et al., 2017; Udawatta et al., 2018).

Research methodology

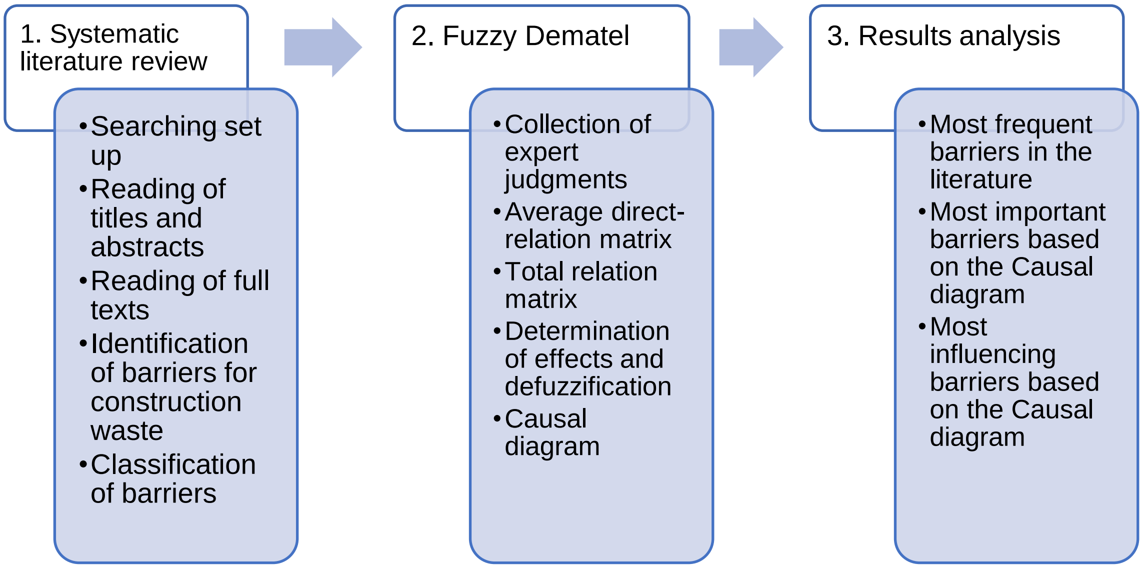
The research conducted to identify and analyze barriers to reducing Construction and Demolition Waste (CDW) on medium-sized commercial construction sites followed a three-step process. Firstly, we employed the systematic literature review (SLR) method to identify and compile the barriers reported in previous studies pertaining to CDW reduction. This rigorous review allowed us to determine the frequency with which these barriers were cited in the existing literature.

Secondly, we utilized the fuzzy DEMATEL method to structure the data collected from a sample of managers working in medium-sized commercial construction sites in Brazil. This method enabled us to analyze and understand the relationships and interactions between these barriers, providing valuable insights.

Finally, by comparing and contrasting the results obtained from both the systematic literature review and the fuzzy DEMATEL analysis, we were able to assess the significance and importance of each identified barrier. While the SLR illuminated pivotal barriers across various countries and construction contexts, the fuzzy DEMATEL analysis delved specifically into medium-sized commercial construction sites within Brazil. This integrative approach facilitated a deeper comprehension of the nuanced challenges surrounding construction and demolition waste (CDW) reduction barriers within this specific subset of the construction industry. The organizational framework of our research endeavor is visually depicted in

Figure 1

Research Method



Source: The authors

Systematic Literature Review (SLR)

The SLR method is crucial for producing reliable and methodical research that yields better results. This method enhances the consistency of the research by allowing the systematic correlation of the research theme with previously published works (Conforto, Amaral, & Silva, 2011).

To commence the literature search process, the research question "What are the primary barriers to reducing CDW?" was defined. Subsequently, articles were searched for on the Scopus platform, utilizing eligibility criteria such as articles published in English from 2012 to 2022, and excluding notes and conference review documents. The search was focused on all the physical sciences, and two search strings, "management AND barrier AND construction AND waste" or "barrier AND reduction AND construction AND waste," were used in the title, abstract, and keywords of the articles. The search results yielded 169 documents.

Two document evaluation stages were implemented, with the first stage involving reading the title, abstract, and introduction of the articles. In this process, articles that were not relevant to the research purpose or those that were repetitive were excluded, leaving 54 articles. In the second stage, the 54 articles were read in full, resulting in 23 articles that identified the barriers. These 23 articles were stored in Mendeley® software for managing and creating bibliographic references, and they were used to obtain the identified barriers to reducing CDW.

Fuzzy Dematel

The DEMATEL (Decision Making Trial and Evaluation Laboratory) method was developed in 1972 at the Memorial Battelle Institute in Geneva as part of the Science and Human Affairs Program by Gabus and Fontela (Tsai & Chou, 2009). This method allows for the structured assessment of cause-and-effect relationships between criteria by analyzing their dependence (Zhang et al., 2019).

To address uncertainties and inaccuracies in decision-making judgments, fuzzy sets have been incorporated into DEMATEL (Mavi & Standing, 2018). The fuzzy Dematel has been employed in several studies to evaluate barriers to the adoption of new technologies, paradigm shifts, or process improvements (Farooque, Jain, hang, & Li, 2020; Feldmann, Birkel, & Hartmann, 2022).

Triangular fuzzy numbers are often used to represent linguistic terms due to their simplicity and computational efficiency. In this representation, the membership function defined by Eq. (1) has a maximum value of 1 when x equals m (Osiro, Lima-Junior,& Carpinetti, 2013).

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x \leq l \\ \frac{x-l}{m-l}, & l \leq x \leq m \\ \frac{x-r}{m-r}, & m \leq x \leq r \\ 0, & x \geq r \end{cases} \qquad (1)$$

Basic operations involving triangular fuzzy numbers can be represented using Eq. (2) to (6), where $\tilde{A}_1 = (l_1, m_1, r_1)$ and $\tilde{A}_2 = (l_2, m_2, r_2)$ are triangular fuzzy number, and k is a constant

(Mavi & Standing, 2018; Zhang et al., 2019).

$$(l_1, m_1, r_1) \oplus (l_2, m_2, r_2) = (l_1 + l_2, m_1 + m_2, r_1 + r_2) \tag{2}$$

$$(l_1, m_1, r_1) \ominus (l_2, m_2, r_2) = (l_1 - r_2, m_1 - m_2, r_1 - l_2) \tag{3}$$

$$(l_1, m_1, r_1) \otimes (l_2, m_2, r_2) = (l_1 l_2, m_1 m_2, r_1 r_2) \tag{4}$$

$$k.(l_1, m_1, r_1) = (k.l_1, k.m_1, k.r_1) \tag{5}$$

$$(l_1, m_1, r_1)^{-1} = (\frac{1}{l_1}, \frac{1}{m_1}, \frac{1}{r_1}) \tag{6}$$

The fuzzy DEMATEL method has been applied in research similar to the objective of this study, as it provides a more appropriate treatment of the uncertainty and imprecision of experts' evaluations through the use of fuzzy logic. Negash et al. (2021) applied fuzzy-DEMATEL to identify regulatory barriers to sustainable CDW management in Somaliland, while Zhang et al. (2019) used the method to address barriers to smart waste management in China's circular economy. Mavi and Standing (2018) also used fuzzy-DEMATEL to analyze critical success factors for managing sustainable construction projects.

In order to apply the fuzzy-DEMATEL in this research, a sequence of six steps was employed based on Mavi and Standing's (2018) methodology. In **step 1**, the *n* barriers were arranged in a matrix $[n \times n]$ format. To analyze the barriers' influence on reducing the generation of CDW in medium-sized commercial construction sites in Brazil, construction managers were asked to evaluate the question "What is the influence of barrier *i* on barrier *j*?", using linguistic variables to express different degrees of influence based on a linguistic term scale. Triangular numbers $\tilde{z}_{ij}$ = (*l*, m, *r*), where *l* represents the lower limit of the interval, *m* the characteristic value, and *r* the upper limit, were used to incorporate fuzzy logic, as shown in Table 1.

Table 1

Linguistic terms for assessing the influence relationships between the criteria

Linguistic terms	Abbreviation	Fuzzy triangular number		
		l	*m*	*r*
No influence	NI	0.00	0.00	0.25
Very low influence	VL	0.00	0.25	0.50
Low influence	L	0.25	0.50	0.75
High influence	H	0.50	0.75	1.00
Very high influence	VH	0.75	1.00	1.00

Source: The authors.

Each construction manager assessed the influence relationships between the barriers, and their judgments were used to construct a matrix $\tilde{Z}^k$ $[n \times n]$, also known as the direct relationship matrix. The p matrices $\tilde{Z}^k$ were combined using Eqs. (2) and (5) to obtain the mean direct relation matrix $\tilde{Z}$. The initial matrix $\tilde{Z}$ was then transformed into the normalized matrix $\tilde{X}$ $[n \times n]$ using Eqs. (7) and (8).

$$S = max_{1 \leq i \leq n}\left(\sum_{j=1}^{n} \tilde{r}_{ij}\right) \quad (7)$$

$$\tilde{X}_{ij} = \frac{\tilde{z}_{ij}}{S} = \left(\frac{l_{ij}}{S}, \frac{m_{ij}}{S}, \frac{r_{ij}}{S}\right) \quad (8)$$

Step 2 consists of obtaining the total relation matrix $\tilde{T}$ using Eq. (9) to (12).

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} \cdots & \tilde{t}_1 \\ \tilde{t}_{n1} \cdots & \tilde{t}_{nn} \end{bmatrix}, \text{ where } \tilde{t}_{ij=(l_{ij}, m_{ij}, r_{ij})} \quad (9)$$

$$matriz\,[l_{ij}] = X_l x\,(I - X_l)^{-1} \quad (10)$$

$$matriz\,[m_{ij}] = X_m x\,(I - X_m)^{-1} \quad (11)$$

$$matriz\,[r_{ij}] = X_r x\,(I - X_r)^{-1} \quad (12)$$

Step 3 is defuzzification of the triangular fuzzy numbers. The center of area t of a fuzzy triangular number is calculated by Eq. (13).

$$t = \frac{(r-l)+(m-l)}{3} + l \quad (13)$$

Step 4 involves the summation of rows and columns of the defuzzified matrix. The direct and indirect influences from barrier i to the remaining barriers are determined by Eq. (14).

Similarly, Eq. (15) is used to identify the influences that barrier j receives from other barriers.

$$D_i = \sum_{j=1}^{n} t_j \quad (14)$$

$$R_j = \sum_{i=1}^{n} t_i \quad (15)$$

Step 5 involves generating the causal diagram with the results from the previous step, allowing for the analysis of the priorities and influence relationships between the barriers. The importance of a barrier is determined by Eq. (16), and the degree of influence of the barrier is determined by Eq. (17). The causal diagram has the values $D_i + R_i$ on the horizontal axis and the values $D_i - R_i$ on the vertical axis. In general, a positive value indicates that the barrier in question influences the others, while a negative value indicates that the barrier is influenced by the others.

$$D_i + R_i \quad (16)$$

$$D_i - R_i \quad (17)$$

In the last step, **Step 6**, the researchers carry out an overall analysis of the results obtained from the previous steps. This includes analyzing the general relations of importance on the $D + R$ axis and influence on the $D - R$ axis. Additionally, the identification of the most significant direct influence relations in the causal diagram is done based on values greater than a threshold value in the defuzzified T matrix, following the methodology of Zhang et al. (2019). To identify the strongest relationships, this work sets a threshold value of values above 1.5 standard deviations from the mean of the total relation matrix (T), consistent with previous studies by Farooque et al. (2020) and Li and Tzeng (2009).

The causal diagram can be divided into four distinct groups, as outlined by Hwang, Hsiao, Chen, and Chern (2016) and Chien, Wu, and Huang (2014). The groups in the causal diagram are illustrated in Figure I presented in the supplementary information material. These groups are characterized by:

Group I – Core Factors: Given their significant attributes of high prominence and strong relation, these factors should be classified as a priority target.

Group II – Driving factors: Having a Low Prominence and a High relation, these factors can be seen as autonomous givers.

Group III – Independent factors: With a Low Prominence and a Low Relation, also has a low interaction with others factors, so they may be judged as acceptable in ordinary situations.

Group IV – By Impact factor: Having a High Prominence and a Low Relation, this factors must be managed but not improved directly. Due to their high levels of interaction with other factors, the causal factors (Group I and II) can be used to generate feedback effects.

In order to gather data for Fuzzy DEMATEL, a standardized questionnaire was devised, comprising two components. The first segment is dedicated to capturing the professional data of specialists, for informative purposes only, without interfering in the application of the proposed method. The second segment entails a matrix $[n \times n]$ for inputting comparison data among barriers, which constitutes Step 1 within the fuzzy DEMATEL methodology. Rigorous validation of each expert's responses was ensured through comprehensive execution of all methodological steps, culminating in the construction of the causal diagram. This meticulous approach to individual data evaluation is expected to enhance the consistency and reliability of the average results derived from all participants.

Results and Discussion

List of barriers

14 barriers were identified in the 23 articles selected in SLR and classified into three categories: technical, economic and legal. This categorization is based on the study presented in section 2. Table 2 presents the eight technical barriers to reducing CDW.

Table 2

Technical barriers to reducing CDW

Code	Barrier	References	Paper quantity
B1	*Lack of a well-developed and coordinated project*	*(Giorgi et al., 2022); (Condotta & Zatta, 2021); (Negash et al., 2021); (Spišáková et al., 2021); (Olanrewaju & Ogunmakinde, 2020); (Pellegrini et al., 2020); (Low et al., 2020); (Mawed et al., 2020); (Vidyasekar & Selvan, 2019); (Liyanage et al., 2019); (Narcis et al., 2019); (Mahpour, 2018); (Udawatta et al., 2018); (Ling & Nguyen, 2013); (de Souza Campos et al., 2013)*	*15*
B2	*Design changes requested by client*	*(Spišáková et al., 2021); (Olanrewaju & Ogunmakinde, 2020); (Pellegrini et al., 2020); (Mawed et al., 2020); (Liyanage et al., 2019); (Narcis et al., 2019)*	*6*
B3	*Inadequate handling during material reception*	*(Olanrewaju & Ogunmakinde, 2020); (Low et al., 2020); (Mawed et al., 2020); (Liyanage et al., 2019); (Narcis et al., 2019)*	*5*
B4	*Improper storage of materials*	*(Olanrewaju & Ogunmakinde, 2020); (Mawed et al., 2020); (Narcis et al., 2019)*	*3*
B5	*Poor quality of construction materials*	*(Spišáková et al., 2021); (Olanrewaju & Ogunmakinde, 2020); (Low et al., 2020); (Ratnasabapathy et al., 2021); (Mawed et al., 2020); (Liyanage et al., 2019); (Narcis et al., 2019); (Mahpour, 2018)*	*8*
B6	*Lack of planning and management on the construction site*	*(Liu et al., 2021); (Negash et al., 2021); (Bao et al., 2020); (Spišáková et al., 2021); (Olanrewaju & Ogunmakinde, 2020); (Pellegrini et al., 2020); (Low et al., 2020); (Bailey et al., 2020); (Ratnasabapathy et al., 2021); (Mawed et al., 2020); (Vidyasekar & Selvan, 2019); (Liyanage et al., 2019); (Narcis et al., 2019); (Mahpour, 2018); (Udawatta et al., 2018); (Owolana & Booth, 2016); (Ling & Nguyen, 2013)*	*17*
B7	*Lack of operational training and environmental education*	*(Yu et al., 2021); (Spišáková et al., 2021); (Olanrewaju & Ogunmakinde, 2020); (Pellegrini et al., 2020); (Low et al., 2020); (Bailey et al., 2020); (Ratnasabapathy et al., 2021); (Mawed et al., 2020); (Vidyasekar & Selvan, 2019); (Liyanage et al., 2019); (Narcis et al., 2019); (Udawatta et al., 2018); (Owolana & Booth, 2016); (Ling & Nguyen, 2013); (Giorgi et al., 2022); (Liu et al., 2021); (Mahpour, 2018); (de Souza Campos et al., 2013).*	*18*
B8	*Weather issues*	*(Mawed et al., 2020); (Narcis et al., 2019)*	*2*

Source: The authors.

Lack of a well-developed and coordinated project means the absence of a complete project, with all the necessary elements and details for its execution. Its information should be sufficient for the proper fulfillment of all stages of the construction work, in accordance with the Brazilian Association of Technical Standards (ABNT - Associação Brasileira de Normas Técnicas) norms and in accordance with Law 8.666 of June 21, 1993 (Brazil, 1993). The lack of these minimum requirements of detail in the projects causes doubts and uncertainties that will result in execution errors, which in turn generate rework and the consequent generation of CDW (Ratnasabapathy et al., 2021; Olanrewaju and Ogunmakinde, 2020; Pellegrini et al., 2020).

Design changes requested by the client are the uncertainties and modifications requested by the contracting party that generate delays, rework, and the consequent generation of CDW (Olanrewaju and Ogunmakinde, 2020; Mawed et al., 2020).

Inadequate handling during material reception refers to the improper handling of employees during reception and movement. Losses during unloading of materials may occur due to the unavailability of ideal equipment (e.g., forklifts) and insufficient labor during unloading (Olanrewaju and Ogunmakinde, 2020; Mawed et al., 2020).

Improper storage of materials refers to poor handling and control practices of materials on the construction site, which includes storing materials in a location compatible with their specifications (Ling and Nguyen, 2013). A well-defined location with suitable storage conditions for any type of material can bring practicality and cost savings, as well as prevent losses in material storage (Olanrewaju and Ogunmakinde, 2020; Mawed et al., 2020; Narcis et al., 2019).

Poor quality of construction materials refers to the use of materials with inadequate specifications and provenance to meet project requirements. The acquisition of low-quality materials or materials without provenance can result in excessive consumption in the execution, low durability, and low material yield (Olanrewaju and Ogunmakinde, 2020; Mawed et al, 2020; Narcis et al., 2019).

Lack of planning and management on the construction site refers to poor management practices integrated with all stages of the project. Adequate planning and management can reduce waste generation, with preventive actions by manager team capable of avoiding rework, corrections, and replacement of materials with the same technical value and also possible to have less environmental impact (Olanrewaju and ogunmakinde, 2020; Negash et al., 2021; Spišáková et al., 2021). A planned construction site includes an area for sorting and segregating the RCC

(Ratnasabapathy et al., 2021; Negash et al., 2021).

The lack of operational training and environmental education in the company refers to the low qualification of labor that hinders the efficiency of CDW management (Ling; Nguyen, 2013). A well-trained and motivated team can avoid losses during the execution of the civil construction project, with a decrease in negligence, rework, or unproductivity (Ratnasabapathy et al., 2021).

Weather issues refers to the unpredictable and uncontrollable weather conditions that can result in losses (Mawed et al., 2020; Narcis et al, 2019).

The second classification of barriers was economic.

Table **3** shows the three economic barriers for reducing CDW.

Table 3

Economic barriers to reducing CDW

Code	Barrier	References	Paper quantity
B9	*Lack of financial resources*	*(Negash et al., 2021); (Spišáková et al., 2021); (Olanrewaju & Ogunmakinde, 2020); (Bailey et al., 2020); (Ratnasabapathy et al., 2021); (Mawed et al., 2020); (Ling & Nguyen, 2013); (de Souza Campos et al., 2013)*	*8*
B10	*lack of economic return from the recycling of CDW*	*(Giorgi et al., 2022); (Yu et al., 2021); (Condotta & Zatta, 2021); (Negash et al., 2021); (Diotti et al., 2021); (Bao et al., 2020); (Spišáková et al., 2021); (Olanrewaju & Ogunmakinde, 2020); (Low et al., 2020); (Bailey et al., 2020); (Ratnasabapathy et al., 2021); (Mawed et al., 2020); (Liyanage et al., 2019); (Mahpour, 2018); (Udawatta et al., 2018); (Owolana & Booth, 2016)*	*16*
B11	*Cost of implementing new technologies*	*(Gagnon et al., 2022); (Giorgi et al., 2022); (Yu et al., 2021); (Liu et al., 2021); (Condotta & Zatta, 2021); (Diotti et al., 2021); (Bao et al., 2020); (Spišáková et al., 2021); (Olanrewaju & Ogunmakinde, 2020); (Low et al., 2020); (Bailey et al., 2020); (Ratnasabapathy et al., 2021); (Mawed et al., 2020); (Vidyasekar & Selvan, 2019); (Liyanage et al., 2019); (Mahpour, 2018); (Udawatta et al., 2018); (Owolana & Booth, 2016); (de Souza Campos et al., 2013)*	*19*

Source: The authors.

The lack of financial resources refers to the absence of sufficient funds for the execution of all services, including the planned contract add-ons (Condotta and Zatta, 2021; Spišáková et al., 2021). The availability of financial resources also determines how the team will use equipment and tools that can add value to the construction, contributing to the quality and consequently the reduction of generated waste (Olanrewaju and ogunmakinde, 2020; Negash et al., 2021).

The lack of economic return from the recycling of CDW refers to the immature market acceptance of the by-products originated from recycling or beneficiation, which could generate financial returns for the companies that apply management on the construction site. For example, the use of waste sawdust for the production of Medium Density Fiberboard (MDF) or for charcoal production (Gagnon et al., 2022). However, uncertainties in finding a consumer market for these demand for recycled products can generate insecurity for managers (Spišáková et al., 2021; Liu et al., 2021).

The cost of implementing new technologies refers to the practice of applying innovative materials and/or equipment for use in construction, which can reduce the amount of generated waste. However, some cultural barriers and the high cost of implementation on the site may affect the use of these technologies (Giorgi et al., 2022; Gagnon et al., 2022). The technologies implemented on the construction site, such as CDW recycling equipment, also contribute to the reduction of generated waste (Liu et al., 2021; Ratnasabapathy et al., 2021). The development of technologies and research is also essential to maintain the expected performance of recycled materials compared to the original material. In addition, without the proper efficiency tests of the recycled material, responsible engineers and architects are not committed to using them in the construction (Condotta and Zatta, 2021; Giorgi et al., 2022).

The third classification of barriers was environmental. Table 4 shows the three environmental barriers for reducing CDW.

Table 4

Legal barriers to reducing CDW

Code	Barrier	References	Paper quantity
B12	Lack of environmental requirements in the contract	(Spišáková et al., 2021); (Olanrewaju & Ogunmakinde, 2020); (Pellegrini et al., 2020); (Ratnasabapathy et al., 2021); (Owolana & Booth, 2016); (Ling & Nguyen, 2013)	6
B13	Lack legislation and government incentive	(Giorgi et al., 2022); (Liu et al., 2021); (Diotti et al., 2021); (Negash et al., 2021); (Spišáková et al., 2021); (Olanrewaju & Ogunmakinde, 2020); (Pellegrini et al., 2020); (Bailey et al., 2020); (Ratnasabapathy et al., 2021); (Maekawa et al., 2013); (Mawed et al., 2020); (Vidyasekar & Selvan, 2019); (Liyanage et al., 2019); (Narcis et al., 2019); (Ling & Nguyen, 2013); (Gagnon et al., 2022); (Yu et al., 2021); (Condotta & Zatta, 2021);(Bao et al., 2020); (Low et al., 2020); (Mahpour, 2018); (Udawatta et al., 2018); (Owolana & Booth, 2016);	23
B14	Lack of construction inspection	(Spišáková et al., 2021); (Olanrewaju & Ogunmakinde, 2020); (Pellegrini et al., 2020); (Bailey et al., 2020); (Ratnasabapathy et al., 2021); (Mawed et al., 2020); (Liyanage et al., 2019); (Mahpour, 2018)	8

Source: The authors.

The lack of environmental requirements in the contract refers to the absence of a legally well-founded contract with regards to environmental aspects, which would oblige the construction manager to faithfully follow correct practices for waste reduction, reuse, recycling, and/or final disposal (Ratnasabapathy et al., 2021; Condotta & Zatta, 2021; Pellegrini et al., 2020). The contract may also impose a maximum volume of waste to be generated at the construction site (Spišáková et al., 2021).

The lack of legislation and governmental incentives refers to the absence of effective legal aspects that oblige managers and others involved in construction to adopt mitigating measures for waste reduction and also to instruct on the correct form of efficient construction waste management (Liu et al., 2021; Condotta & Zatta, 2021; Olanrewaju & Ogunmakinde, 2020). The lack of government action in enforcing these laws hinders the management of CDW (Ling & Nguyen, 2013). Public policy incentives can boost waste reduction by benefiting construction companies that opt for reuse, recycling, or other sustainable approaches (Gagnon et al., 2022;

Liu et al., 2021; Ratnasabapathy et al., 2021). The government can impose higher taxes and costs for landfill use, which would encourage CDW reduction at the construction site (Ratnasabapathy et al., 2021; Negash et al., 2021).

The lack of construction site inspection refers to the absence of responsible supervision, which would oblige the construction manager to maintain a minimum quality level, avoiding possible rework or waste (Liu et al., 2021; Negash et al., 2021; Olanrewaju & Ogunmakinde, 2020; Liyanage et al., 2019).

The barriers to reducing CDW within construction sites, as identified in the 23 articles of the SLR, were classified into three categories: Technical, Economic, and Legal. Of the 14 identified barriers, eight were legal, three were economic, and three were technical. The frequency of citations of these barriers in studies conducted over the past ten years, as shown in the last column of Tables 2, 3, and 4, is an indicator of their respective relevance in the literature.

Among the technical barriers, the most cited were the lack of operational training and environmental education, and the lack of planning and management on the construction site, with 18 and 17 citations respectively. This indicates a greater concern for management and personnel training aspects on the construction site than those related to the logistics phase of material movement and storage, as the least cited were improper storage of materials (3) and weather issues (2).

In terms of economic barriers, the cost of implementing new technologies (19) was the most cited. This indicates the importance of improving the economic competitiveness of more sustainable alternatives compared to traditional technologies. The lack of financial resources was the barrier with the lowest number of citations (8) in this category.

Among the legal barriers, the lack of legislation and government incentives (23) was the most cited, being mentioned in all articles selected in the SLR. This result shows the importance of public authorities in promoting a reduction in the generation and release of waste in construction sites. The lack of environmental requirements in the contract (6) was the barrier with the lowest number of citations.

Fuzzy Dematel results

The analysis of the barriers raised by SLR was carried out by construction managers with a civil engineering background, who worked on commercial construction sites in Brazil. The initial sample consisted of 22 experts construction managers who responded to the questionnaire. After verification, two participants who returned the matrix $[n \times n]$ with incomplete answers and one with contradictory answers were excluded. The characteristics of the 19 experts whose responses were considered in the study are presented by Table I in the supplementary information material.

Following step 1 of the DEMATEL fuzzy application, the experts were solicited to assess the impact of one barrier on another, employing the linguistic terms outlined in Table 1. The list of barriers can be seen from Table 2 to Table 4. Table 5 shows the paired assessment made by expert 1. For instance, the expert 1 evaluated that Barrier 1 (Lack of a well-developed and coordinated project) has a Very High influence on Barrier 2 (Design changes requested by the client). The linguistic evaluations carried out by the other experts are presented in tables II to XIX of the supplementary information material.

Table 5

Paired linguistic assessment by expert 1

E1	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
B1	-	VH	L	H	H	VH	L	NI	H	H	VH	VL	VL	H
B2	L	-	VL	VL	L	H	VL	NI	H	H	VH	H	NI	NI
B3	NI	VL	-	VH	NI	NI	NI	NI	NI	VH	H	VL	NI	NI
B4	NI	L	H	-	NI	NI	NI	L	L	VH	H	VL	NI	NI
B5	NI	H	NI	NI	-	NI	NI	NI	NI	H	NI	VL	NI	NI
B6	VH	VH	VH	VH	H	-	H	NI	H	H	L	VH	H	VH
B7	VL	L	VH	VH	H	H	-	NI	H	L	VH	H	VH	VH
B8	L	H	L	H	VL	NI	NI	-	H	L	VL	L	NI	NI
B9	H	VH	L	L	VH	VL	H	NI	-	L	VH	H	VL	H
B10	VL	H	NI	NI	H	NI	VL	NI	L	-	H	VL	L	VL
B11	H	VH	VL	VL	H	VL	H	NI	VH	H	-	VH	L	VL
B12	VH	NI	H	VH	VL	VH	H	NI	L	H	L	-	NI	VL
B13	H	VL	H	H	VL	H	H	NI	NI	H	L	VH	-	VH
B14	L	NI	VH	VH	VL	L	VL	NI	L	L	L	VL	H	-

Source: The authors.

Afterwards, the evaluations of the 19 experts were converted into triangular fuzzy numbers based on Table 1. Table 6 shows the assessments of expert 1 translated into triangular fuzzy numbers. The tables converted into triangular fuzzy numbers for the other experts (Tables XX to XXXVII) are presented in the supplementary information material.

Table 6

Paired linguistic evaluation of expert 1 converted into triangular fuzzy numbers

E1	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
B1	(0 0 0)	(0,75 1 1)	(0,25 0,5 0,75)	(0,5 0,75 1)	(0,5 0,75 1)	(0,75 1 1)	(0,25 0,5 0,75)	(0 0 0,25)	(0,5 0,75 1)	(0,5 0,75 1)	(0,75 1 1)	(0 0,25 0,5)	(0 0,25 0,5)	(0,5 0,75 1)
B2	(0,25 0,5 0,75)	(0 0 0)	(0 0,25 0,5)	(0 0,25 0,5)	(0,25 0,5 0,75)	(0,5 0,75 1)	(0 0,25 0,5)	(0 0 0,25)	(0,5 0,75 1)	(0,5 0,75 1)	(0,75 1 1)	(0,5 0,75 1)	(0 0 0,25)	(0 0 0,25)
B3	(0 0 0,25)	(0 0,25 0,5)	(0 0 0)	(0,75 1 1)	(0 0 0,25)	(0 0 0,25)	(0 0 0,25)	(0 0 0,25)	(0 0 0,25)	(0,75 1 1)	(0,5 0,75 1)	(0 0,25 0,5)	(0 0 0,25)	(0 0 0,25)
B4	(0 0 0,25)	(0,25 0,5 0,75)	(0,5 0,75 1)	(0 0 0)	(0 0 0,25)	(0 0 0,25)	(0 0 0,25)	(0,25 0,5 0,75)	(0,25 0,5 0,75)	(0,75 1 1)	(0,5 0,75 1)	(0 0,25 0,5)	(0 0 0,25)	(0 0 0,25)
B5	(0 0 0,25)	(0,5 0,75 1)	(0 0 0,25)	(0 0 0,25)	(0 0 0)	(0 0 0,25)	(0 0 0,25)	(0 0 0,25)	(0 0 0,25)	(0,5 0,75 1)	(0 0 0,25)	(0 0,25 0,5)	(0 0 0,25)	(0 0 0,25)
B6	(0,75 1 1)	(0,75 1 1)	(0,75 1 1)	(0,75 1 1)	(0,5 0,75 1)	(0 0 0)	(0,5 0,75 1)	(0 0 0,25)	(0,5 0,75 1)	(0,5 0,75 1)	(0,25 0,5 0,75)	(0,75 1 1)	(0,5 0,75 1)	(0,75 1 1)
B7	(0 0,25 0,5)	(0,25 0,5 0,75)	(0,75 1 1)	(0,75 1 1)	(0,5 0,75 1)	(0,5 0,75 1)	(0 0 0)	(0 0 0,25)	(0,5 0,75 1)	(0,25 0,5 0,75)	(0,75 1 1)	(0,5 0,75 1)	(0,75 1 1)	(0,75 1 1)
B8	(0,25 0,5 0,75)	(0,5 0,75 1)	(0,25 0,5 0,75)	(0,5 0,75 1)	(0 0,25 0,5)	(0 0 0,25)	(0 0 0,25)	(0 0 0)	(0,5 0,75 1)	(0,25 0,5 0,75)	(0 0,25 0,5)	(0,25 0,5 0,75)	(0 0 0,25)	(0 0 0,25)
B9	(0,5 0,75 1)	(0,75 1 1)	(0,25 0,5 0,75)	(0,25 0,5 0,75)	(0,75 1 1)	(0 0,25 0,5)	(0,5 0,75 1)	(0 0 0,25)	(0 0 0)	(0,25 0,5 0,75)	(0,75 1 1)	(0,5 0,75 1)	(0 0,25 0,5)	(0,5 0,75 1)
B10	(0 0,25 0,5)	(0,5 0,75 1)	(0 0 0,25)	(0 0 0,25)	(0,5 0,75 1)	(0 0 0,25)	(0 0,25 0,5)	(0 0 0,25)	(0,25 0,5 0,75)	(0 0 0)	(0,5 0,75 1)	(0 0,25 0,5)	(0,25 0,5 0,75)	(0 0,25 0,5)
B11	(0,5 0,75 1)	(0,75 1 1)	(0 0,25 0,5)	(0 0,25 0,5)	(0,5 0,75 1)	(0 0,25 0,5)	(0,5 0,75 1)	(0 0 0,25)	(0,75 1 1)	(0,5 0,75 1)	(0 0 0)	(0,75 1 1)	(0,25 0,5 0,75)	(0 0,25 0,5)
B12	(0,75 1 1)	(0 0 0,25)	(0,5 0,75 1)	(0,75 1 1)	(0 0,25 0,5)	(0,75 1 1)	(0,5 0,75 1)	(0 0 0,25)	(0,25 0,5 0,75)	(0,5 0,75 1)	(0,25 0,5 0,75)	(0 0 0)	(0 0 0,25)	(0 0,25 0,5)
B13	(0,5 0,75 1)	(0 0,25 0,5)	(0,5 0,75 1)	(0,5 0,75 1)	(0 0,25 0,5)	(0,5 0,75 1)	(0,5 0,75 1)	(0 0 0,25)	(0 0 0,25)	(0,5 0,75 1)	(0,25 0,5 0,75)	(0,75 1 1)	(0 0 0)	(0,75 1 1)
B14	(0,25 0,5 0,75)	(0 0 0,25)	(0,75 1 1)	(0,75 1 1)	(0 0,25 0,5)	(0,25 0,5 0,75)	(0 0,25 0,5)	(0 0 0,25)	(0,25 0,5 0,75)	(0,25 0,5 0,75)	(0,25 0,5 0,75)	(0 0,25 0,5)	(0,5 0,75 1)	(0 0 0)

Source: The authors.

The 19 tables of paired expert judgments converted into triangular fuzzy numbers were aggregated using Eq. (2) and Eq. (5), resulting in the average direct relationship matrix $\tilde{Z}$, illustrated in Table 7. Then, Eqs. (7) and (8) were used to normalize the $\tilde{Z}$ matrix and obtain the normalized matrix $\tilde{X}$ represented in Table 8.

In step 2, matrix $\tilde{T}$ (presented by Table 9) was obtained from the normalized matrix $\tilde{X}$ using Eq. (9) to (12). In step 3, matrix $\tilde{T}$ was defuzzified using center of area method, Eq. (13), to obtain the matrix T as show in Table 10.

Columns D and R in Table 10 presents the results of step 4: the total effects exerted by each barrier D_i calculated with Eq. (14) and the total effects received by each barrier R_i calculated with Eq. (15). The last columns show the values obtained in step 5, the values of $D_i + R_i$, Eq. (16), and $D_i - R_i$, Eq. (17), which are used for determination of the causal diagram, shown in Figure 2. This diagram also allows the analysis of the most important barriers, those further to the right, and the most influential barriers, those higher up

Table 7

Average direct relation matrix $\tilde{Z}$.

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
B1	(0, 0, 0)	(0.67, 0.92, 1)	(0.16, 0.32, 0.55)	(0.29, 0.5, 0.74)	(0.29, 0.51, 0.74)	(0.68, 0.93, 0.99)	(0.41, 0.59, 0.75)	(0.04, 0.11, 0.36)	(0.59, 0.82, 0.92)	(0.24, 0.43, 0.67)	(0.47, 0.7, 0.88)	(0.38, 0.57, 0.74)	(0.33, 0.51, 0.7)	(0.55, 0.76, 0.86)
B2	(0.67, 0.92, 0.99)	(0, 0, 0)	(0.33, 0.53, 0.7)	(0.38, 0.58, 0.74)	(0.26, 0.46, 0.67)	(0.61, 0.84, 0.95)	(0.36, 0.54, 0.7)	(0.13, 0.28, 0.51)	(0.61, 0.84, 0.95)	(0.21, 0.39, 0.62)	(0.46, 0.64, 0.79)	(0.45, 0.66, 0.83)	(0.24, 0.39, 0.61)	(0.49, 0.68, 0.8)
B3	(0.28, 0.42, 0.63)	(0.26, 0.42, 0.63)	(0, 0, 0)	(0.62, 0.87, 0.97)	(0.34, 0.57, 0.78)	(0.5, 0.72, 0.86)	(0.53, 0.75, 0.89)	(0.32, 0.53, 0.75)	(0.36, 0.55, 0.76)	(0.25, 0.45, 0.66)	(0.25, 0.46, 0.68)	(0.28, 0.47, 0.68)	(0.22, 0.37, 0.59)	(0.47, 0.7, 0.88)
B4	(0.29, 0.46, 0.67)	(0.3, 0.47, 0.7)	(0.57, 0.8, 0.95)	(0, 0, 0)	(0.39, 0.62, 0.79)	(0.59, 0.83, 0.95)	(0.54, 0.76, 0.89)	(0.38, 0.58, 0.76)	(0.46, 0.68, 0.83)	(0.34, 0.57, 0.78)	(0.26, 0.49, 0.72)	(0.3, 0.5, 0.71)	(0.29, 0.46, 0.66)	(0.53, 0.75, 0.89)
B5	(0.33, 0.51, 0.74)	(0.29, 0.47, 0.67)	(0.37, 0.58, 0.78)	(0.43, 0.63, 0.79)	(0, 0, 0)	(0.47, 0.68, 0.84)	(0.39, 0.59, 0.76)	(0.32, 0.49, 0.67)	(0.61, 0.82, 0.88)	(0.39, 0.64, 0.86)	(0.43, 0.62, 0.8)	(0.34, 0.54, 0.72)	(0.25, 0.42, 0.64)	(0.49, 0.68, 0.82)
B6	(0.62, 0.87, 0.96)	(0.61, 0.86, 0.96)	(0.62, 0.87, 0.97)	(0.62, 0.87, 0.97)	(0.54, 0.79, 0.96)	(0, 0, 0)	(0.5, 0.74, 0.88)	(0.24, 0.39, 0.61)	(0.57, 0.8, 0.92)	(0.33, 0.54, 0.75)	(0.41, 0.63, 0.83)	(0.41, 0.62, 0.82)	(0.26, 0.46, 0.68)	(0.61, 0.82, 0.88)
B7	(0.36, 0.57, 0.75)	(0.29, 0.47, 0.68)	(0.63, 0.88, 0.99)	(0.61, 0.86, 0.96)	(0.38, 0.61, 0.79)	(0.58, 0.83, 0.97)	(0, 0, 0)	(0.14, 0.24, 0.47)	(0.5, 0.72, 0.87)	(0.38, 0.61, 0.78)	(0.51, 0.74, 0.89)	(0.37, 0.58, 0.76)	(0.32, 0.53, 0.72)	(0.46, 0.66, 0.79)
B8	(0.13, 0.24, 0.46)	(0.2, 0.36, 0.58)	(0.3, 0.49, 0.7)	(0.43, 0.63, 0.82)	(0.22, 0.39, 0.61)	(0.32, 0.49, 0.7)	(0.13, 0.22, 0.46)	(0, 0, 0)	(0.09, 0.2, 0.45)	(0.07, 0.17, 0.42)	(0.09, 0.21, 0.46)	(0.09, 0.18, 0.43)	(0.05, 0.11, 0.36)	(0.16, 0.26, 0.49)
B9	(0.59, 0.83, 0.95)	(0.57, 0.8, 0.93)	(0.42, 0.64, 0.84)	(0.45, 0.68, 0.86)	(0.64, 0.88, 0.96)	(0.57, 0.8, 0.92)	(0.61, 0.84, 0.96)	(0.12, 0.21, 0.45)	(0, 0, 0)	(0.42, 0.67, 0.88)	(0.67, 0.92, 0.99)	(0.41, 0.64, 0.84)	(0.29, 0.5, 0.71)	(0.5, 0.72, 0.87)
B10	(0.34, 0.55, 0.76)	(0.28, 0.45, 0.67)	(0.22, 0.39, 0.63)	(0.32, 0.5, 0.74)	(0.38, 0.61, 0.8)	(0.26, 0.42, 0.64)	(0.38, 0.59, 0.79)	(0.13, 0.25, 0.49)	(0.37, 0.59, 0.8)	(0, 0, 0)	(0.41, 0.63, 0.84)	(0.36, 0.57, 0.78)	(0.39, 0.62, 0.82)	(0.24, 0.43, 0.64)
B11	(0.39, 0.61, 0.84)	(0.37, 0.58, 0.79)	(0.3, 0.51, 0.71)	(0.38, 0.61, 0.82)	(0.5, 0.72, 0.88)	(0.5, 0.75, 0.91)	(0.54, 0.78, 0.91)	(0.12, 0.26, 0.49)	(0.61, 0.84, 0.93)	(0.47, 0.7, 0.87)	(0, 0, 0)	(0.38, 0.61, 0.8)	(0.36, 0.58, 0.82)	(0.29, 0.47, 0.68)
B12	(0.39, 0.59, 0.76)	(0.38, 0.57, 0.78)	(0.34, 0.57, 0.78)	(0.37, 0.55, 0.74)	(0.38, 0.61, 0.82)	(0.54, 0.79, 0.92)	(0.45, 0.7, 0.87)	(0.12, 0.25, 0.47)	(0.29, 0.51, 0.76)	(0.39, 0.62, 0.83)	(0.34, 0.58, 0.79)	(0, 0, 0)	(0.39, 0.59, 0.78)	(0.46, 0.67, 0.8)
B13	(0.39, 0.58, 0.78)	(0.28, 0.45, 0.68)	(0.37, 0.55, 0.75)	(0.36, 0.57, 0.76)	(0.37, 0.58, 0.78)	(0.46, 0.7, 0.88)	(0.49, 0.72, 0.89)	(0.18, 0.28, 0.49)	(0.25, 0.41, 0.66)	(0.45, 0.67, 0.86)	(0.39, 0.62, 0.84)	(0.51, 0.74, 0.86)	(0, 0, 0)	(0.51, 0.72, 0.84)
B14	(0.53, 0.72, 0.82)	(0.43, 0.63, 0.76)	(0.47, 0.68, 0.83)	(0.5, 0.71, 0.84)	(0.45, 0.68, 0.86)	(0.62, 0.86, 0.92)	(0.47, 0.7, 0.86)	(0.12, 0.22, 0.45)	(0.39, 0.61, 0.79)	(0.29, 0.49, 0.71)	(0.3, 0.5, 0.72)	(0.33, 0.55, 0.76)	(0.3, 0.49, 0.7)	(0, 0, 0)

Source: The authors.

Table 8

Normalized matrix $\tilde{X}$

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
B1	(0, 0, 0)	(0.06, 0.08, 0.09)	(0.01, 0.03, 0.05)	(0.03, 0.04, 0.07)	(0.03, 0.05, 0.07)	(0.06, 0.08, 0.09)	(0.04, 0.05, 0.07)	(0, 0.01, 0.03)	(0.05, 0.07, 0.08)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.08)	(0.03, 0.05, 0.07)	(0.03, 0.05, 0.06)	(0.05, 0.07, 0.08)
B2	(0.06, 0.08, 0.09)	(0, 0, 0)	(0.03, 0.05, 0.06)	(0.03, 0.05, 0.07)	(0.02, 0.04, 0.06)	(0.05, 0.08, 0.08)	(0.03, 0.05, 0.06)	(0.01, 0.02, 0.05)	(0.05, 0.08, 0.08)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.05)	(0.04, 0.06, 0.07)
B3	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0, 0, 0)	(0.06, 0.08, 0.09)	(0.03, 0.05, 0.07)	(0.04, 0.06, 0.08)	(0.05, 0.07, 0.08)	(0.03, 0.05, 0.07)	(0.03, 0.05, 0.07)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.02, 0.03, 0.05)	(0.04, 0.06, 0.08)
B4	(0.03, 0.04, 0.06)	(0.03, 0.04, 0.06)	(0.05, 0.07, 0.08)	(0, 0, 0)	(0.04, 0.06, 0.07)	(0.05, 0.07, 0.08)	(0.05, 0.07, 0.08)	(0.03, 0.05, 0.07)	(0.04, 0.06, 0.07)	(0.03, 0.05, 0.07)	(0.02, 0.04, 0.06)	(0.03, 0.04, 0.06)	(0.03, 0.04, 0.06)	(0.05, 0.07, 0.08)
B5	(0.03, 0.05, 0.07)	(0.03, 0.04, 0.06)	(0.03, 0.05, 0.07)	(0.04, 0.06, 0.07)	(0, 0, 0)	(0.04, 0.06, 0.08)	(0.04, 0.05, 0.07)	(0.03, 0.04, 0.06)	(0.05, 0.07, 0.08)	(0.04, 0.06, 0.08)	(0.04, 0.06, 0.07)	(0.03, 0.05, 0.06)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.07)
B6	(0.06, 0.08, 0.09)	(0.05, 0.08, 0.09)	(0.06, 0.08, 0.09)	(0.06, 0.08, 0.09)	(0.05, 0.07, 0.09)	(0, 0, 0)	(0.04, 0.07, 0.08)	(0.02, 0.04, 0.05)	(0.05, 0.07, 0.08)	(0.03, 0.05, 0.07)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.06)	(0.05, 0.07, 0.08)
B7	(0.03, 0.05, 0.07)	(0.03, 0.04, 0.06)	(0.06, 0.08, 0.09)	(0.05, 0.08, 0.09)	(0.03, 0.05, 0.07)	(0.05, 0.07, 0.09)	(0, 0, 0)	(0.01, 0.02, 0.04)	(0.04, 0.06, 0.08)	(0.03, 0.05, 0.07)	(0.05, 0.07, 0.08)	(0.03, 0.05, 0.07)	(0.03, 0.05, 0.06)	(0.04, 0.06, 0.07)
B8	(0.01, 0.02, 0.04)	(0.02, 0.03, 0.05)	(0.03, 0.04, 0.06)	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.05)	(0.03, 0.04, 0.06)	(0.01, 0.02, 0.04)	(0, 0, 0)	(0.01, 0.02, 0.04)	(0.01, 0.02, 0.04)	(0.01, 0.02, 0.04)	(0.01, 0.02, 0.04)	(0, 0.01, 0.03)	(0.01, 0.02, 0.04)
B9	(0.05, 0.07, 0.08)	(0.05, 0.07, 0.08)	(0.04, 0.06, 0.08)	(0.04, 0.06, 0.08)	(0.06, 0.08, 0.09)	(0.05, 0.07, 0.08)	(0.05, 0.08, 0.09)	(0.01, 0.02, 0.04)	(0, 0, 0)	(0.04, 0.06, 0.08)	(0.06, 0.08, 0.09)	(0.04, 0.06, 0.08)	(0.03, 0.04, 0.06)	(0.04, 0.06, 0.08)
B10	(0.03, 0.05, 0.07)	(0.02, 0.04, 0.06)	(0.02, 0.04, 0.06)	(0.03, 0.04, 0.07)	(0.03, 0.05, 0.07)	(0.02, 0.04, 0.06)	(0.03, 0.05, 0.07)	(0.01, 0.02, 0.04)	(0.03, 0.05, 0.07)	(0, 0, 0)	(0.04, 0.06, 0.08)	(0.03, 0.05, 0.07)	(0.04, 0.06, 0.07)	(0.02, 0.04, 0.06)
B11	(0.04, 0.05, 0.08)	(0.03, 0.05, 0.07)	(0.03, 0.05, 0.06)	(0.03, 0.05, 0.07)	(0.04, 0.06, 0.08)	(0.04, 0.07, 0.08)	(0.05, 0.07, 0.08)	(0.01, 0.02, 0.04)	(0.05, 0.08, 0.08)	(0.04, 0.06, 0.08)	(0, 0, 0)	(0.03, 0.05, 0.07)	(0.03, 0.05, 0.07)	(0.03, 0.04, 0.06)
B12	(0.04, 0.05, 0.07)	(0.03, 0.05, 0.07)	(0.03, 0.05, 0.07)	(0.03, 0.05, 0.07)	(0.03, 0.05, 0.07)	(0.05, 0.07, 0.08)	(0.04, 0.06, 0.08)	(0.01, 0.02, 0.04)	(0.03, 0.05, 0.07)	(0.04, 0.06, 0.07)	(0.03, 0.05, 0.07)	(0, 0, 0)	(0.04, 0.05, 0.07)	(0.04, 0.06, 0.07)
B13	(0.04, 0.05, 0.07)	(0.02, 0.04, 0.06)	(0.03, 0.05, 0.07)	(0.03, 0.05, 0.07)	(0.03, 0.05, 0.07)	(0.04, 0.06, 0.08)	(0.04, 0.06, 0.08)	(0.02, 0.02, 0.04)	(0.02, 0.04, 0.06)	(0.04, 0.06, 0.08)	(0.04, 0.06, 0.08)	(0.05, 0.07, 0.08)	(0, 0, 0)	(0.05, 0.06, 0.08)
B14	(0.05, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.07)	(0.04, 0.06, 0.08)	(0.04, 0.06, 0.08)	(0.06, 0.08, 0.08)	(0.04, 0.06, 0.08)	(0.01, 0.02, 0.04)	(0.04, 0.05, 0.07)	(0.03, 0.04, 0.06)	(0.03, 0.04, 0.06)	(0.03, 0.05, 0.07)	(0.03, 0.04, 0.06)	(0, 0, 0)

Source: The authors.

Table 9

Matrix X

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14
B1	(0,03; 0,12; 0,57)	(0,09; 0,19; 0,64)	(0,04; 0,15; 0,62)	(0,06; 0,17; 0,66)	(0,06; 0,17; 0,65)	(0,1; 0,22; 0,72)	(0,07; 0,18; 0,66)	(0,02; 0,07; 0,43)	(0,09; 0,2; 0,67)	(0,05; 0,14; 0,6)	(0,07; 0,18; 0,65)	(0,06; 0,16; 0,61)	(0,05; 0,14; 0,56)	(0,08; 0,19; 0,65)
B2	(0,09; 0,2; 0,65)	(0,03; 0,12; 0,55)	(0,06; 0,16; 0,63)	(0,07; 0,18; 0,66)	(0,05; 0,16; 0,64)	(0,09; 0,22; 0,71)	(0,07; 0,18; 0,65)	(0,03; 0,09; 0,44)	(0,09; 0,2; 0,67)	(0,04; 0,14; 0,59)	(0,07; 0,17; 0,64)	(0,07; 0,17; 0,61)	(0,04; 0,13; 0,55)	(0,08; 0,19; 0,64)
B3	(0,05; 0,15; 0,61)	(0,05; 0,14; 0,6)	(0,03; 0,11; 0,56)	(0,08; 0,19; 0,67)	(0,06; 0,16; 0,64)	(0,08; 0,19; 0,69)	(0,08; 0,18; 0,66)	(0,04; 0,1; 0,45)	(0,06; 0,17; 0,64)	(0,04; 0,14; 0,59)	(0,05; 0,15; 0,62)	(0,05; 0,14; 0,59)	(0,04; 0,12; 0,54)	(0,07; 0,18; 0,64)
B4	(0,06; 0,16; 0,64)	(0,06; 0,16; 0,63)	(0,08; 0,19; 0,67)	(0,03; 0,13; 0,62)	(0,06; 0,18; 0,67)	(0,09; 0,21; 0,73)	(0,08; 0,19; 0,69)	(0,05; 0,11; 0,47)	(0,07; 0,19; 0,68)	(0,05; 0,16; 0,63)	(0,05; 0,16; 0,65)	(0,05; 0,15; 0,62)	(0,05; 0,13; 0,57)	(0,08; 0,19; 0,67)
B5	(0,06; 0,16; 0,63)	(0,05; 0,15; 0,61)	(0,06; 0,17; 0,63)	(0,07; 0,18; 0,66)	(0,03; 0,12; 0,58)	(0,08; 0,2; 0,7)	(0,07; 0,18; 0,66)	(0,04; 0,1; 0,45)	(0,08; 0,19; 0,66)	(0,06; 0,16; 0,62)	(0,07; 0,17; 0,64)	(0,06; 0,15; 0,61)	(0,04; 0,13; 0,55)	(0,07; 0,18; 0,64)
B6	(0,09; 0,21; 0,71)	(0,09; 0,21; 0,7)	(0,09; 0,21; 0,72)	(0,09; 0,22; 0,75)	(0,08; 0,21; 0,73)	(0,05; 0,17; 0,71)	(0,08; 0,21; 0,74)	(0,04; 0,11; 0,49)	(0,09; 0,22; 0,74)	(0,06; 0,17; 0,67)	(0,07; 0,19; 0,71)	(0,07; 0,18; 0,68)	(0,05; 0,15; 0,61)	(0,09; 0,22; 0,72)
B7	(0,06; 0,18; 0,66)	(0,06; 0,16; 0,64)	(0,09; 0,2; 0,68)	(0,09; 0,21; 0,71)	(0,07; 0,18; 0,68)	(0,09; 0,22; 0,75)	(0,04; 0,14; 0,63)	(0,03; 0,09; 0,46)	(0,08; 0,2; 0,69)	(0,06; 0,16; 0,64)	(0,08; 0,19; 0,68)	(0,06; 0,17; 0,64)	(0,05; 0,14; 0,58)	(0,08; 0,19; 0,67)
B8	(0,03; 0,08; 0,44)	(0,03; 0,09; 0,44)	(0,04; 0,1; 0,46)	(0,05; 0,12; 0,49)	(0,03; 0,1; 0,46)	(0,04; 0,12; 0,51)	(0,03; 0,09; 0,46)	(0,01; 0,03; 0,28)	(0,02; 0,08; 0,46)	(0,02; 0,07; 0,42)	(0,02; 0,08; 0,44)	(0,02; 0,07; 0,42)	(0,01; 0,06; 0,38)	(0,03; 0,09; 0,45)
B9	(0,09; 0,21; 0,71)	(0,08; 0,2; 0,7)	(0,07; 0,19; 0,71)	(0,08; 0,21; 0,74)	(0,09; 0,22; 0,73)	(0,1; 0,24; 0,79)	(0,09; 0,22; 0,74)	(0,03; 0,09; 0,48)	(0,04; 0,15; 0,66)	(0,07; 0,18; 0,68)	(0,09; 0,22; 0,72)	(0,07; 0,18; 0,68)	(0,05; 0,15; 0,62)	(0,08; 0,21; 0,72)
B10	(0,05; 0,15; 0,6)	(0,05; 0,14; 0,58)	(0,04; 0,14; 0,59)	(0,05; 0,15; 0,63)	(0,06; 0,16; 0,62)	(0,05; 0,16; 0,66)	(0,06; 0,16; 0,63)	(0,02; 0,08; 0,42)	(0,06; 0,16; 0,63)	(0,02; 0,09; 0,52)	(0,06; 0,15; 0,62)	(0,05; 0,14; 0,59)	(0,05; 0,13; 0,54)	(0,05; 0,15; 0,6)
B11	(0,07; 0,18; 0,67)	(0,06; 0,17; 0,65)	(0,06; 0,17; 0,66)	(0,07; 0,18; 0,7)	(0,07; 0,19; 0,69)	(0,08; 0,21; 0,74)	(0,08; 0,2; 0,7)	(0,02; 0,09; 0,46)	(0,09; 0,2; 0,7)	(0,07; 0,17; 0,64)	(0,03; 0,12; 0,61)	(0,06; 0,17; 0,64)	(0,05; 0,15; 0,59)	(0,06; 0,17; 0,66)
B12	(0,06; 0,17; 0,64)	(0,06; 0,16; 0,63)	(0,06; 0,16; 0,64)	(0,06; 0,17; 0,67)	(0,06; 0,17; 0,66)	(0,08; 0,21; 0,72)	(0,07; 0,19; 0,68)	(0,02; 0,08; 0,44)	(0,06; 0,17; 0,67)	(0,06; 0,16; 0,62)	(0,06; 0,16; 0,65)	(0,03; 0,11; 0,56)	(0,05; 0,14; 0,57)	(0,07; 0,18; 0,65)
B13	(0,06; 0,17; 0,64)	(0,05; 0,15; 0,62)	(0,06; 0,16; 0,64)	(0,06; 0,17; 0,67)	(0,06; 0,17; 0,66)	(0,08; 0,2; 0,72)	(0,07; 0,19; 0,68)	(0,03; 0,08; 0,44)	(0,05; 0,16; 0,65)	(0,06; 0,16; 0,62)	(0,06; 0,17; 0,65)	(0,07; 0,17; 0,63)	(0,02; 0,09; 0,5)	(0,08; 0,18; 0,65)
B14	(0,08; 0,18; 0,64)	(0,07; 0,17; 0,62)	(0,07; 0,18; 0,64)	(0,08; 0,19; 0,67)	(0,07; 0,18; 0,66)	(0,09; 0,22; 0,72)	(0,08; 0,19; 0,67)	(0,02; 0,08; 0,44)	(0,07; 0,18; 0,66)	(0,05; 0,15; 0,61)	(0,06; 0,16; 0,64)	(0,06; 0,16; 0,62)	(0,05; 0,14; 0,56)	(0,03; 0,13; 0,58)

Source: The authors.

Table 10

Matrix T

	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12	B13	B14	D	R	D+R	D-R
B1	0,243	0,306	0,270	0,297	0,290	0,347	0,304	0,173	0,318	0,265	0,300	0,278	0,249	0,308	3,95	4,01	7,95	-0,06
B2	0,312	0,233	0,283	0,300	0,285	0,339	0,298	0,183	0,318	0,260	0,294	0,282	0,239	0,301	3,93	3,87	7,80	0,06
B3	0,270	0,262	0,233	0,314	0,285	0,322	0,305	0,199	0,290	0,257	0,272	0,261	0,231	0,295	3,80	4,00	7,80	-0,20
B4	0,286	0,280	0,311	0,260	0,302	0,345	0,320	0,211	0,312	0,278	0,288	0,276	0,249	0,312	4,03	4,24	8,27	-0,20
B5	0,284	0,272	0,287	0,304	0,245	0,327	0,301	0,199	0,314	0,278	0,292	0,273	0,241	0,300	3,92	4,09	8,01	-0,17
B6	0,339	0,330	0,339	**0,354**	0,341	0,309	0,345	0,213	0,349	0,300	0,325	0,310	0,270	0,342	4,47	4,58	9,05	-0,12
B7	0,300	0,286	0,322	0,334	0,309	**0,353**	0,267	0,191	0,323	0,287	0,314	0,289	0,259	0,312	4,15	4,23	8,38	-0,08
B8	0,182	0,186	0,202	0,221	0,197	0,222	0,191	0,107	0,188	0,169	0,181	0,172	0,151	0,189	2,56	2,59	5,15	-0,03
B9	0,338	0,327	0,324	0,342	0,346	**0,373**	**0,353**	0,200	0,286	0,310	0,344	0,311	0,273	0,336	4,46	4,20	8,67	0,26
B10	0,269	0,255	0,258	0,278	0,278	0,290	0,284	0,172	0,283	0,210	0,277	0,260	0,242	0,265	3,62	3,74	7,36	-0,12
B11	0,303	0,292	0,294	0,315	0,316	0,345	0,327	0,190	0,330	0,294	0,253	0,290	0,263	0,298	4,11	4,01	8,12	0,10
B12	0,291	0,282	0,289	0,302	0,298	0,337	0,311	0,183	0,298	0,279	0,291	0,230	0,256	0,301	3,95	3,80	7,74	0,15
B13	0,290	0,273	0,288	0,301	0,295	0,330	0,313	0,186	0,290	0,282	0,294	0,288	0,205	0,304	3,94	3,38	7,32	0,56
B14	0,301	0,286	0,298	0,313	0,303	0,343	0,313	0,183	0,305	0,270	0,287	0,277	0,248	0,249	3,98	4,11	8,09	-0,13

Source: The authors.

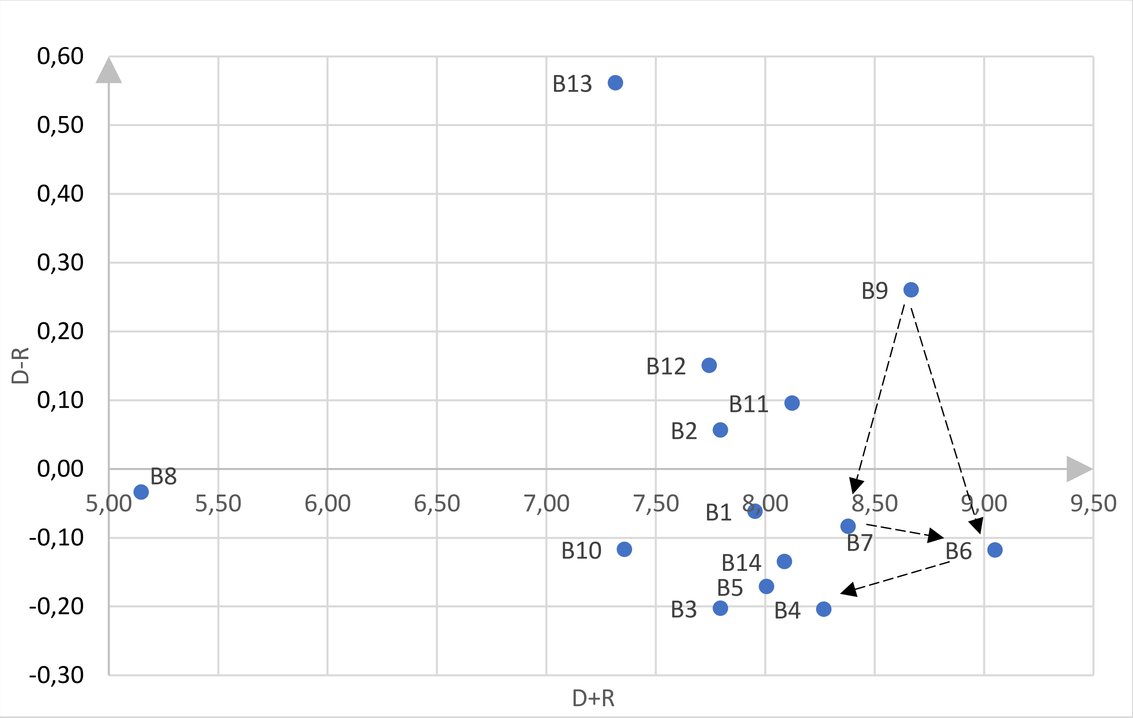
Figure 2 illustrates that B13 (lack of legislation and government incentives) is the most influential barrier among all the analyzed barriers, as it has the highest $D_i - R_i$ value. Hence, improvements in this barrier would provide benefits to other barriers and generate significant impacts in reducing CDW at construction sites. This is supported by previous studies that emphasize the relevance of public authorities and legal aspects in reducing waste generated at construction sites (Condotta & Zatta, 2021; Liu et al., 2021; Olanrewaju & Ogunmakinde, 2020). Government participation and incentives are critical for managers to implement waste reduction measures, as stated by Ling et al. (2013).

Barrier B9, witch denotes lack of financial resources, emerged as both the second most influential and the second most significant obstacle, solidifying its status as a core factor. This is because decision-making in construction works may be limited when there are financial constraints, which could impact the management of CDW at construction sites or lead to the purchase of low-quality materials that generate surplus waste on the construction site (Condotta & Zatta, 2021; Negash et al., 2021; Spišáková et al., 2021).

Barrier B6 (lack of planning and management on the construction site) presented the highest value of (D+R). Therefore, it can be considered the most important barrier for reducing CDW at construction sites. These findings are consistent with previous studies that highlight the importance of project managers anticipating unforeseen circumstances, rework, and planning service stages (Negash et al., 2021; Olanrewaju & Ogunmakinde, 2020; Spišáková et al., 2021).

Figure 2

Causal diagra



Source: The authors.

The study reveals that barriers B2 (design changes required by client), B11 (costs of implementing new technologies), and B12 (lack of environmental requirements in the contract) exhibit significant influence on the others and possess considerable importance according to their values obtained on the (D-R) and (D+R) axes. The lack of environmental requirements in the contract, for instance, was perceived by managers as an essential barrier to reducing CDW, as well-designed contracts enable better control of the activities performed (Condotta & Zatta, 2021; Pellegrini et al., 2020; Ratnasabapathy et al., 2021; Spišáková et al., 2021).

Regarding the (D-R) axis, barriers B3 (inadequate handling during material reception) and B4 (improper storage of materials) were identified as the most influenced by other barriers, given their operational characteristics. These barriers are influenced by other barriers more directly related to planning, such as B9 (Lack of financial resources), B6 (Lack of planning and management on the construction site), barrier B7 (lack of operational training and environmental education), and B13 (Lack of legislation and government incentive) (Olanrewaju & Ogunmakinde, 2020).

On the (D+R) axis, barrier B8 (weather issues) was found to be the least important. While climate phenomena cannot be prevented from occurring (Mawed et al., 2020; Narcis et al., 2019), Brazil does not experience earthquakes, tornadoes, or hurricanes. Furthermore, periods of intense rainfall are regular according to the seasons. As a result, planning with measures already consolidated in construction sites has helped mitigate the risks of losses and undue generation of CDW. The B10 barrier (lack of economic return from the recycling of CDW) was considered the second least important by the specialists. This may be due to the fact that construction managers perceive the economic return with recycling as small or negligible for management costs (Zhang et al., 2019). In countries where recycling is more highly remunerated, this barrier may be considered more important.

Table 11 summarizes our findings, providing a clear categorization of the factors involved. It's noteworthy to mention that our core factors, classified as Group I due to their high prominence and strong relation, consist primarily of B9 and B11. These factors fall under the category of Economic Barriers as depicted in Table 3, underlining their significance and the need to prioritize them.

Moreover, the driving factors, classified as Group II for their low prominence but high relation, prominently include B12 and B13. These factors are largely classified as Environmental Barriers as per Table 4, functioning as autonomous contributors within the system.

The independent factors, denoted as Group III for their low prominence and low relation, along with the by-impact factors, classified as Group IV for their high prominence and low relation, are predominantly linked with Technical Barriers as listed in Table 2. While the independent factors have limited interaction with other factors, making them acceptable in most situations, the by-impact factors need management due to their high interaction levels, even though they should not be directly improved. Their improvement can be indirectly achieved through effective handling of the causal factors, that is, Group I and Group II factors.

Table 11

Barriers categories on the four quadrant causal diagram

Group	Factors
Group I – Core Factors	B9, B11
Group II – Driving factors	B2, B12, B13
Group III – Independent factors	B3, B5, B8, B10
Group IV – By Impact factor	B1, B4, B6, B7, B14

Source: The authors.

In **Step 6**, Table 10 highlights the most significant influence relationships, represented in bold, with values greater than 0.351 (mean plus 1.5 standard deviations). These relationships are also depicted in Figure 2

Causal diagra. The findings indicate that Barrier B6 (lack of planning and management on the construction site) has a substantial effect on B4 (improper storage of materials), revealing that the absence of planning directly impacts the organization and arrangement of materials at the construction site (Narcis et al., 2019).

Additionally, Barrier B7 (lack of operational training and environmental education) influences B6 (lack of planning and management on the construction site), implying that to achieve effective planning and management, employees must first undergo professional training, along with environmental education that fosters a sense of belonging and care for the environment (Liyanage et al., 2019; Vidyasekar & Selvan, 2019; Zhang et al., 2019).

Furthermore, Barrier B9 (lack of financial resources) has a direct impact on both B6 (lack of planning and management on the construction site) and B7 (lack of operational training and environmental education). This underscores the necessity for investment in education and training to enhance workers' development and qualification in carrying out their tasks, as well as in environmental awareness to reduce CDW (Bailey et al., 2020; Mahpour, 2018; Vidyasekar and Selvan, 2019). Similarly, better planning and management of works necessitates investment in more qualified professionals, along with appropriate equipment and software, to achieve a more precise flow of information and better control of activities

(Olanrewaju & Ogunmakinde, 2020).

The comparison between the fuzzy Dematel results and the frequency of citations in the SLR revealed both similarities and differences. One of the similarities was the significance of B13 (Lack of legislation and government incentives), which was cited in all the references of the SLR and was considered the most influential barrier by the fuzzy Dematel. Additionally, technical barriers such as B6 (lack of planning and management on the construction site) and B7 (lack of operational training and environmental education) were frequently mentioned in the literature and were also deemed highly significant by the work managers. Conversely, B8 (weather issues) and B3 (inadequate handling during material reception) were infrequently mentioned in the literature and were considered to have little impact according to the fuzzy Dematel.

However, the most notable difference in results was related to B9 (lack of financial resources), which had the lowest frequency of citations in SLR as an economic barrier. Nonetheless, B9 ranked second in terms of D-R and D+R values, meaning it was the second most influential and important barrier, respectively, according to construction managers and fuzzy Dematel. This discrepancy between the literature results and the perspective of medium-sized commercial construction site managers may be attributed to the unique characteristics of the Brazilian construction sector. Budget constraints have always been a significant hurdle to improving medium-sized commercial projects in Brazil, including those aimed at implementing circular economy principles. Additionally, the economic downturn and high inflation in the years preceding the study may have heightened construction managers' concerns regarding this barrier.

Conclusions

In conclusion, the principles of the 3R highlight that reduction is a less complex and cost-effective approach that should be encouraged in civil construction works, which generate a significant amount of solid waste in landfills. With the increasing share of GDP held by the service sector in developing countries, such as Brazil, it is essential to investigate the barriers to reducing CDW in medium-sized commercial works, including commercial buildings, schools, and restaurants, to promote circular economy initiatives.

This study aimed to identify barriers to reducing CDW at construction sites using an SLR, and to analyse these barriers using fuzzy Dematel with managers of medium-sized commercial works in Brazil. The SLR identified 14 barriers, with B13 (lack of legislation and government incentive) being the most cited, followed by B11 (cost of implementing new technologies), B7 (lack of operational training and environmental education), and B6 (lack of planning and management on construction site). The fuzzy Dematel analysis also highlighted the influence of B13 and B9 (lack of financial resources), and the importance of B6 and B9. While similarities were found between the SLR and the fuzzy Dematel results, the lack of financial resources (B9) was the most significant difference between the literature survey and the perspective of construction managers. The limited financial resources, high interest rates, and inflation in the Brazilian construction market could be a possible cause of this divergence.

The results indicate that different actors need to collaborate to overcome barriers to reducing CDW in medium-sized commercial works in Brazil. Policymakers need to establish laws to discourage the practice of sending CDW to landfills by increasing the cost of this practice. Government, banks, and investors must work to increase the availability of capital for CDW reduction initiatives due to the lack of financial resources. Civil construction professionals should develop a culture of greater awareness for the reduction of CDW throughout the construction life cycle, with training for the entire work team to address the lack of planning and management of the work and the lack of operational training and environmental education.

However, this study's focus on managers of medium-sized commercial works in Brazil is a limitation, and the results cannot be generalized to other countries. Moreover, different stakeholders, such as researchers and politicians, may have different opinions regarding these barriers. Future research could include samples from other stakeholders or other countries with diverse legal, cultural, and economic backgrounds, which would contribute to a better understanding of the CDW reduction problem on construction sites.

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