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# Identification of Methods of Reducing Construction Waste in Construction Enterprises Based on Surveys

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**Abstract:** The article presents the analysis of the dependence between methods of reducing construction waste and the size of the construction enterprise. The analysis was carried out for the following construction products: steel, concrete, wood, and small-sized (ceramic, concrete) and finishing (ceramic and stone tiles) products. Based on the literature review, the 13 most frequently used methods of reducing construction waste were identified. Surveys were then conducted among 140 construction enterprises. The research was conducted in Sharjah in the United Arab Emirates. In order to test whether there is a relationship between the used waste-reduction method for a given construction product and the size of the enterprise, the Pearson chi-square test of independence was used. The null hypothesis and the alternative hypothesis were formulated, and the critical level of significance $\alpha = 0.05$ was adopted. The results were statistically significant for 7 methods of reducing construction waste. The identified methods include appropriate storage, the training of employees in the field of waste management, the use of monitoring systems, the appropriate transport and unloading of products, the appropriate involvement of subcontractors, the use of prefabricated elements, and the reuse of products on the construction site. Based on the conducted research, it was found that these methods are more often used with an increase in the size of the enterprise. The presented analysis emphasizes the urgent need to improve, integrate, and adjust the promotion of both the reduction of construction waste and the benefits of this reduction in construction enterprises, especially those of the smallest size.

**Keywords:** construction enterprise; construction waste; methods of reducing construction waste; survey research; chi-square test

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## 1. Introduction

The natural environment is constantly being exploited. In order to protect natural resources from destructive human activity, the concept of sustainable development was developed. It was first presented on 26 May 1969, by the United Nations (UN) in the report "Problems of the human environment". This report is considered to be a turning point in the perception of the devastating impact of humans on the environment [1,2]. Sustainable development aims to prevent the deepening destruction of the environment while at the same time satisfying the needs of mankind and enabling unlimited progress. The concept of sustainable development should be applied in all areas of human life [3]. The current assumptions of sustainable development were presented during the UN summit in New York on 25–27 September 2015, in a document entitled "Transforming our world: Agenda for Sustainable Development—2030". Sustainable Development Goals have been incorporated into the legislation of UN member states. In the regulation of the European Parliament and the Council of the European Union from 2011, a sustainable construction was introduced as a new basic requirement [4]. Since then, reusing and recycling construction products has not only become a choice but also a necessity. Countries that changed their law according to the new requirements reduced the production of construction waste, which was proven by the analysis of statistics from 2016 performed by Wing-Yan Tam and Lu [5]. Appropriate waste management is included in the 2008/98/EC Directive, which is based on the latest UN assumptions from the 2030 Agenda. The hierarchy of proceeding with waste is written in such a way that the first and most desirable method (reduction) minimizes the amount of generated waste by reducing the use of construction products that cause this waste. The second method (re-consumption) involves the reuse of products that were originally produced as disposable but can still have auxiliary functions. The third principle (recycling) emphasizes the need to recycle the waste that can be processed and used in the production of new construction products [6]. For proper waste management to be as effective as possible, the activities of industrial, research, civic, and public authorities should be combined [7,8]. It has been also proven that the appropriate management of construction waste not only brings environmental, but also economic benefits [9,10].

In the subject literature, construction waste is defined in many ways. One of them is the definition of waste as materials produced "in the process of the production, construction, renovation, or demolition of structures" [11]. A more detailed definition was created by A. Denmark [12]. It reads: "Construction and demolition waste is a complex waste stream that consists of a wide variety of materials such as rubble, earth, concrete, steel, wood and a mixture of materials resulting from various construction activities, including soil removal, demolition, road construction and the modernization of buildings." A European Union (EU) report from 1999 defines construction waste to be a wide range of materials resulting from the complete or partial demolition of buildings or roads, the construction of buildings/roads, the removal of soil, construction works, and building/road restoration works [13]. According to the works of B. Kourmpanis (2008), construction waste differs in individual countries due to the economic and cultural situation of these countries, the characteristics of waste classified as construction waste, and the type of recorded data [14]. Due to divergences in the definition of construction waste in different countries, the EU has developed a European Waste Catalog for its Member States [15]. In the United Arab Emirates (UAE), federal law generally defines waste as all toxic and non-toxic waste, including nuclear waste, which must be disposed of and recycled in accordance with the law. These wastes include solid waste, such as municipal, industrial, agricultural, medical, and construction waste [16]. To sum up, construction waste can be defined as the difference "between the materials ordered and those used to construct a building" [17].

Construction waste can be classified according to the type of material that was used in the production of a construction product [11,13,14,18]. One example includes the division of construction waste in the European Union into concrete, bricks, ceramic tiles, ceramics and gypsum-based materials, wood, glass, plastics, asphalt, tar and tarred products, metals (including metal alloys), soil and earth, insulating materials, mixed construction waste, and hazardous construction waste [15]. Construction waste can also be distinguished according to the properties of the materials, e.g., recyclable and non-recyclable waste, potentially biodegradable waste, waste that is potentially suitable for disposal at a landfill, and waste that is potentially suitable for incineration [11]. Another way to classify construction waste involves the consideration of its origin, e.g., from the construction of a new building, reworks or demolition [11,19,20], or related to the function of a building [21,22] or the source where this waste was generated [23–28].

The knowledge concerning the sources of generating waste facilitates the identification of methods for reducing this waste. The sources of construction waste in the life cycle of a building were first identified by Gavilan and Bernold (1994) during their research carried out in the Netherlands. They distinguished the following sources where construction waste is generated in the production process: (1) design, (2) procurement, (3) handling of materials, (4) operation, (5) residual, including scrap and nonconsumables, and (6) other sources [17]. In 2000, Lingard, on the basis of the research conducted among employees of general contractors, classified four sources of construction waste and added a behavioral theme to the existing knowledge: (1) production and delivery, (2) transport and storage, (3) construction, and (4) culture related [23].

The influence of the behavioral factor on the production of construction waste has been more widely studied and also confirmed in other scientific studies [24,25,29,30]. In 2004, a survey conducted in Singapore among general contractors identified four main sources of construction waste: (1) design, (2) production and delivery, (3) material management, and (4) construction [26]. The results of these both studies, which were carried out in 1994 and 1996, and following ones confirmed that the maximum number of sources of the construction waste occur at the design stage [23,27–29]. Based on a subject literature review [21–28,31–33], 13 methods of reducing the amount of construction waste used in construction companies were found. These methods are discussed in detail in Table 1 in the next chapter.

**Table 1.** The methods of reducing construction waste used in construction enterprises.

| Lp. | Method of Reducing Construction Waste | Benefits |
|---|---|---|
| 1 | Appropriate storage | Protection against mechanical damage and weather conditions; |
| 2 | Ordering products of an appropriate size | Minimizing the need for cutting to size elements; eliminating waste; |
| 3 | Training employees in the field of waste management | Reduction of losses caused by the inadequate processing of products; |
| 4 | Use of systems for monitoring the flow of products on the construction site | Reducing the risk of making mistakes in the management of construction products; |
| 5 | Appropriate transport and unloading | Damage prevention; |
| 6 | Appropriate involvement of subcontractors | Reduction of the amount of waste on the construction site; |
| 7 | Security of the construction site | The prevention of theft, vandalism, and double-ordering; |
| 8 | Use of prefabricated elements | Minimizing the amount of waste related to the production of elements on the construction site; |
| 9 | Waste segregation on the construction site | Preventing contamination of products by providing containers for each type of waste. Non-contaminated waste can be recycled or reused; |
| 10 | Designation of a place for waste segregation | Recovering products for reuse in the designated area, e.g., removing nails from wooden elements or crushing concrete elements; |
| 11 | Reuse of products on the construction site | E.g., formwork timber used several times; use of concrete or ceramic and stone waste as rubble for temporary roads and pavements; |
| 12 | Delivery of products according to the schedule | Reduction of storage time and the risk of damage; |
| 13 | Development of a waste-disposal plan | Easier management of construction waste. |

The aim of the conducted research and analyses is to find out whether the application of construction waste-reduction methods with regards to selected construction materials depends on the size of the enterprise. In terms of the number of people employed, the enterprises were classified into five groups: (1) from 1 to 9 employees, (2) from 10 to 49 employees, (3) from 50 to 99 employees, (4) from 100 to 249 employees, and (5) 250 employees and more. The analyses were based on the results of a survey conducted among engineers employed in construction companies. The research was conducted in Sharjah, United Arab Emirates (UAE). The analyzes were performed with the use of the SPSS 26 computer program.

## 2. Materials and Methods

The methods of reducing construction waste that are used in construction companies, which were identified based on the literature review, are presented in Table 1. The benefits of using each of them are also listed. Research was carried out for the following construction products: steel, concrete, wood, and small-sized (ceramic, concrete) and finishing (ceramic and stone tiles) elements.

### *2.1. Size and Structure of the Studied Population*

The population of the studied enterprises consists of five subpopulations. Each of them includes enterprises with a certain number of employees. The groups have been derived from the population as per the characteristic of construction enterprises. In Sharjah, construction companies employ a limited number of people to keep low insurance and municipality fees, and they outsource work to subcontractors. The survey was conducted using the technique of personal interviews and telephone interviews due to the possibility of obtaining the most accurate data and immediate clarification of ambiguities in the obtained answers. The research was carried out in 140 enterprises of general contractors. The structure of the population is presented in Table 2.

**Table 2.** Structure of the studied population of enterprises.

| Number of Employees Hired in the Assessed Enterprises | Number of Enterprises $n_i$ | Percentage Share |
|---|---|---|
| 1–9 employees | 42 | 30% |
| 10–49 employees | 41 | 29% |
| 50–99 employees | 15 | 11% |
| 100–249 employees | 20 | 14% |
| 250 employees and more | 22 | 16% |
| Total | 140 | 100% |

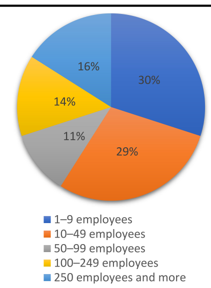
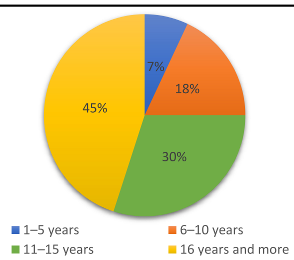



Table 2 presents the number and percentage share of the enterprise sizes in the studied population. In the surveyed representative group, 42 enterprises (30%) employ from 1 to 9 employees, 41 enterprises (29%) employ from 10 to 49 employees, 15 enterprises (11%) employ from 50 to 99 employees, 20 enterprises (14%) employ between 100 and 249 employees, and 22 enterprises (16%) employ 250 employees or more. The largest sub-population includes enterprises that employ the least workers.

Research was also carried out with regards to the companies' experience in the market of construction works. The results of the surveys are presented in Table 3.

**Table 3.** Experience in the construction market among the surveyed companies.

| Years of Experience in the Construction Market | Number of Enterprises $n_i$ | Percentage Share |
|---|---|---|
| 1–5 | 10 | 7% |
| 6–10 | 25 | 18% |
| 11–15 | 42 | 30% |
| 16 and more | 63 | 45% |
| Total | 140 | 100% |




Among the surveyed companies, 63 companies (45%) had 16 years or more of experience in the construction market, 42 companies (30%) had 11 to 15 years of experience, 25 companies (18%) had 6 to 10 years of experience, and 10 enterprises (7%) had between 1 and 5 years of experience. To sum up, the most numerous group were the oldest enterprises, with 16 years of experience or more.

### *2.2. Methodology of Identifying Methods of Reducing Construction Waste with Regards to the Size of the Enterprise*

In the subject literature review, the correlation analysis of two variables is especially popular [34–36]. In the presented paper, the subject of the study is to determine the relationship between the method of reducing construction waste in relation to a given construction product and the size of the construction enterprise. For this purpose:

- The answers of the respondents concerning the applied methods of waste reduction were qualified into five groups with regards to particular construction products. Each of these groups represented a certain size of an enterprise. In each group, the number of positive answers (YES) and the number of negative answers (NO) were determined;

- In order to test whether there is a relationship between the waste-reduction method used in the case of a given construction product and the size of the enterprise, the Pearson chi-square ($\chi^2$) test of independence was used [37]. This test is used to check the relationship between the two nominal variables X and Y. In the conducted research, the nominal variable X is the size of the enterprise, while the nominal variable Y is the answer Yes/No in relation to the tested reduction method.
- The Pearson chi-square test is based on comparing the values obtained in the study (the so-called observed or empirical frequencies) with theoretical values calculated based on the assumption that there is no relationship between variables X and Y. The chi-square test statistic has the form of formula (1):

$$\chi^2 = \sum_{i=1}^{r}\sum_{j=1}^{c} \frac{\left(O_{ij} - E_{ij}\right)^2}{E_{ij}}, \tag{1}$$

where:

$\chi^2$—chi-square statistic,
$O_{ij}$—observed counts obtained from surveys,
$E_{ij}$—theoretical counts,
$r$—number of levels of variable X (X = 5) (number of enterprise groups), and
$c$—number of levels of variable Y (Y = 2) (number of possible answers).

Chi-square statistics were calculated using the SPSS-26 computer program. The chi-square statistic has a distribution of $\chi^2$ with $(r - 1)(c - 1)$ degrees of freedom. In the analyzed case, the number of degrees of freedom is 4. The $p$ value determined for the chi-square test statistic is compared with the significance level α. The critical significance level of $\alpha = 0.05$ was adopted in the analyzes.

The null hypothesis $H_0$ and the alternative hypothesis $H_1$ were formulated:

- $H_0$: Variables $X$ and $Y$ are independent if $p > \alpha$
- $H_1$: Variables $X$ and $Y$ are not independent if $p \leq \alpha$

where:

$p$—the probability (the value of $p$ is compared to the theoretical value of α)
α—the significance level.

If $p > \alpha \Rightarrow$ it can be assumed that there are no reasons to reject hypothesis $H_0$. This means that there is no significant relationship between the size of the enterprise and the use of the analyzed method of reducing construction waste. The result is statistically insignificant.

If $p \leq \alpha \Rightarrow$ it can be assumed that there are reasons for rejecting hypothesis $H_0$. Based on the tested sample, it can be assumed that there is a relationship between the size of the enterprise and the use of the analyzed method of reducing construction waste. The result is statistically significant.

## 3. Results

Calculations of the chi-square test were performed for all the tested methods of reducing construction waste in relation to all the analyzed construction products. Table 4 only presents those results that are statistically significant, namely the statistics of frequency and percentage rates of YES and NO responses as well as the calculated values of the $\chi^2$ (4) test and probability $p$. Other calculation results, which are not included in the table below, show that there is no significant relationship between the size of the enterprise and the use of the analyzed method of reducing construction waste.

**Table 4.** The statistics of the chi-square test and probability *p* of the occurrence of methods of reducing construction waste that were used by construction companies, with their size also provided.

| Methods of Reducing Construction Waste | Construction Products | Answer | Enterprise Size (Number of Employees) | | | | | | | | | | | | Chi2(4); Probability *p* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1–9 | | 10–49 | | 50–99 | | 100–249 | | 250 and More | | Total | | |
| | | | *n* | % | *n* | % | *n* | % | *n* | % | *n* | % | *n* | % | |
| Appropriate storage | small-sized products | Yes | 20 | 47.6% | 24 | 58.5% | 8 | 53.3% | 16 | 80.0% | 18 | 81.8% | 86 | 61.4% | *Chi*2(4) = 10.711; |
| | | No | 22 | 52.4% | 17 | 41.5% | 7 | 46.7% | 4 | 20.0% | 4 | 18.2% | 54 | 38.6% | $p$ = 0.03 |
| | ceramic and stone tiles | Yes | 23 | 54.8% | 25 | 61.0% | 8 | 53.3% | 18 | 90.0% | 18 | 81.8% | 92 | 65.7% | *Chi*2(4) = 11.433; |
| | | No | 19 | 45.2% | 16 | 39.0% | 7 | 46.7% | 2 | 10.0% | 4 | 18.2% | 48 | 34.3% | $p$ = 0.022 |
| | wood | Yes | 25 | 59.5% | 27 | 65.9% | 10 | 66.7% | 18 | 90.0% | 20 | 90.9% | 100 | 71.4% | *Chi*2(4) = 11.179; |
| | | No | 17 | 40.5% | 14 | 34.1% | 5 | 33.3% | 2 | 10.0% | 2 | 9.1% | 40 | 28.6% | $p$ = 0.025 |
| Training employees in the field of waste management | small-sized products | Yes | 24 | 57.1% | 26 | 63.4% | 9 | 60.0% | 19 | 95.0% | 13 | 59.1% | 91 | 65.0% | *Chi*2(4) = 9.60; |
| | | No | 18 | 42.9% | 15 | 36.6% | 6 | 40.0% | 1 | 5.0% | 9 | 40.9% | 49 | 35.0% | $p$ = 0.048 |
| Use of monitoring systems | steel | Yes | 24 | 57.1% | 19 | 46.3% | 11 | 73.3% | 17 | 85.0% | 18 | 81.8% | 89 | 63.6% | *Chi*2(4) = 13.751; |
| | | No | 18 | 42.9% | 22 | 53.7% | 4 | 26.7% | 3 | 15.0% | 4 | 18.2% | 51 | 36.4% | $p$ = 0.008 |
| | concrete | Yes | 24 | 57.1% | 21 | 51.2% | 11 | 73.3% | 17 | 85.0% | 18 | 81.8% | 91 | 65.0% | *Chi*2(4) = 11.272; |
| | | No | 18 | 42.9% | 20 | 48.8% | 4 | 26.7% | 3 | 15.0% | 4 | 18.2% | 49 | 35.0% | $p$ = 0.024 |
| | small-sized products | Yes | 19 | 45.2% | 18 | 43.9% | 8 | 53.3% | 17 | 85.0% | 16 | 72.7% | 78 | 55.7% | *Chi*2(4) = 13.754; |
| | | No | 23 | 54.8% | 23 | 56.1% | 7 | 46.7% | 3 | 15.0% | 6 | 27.3% | 62 | 44.3% | $p$ = 0.008 |
| | ceramic and stone tiles | Yes | 18 | 42.9% | 18 | 43.9% | 9 | 60.0% | 17 | 85.0% | 17 | 77.3% | 79 | 56.4% | *Chi*2(4) = 16.369; |
| | | No | 24 | 57.1% | 23 | 56.1% | 6 | 40.0% | 3 | 15.0% | 5 | 22.7% | 61 | 43.6% | $p$ = 0.003 |
| | wood | Yes | 22 | 52.4% | 16 | 39.0% | 10 | 66.7% | 17 | 85.0% | 16 | 72.7% | 81 | 57.9% | *Chi*2(4) = 14.996; |
| | | No | 20 | 47.6% | 25 | 61.0% | 5 | 33.3% | 3 | 15.0% | 6 | 27.3% | 59 | 42.1% | $p$ = 0.005 |
| Appropriate transport and unloading of products | small-sized products | Yes | 34 | 81.0% | 31 | 75.6% | 9 | 60.0% | 19 | 95.0% | 21 | 95.5% | 114 | 81.4% | *Chi*2(4) = 10.777; |
| | | No | 8 | 19.0% | 10 | 24.4% | 6 | 40.0% | 1 | 5.0% | 1 | 4.5% | 26 | 18.6% | $p$ = 0.029 |
| Appropriate involvement of subcontractors | steel | Yes | 20 | 47.6% | 20 | 48.8% | 11 | 73.3% | 16 | 80.0% | 16 | 72.7% | 83 | 59.3% | *Chi*2(4) = 10.671; |
| | | No | 22 | 52.4% | 21 | 51.2% | 4 | 26.7% | 4 | 20.0% | 6 | 27.3% | 57 | 40.7% | $p$ = 0.031 |
| | small-sized products | Yes | 11 | 26.2% | 18 | 43.9% | 9 | 60.0% | 12 | 60.0% | 17 | 77.3% | 67 | 47.9% | *Chi*2(4) = 17.855; |
| | | No | 31 | 73.8% | 23 | 56.1% | 6 | 40.0% | 8 | 40.0% | 5 | 22.7% | 73 | 52.1% | $p$ = 0.001 |
| | wood | Yes | 17 | 40.5% | 17 | 41.5% | 10 | 66.7% | 12 | 60.0% | 17 | 77.3% | 73 | 52.1% | *Chi*2(4) = 11.495; |
| | | No | 25 | 59.5% | 24 | 58.5% | 5 | 33.3% | 8 | 40.0% | 5 | 22.7% | 67 | 47.9% | $p$ = 0.022 |
| The use of prefabricated elements | steel | Tak | 7 | 16.7% | 22 | 53.7% | 7 | 46.7% | 9 | 45.0% | 9 | 40.9% | 54 | 38.6% | *Chi*2(4) = 13.259; |
| | | No | 35 | 83.3% | 19 | 46.3% | 8 | 53.3% | 11 | 55.0% | 13 | 59.1% | 86 | 61.4% | $p$ = 0.01 |
| | small-sized products | Yes | 1 | 2.4% | 6 | 14.6% | 3 | 20.0% | 7 | 35.0% | 5 | 22.7% | 22 | 15.7% | *Chi*2(4) = 12.315; |
| | | No | 41 | 97.6% | 35 | 85.4% | 12 | 80.0% | 13 | 65.0% | 17 | 77.3% | 118 | 84.3% | $p$ = 0.015 |
| Reuse of products on the construction site | wood | Yes | 34 | 81.0% | 20 | 48.8% | 10 | 66.7% | 17 | 85.0% | 14 | 63.6% | 95 | 67.9% | *Chi*2(4) = 13.027; |
| | | No | 8 | 19.0% | 21 | 51.2% | 5 | 33.3% | 3 | 15.0% | 8 | 36.4% | 45 | 32.1% | $p$ = 0.011 |
| | concrete | Yes | 34 | 81.0% | 25 | 61.0% | 9 | 60.0% | 18 | 90.0% | 13 | 59.1% | 99 | 70.7% | *Chi*2(4) = 9.862; |
| | | No | 8 | 19.0% | 16 | 39.0% | 6 | 40.0% | 2 | 10.0% | 9 | 40.9% | 41 | 29.3% | $p$ = 0.043 |
| | small-sized products | Yes | 33 | 78.6% | 21 | 51.2% | 9 | 60.0% | 19 | 95.0% | 15 | 68.2% | 97 | 69.3% | *Chi*2(4) = 14.825; |
| | | No | 9 | 21.4% | 20 | 48.8% | 6 | 40.0% | 1 | 5.0% | 7 | 31.8% | 43 | 30.7% | $p$ = 0.005 |
| | ceramic and stone tiles | Yes | 30 | 71.4% | 19 | 46.3% | 10 | 66.7% | 17 | 85.0% | 12 | 54.5% | 88 | 62.9% | *Chi*2(4) = 11.056; |
| | | No | 12 | 28.6% | 22 | 53.7% | 5 | 33.3% | 3 | 15.0% | 10 | 45.5% | 52 | 37.1% | $p$ = 0.026 |

## 4. Discussion

The analysis of the results of the calculations included in Table 4 helped to indicate methods of reducing waste, the application of which depends on the size of the construction company, to be indicated with a probability greater than 0.95. A significant statistical dependence was found for seven methods of reducing construction waste, namely appropriate storage, employee training in the field of waste management, use of monitoring systems, appropriate transport and unloading of products, appropriate involvement of subcontractors, use of prefabricated elements, and the reuse of products on the construction site. In all these cases, the statistic *Chi*2(4) > 9.487, and $p < 0.05$. No statistically significant correlation was found for the other six methods of reducing construction waste, namely ordering products to size and in the appropriate quantity, the security of the construction site, waste segregation on the construction site, the designation of a place for waste segregation on the construction site; timely delivery, and having a waste disposal plan. In all these cases, the value of the statistic *Chi*2(4) > 9.487, and $p > 0.05$. This means that the application of a given reduction method does not depend on the size of the enterprise. A detailed summary of the test results is provided in Table 5.

**Table 5.** Summary of research results.

| # | Method of Reducing Construction Waste | The Results of The Calculations Confirm: Statistically Significant Correlation between the Size of the Enterprise and: | Non-Statistically Significant Correlation between the Size of the Enterprise and: |
|---|---|---|---|
| 1 | Appropriate storage | • small-sized products<br>• ceramic and stone tiles<br>• wood | • steel<br>• concrete |
| 2 | Training employees in the field of waste management | • small-sized products | • steel<br>• concrete<br>• ceramic and stone tiles<br>• wood |
| 3 | Use of monitoring systems | • steel<br>• concrete<br>• small-sized products<br>• ceramic and stone tiles<br>• wood | |
| 4 | Appropriate transport and unloading of products | • small-size products | • steel<br>• concrete<br>• ceramic and stone tiles<br>• wood |
| 5 | Appropriate involvement of subcontractors | • steel<br>• small-sized products<br>• wood | • concrete<br>• ceramic and stone tiles |
| 6 | The use of prefabricated elements | • steel<br>• small-sized products | • concrete<br>• ceramic and stone tiles<br>• wood |
| 7 | Reuse of products on the construction site | • concrete<br>• small-sized products<br>• ceramic and stone tiles<br>• wood | • steel |

Table 6 lists the construction products for which a statistically significant correlation was found between the method of reducing construction waste and the size of the enterprise. Moreover, for each construction product, the strength of this relationship (*PW*) was determined. The frequency of the affirmative answer (YES) indicated by the respondents was adopted as a measure of this strength. The following designations were adopted:

$PW = 1$ when the frequency is $\leq$60%,
$PW = 2$ when the frequency is between 61% and 75%, and
$PW = 3$ when the frequency is between 76% and 100%

**Table 6.** Construction products for which a statistically significant correlation was found between the method of reducing construction waste and the size of the construction enterprise.

| # | Construction Product | Method of Reducing Construction Waste | Enterprise Size (Number of Employees) 1–9 | 10–49 | 50–99 | 100–249 | 250 and More |
|---|---|---|---|---|---|---|---|
| 1 | steel | Appropriate storage | - | - | - | - | - |
| | concrete | | - | - | - | - | - |
| | small-sized products | | 1 | 1 | 1 | 3 | 3 |
| | ceramic and stone tiles | | 1 | 2 | 1 | 3 | 3 |
| | wood | | 1 | 2 | 2 | 3 | 3 |
| 2 | steel | Training employees in the field of waste management | - | - | - | - | - |
| | concrete | | - | - | - | - | - |
| | small-sized products | | 1 | 2 | 1 | 3 | 3 |
| | ceramic and stone tiles | | - | - | - | - | - |
| | wood | | - | - | - | - | - |
| 3 | steel | Use of monitoring systems | 1 | 1 | 2 | 3 | 3 |
| | concrete | | 1 | 1 | 2 | 3 | 3 |
| | small-sized products | | 1 | 1 | 1 | 3 | 2 |
| | ceramic and stone tiles | | 1 | 1 | 1 | 3 | 3 |
| | wood | | 1 | 1 | 2 | 3 | 2 |

**Table 6.** *Cont.*

| # | Construction Product | Method of Reducing Construction Waste | Enterprise Size (Number of Employees) | | | | |
|---|---|---|---|---|---|---|---|
| | | | 1–9 | 10–49 | 50–99 | 100–249 | 250 and More |
| 4 | steel | Appropriate transport and unloading of products | - | - | - | - | - |
| | concrete | | - | - | - | - | - |
| | small-sized products | | 3 | 2 | 1 | 3 | 3 |
| | ceramic and stone tiles | | - | - | - | - | - |
| | wood | | - | - | - | - | - |
| 5 | steel | Appropriate involvement of subcontractors | 1 | 1 | 2 | 3 | 2 |
| | concrete | | - | - | - | - | - |
| | small-sized products | | 1 | 1 | 1 | 1 | 3 |
| | ceramic and stone tiles | | - | - | - | - | - |
| | wood | | 1 | 1 | 2 | 1 | 3 |
| 6 | steel | Use of prefabricated elements | 1 | 1 | 1 | 1 | 1 |
| | concrete | | - | - | - | - | - |
| | small-sized products | | 1 | 1 | 1 | 1 | 1 |
| | ceramic and stone tiles | | - | - | - | - | - |
| | wood | | - | - | - | - | - |
| 7 | steel | Reuse of products on the construction site | - | - | - | - | - |
| | concrete | | 3 | 2 | 1 | 3 | 1 |
| | small-sized products | | 3 | 1 | 1 | 3 | 2 |
| | ceramic and stone tiles | | 2 | 1 | 2 | 3 | 1 |
| | wood | | 3 | 1 | 2 | 3 | 2 |

Based on the results of the research, the following conclusions were drawn:

1. Out of the 13 analyzed methods, a statistically significant correlation between the size of the enterprise and the method of reducing construction waste was found in the case of seven methods. These include appropriate storage, the training of employees in the field of waste management, the use of monitoring systems, the appropriate transport and unloading of products, the appropriate involvement of subcontractors, the use of prefabricated elements, and the reuse of products on the construction site (justification in Table 4). As the size of the enterprise grows, these methods are used more frequently;
2. Each group of analyzed methods of waste reduction includes construction products for which no statistically significant correlation was found between their use and the size of the enterprise. No such dependence was found with regards to the method of:
   - Appropriate storage in the case of steel and concrete;
   - Training of employees in the field of waste management in the case of steel, concrete, and wood;
   - Appropriate transport and unloading of products in the case of steel, concrete, and wood;
   - Appropriate involvement of subcontractors in the case of concrete and ceramic and stone tiles;
   - Use of prefabricated elements in the case of concrete, wood, and ceramic and stone tiles; and
   - Reuse of products on site in the case of steel.
3. The use of seven separate methods of reducing construction waste in enterprises of certain sizes is as follows:

   3.1. In enterprises employing 250 or more employees, the following methods are used:

   3.1.1. Most often (PW = 3):
   - Appropriate storage in relation to small-sized products, wood, and ceramic and stone tiles;
   - Training of employees in the field of waste management in the case of small-sized products;

- Use of monitoring systems in the case of steel, concrete, ceramic and stone products;
- Appropriate transport and unloading of products in relation to small-sized products; and
- Appropriate involvement of subcontractors in the case of small-sized products and wood.

3.1.2 Often (PW-2):

- Use of monitoring systems in the case of small-sized products and wood;
- Appropriate involvement of subcontractors in the case of steel products; and
- Reuse of products on the construction site in the case of small-sized products and wood.

3.1.3. Rare (PW = 1):

- Use of prefabricated elements in relation to steel and small-sized products;
- Reuse of products on the construction site in the case of concrete products and ceramic and stone tiles.

3.2. In enterprises employing from 100 to 249 employees, the following methods are used:

3.2.1. Most often (PW = 3):

- Appropriate storage with regards to small-sized products, wood, and ceramic and stone tiles;
- Training employees in the field of waste management with regards to small-sized products;
- Use of monitoring systems in relation to all the groups of analyzed construction products;
- Appropriate transport and unloading of products with regards to small-sized products;
- Appropriate involvement of subcontractors with regards to steel products; and
- Reuse of products on the construction site with regards to concrete, small-sized products, wood, and ceramic and stone tiles;

3.2.2. Often (PW-2):

- No such cases were observed.

3.2.3. Rare (PW = 1):

- Appropriate involvement of subcontractors with regards to small-sized products and wood;
- Use of prefabricated elements with regards to steel and small-sized products.

3.3. In enterprises employing from 50 to 99 employees, the following methods are used:

3.3.1. Most often (PW = 3):

- No such cases were observed.

3.3.2. Often (PW-2):

- Appropriate storage with regards to wooden products;
- Use of monitoring systems with regards to steel, concrete and wooden products;
- Appropriate involvement of subcontractors with regards to steel and wooden products; and

- Reuse of products on the construction site with regards to wood, and ceramic and stone tiles.

3.3.3. Rare (PW = 1):

- Appropriate storage with regards to small-sized products and ceramic and stone tiles;
- Training employees in the field of waste management with regards to small-sized products;
- Use of monitoring systems with regards to small-sized products and ceramic and stone tiles;
- Appropriate transport and unloading of products with regards to small-sized products;
- Appropriate involvement of subcontractors with regards to small-sized products;
- Application of prefabricated elements with regards to steel and small-sized products; and
- Reuse of products on the construction site with regards to concrete and small-sized products.

3.4. In enterprises employing from 10 to 49 employees, the following methods are used:

3.4.1. Most often (PW = 3):

- No such cases were observed.

3.4.2. Often (PW-2):

- Appropriate storage with regards to wood and ceramic and stone tiles;
- Training employees in the field of waste management with regards to small-sized products;
- Appropriate transport and unloading of products with regards to small-sized products; and
- Reuse of products on the construction site with regards to concrete products.

3.4.3. Rare (PW = 1):

- Appropriate storage with regards to small-sized products;
- Use of monitoring systems with regards to all the groups of analyzed construction products;
- Appropriate involvement of subcontractors with regards to steel, small-sized, and wooden products;
- Use of prefabricated elements with regards to steel and small-sized products; and
- Reuse of products on the construction site with regards to small-sized products, wood, and ceramic and stone tiles.

3.5. In enterprises employing from 1 to 9 employees, the following methods are used:

3.5.1. Most often (PW = 3):

- Appropriate transport and unloading of products with regards to small-sized products;
- Reuse of products on the construction site in relation to concrete, small-sized, and wooden products.

3.5.2. Often (PW-2):

- Reuse of products on the construction site with regards to ceramic and stone tiles.

3.5.3. Rare (PW = 1):

- Appropriate storage with regards to small-sized products, wood, and ceramic and stone tiles;
- Training employees in the field of waste management with regards to small-sized products;
- Use of monitoring systems with regards to all the groups of analyzed construction products;
- Appropriate involvement of subcontractors with regards to steel, small-sized, and wooden products; and
- Use of prefabricated elements with regards to steel and small-sized products.

## 5. Conclusions

The subject of the study was to determine the relationship between 13 methods of reducing construction waste and the size of the construction enterprise in relation to selected construction products. The selected construction products included steel, concrete, small-sized products, wood, and ceramic and stone tiles. Enterprises were divided into groups according to the number of employees, namely from 1 to 9 employees, from 10 to 49 employees, from 50 to 99 employees, from 100 to 249 employees, and for 250 employees and more. Employee surveys were conducted in enterprises belonging to the designated groups. The values of the chi-square test for the significance level of 0.05 and the degree of freedom 4 confirmed a statistically significant correlation between the size of the enterprise and seven methods of reducing construction waste, which included appropriate storage, the training of employees in waste management, the use of monitoring systems, the appropriate transport and unloading of products, the appropriate involvement of subcontractors, the use of prefabricated elements, and the reuse of products on the construction site. The dependence between the use of waste-reduction methods and the size of the enterprise did not always apply to all tested construction products, e.g., no statistically significant correlation was found in relation to steel and concrete in the case of the appropriate storage method. For the remaining six methods of reducing construction waste, no statistical correlation was found between the application of these methods and the size of the enterprise, but this does not mean that these methods were not used. The use of these methods or their non-application may be influenced by other factors that are not included in these studies.

In further research, it is recommended to focus on behavioral motives that can have a large impact on the use of methods that reduce construction waste in construction enterprises.

Studies presented in this paper make a significant contribution to the existing research concerning the reduction of construction waste. In conclusion, based on the conducted research, it was found that the bigger the enterprise, the more methods of reducing construction waste were applied. It can be assumed that larger construction enterprises have more human resources and financial support to plan, organize, and implement more methods of reducing construction waste than smaller enterprises. Therefore, it is crucial that governmental bodies will support reduction of construction waste by providing necessary trainings and financial support and will effectively require it. Thus, the presented analysis emphasizes the urgent need to improve, integrate, and adjust the promotion of the reduction of construction waste and the benefits of this reduction in construction enterprises, especially those of the smallest size.

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