sustainability

MDPI

Article

Recycling and Upcycling in the Practice of Waste Management of Construction Giants

Guanru Wang [1], Dariusz Krzywda [2,*], Sergey Kondrashev [3] and Lubov Vorona-Slivinskaya [4]

1 College of Life Science, Harbin Institute of Technology, Harbin 610056, China; bio-hitguanruwoon@outlook.com
2 Faculty of Management, Czestochowa University of Technology, 42201 Czestochowa, Poland
3 Department of Chemistry, Sechenov First Moscow State Medical University, 119991 Moscow, Russia; Sk9262718531@gmail.com
4 Department of Construction Technology, Saint Petersburg State University of Architecture and Civil Engineering (SPbGASU), 190005 Saint Petersburg, Russia; Ly161@yandex.ru
* Correspondence: dariusz.krzywda@pcz.pl

Abstract: The purpose of this study was to assess the impact of recycling and upcycling technologies on the level of efficiency of large construction companies in the context of waste management practice. The research methodology was based on regression analysis and factorial analysis of variance. Based on the assessment of waste management efficiency in the context of recycling (upcycling), the positive dynamics of the efficiency of its implementation was determined in comparison with traditional waste disposal. The levels of the relationship among net profit, investment in waste management, and recycling efficiency for the companies under study were determined. Regression analysis of the impact of recycling efficiency on the performance of the companies under study in the context of waste management demonstrated a positive effect of an increase in the efficiency of recycling (upcycling) on the net profit of all companies under study. However, at the same time, there was a different effect and degree of influence of this indicator according to the formed scenarios. Despite the high efficiency of recycling (upcycling), the prospective increase in its level does not have a proportional relationship with profit but depends on the development factors of the construction company. Two-way analysis of variance demonstrated a strong influence of the efficiency of recycling (upcycling) and waste disposal on waste management efficiency. It was proven that companies that currently have a high level of recycling (upcycling) efficiency are practically not focused on traditional waste disposal, since recycling has a more significant and positive impact on the effectiveness of their activities.

Keywords: construction; construction waste; circular economy; recycling; sustainable development

Citation: Wang, G.; Krzywda, D.; Kondrashev, S.; Vorona-Slivinskaya, L. Recycling and Upcycling in the Practice of Waste Management of Construction Giants. *Sustainability* **2021**, *13*, 640. https://doi.org/10.3390/su13020640

Received: 30 November 2020
Accepted: 4 January 2021
Published: 11 January 2021

1. Introduction

In the past few years, the circular economy has attracted more and more attention around the world as a way to overcome the existing production and consumption pattern based on constant growth and increase in resources' capacity. The concept of a circular economy is increasingly seen as a major agenda item and challenge for the construction sector. Currently, the global problem of scarcity of resources and the need to reduce waste generation make the discussion about environmentally friendly production models more serious than ever before [1]. The construction sector is one of the world's largest waste generators. Thus, a circular economy can help reduce the environmental impact of a construction sector [2].

Construction companies along with the construction materials industry intensively and constantly consume huge amounts of natural resources and generate significant portions of construction waste. Thanks to this, construction gives rise to many environmental and social issues. As construction companies play a key role in sustainable development and because they use too many resources and land, even more attention needs to be paid to their economic development. For instance, the construction companies themselves are actively incorporating recycling practices. In addition, one should keep in mind that construction products and real estate represent a class of assets associated with intense carbon emissions. Therefore, the construction industry may be considered a key component in delivering the world for a sustainable future [3]. From this perspective, it is important to find new ways and methods to green the construction and building operations and ensure that the economic interests of all stakeholders involved in the development of construction projects are met [4].

In-house recycling is an important step not only towards the development of environmentally friendly investment and construction projects (sustainable construction), but also towards implementing those projects efficiently. In this case, recycling is seen as a response of the construction industry to challenges brought by sustainable development in socioeconomic and environmental spheres [5].

The recycling of construction and demolition waste (CDW) has achieved significant success in the EU and US, and their levels of waste processing exceeded 80% [6,7]. In Russia, recycling is just beginning to gain popularity among construction companies [8]. A building is a structure experiencing complex interactions throughout its lifespan, which is why the CDW recycling practices involve many parties. The bulk of CDW comes from private actors. In the future, the recycling of materials is likely to be performed by enterprises and subsidiaries that previously have built and demolished the building [9].

Developing a system of standards to balance the development of green construction waste management will bring significant changes to the economic, social, environmental, and ethical spheres. The imitation of the concepts of the development of technocentrism is unacceptable today. As part of the implementation of green building, it is possible to envisage the modernization of the industry by introducing environmental standards, the market of secondary raw materials by means of recycling, and the development of a methodology for assessing production efficiency based on the concept of resource conservation with the processing of appropriate tools [10,11].

The most important factors for minimizing waste are reduction, reuse, and recycling, also known as the 3R strategy [12]. Recycling, one of the key ways to minimize waste, offers the following benefits: (1) reduced demand for materials made from primary resources; (2) reduced use of energy for transporting waste and producing primary materials; and (3) the disposal of waste that would otherwise take up the landfill. Waste from construction and demolition have two sides of origin: materials arising from the demolition, construction, reconstruction, or alteration of buildings, as well as the construction, replacement, repair, or alteration of infrastructure such as roads, tunnels, sewers, water, electricity, telecommunications, and airports [13].

Reducing waste and promoting high-quality waste management involve promoting the future cyclic use of building elements, components, and parts, with a focus on generating less waste and on the potential for reuse or high-quality recycling of key building elements after deconstruction. This includes efforts to develop the value chain: first, reuse or recycle resources (i.e., materials) in such a way that most of the material's value is conserved and recovered at the end of the building's life, and, second, the design of components and use of various construction methods for reuse (or recycling to avoid reuse) [14]. Increased recycling levels lead to more jobs in the overall solid waste industry [15].

The major economic challenges facing the construction company when introducing recycling practices are associated with the stakeholders' doubts over financial benefits of recycling. Despite these concerns, recycling can still be considered an integral part of sustainable construction and an approach for enhancing efficiency, productivity, and profitability of the company [16]. The main obstacles to positive changes are insufficient customer demand, top management's fear of low profit margins, and the failure of short-term expenditures to contribute to long-term sustainability [17]. The above aspects reinforce the need to implement recycling programs and detailed methodological approaches to assessing their impact on the construction industry. The limiting factors that can constrain the development of recycling practice in construction companies are the long payback periods and low finance [18,19].

The construction industry plays a vital role in the global economy. Given the relevance and diversity of environmental issues that it encounters, many researchers have put their efforts to solve the problems of recycling and sustainability in the sector. In general, the investigation tackled the following issues:

(1) improvement of technologies on construction waste recycling [20];
(2) assessment and modeling of certain aspects of construction object's life cycle [21,22];
(3) creation of new materials from the construction waste [23,24];
(4) cost-effective methods to assess assets and risks in recycling projects [25];
(5) information technologies for solving recycling challenges in construction [26];
(6) improvement of legal regulation mechanisms and the creation of a recycling policy [17]; and
(7) application of recycling principles against the backdrop of sustainable development in the construction industry [27,28].

However, even though construction companies have the ability to incorporate various waste recycling (upcycling) practices, the methodological framework for decision-making is rather poor. This study aimed to fill this gap by developing a methodological approach for the assessment of waste management efficiency in the context of recycling at construction enterprises. This determined the purpose of this study—to assess the degree of influence of recycling and upcycling technologies on the level of efficiency of large construction companies in the context of waste management practice. Based on the formed research goal, the following hypotheses were identified:

H1. *Recycling and upcycling affect the waste management efficiency of a large construction company.*

H2. *Traditional waste disposal significantly affects the waste management efficiency of a large construction company.*

H3. *The combined use of recycling and waste disposal has a significant impact on the waste management efficiency of a large construction company.*

2. Materials and Methods

The study was carried out using materials from three construction companies—Hochtief (Essen, Germany), Kiewit (Omaha, NE, USA), and LSR Group (St. Petersburg, Russia)—during 2015–2019. These companies were selected for the study since they occupy a leading position in the construction industry of their country and use the concept of waste management in their activities. The initial data for the study were the financial and corporate reporting of the specified companies for the stated period.

The logic of this study assumed the implementation of several interrelated stages:

1. Determination of the relationship between the level of recycling efficiency, the company's profit and its investment in waste management.

The paper proposes the following methodological approach for determining the efficiency indicator of recycling (upcycling). It is assumed that the costs of disposal of construction waste (DC_{cw}) consist of waste collection costs (CC_{cw}) and costs of intermediate works (SC_{cw}) on collected construction waste sorting. They can be expressed this way:

$$DC_{cw} = CC_{cw} + SC_{cw} \tag{1}$$

The total cost of disposal of construction waste can be divided into the costs incurred in landfill disposal and the costs incurred in recycling [29]. Moreover, the costs (LC_{cw}), incurred for disposal at the landfill consist of collection and transportation costs as well as disposal costs [26], which is reflected in the following equation:

$$LC_{cw} = DC_{cw} - SC_{cw} + TC_{cw} + RC_{cw} \quad (2)$$

where TC_{cw} is the cost of transporting construction waste to the landfill; RC_{cw} is the cost of disposal of construction waste.

Intermediate operating costs SC_{cw} for the classification of construction waste collected in Equation (2) are excluded from the construction waste processing cost (DC_{cw}) in accordance with the conditions of waste disposal.

Recycling costs (ReC_{cw}) are calculated as follows [26]:

$$ReC_{cw} = DC_{cw} + SCR_{cw} + PC_{rg} - PC_{rg} \quad (3)$$

where SCR_{cw} is the transportation cost to the processing facility; PC_{rg} is the production cost of processed material; SC_{rg} is the cost of selling processed products. In Equation (3), PC_{rg} reduces processing costs (ReC_{cw}) on income from product sales.

Transportation costs in this study were determined on the basis of the constant cost of transporting construction waste. This assumption may be a limitation of the study, since the cost of transporting construction waste may vary depending on the region, but depends on the type of object being transported, the type of vehicle, and the distance of transportation. At the same time, the prices for intermediate waste processing and waste disposal differ. This is due to the fact that, in the case of intermediate waste processing, this is preliminary work (crushing and pre-sorting) before transportation, and the volume is relatively small for the same weight compared to the waste that needs to be disposed of, which reduces transportation costs.

This study considers recycling cost PC_{rg} as the cost of obtaining recycled construction waste and converting it into a finished product. Moreover, the cost of selling products for disposal (SC_{rg}) involves the determination of the price per unit of delivery of the product (see Equation (3)). At the same time, there is a limitation of this study, since it is difficult to accurately assess the cost of production of building material, therefore it is estimated through the selling price of the product. As production costs increase PC_{rg}, selling price SC_{rg} increases, so one can assume that PC_{rg} and SC_{rg} have the following linear or nonlinear relationship. This study assumes that PC_{rg} and SC_{rg} have a linearly proportional relationship:

$$PC_{rg} = \left(1 - pm_{rg}\right) \cdot SC_{rg} \quad (4)$$

where pm_{rg} represents the profit margin (%) of the sales of the recycled product [30].

The proposed indicator of waste management efficiency in the context of the effectiveness of construction waste recycling is the ratio between costs LC_{cw} and recycling costs ReC_{cw}, incurred in waste processing as defined above. This ratio can be displayed by applying LC_{cw} and ReC_{cw}, defined in Equations (2) and (3), respectively. Thus, one can get:

$$RE_c = \frac{DC_{cw} - SC_{cw} + TC_{cw} + RC_{cw}}{DC_{cw} + SCR_{cw} + PC_{rg} - PC_{rg}} \quad (5)$$

If $RE_c > 1$, i.e., if the processing cost (ReC_{cw}) is less than disposal cost (LC_{cw}), it means that there is a benefit to a company from recycling (which also varies depending on the type of secondary product to be recycled). In Equation (5), TC_{cw}, SCR_{cw}, and RC_{cw} are the general (fixed) costs that apply regardless of the type of recycled secondary product, while SC_{cw} and SC_{rg} are general (fixed) costs that depend on the type of secondary product. At the same time, transportation costs TC_{cw} and SCR_{cw} may depend on transportation distance.

Based on the ratio of the recycling efficiency indicator (RE_c), net profit, and volumes of investments in waste management of the studied companies, the interdependence of these indicators for the period 2015–2019 was analyzed. Taking into account the revealed dependencies, the transition to the next stage was carried out-the equations of linear regression were formed.

1. Modeling the predicted results (profit and investment) based on the constructed linear regression equations for the construction companies under study. For this, three waste management efficiency scenarios were created. The waste management efficiency in this case is defined as a ratio of construction waste disposal to the cost of recycling or processing. Thus, the prediction was made about changes in the costs of waste collection, transport, and disposal in a landfill.
2. Changes in processing cost (costs of transporting waste to a recycling facility, waste recycling, and sale). In the first scenario, the recycling efficiency is higher by 10%, in the second scenario by 20%, and in the third scenario by 30%.
3. Conducting two-way ANOVA (Analysis of Variance) with repetitions to determine the degree of influence of the level of waste disposal and recycling on the level of waste management of the construction companies under study. The ANOVA allows for the identification of both the synergistic effect of two factors and the interaction between them. This study used ANOVA to determine the relationship between waste management efficiency Y (RE_c) and two variables (factors), which are within the construction enterprise's control and influence, namely LC_{cw} and ReC_{cw}. The independent variables used in this study are the disposal cost and the processing cost [31]. The levels for the processing cost are designated as "Factor (recycling) j" (*j* runs from 1 to a), and the levels for the disposal cost are designated as "Factor (disposal) i" (*i* runs from 1 to b). For each pair of factor levels, there is one sample of measures *m*. Each of the measurement data be designated as "k" (*k* runs from 1 to m).
4. The values of RE_c (Y) obtained by solving Equation (5) at varying levels of *j* "Factor (recycling)" and *i* "Factor (disposal)" are denoted as Y_{ijk}. Overall, there are 6 samples $(\text{a} \times \text{b} = 3 \times 2)$.

A fragment of the original data (for the Hochtief company) is shown as an example in Table 1.

Table 1. Initial data for two-way analysis of variance with repetitions for Hochtief.

Factors	Factor (Disposal) 1	Factor (Disposal) 2	Factor (Disposal) 3
Factor (recycling) 1	7.536	7.932	8.329
Factor (recycling) 2	7.159	7.536	7.912
Factor (recycling) 3	6.801	7.159	7.517
Factor (recycling) 4	6.461	6.801	7.141
Factor (recycling) 5	6.138	6.461	6.784
Factor (recycling) 6	5.846	6.153	6.461
Factor (recycling) 7	5.567	5.860	6.153
Factor (recycling) 8	5.302	5.581	5.860
Factor (recycling) 9	5.050	5.315	5.581

Source: Generated by the authors.

When forming the initial data for the two-way analysis of variance with repetitions, a matrix was formed in which assumptions were made about deviations in the negative and positive directions from the explicit indicators of disposal and recycling by 5% for each option. Let us assume that variances for all samples σ^2 are unknown but equal. Let us also assume that "Factor (recycling) 5" and "Factor (disposal) 2" are based on the value as of 2019 and can take on values with a 5% increase towards "Factor (recycling) 6" and "Factor (disposal) 3" and a decrease towards "Factor (recycling) 4" and "Factor (disposal) 1". The waste management efficiency is determined based on the cost of construction waste disposal and the cost of recycling through RE_c. By determining the share of the influence of each of the factors in the total aggregate, the degree of influence of waste disposal and recycling on the final result in percentage was determined. Thus, the two-way analysis of variance with repetitions in this study served as a tool to determine the degree of influence of the level of waste disposal and recycling on the level of waste management of the studied construction companies.

3. Results

The surveyed companies—Hochtief, Kiewit and LSR Group—use waste management in their activities. Hochtief always adapts environmental protection measures to the respective project. Especially when implementing projects in the framework of public–private partnerships, it takes into account the top-down technique for underground construction and together with clients develops concepts that ensure resource savings, climate-friendliness, and low maintenance costs, both in construction and in the transport infrastructure. Already at the design stage, the recycling or upcycling of materials is assessed, thereby helping to minimize emissions harmful to the environment and climate, as well as conserve resources.

Kiewit, for example, has completed a $115 million runway renovation project at McCarran, Las Vegas, with an 8600 ft runway, two taxiways, drainage, demolition, utilities, electrical and communication works, and concrete and asphalt pavement. The project was built in 66 different phases and ran through a number of existing warehouse taxiways to provide access to active businesses. The amount included 83,000 square yards of concrete; 250,000 tons of asphalt; and over 35,000 ft of drainage pipe ranging from 18 to 66 inches. However, most of the existing coverage had to be removed. Kiewit crushed and took off-site asphalt pavement for recycling and crushed and recycled on-site the concrete pavement for aggregate.

The LSR Group is also committed to minimizing waste generation and is looking for solutions to reuse different types of waste. LSR Group regularly monitors compliance with the agreed waste generation and disposal limits, as well as compliance with the requirements for temporary waste accumulation sites. For example, in 2018, the company transferred construction waste to third-party organizations: 41% for neutralization (change of the weight and physicochemical properties of waste to minimize its adverse impact on the environment and humans), 36% for disposal, and 23% for placement at third-party facilities.

An assessment of waste management effectiveness in the context of recycling (upcycling) and disposal in construction companies Hochtief, Kiewit, and LSR Group is shown in Figure 1.

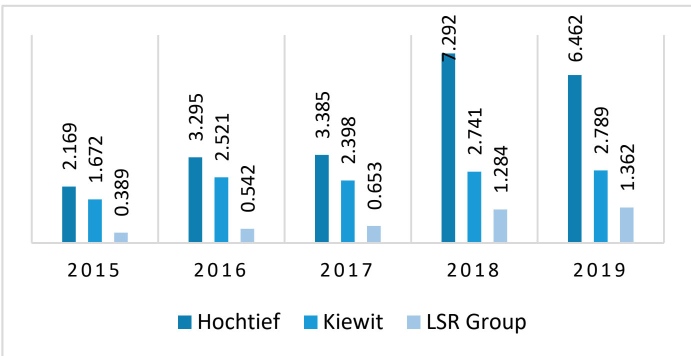

Figure 1. Efficiency of recycling (upcycling) (RE_c) of the surveyed construction companies in the context of waste management. Source: Compiled by the authors based on companies' materials.

During the study period, LSR Group did not provide investments in development, renovation of fixed assets (equipment), and intangible assets (technologies). Although the company did not have investments in development, there was strategic planning and implementation of a development strategy—namely, a strategy of concentrated growth (an increase in the supply of construction products within the primary real estate market and an increase in sales volumes within the mastered market niche). At the same time, the company is not focused on the introduction of recycling and upcycling within the framework of the specified development strategies, which is confirmed by the lack of appropriate investments. The value of waste management efficiency (RE_c) until 2017 was at the level from 0 to 1, that is, at an average constant level. This value of the indicator shows the fulfillment of strategic targets, but the lack of synergy and significant progress. The latter is due to insufficient provision of technologies and equipment. The lack of investment in the conditions of the continuous growth of strategic development indicators at the enterprise indicates, e.g., the possibility of the loss of manufacturability level and equipment for the purpose of implementing waste management. The ratio of the net profit indicator, the volume of investments in waste management, and the efficiency of recycling for 2015–2019 is shown in Figure 2.

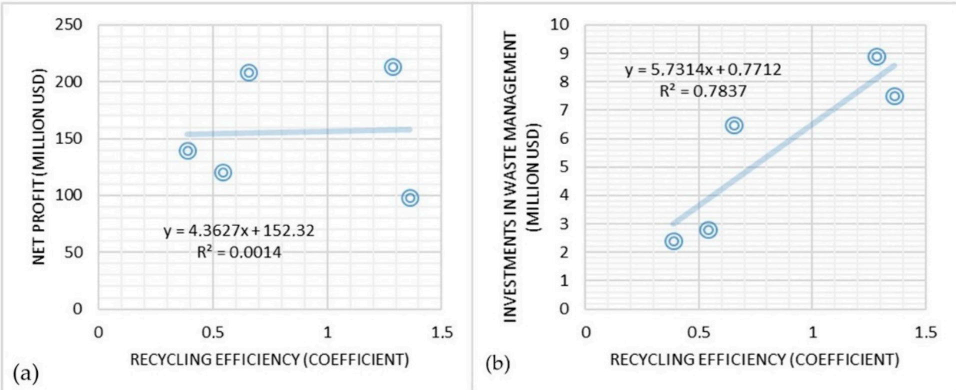

Figure 2. Correlation between: net profit and the level of recycling efficiency in the LSR Group (**a**); and investment volumes and the level of recycling efficiency in the LSR Group (**b**). Source: Compiled by the authors.

It can be argued that there is a significant relationship between investment in waste management and recycling efficiency, since $R^2 = 0.78$, which is rather close to 1. At the same time, there is practically no relationship with the level of the company's net profit. This indicates the active policy of the LSR Group towards waste management over the past five years. However, given the fact that the implemented projects have a long payback period, one can expect an increase in efficiency in the near future. Otherwise, they can be considered ineffective.

Kiewit has invested in development, renovation of fixed assets (equipment), and intangible assets (technologies). Accordingly, this was laid down at the planned strategic level. Taking into account the availability of investments in waste management, the company carries out strategic planning and implements:

- a strategy of concentrated growth (sale of a highly competitive portfolio of real estate objects within the framework of the primary real estate market);
- an integrated growth strategy (development of new market segments for the promotion and sale of construction products by reaching consumers with low income); and
- innovative local strategy.

In 2019, the enterprise had the largest volumes of income (proceeds) from the sale of construction products in the direction of implementing an integrated growth strategy (development of new market segments and promotion and sale of construction products by reaching consumers with low incomes). The ratio of the net profit indicator, the volume of investments in waste management and the efficiency of recycling for 2015–2019 is shown in Figure 3.

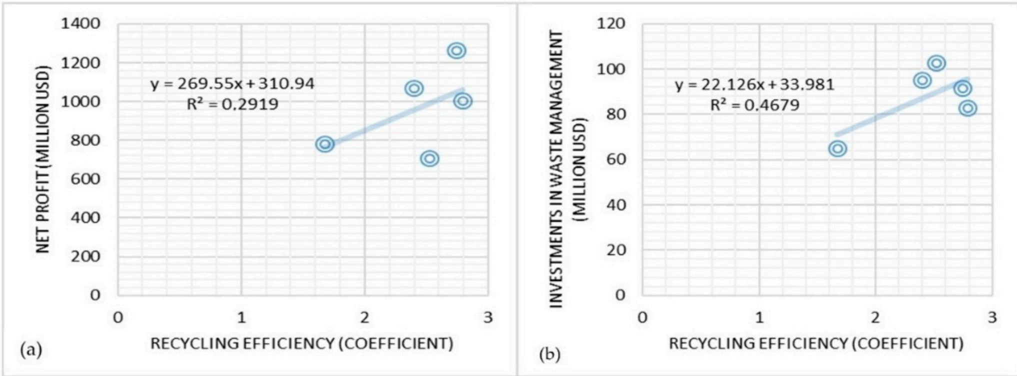

Figure 3. Correlation between: net profit and recycling efficiency in Kiewit (**a**); and investment volumes and recycling efficiency in Kiewit (**b**). Source: Compiled by the authors.

This has been facilitated by a reduction in the level of costs based on recycling and upcycling in the context of waste management. The efficiency of recycling in waste management of the surveyed enterprise (RE_c) in 2019 was 2.789. At the same time, the highest value of this indicator was noted in the implementation of the integrated growth strategy (development of new market segments and promotion and sale of construction products by reaching consumers with low incomes), which was due to lower costs compared to other areas. The relationship between investment in waste management and recycling efficiency is significantly higher compared to the impact on net profit. This indicates the effectiveness of investment projects implemented in the company in the context of waste management. However, due to their long-term orientation, they do not yet bring high volumes of profit, although the result is being observed.

Hochtief strives for a consistently high recycling rate (including regeneration) of at least 85% annually. Hochtief's diversified project activities lead to fluctuations, as large infrastructure and mining projects, for example, generate particularly large volumes of waste at certain stages. In other construction projects, the company reuses as much waste as possible, for example, as backfill. The ratio of net profit indicator, the volume of investments in waste management, and efficiency of recycling for 2015–2019 is shown in Figure 4.

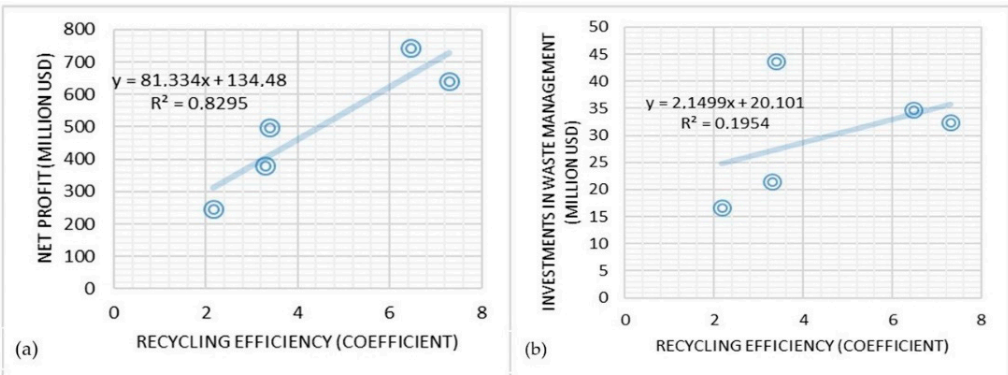

Figure 4. Relationship between: net profit and recycling efficiency at Hochtief (**a**); and investment volumes and recycling efficiency at Hochtief (**b**). Source: Compiled by the authors.

Fluctuations in waste volumes are normal due to large fluctuations in business projects. Some of the projects implemented in 2018 were particularly resource intensive. Where possible, waste is reused in other projects, with an overall recycling rate of 81.3% in 2019 (2018: 87.1%). Hochtief develops waste management concepts for each project at an early stage to facilitate the economic and environmental design of material flows. Whenever possible, materials should be reused in the same project. Dedicated tools such as Turner Waste Tracking System are used in some areas to calculate and categorize by type. Due to the cleanest possible separation of construction waste, the company achieves a very high recycling quality. At Hochtief, however, the term recycling covers both recycling and upcycling. The Hochtief recycling rate is the volume of all recycled and reused waste as a percentage of the total waste. At the same time, there is a high relationship between the efficiency of recycling and net profit, since $R^2 = 0.83$, which is very close to 1. There is no strong link between investment in waste management and recycling efficiency. This may be due to a cumulative investment effect, as a result of which the sensitivity to investment projects decreases.

The results of modeling the possible impact of increasing recycling efficiency on the activities of the companies under study are shown in Table 2. In this case, there was an increase in coefficients in the equations of dependence between recycling efficiency and net profit (y_{NP}) and between recycling efficiency and investments in waste management (y_{Inv}), as shown in Figure 4. Three recycling efficiency scenarios were developed, in which recycling efficiency increased by 10%, 20%, and 30%, respectively. Based on the proposed scenarios, y_{NP} and y_{Inv} were determined.

Table 2. Regression modeling of the impact of recycling efficiency on the net profit and investment volumes of the surveyed companies in the context of waste management.

Regression Models	Hochtief			Kiewit			LSR Group		
	a	**b**	**-**	**a**	**b**	**-**	**a**	**b**	**-**
Net profit (y_{NP})	134.48	81.334	-	310.94	269.55	-	152.320	4.3627	-
Investments in WM (y_{Inv})	20.101	2.1499	-	33.981	22.126	-	0.771	5.731	-
Scenario modeling	x	y_{NP}	y_{Inv}	x	y_{NP}	y_{Inv}	x	y_{NP}	y_{Inv}
Scenario 1	7.108	712.618	35.383	3.068	1137.892	101.861	1.498	158.856	9.358
Scenario 2	7.754	765.176	36.772	3.347	1213.070	108.032	1.634	159.450	10.139
Scenario 3	8.401	817.734	38.161	3.626	1288.247	114.203	1.771	160.045	10.919

Source: Compiled by the authors.

For all the companies under study, one can state the fact of a positive impact of recycling on net profit, since with each increase in its efficiency indicator, according to the next scenario, there is an increase in net profit. However, the highest predicted result for Kiewit should be highlighted. A 1% increase in waste management efficiency based on recycling (upcycling) contributes to an increase in profits by 15.4%. At the same time, the need to increase investment in waste management is an increase of 1.3%. For Hochtief, a 1% increase in the level of waste management efficiency based on recycling (upcycling) could lead to an increase in net profit by 4.2%, and investment in this area by 1.6%. For LSR Group, a 3.9% increase in net profit is observed, while it is necessary to increase investment in waste management by 2.3%. For a more in-depth study of the impact of recycling (upcycling) and waste disposal on waste management efficiency, factor analysis was carried out. The results are shown in Table 3. Data in Table 3 include variation sources, the sum of squares indicating the amount of variation of the estimated factor level mean around the overall mean (SS), the degree of freedom (df), F-statistic values, p-values, and F-critical values. The degree of influence of each examined factor was determined by the p-value. The significance level was set to $p < 0.05$.

Table 3. Indicators of two-way ANOVA for the surveyed construction companies.

Company	Variation Source	*SS*	*df*	*MS*	*F*	*p-Value*	*Fcrit.*
Hochtief	Recycling/upcycling	17.280	2	8.640	78.709	0.000	3.555
	Disposing	1.921	2	0.960	8.749	0.002	3.555
	Interaction	0.029	4	0.007	0.066	0.991	2.928
Kiewit	Recycling/upcycling	8.808	2	4.404	83.419	0.000	3.555
	Disposing	0.713	2	0.356	6.752	0.006	3.555
	Interaction	0.035	4	0.009	0.168	0.952	2.928
LSR Group	Recycling/upcycling	0.285	2	0.143	79.975	0.000	3.555
	Disposing	0.156	2	0.078	43.690	0.000	3.555
	Interaction	0.001	4	0.000	0.118	0.974	2.928

Note: SS is the sum of squares indicating the amount of variation of the estimated factor level mean around the overall mean; df is degree of freedom; and F is the statistic. Source: Compiled by the authors.

Based on the analysis of variance, taking into account the use of recycling (upcycling) and disposal of construction waste, it can be argued that these factors have a strong influence on waste management efficiency, because the *p*-value for all single variants of the influence of factors is below 0.05. This proves Hypotheses H1 and H2. A closer connection is present in the context of the introduction of recycling (upcycling). The interaction of both factors at the same time is almost impossible (p-value > 0.05); therefore, Hpothesis H3 has no confirmation. The most tangible impact of recycling (upcycling) is on Kiewit (84%) and Hochtief (82%). For LSR Group, this figure is 60%, and the disposal factor has a fairly strong influence (32%). The results obtained indicate that companies that currently have a high level of recycling (upcycling) efficiency are practically not focused on traditional waste disposal, since recycling has a more significant and positive impact on the efficiency of their activities.

4. Discussion

The proposed indicator of waste management efficiency is based on a cost approach. At the same time, the modeling of the influence of changes in this indicator on the performance of construction companies, expressed in the context of profitability, was carried out. Therefore, the advantage of the proposed methodological approach is that it is balanced. Based on the assumptions made in the study, companies can form an adaptive mechanism for waste management processes in order to improve their efficiency, save resources and introduce new technologies in the context of recycling (upcycling) [32]. At the same time, companies are given the opportunity to identify possible risks of the implementation of recycling (upcycling), the formation of alternative scenarios for the impact of relevant projects, programs, and other activities on its effectiveness [33].

This study confirms that recycling provides a high level of potential economic benefit. This may be due to the creation of income from the sale of materials, the formation of a waste-free construction site in order to save space, etc. The use of recycling contributes to a positive reputation for a company, which is very important for the construction giants that operate in international markets [34].

The limitation of this study is the neglect of some of the problems associated with recycling and upcycling. The idea of recycling waste generated as a result of neutralization and recycling is not always supported, and preference is given to new building materials that are not readily available. Another issue is the use of problematic and unaesthetic constructions that are not mechanically stable [11]. Waste can be treated by shrinking, recycling, and reusing. However, this process inevitably entails costs associated with additional requirements for inventory and waste processing, and this becomes a deterrent to the introduction of recycling and upcycling. Official institutions, referring to legal norms and rules, play a decisive role in motivating firms and individuals to implement recycling and upcycling [3]. In addition, the practice of using off-site products and components (low-waste construction technology), material-specific waste handling (waste sorting), and construction and material standardization are also important to help reduce construction waste on-site and proper handling of building materials [35].

The proposed methodological approach is limited to a narrow range of variables. For instance, the study examined the relationship between net profit and recycling efficiency. The net profit is influenced by many factors, and recycling efficiency is one of them. A weak connection between recycling efficiency and net profit was found in two enterprises under consideration. At the same time, the recycling rate is also influenced by multiple factors. Therefore, an in-depth factor analysis may require the use of multiple linear regression. Expanding the range of variable may reduce the risk of bias. At the same time, future studies can involve a greater number of companies to determine the general trends by region or country. The ANOVA statistical method has been proven a feasible tool in determining the impact of factors.

This study highlights the significant benefits of upcycling for waste management by construction giants. Recycling (upcycling) improves the efficiency of construction waste management by reducing the need to purchase new materials. However, for some companies, there may be lower potential savings compared to waste disposal. This may require additional resources or the involvement of third parties, the use of their equipment or expertise. It is necessary to take into account the properties of individual materials, which are important for the possible implementation of recycling [36], as well as fluctuations in the development of the companies under study [37]. Therefore, in the future, this study can be deepened in the direction of modeling the efficiency of recycling (upcycling), taking into account a specific set of variables characteristic of each company under study. At the same time, it is possible to expand the field of research based on separation of directions for analyzing recycling and upcycling effectiveness. It is also possible to expand the study of the spectrum of influence of recycling (upcycling) on the environment and sustainable development of countries and regions [37].

Building material, which is often harmless at first glance, actually has a significant environmental effect if all stages of its life cycle are taken into account: mining, preparation of raw materials, and production and transportation to the place of sale [38]. Therefore, at all stages of the life cycle of construction products, it is necessary to provide for the planned and consistent implementation of organizational, legal, and technical measures based on the selected parameters of an environmental, resource-saving, and resource-reproducing nature based on an integrated environmental and economic management model. The main goal of this is to ensure the minimum environmental costs for the given and existing technical development of construction. At the same time, an economic and social justification for the construction of new processing enterprises is necessary, as well as the reorganization of existing ones, which have insufficiently loaded production areas. The research results may overlap with the issues of an appropriate regulatory framework development for the use of secondary products from construction waste for the manufacture of construction materials, as well as technical research aimed at the development of construction materials using recycled construction waste.

5. Conclusions

Based on the assessment of the efficiency of waste management in the context of recycling (upcycling) and disposal in construction companies, it is possible to assert a positive result and an upward trend for the companies under study for the period 2015–2019. Despite the insufficient efficiency of recycling (upcycling) of one of the companies at the beginning of the study period, its transformation in a positive direction was detected during 2018–2019. This confirms the indisputable positive dynamics of recycling (upcycling) of construction waste in comparison with their traditional disposal in the process of company's waste management.

The analysis of the ratios of the net profit indicator, the volume of investments in waste management, and the efficiency of recycling (upcycling) for the study period provided an opportunity to form and identify the interdependence of these indicators for construction giants. On this basis, a significant relationship was determined between investments in waste management and the efficiency of recycling for one of the surveyed companies, which has just begun to benefit from its implementation in the last two years. In this case, it can be argued that there is a low level of relationship between the efficiency of recycling (upcycling) and net profit, since in such conditions a company is strategically set to implement recycling (upcycling) to obtain benefits in the long term. A key prerequisite for this may be the long payback period of recycling (upcycling) projects compared to the disposal of construction waste.

The two companies are characterized by a relationship between the amount of investment in waste management and recycling efficiency. Its level is significantly higher compared to the impact on net profit. This indicates the effectiveness of the companies' waste management policies in the context of recycling (upcycling), yet the study is limited to a narrow range of variables. If a company is characterized by a high level of efficiency of recycling (upcycling), but there is practically no relationship between this indicator and investments in waste management, it can be argued that there are two possible options for business development in this context. The first option provides for a softening of the implementation of the policy in this direction, since the company already has a fairly high result. Such actions are aimed at obtaining and maintaining advantageous positions formed in previous years. However, this option can be used in the short term. The second option involves focusing on investment in innovative recycling (upcycling) projects. This can serve to improve the efficiency of waste management in the long term in achieving strategic intentions in this context.

The implemented regression modeling of the impact of recycling efficiency on the net profit and the volume of investments of the studied companies in the context of waste management demonstrated a positive effect of recycling (upcycling) on the net profit of all studied companies. At the same time, for each of the companies under study, there is a different effect and degree of influence of this indicator according to the formed scenarios. The range of difference between the obtained results of the predicted increase in waste management efficiency based on recycling (upcycling) by 1% starts from 10%. At the same time, the range of the need to increase investment in waste management is from 1.3% to 2.4%. Thus, despite the fairly high efficiency of recycling (upcycling), the prospective increase in its level does not have a proportional relationship with profit but depends on the development factors of the construction company. For the purpose of a deeper study and comparison of the impact of recycling (upcycling) on waste management efficiency, a two-way analysis of variance was carried out. The results demonstrate a strong influence of these factors on the efficiency of waste management, especially in the context of the introduction of recycling (upcycling). At the same time, it was recorded that the simultaneous interaction of both factors is practically impossible. This indicates the mutual exclusion of these factors. At the same time, for two companies under study, the degree of influence of the efficiency of recycling (upcycling) is more than 80%. For the third one, at this stage of development, the factor of construction waste disposal is still tangible. The results obtained allow asserting that the companies that have a high level of recycling (upcycling) efficiency are practically not focused on traditional waste disposal, since recycling has a more significant and positive impact on the efficiency of their activities.

Since the recycling efficiency of a company can be influenced by many factors, future studies need to include more business-specific variables. In the future, this study can be deepened in the direction of modeling the effectiveness of recycling (upcycling), taking into account the expansion of the set of variables based on the specifics of the functioning of each studied company. This will allow the proposed methodological approach to be applied in other industries. On this basis, it is possible to continue the study in the context of assessing the impact of recycling (upcycling) on the environment and sustainable development of countries and regions.

Author Contributions: Conceptualization, G.W., D.K. and L.V.-S.; methodology, S.K. and L.V.-S.; software, G.W. and S.K.; validation, G.W. and L.V.-S.; formal analysis, S.K.; investigation, G.W., S.K. and L.V.-S.; resources, G.W. and D.K.; data curation, L.V.-S.; writing—original draft preparation, G.W. and L.V.-S.; writing—review and editing, S.K. and D.K.; visualization, G.W. and L.V.-S.; and supervision, S.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data will be available on request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Abramov, A.V.; Vorona-Slivinskaya, L.H.; Kusraeva, O.S. Recycling of industrial waste. *Risk Manag. Probl. Technosphere* **2012**, *2*, 84–87.
2. Afshari, A.R.; Górecki, J. Circular Economy in Construction Sector. *BGJ Consult.* **2019**, *1*, 15–44.
3. Wang, X.; Yu, R.; Shui, Z.; Song, Q.; Liu, Z.; Liu, Z.; Wu, S. Optimized treatment of recycled construction and demolition waste in developing sustainable ultra-high performance concrete. *J. Clean. Prod.* **2019**, *221*, 805–816. [CrossRef]
4. Baldassarre, B.; Schepers, M.; Bocken, N.; Cuppen, E.; Korevaar, G.; Calabretta, G. Industrial Symbiosis: Towards a design process for eco-industrial clusters by integrating Circular Economy and Industrial Ecology perspectives. *J. Clean. Prod.* **2019**, *216*, 446–460. [CrossRef]
5. Oliveira Neto, G.C.; Correia, J.M. Environmental and economic advantages of adopting reverse logistics for recycling construction and demolition waste: A case study of Brazilian construction and recycling companies. *Waste Manag. Res.* **2019**, *37*, 176–185. [CrossRef] [PubMed]
6. Gálvez-Martos, J.L.; Styles, D.; Schoenberger, H.; Zeschmar-Lahl, B. Construction and demolition waste best management practice in Europe. *Resour. Conserv. Recycl.* **2018**, *136*, 166–178. [CrossRef]
7. Aslam, M.S.; Huang, B.; Cui, L. Review of construction and demolition waste management in China and USA. *J. Environ. Manag.* **2020**, *264*, 110445. [CrossRef] [PubMed]
8. Fedotkina, O.; Gorbashko, E.; Vatolkina, N. Circular economy in Russia: Drivers and barriers for waste management development. *Sustainability* **2019**, *11*, 5837. [CrossRef]
9. Mhatre, P.; Panchal, R.; Singh, A.; Bibyan, S. A Systematic Literature Review on the Circular Economy Initiatives in the European Union. *Sustain. Prod. Consum.* **2020**, *26*, e00384.
10. Lu, W.; Chi, B.; Bao, Z.; Zetkulic, A. Evaluating the effects of green building on construction waste management: A comparative study of three green building rating systems. *Build. Environ.* **2019**, *155*, 247–256. [CrossRef]
11. Voskresenskaya, E.; Vorona-Slivinskaya, L.; Panov, S. Environmental safety of green construction and requirements of urban planning legislation. In *E3S Web of Conferences*; EDP Sciences: Ulis, France, 2019; Volume 91, p. 07010.
12. Turkyilmaz, A.; Guney, M.; Karaca, F.; Bagdatkyzy, Z.; Sandybayeva, A.; Sirenova, G. A Comprehensive Construction and Demolition Waste Management Model using PESTEL and 3R for Construction Companies Operating in Central Asia. *Sustainability* **2019**, *11*, 1593. [CrossRef]
13. Tam, V.W.; Le, K.N.; Wang, J.Y.; Illankoon, I.M. Practitioners recycling attitude and behaviour in the Australian construction industry. *Sustainability* **2018**, *10*, 1212. [CrossRef]
14. Pantini, S.; Rigamonti, L. Is selective demolition always a sustainable choice? *Waste Manage.* **2020**, *103*, 169–176. [CrossRef] [PubMed]
15. Liu, Y.; Park, S.; Yi, H.; Feiock, R. Evaluating the employment impact of recycling performance in Florida. *Waste Manage.* **2020**, *101*, 283–290. [CrossRef] [PubMed]
16. Gorecki, J. Circular Economy maturity in construction companies. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, UK, 2019; Volume 471, p. 112090.
17. Huang, B.; Wang, X.; Kua, H.; Geng, Y.; Bleischwitz, R.; Ren, J. Construction and demolition waste management in China through the 3R principle. *Resour. Conserv. Recycl.* **2018**, *129*, 36–44. [CrossRef]
18. Luciano, A.; Cutaia, L.; Cioffi, F.; Sinibaldi, C. Demolition and construction recycling unified management: The DECORUM platform for improvement of resource efficiency in the construction sector. *Environ. Sci. Pollut. Res.* **2020**, 1–12. [CrossRef]
19. Shooshtarian, S.; Caldera, S.; Maqsood, T.; Ryley, T. Using Recycled Construction and Demolition Waste Products: A Review of Stakeholders' Perceptions, Decisions, and Motivations. *Recycling* **2020**, *5*, 31. [CrossRef]
20. Di Maria, A.; Eyckmans, J.; Van Acker, K. Use of LCA and LCC to help decision-making between downcycling versus recycling of construction and demolition waste. In *Advances in Construction and Demolition Waste Recycling*; Woodhead Publishing: Sawston, UK, 2020; pp. 537–558.

21. Teh, S.H.; Wiedmann, T.; Moore, S. Mixed-unit hybrid life cycle assessment applied to the recycling of construction materials. *J. Econ. Struct.* **2018**, *7*, 13. [CrossRef]
22. Núñez-Cacho, P.; Górecki, J.; Molina, V.; Corpas-Iglesias, F.A. New measures of circular economy thinking in construction companies. *J. EU Res. Bus.* **2018**, *2018*, 909360. [CrossRef]
23. Zhang, L.W.; Sojobi, A.O.; Kodur, V.K.R.; Liew, K.M. Effective utilization and recycling of mixed recycled aggregates for a greener environment. *J. Clean. Prod.* **2019**, *236*, 117600. [CrossRef]
24. Zhang, C.; Hu, M.; Dong, L.; Gebremariam, A.; Miranda-Xicotencatl, B.; Di Maio, F.; Tukker, A. Eco-efficiency assessment of technological innovations in high-grade concrete recycling. *Resour. Conserv. Recycl.* **2019**, *149*, 649–663. [CrossRef]
25. Ghisellini, P.; Ulgiati, S. Economic assessment of circular patterns and business models for reuse and recycling of construction and demolition waste. In *Advances in Construction and Demolition Waste Recycling*; Woodhead Publishing: Sawston, UK, 2020; pp. 31–50.
26. Xiao, S.; Dong, H.; Geng, Y.; Brander, M. An overview of China's recyclable waste recycling and recommendations for integrated solutions. *Resour. Conserv. Recycl.* **2018**, *134*, 112–120. [CrossRef]
27. Cai, G.; Waldmann, D. A material and component bank to facilitate material recycling and component reuse for a sustainable construction: Concept and preliminary study. *Clean Technol. Environ. Policy* **2019**, *21*, 2015–2032. [CrossRef]
28. Jain, S.; Singhal, S.; Pandey, S. Environmental life cycle assessment of construction and demolition waste recycling: A case of urban India. *Resour. Conserv. Recycl.* **2020**, *155*, 104642. [CrossRef]
29. Sobotka, A.; Sagan, J. Cost-saving Environmental Activities on Construction Site–Cost Efficiency of Waste Management: Case Study. *Procedia Eng.* **2016**, *161*, 388–393. [CrossRef]
30. Kwon, K.; Kim, D.G.; Lee, H.J.; Seo, E.A. Probability-based Cost Analysis for Recycling Secondary Products from Construction Waste. *J. Korean Recycl. Constr. Resour. Inst.* **2020**, *8*, 227–234.
31. Jin, R.; Li, B.; Zhou, T.; Wanatowski, D.; Piroozfar, P. An empirical study of perceptions towards construction and demolition waste recycling and reuse in China. *Resour. Conserv. Recycl.* **2017**, *126*, 86–98. [CrossRef]
32. Luangcharoenrat, C.; Intrachooto, S.; Peansupap, V.; Sutthinarakorn, W. Factors influencing construction waste generation in building construction: Thailand's perspective. *Sustainability* **2019**, *11*, 3638. [CrossRef]
33. Mukherjee, C.; Denney, J.; Mbonimpa, E.G.; Slagley, J.; Bhowmik, R. A review on municipal solid waste-to-energy trends in the USA. *Renew. Sust. Energ. Rev.* **2020**, *119*, 109512. [CrossRef]
34. Hu, Q.; Peng, Y.; Guo, C.; Cai, D.; Su, P. Dynamic Incentive Mechanism Design for Recycling Construction and Demolition Waste under Dual Information Asymmetry. *Sustainability* **2019**, *11*, 2943. [CrossRef]
35. Hasmori, M.F.; Zin, A.F.M.; Nagapan, S.; Deraman, R.; Abas, N.; Yunus, R.; Klufallah, M. The on-site waste minimization practices for construction waste. In *IOP Conference Series: Materials Science and Engineering*; IOP Publishing: Bristol, UK, 2020; Volume 713, p. 012038.
36. Iacoboaea, C.; Aldea, M.; Petrescu, F. Construction and demolition waste-a challenge for the European Union? *Theor. Empir. Res. Urban Manag.* **2019**, *14*, 30–52.
37. Boichenko, K.S.; Tepliuk, M.A.; Rekova, N.Y.; Stashkevych, I.I.; Morkūnas, M. Management of Fluctuation of Financial and Economic Integrated Development of Innovative Enterprise. *Financ. Credit. Act. Probl. Theory Pract.* **2019**, *3*, 62–69. [CrossRef]
38. VilloriaSáez, P.; Del Río Merino, M.; Porras-Amores, C.; Santa Cruz Astorqui, J.; González Pericot, N. Analysis of Best Practices to Prevent and Manage the Waste Generated in Building Rehabilitation Works. *Sustainability* **2019**, *11*, 2796. [CrossRef]