Cost-Saving Environmental Activities On Construction Site – Cost Efficiency of Waste Management: Case Study

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Abstract

Realization of Millennium Development Goals should be also reflected in construction industry. Sustainable consumption and production patterns can be associated with implementing and developing reverse logistics system on construction site to close the supply chain of construction materials. Initiating activities are undertaken already at the construction site, conditioning thereby further possibilities of resource recovery, stages of the recovery process, and total costs. Hence, the type, quantity and the quality of waste affect the cost of its collection – which can be a significant item in a project’s budget. The paper provides an overview of the existing national recovery systems and waste policies to provide background for the case study. A crucial part of the research is an analysis of three waste management scenarios for a particular construction project. “Anthropocentric”, “current” and “ecocentric” approaches were studied in terms of waste collection costs. Two extreme approaches were created as an alternative to usual waste management policy applied on construction site. The “antropocentric” approach is a reflection of ill-conceived waste management - assuming no segregation, which leads to high costs of waste processing. The “ecocentric” approach, in turn, assumes direct sales of sorted waste at lower prices, and also by reverse logistics within the project, thereby providing cost savings. The results show that policy of waste disposal encourages and even forces entrepreneurs to implement reverse logistics despite the additional duties and requirements. General conclusions of research confirm that currently operating systems of waste management on site are sustainable, but nevertheless, it is still possible to make them more eco-efficient and, at the same time, more profitable. This was proved in the analysis of the “Ecocentric” scenario, which could be also called as “Economic”.

Keywords: waste management; construction site; sustainable development; C&D debris

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1. Introduction

1.1. Sustainable development goals in construction industry

The new Agenda for Sustainable Development requires everyone, with no exceptions, to implement seventeen integrated and interrelated goals of sustainable development, expressed in 169 targets [1]. Due to the universal character of the obligation an issue to be considered is how the construction industry can contribute to the implementation of the postulations specified in the agenda. The article reflects the authors’ interest in the twelfth goal of the agenda, with its requirement to ensure sustainable consumption as well as develop and maintain sustainable production patterns. Its implementation in construction industry may be achieved by referring to sustainable materials management, e.g. by creating reverse chains for raw materials and construction products, i.e. the development of reverse logistics (RL). A certain achievement in this area of construction is the development of methods of facility deconstruction [2] and recycling technology [3]. When building a recovery network, some tips may be adopted from the production branch [4],[5]. Thus, we are able to substitute the use of non-renewable materials used in the production of construction products while minimizing the constantly increasing amount of waste deposited at landfill sites. This is certainly not an innovative concept – a market of recovered construction products has “naturally” functioned on the market for years. Nevertheless, to fully implement the twelfth goal of the agenda in construction the implemented reverse chains must be “balanced”, i.e. effective in the environmental and economic dimension while at the same time taking account of social aspects, which include, for instance, product safety. This is basically a challenge for the developed countries which have already implemented recovery systems but should consistently work at their improvement. The experience gathered in the process will undoubtedly support the systems being created in the developing countries.

1.2. “Waste-product” transformation

Recovery processes are aimed at transformation of waste into the form of raw materials, semi-products or products. However, to speak about a “waste-product” transformation, additional conditions must be met [6]: it must be re-used in the circulation of materials and construction products in the economy, i.e. applied for particular purposes; be in demand; meet technical requirements; cannot have negative effect on human life and health or the environment; meet specific requirements of the EU. There are numerous possibilities – directions of the recovery management for a type of material or construction product. In search of acceptable variants, it is possible to use the hierarchy of waste handling [7], i.e. successively consider reusing, resale, repairing, refurbishing, or other methods – the ultimate being energy recovery or, as a last resort, waste disposal. Selecting a particular solution a construction enterprise, which has generated waste as result of a construction project, first of all must consider the possibilities of introducing measures related to recovery, costs and the existing demand for the product obtained after waste transformation – so as not to lead to a long-term capital freeze, which is even more important because the products will often be stored at the construction site itself and this is usually a very limited space (making logistic services more difficult). It should be taken into account that recovery is connected with planning, designing, control of flows of those materials and of related information [8] – which requires additional engagement from the investment process members. Studies conducted in Catalonia [9] prove that in the scope of effective waste management at the construction site the most common practice is to take care of waste collection and storage and the selection of an authorized recipient – where the main criterion will be its closest location. The least commonly applied solution is the creation of individual recovery projects for particular investments. It may, however, turn out that resourcefulness in waste management can generate a significant financial profit [10],[11],[12],[13]. In order to become acquainted with the problem of cost-effectiveness of the existing recovery processes, financial analysis of waste management has been conducted in the article, in relation to waste generated during general repair of a residential building.

2. Research methodology

The object of the analysis is a construction project involving “complete renovation of the rooms of student hostel DS-2 “Babilon” of University of Science and Technology in Krakow”. The project of reconstruction and complete
renovation of the building rooms does not involve changing the present function of the building. The only element changed is the functional layout of the rooms and the standard [14]. Nevertheless, the dismantling conducted as part of the renovation generated nearly 3600 Mg of waste, classified into eight types of waste in accordance with the catalogue applicable in the EU.

The study is aimed at the assessment of financial effectiveness of waste management at the construction site from the construction work contractor’s perspective, i.e. it is related to a section of a logistic chain of recovery – from the generation of waste at the site to its transfer to the recipient – for further processing. The waste management conducted at the site is crucial for further processes due to the quality of generated waste which determines further directions – the possibilities and costs of recovery processes. Three scenarios of waste management have been analysed:

- “current” scenario – is a description of waste management method during the repair of the building.
- “anthropocentric” scenario – represents extremely ineffective waste management at the site, waste is not segregated as part of the undertaking. Such a scenario may be implemented if the costs of waste management are on the investor’s side or if the contractors are not aware of the waste market existence.
- “ecocentric” scenario – also referred to as “economic” – reflects the implementation of tasks for sustainable development by shortening of logistic chains in waste management with consideration to environmental aspects – actions are, however, motivated by financial account.

3. Results and discussions

3.1. “Current” scenario

The actual course of waste management processes at the site has been reproduced on the basis of the observation of works. Information on the incurred costs of transferring waste for reprocessing have been obtained during source analyses – the invoices for waste collection and so called waste cards. The amount of generated waste and the costs of their processing has been presented in Table 1.

Table 1. Waste management in the “current” scenario

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Amount [Mg]</th>
<th>Unit costs of waste collection [PLN/Mg]</th>
<th>Total cost of waste collection [PLN]</th>
<th>Participation in costs [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 01 01 concrete</td>
<td>2200</td>
<td>-9,5</td>
<td>-20900</td>
<td>14,56</td>
</tr>
<tr>
<td>17 01 02 bricks</td>
<td>900</td>
<td>-9,5</td>
<td>-8550</td>
<td>5,95</td>
</tr>
<tr>
<td>17 01 03 tiles and ceramics</td>
<td>300</td>
<td>-9,5</td>
<td>-2850</td>
<td>1,98</td>
</tr>
<tr>
<td>17 09 04 mixed construction and demolition wastes other than those mentioned in 17 09 01, 17 09 02 and 17 09 03</td>
<td>104,5</td>
<td>-770,5</td>
<td>-80530</td>
<td>56,08</td>
</tr>
<tr>
<td>03 01 05 sawdust, shavings, cuttings, wood, particle board and veneer other than those mentioned in 03 01 04</td>
<td>49,57</td>
<td>-343</td>
<td>-17000</td>
<td>11,84</td>
</tr>
<tr>
<td>17 06 04 insulation materials other than those mentioned in 17 06 01 and 17 06 03</td>
<td>22,63</td>
<td>-479</td>
<td>-10831</td>
<td>7,54</td>
</tr>
<tr>
<td>17 02 01 wood</td>
<td>12,06</td>
<td>-244</td>
<td>-2940</td>
<td>2,05</td>
</tr>
<tr>
<td>17 04 05 iron and steel</td>
<td>6,55</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>- 143 601</strong></td>
<td></td>
<td></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>
On the basis of the collected data a Pareto-Lorenz diagram was developed (Fig. 1) providing information on sensitive waste groups for the enterprise. Waste coded 17 09 04 (mixed construction and demolition wastes) and 03 01 05 (sawdust, shavings, cuttings, wood, particle board, veneer and other) generated high costs of waste transfer due to a high unit price of their collection, whereas the high cost of concrete rubble (17 01 01) resulted from its tonnage.

![Pareto-Lorenz diagram](image)

Fig. 1. Pareto-Lorenz diagram for generated waste in the “current” scenario.

Lower unit prices of collecting wastes from groups 17 01 01, 17 01 02, 17 01 03 were achieved due to the existing market of recovered aggregates. The waste was transferred to an enterprise processing rubble into aggregate which at a further stage was used to reinforce the ground, build embankments, etc.

3.2. “Anthropocentric” scenario

This scenario assumed that waste is not collected selectively, therefore the costs of waste \( W_k \) transfer for reprocessing were determined as the product of the overall waste tonnage \( \sum Q_l \) and the unit price of mixed waste collection \( C_{ozm} \):

\[
W_k = \sum_{l=1}^{N} Q_l \cdot C_{ozm}
\]  

The summary of costs for this variant has been presented in table 2.

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Amount [Mg]</th>
<th>Unit costs of waste collection [PLN/Mg]</th>
<th>Total cost of waste collection [PLN]</th>
<th>Participation in costs [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 09 04 mixed construction and demolition wastes other than those mentioned in 17 09 01, 17 09 02 and 17 09 03</td>
<td>3595.3</td>
<td>-770.5</td>
<td>-2 770 179</td>
<td>100%</td>
</tr>
</tbody>
</table>
3.3. “Ecocentric” scenario

Optimisation of the existing systems (reflected in the “current” scenario) requires finding alternative and additional logistic chains of recovery for the collection of generated waste. The possibilities of reusing waste from the first stage of the project (dismantling) were identified on the basis of the BoQ of renovation works. On this basis logistic loops were created for most 17 01 02 waste (bricks) that closed within the construction site, i.e. their reuse for the purposes of the erection of the designed partition walls. However, the implementation of brick recovery at the site required additional processes related to the preparation of material for reuse, which certainly was connected with additional expenditure estimated using detailed calculation of construction works, in the formula of unit prices based on the national contractor’s estimator (KNR 4-04 1001-02) and catalogue prices (Intercenbud) as well as proprietary market analyses. It should also be noted that recovery implementation resulted in material savings (purchase amounts).

The current scenario assumes recovery for waste 17 01 01 (concrete) and the remaining part of waste 17 01 02 (bricks) by subjecting the wastes to the processes of crushing and screening at the construction site (mobile crushers) and then selling at the prices of concrete and brick aggregate. Such approach was connected with additional costs of the crushing services but the profit from sale turned out to compensate the incurred costs. The proposed purchase prices for the recovered product prices are at the lowest limit in the offer range, in view of the assumed continuous demand for the product.

Waste no. 17 02 01 was transferred for material or energy recovery at zero costs – there are contractors on the market that perform dismantling of wooden structures and waste collection at the price of the recovered material. A complete summary of waste amounts and respective recovery methods is presented in Table 3.

Table 3. Waste management in the “ecocentric” scenario.

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>purpose</th>
<th>Amount [Mg]</th>
<th>additional operations</th>
<th>Unit costs of waste collection/operations [PLN/Mg]</th>
<th>Total cost [PLN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 01 01</td>
<td>crushing and sale</td>
<td>2200</td>
<td>Crushing service^1</td>
<td>-12</td>
<td>-26400</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sale^2</td>
<td>15</td>
<td>33000</td>
</tr>
<tr>
<td>17 01 02</td>
<td>Walls (reuse)</td>
<td>626,2</td>
<td>Preparation of brick for reuse</td>
<td>-88,58</td>
<td>-55467</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Material savings</td>
<td>233</td>
<td>145967</td>
</tr>
<tr>
<td>17 01 02</td>
<td>crushing and sale</td>
<td>273,8</td>
<td>Crushing service^1</td>
<td>-12</td>
<td>-3286</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Sale^2</td>
<td>8</td>
<td>2190</td>
</tr>
<tr>
<td>17 02 01</td>
<td>Handover</td>
<td>12,06</td>
<td>none</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Costs of other waste collection (as in the “current” scenario):</td>
<td></td>
<td></td>
<td></td>
<td>-111211</td>
</tr>
<tr>
<td></td>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>-15207</strong></td>
<td></td>
</tr>
</tbody>
</table>

^1 including operating costs.  ^2 Under the assumption constant demand or long-term contracts with the recipient.

4. Summary and conclusions

Each consecutive scenario – beginning with the “anthropocentric” and ending with “ecological” was characterized by a reduction of the cost of waste transfer for reprocessing at a simultaneous environmental contribution – thus being more sustainable. The comparative scale of waste reprocessing costs burdening the budget for alternative variants is presented in Figure 2.
The results of the analyses confirm the core of effective management of construction waste during the process of the project completion based on the creation and the improvement of the effectiveness of logistic chains of construction waste recovery. The system implemented at the construction site allowed savings in the amount of PLN 2,626,578 compared to the extremely uneconomical approach, i.e. transfer of mixed waste for disposal. The implementation of the “ecological” scenario, however, showed additional possibilities of increasing the system effectiveness, by its further development and shortening of logistic chains of recovery, which would ultimately result in further savings in the amount of PLN 128,394. The effectiveness of the system, however, results in an increase in complexity of logistic chains that require planning and designing – it is difficult to comprise them in a set of uniform procedures and standards due to the individual character of each construction project.

Implementation of the above recovery methods, their consistent improvements may in a longer perspective become an element of the financial strategy for a construction enterprise. Nevertheless, it requires specialist knowledge and experience in the scope of technology and recovery processes for different construction wastes, namely the development of an entire know – how package, i.e. unpatented practical information and its reference to each individual construction project.

References