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Management of reverse logistics supply chains in construction projects

Anna Sobotka[a], Joanna Sagan[a]*, Magdalena Baranowska[a], Ewelina Mazur [a]

* *AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Krakow, Poland*

Abstract

The paper discusses reverse logistics of construction products and materials during repair and demolishing works. In search of effective demolishing waste management methods the following options are considered in order of priority: reusing, resale, repairing, refurbishing, or other methods, ending with energy recovery, and finally disposal.

All these methods are related to planning and organizing supply chains, which here are called reverse supply chains, encompassing physical flows of waste and accompanying information.

Detailed examples which occur in logistics of such projects are discussed using an example. Disposal costs and increasingly rigorous waste management laws encourage effective waste management. The research and analyses indicate that launching reverse supply chains within a project has a significant added value for a business.

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Keywords: reverse logistics, supply chain management, construction wastes

* Corresponding author. Tel.: +48 668 40 40 45.
E-mail address: czajaj@agh.edu.pl

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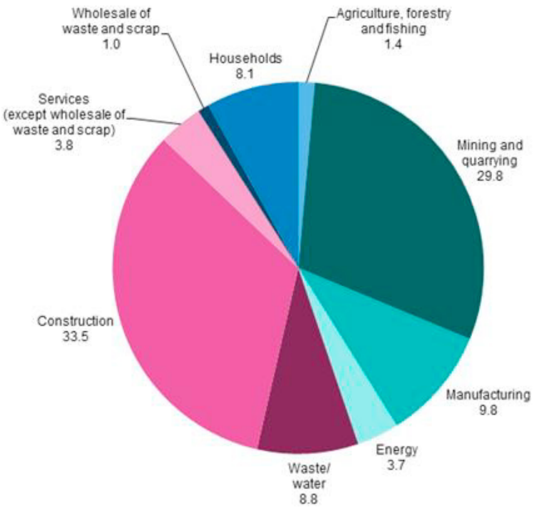
1. Introduction

Waste management is a key environmental, social and economic issue, as well as a growing problem due to the amount of waste generated in Europe each year. Construction sector generates about 35.5% (Fig. 1a) of all waste, hence construction engineers must manage almost 871 million tons of waste a year [1]. The waste structure differs in individual EU countries, but concrete and bricks have the highest share in percent (Fig. 1b).

a)



b)

C&D waste	% - Min	% - Max
concrete	12%	40%
brick	8%	54%
asphalt	4%	26%
wood	2%	4%
metal	2%	4%
gypsum	0,2%	0,4%
Other	2%	36%

Fig. 1. (a) Waste generation by economic activities and households 2014 [1]; (b) Material composition of C&D waste in EU[2].

Such obligation results from EU directives, and in Poland directly from the Waste Act 2012 of 24 December 2012 (as amended) [3] according to which *a waste producer means anyone whose activities produce waste, […] as a result of providing services in the area of construction, demolition and repair of buildings, […]* (Art. 3 of the Waste Act). The waste producer becomes also a waste holder, which entails numerous legal obligations, including for waste management and the related costs (Art. 22). The construction waste management process is complex, the engineer's main tasks in that regard include planning and designing, waste collection, storage, transport, recovery or sending for disposal – understood as transfer of waste to businesses which operations include waste recovery or landfilling. Knowledge of methods and available technologies, as well as possibilities of construction waste processing is a basis to build reverse logistic chains. However, recovery is not always profitable; sometimes there are additional limiting circumstances such as time and place on site, which prevent or limit the aforementioned activities . A market research in terms of waste disposal costs is therefore also important. However, there are numerous logistic streams that can be used for waste management. After rejecting streams that cannot be implemented due to existing limitations, there are a few waste management variants worth considering which will be related to development of logistic chains.

2. Development of waste management models

2.1. Tools and methods

The possibilities of construction waste reuse and the required processes and research were determined using literature review and numerous case studies (section 2.2). Market prices of a dozen waste disposal plants were analyzed (section 2.3). The costs of construction works were determined using Contractors Estimators, current

Sekocenbud price database, and market prices of services. Based on that, by analyzing selected construction projects, the paper presents and proposes extensive waste management models and total costs of individual solutions.

2.2. The possibility of recovering selected construction waste

A lot of material types are used in the construction sector. A few hundred of various products are needed to erect a complete building. This paper analyses selected materials used on a mass scale, i.e. concrete, brick, wood and their wastes.

Pre-crushed concrete and brick debris has a broad variety of application. Low-quality recycled concrete aggregate can be used to build temporary roads, road base, lean concrete, etc. [4][5]. In case of concrete waste transformation to concrete aggregate, the product must meet relevant requirements. Many countries have specific requirements for recycled aggregate which are summarized in [6]. Such solution requires of course more sophisticated waste processing methods [7] and an extensive flow of information on product quality. The regulations generally also limit the use of aggregate in terms of building element exposure class and aggregate content in the concrete mix [6].

Otherwise, in case of deconstruction of masonry elements, bricks can be recovered for construction purposes, but their technical parameters must be checked before the reuse, for example by means of diagnostic non-destructive testing (NDT) [8].

Wooden elements are also often used in Poland, and their potential depends directly on timber quality, which can be preliminarily evaluated using a macroscopic analysis. If wood does not meet the basic requirements, it still can be used as a source of energy. When wood successfully passes the macroscopic and mycological evaluation, it can be reused as both finishing and load-bearing elements, however additional non-destructive testing will be required in the latter case to determine the load-carrying capacity. All mentioned materials and accompanying processes within recovery are presented in Fig.2.

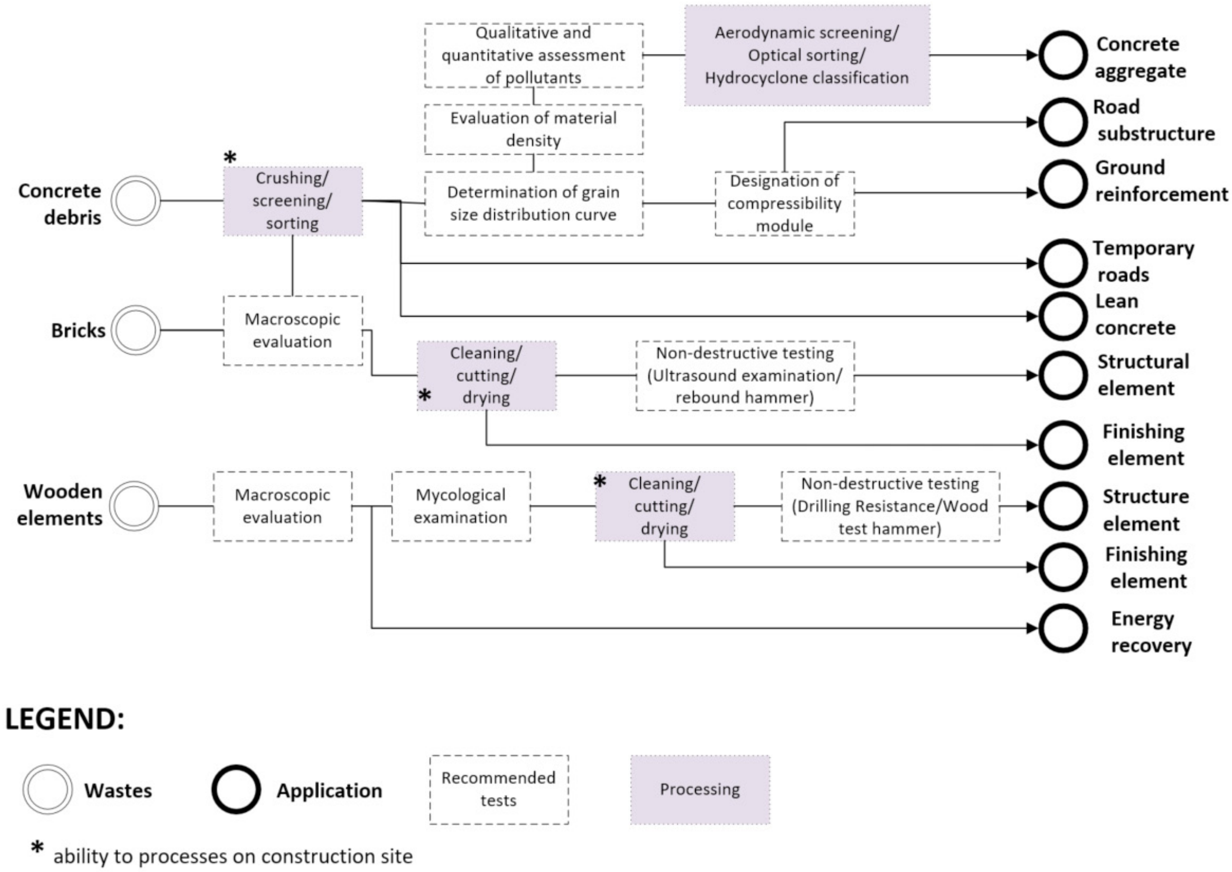
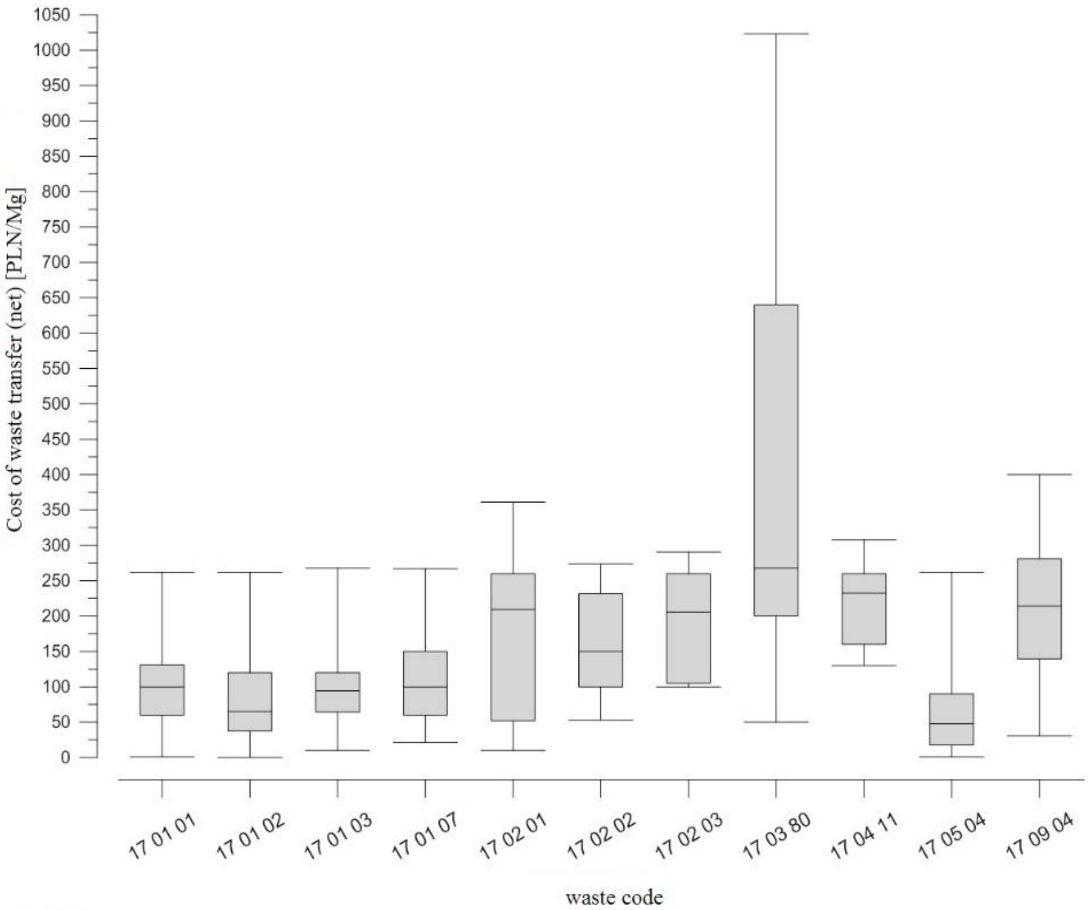


Fig. 2. Opportunities and conditions of recovering construction materials and products (based on [9] [4][5] [10])

2.3. Choosing the recipient

Sending the unused waste for disposal is an important issue from the point of view of economically effective waste management. It entails the cost evaluation problem as there is no a collective price list of such services, however an additional work devoted to variant analysis could bring benefits. Figure 3 presents the costs divergence for selected construction wastes among a few dozen waste disposal plants in Poland. Current prices for receiving waste differ by as much as 100% and even more. The largest variations were noted in case of waste tar paper disposal where the highest recorded price (PLN 1023,28 per Mg) is almost seven times higher than the lowest price. In addition, the terms of receiving waste should also be reviewed, as in some plants the price for the same waste category depends on the waste size (e.g. there were different prices for debris below and above 30 cm).



LEGEND:

17 01 01	Concrete
17 01 02	Bricks
17 01 03	Tiles and ceramics
17 01 07	Mixture of concrete, bricks, tiles and ceramics other than those mentioned in 17 01 06
17 02 01	Wood
17 02 02	Glass
17 02 03	Plastic
17 03 80	Waste tar paper
17 04 11	Cables other than those mentioned in 17 04 10
17 05 04	Soil and stones other than those mentioned in 17 05 03
17 09 04	Mixed construction and demolition wastes other than those mentioned in 17 09 01, 17 09 02 and 17 09 03

Fig. 3. Waste disposal costs variations in Poland [own work]

The essence of finding variants from among the waste disposal plants is exemplified by concrete waste generated during a project in Gdansk. Location and price for concrete waste disposal is presented in Figure 4.

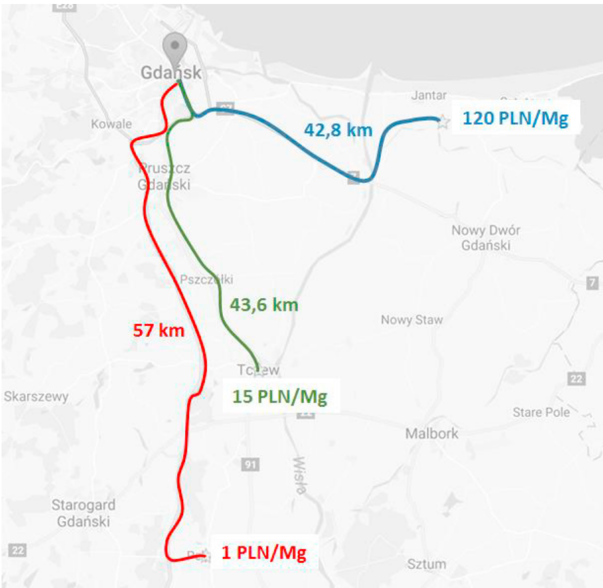


Fig. 4. Location of waste disposal plants near Gdansk [own work]

The relationship between summary transport and disposal costs and the waste tonnage is shown in the figure 5. Such significant variations of waste disposal prices necessitates a thorough market analysis.

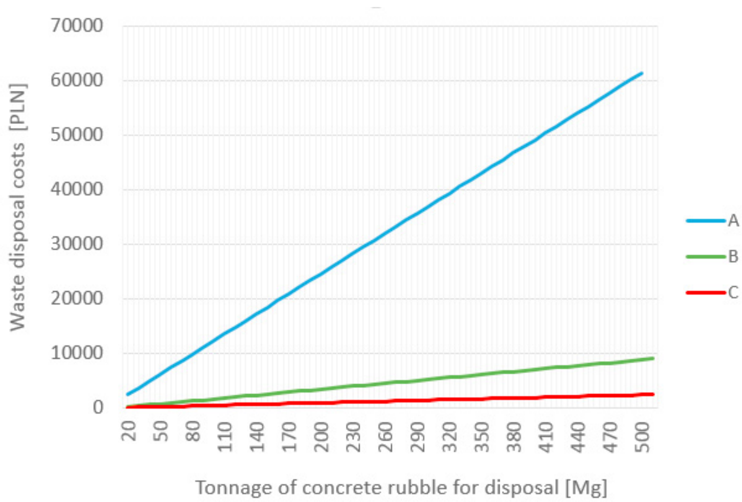


Fig.5. Summary transport and disposal costs in different variants as a function of tonnage [own work].

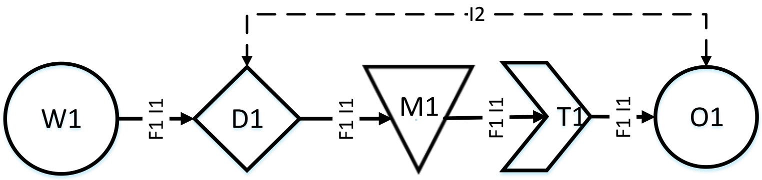
3. Example of logistic chain development

The analyzed project involved a demolition of a multi-family residential building with basement. The take-off included preparatory works, that is fencing and placement of demolition information board. The second part of the take-off involved demolition. The building is masonry. Walls and foundations are made of solid bricks on cement and cement-lime mortar. Wooden roof truss, roofing (tarpaper), metal parts (pipework, gutters), and windows and doors are also to be demolished. The floors in the buildings are with sound boarding, on steel beams. The list of waste is presented in Table 1.

Table 1. List of generated waste.

Type of waste	**Amount** [Mg]
17 01 02 bricks	1863.42
17 02 01 wood	44.7
17 01 82 other construction and demolition wastes	16.61
17 04 05 steel	3.47
17 03 80 waste tar paper	1.08
17 01 01 concrete	0.69
17 02 02 glass	0.29

In case of absence of separate waste collection it is not possible to build reverse supply chains. It is an example of linear management (Fig. 6). The only possibility to optimize waste management is to look for a waste disposal plant for which the waste disposal and transport costs will be minimum.



Flow of generated demolition waste (F1) and accompanying information (I1); decision to send mixed waste for disposal (D1); storage demolition waste (M1); waste transport (T1); waste disposal plant (O1); information about disposal conditions (I2)

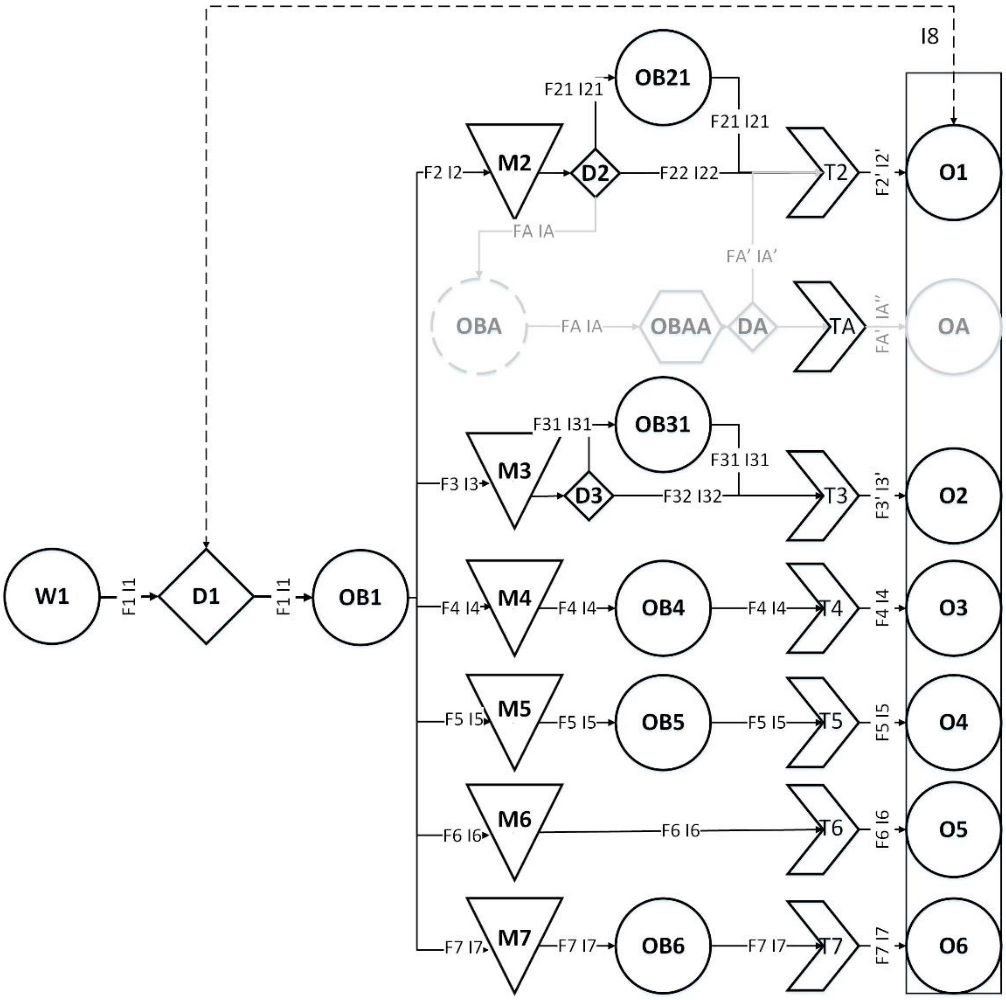
Fig. 6. Linear management of construction materials and products [own work].

Separate waste collection is the key to develop reverse supply chains. Without waste quality testing on site, and with only simple processing on site (mobile crushing, cleaning, etc.) and by means of differentiating the waste disposal plants, the reverse supply chain becomes significantly expanded (Fig. 7, black lines), bringing savings in the process.

Further expansion of the reverse supply chain to include, for example, wood recovery as structural material (Fig. 7, grey line) requires selecting potentially useable elements, processing them (cleaning, drying), and non-destructive testing and mycological evaluation. This would provide a basis to determine if a given timber element can be reused for structural purposes.

Expansion of logistic chains is related to finding recipients, to storage yard organization, mobile processing lines, experts opinions which entails extra costs and is an additional duty to be performed by site management.

However, waste management according to presented concept brings financial benefits. In the presented case, the waste disposal costs in the linear approach were estimated at PLN -15 370. Adding more recipients to the model and simple recovery processes allowed saving PLN 15 301. As a result of further efforts in testing timber beams for construction purpose, the waste disposal costs may actually be positive, estimated at PLN 5856.



Demolition waste (F1) and accompanying information (I1); managing of waste for separate collection and recovery (D1); separate waste collection (OB1); physical waste flows and information flows by category (F2-F7, I2-I7); waste storage by category (M2-M7); sorting wood (D2) and steel waste (D3) based on macroscopic evaluation; removing plaster from soffit (OB2); steel cleaning (OB3); wood waste sent for cleaning and accompanying information (F21,I21); wood waste sent directly for energy recovery (F22, I22); crushing of concrete waste (OB4); crushing of brick waste (OB5); crushing of window panes (OB6); information from waste disposal plants on disposal terms (I8); waste transport by category (T2-T7), flow of generated wood waste for energy recovery and accompanying information (F2',I2'), steel waste sent for cleaning and accompanying information (F31,I31); steel waste sent directly to scrap yard (F32, I32); flow of metal waste to scrapping and accompanying information (F3',I3'); recipients of fuel wood (O1), scrap yard (O2), recipients of ungraded concrete (O3) and brick aggregate (O4); recipient of other unsorted waste (O5), recipient of glass waste (O6); flow of waste separated for structural purposed by means of macroscopic evaluation and accompanying information (FA, IA); wood processing – cleaning, drying (OBA); mycological evaluation and NDT (OBBA), sending wood for energy recovery or for use as structural elements (DA); flow of wood waste and information sent to energy recovery (FA',IA') and for use as structural elements (FA'',IA''), recipient of structural wood elements (OA).

Fig. 7. Expanded waste management model in a project [own work].

4. Summary

Construction waste management is the key element in demolition and repair projects. High waste disposal costs demand a well-thought-out waste management, including differentiation of waste recipients. The basis for expansion of reverse supply chain is separate waste collection. Expanding the logistic chain to include many waste recipients can bring a significant added value to the business, requiring only market analysis, simple tools (macroscopic evaluation) and processes (cleaning, crushing, screening, cutting, drying), which may take place at a construction site. Recovery of construction products for structural purposes requires higher quality, and consequently more refined methods of processing (e.g. aerodynamic screening, hydrocyclone classification, optical sorting) and testing (e.g. non-destructive testing, mycological examination, compressibility module) of materials and products. In Poland such refined recovery methods of concrete are rare, due to the lack of ready-made technological lines. Much more noticeable, however, is the recovery of wooden structural components and bricks recovery.

An economic system that should strive for sustainable development contains, however, an inconsistency. A free market price for waste disposal leads to precedents where long-distance transport of waste is financially justified, with a detrimental effect on the environment.

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