
Строительные материалы и изделия
Construction Materials and Products

journal homepage: https://bstu-journals.ru

ISSN
2618-7183

**DOI: 10.58224/2618-7183-2023-6-5-7**

# Recycling of Municipal Solid Waste in Construction

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**Abstract.** This article discusses a promising direction focused on the use of recycled municipal solid waste in construction. In Russia, there are problems related to municipal solid waste management, which necessitates the modernization of this process and confirms the relevance of the issues raised. Analysis and use of the experience of foreign countries in the processing of municipal solid waste and its secondary use in Russia contributes to the search for a more environmentally responsible approach that entails both economic and social benefits. The use of solid municipal waste recycling products in construction is aimed at minimizing the negative impact on the environment and is a step towards the transition to a circular economy, where waste is turned into valuable resources.
The article reflects on the various methods of recycling municipal waste and analyzes the priority areas for the processing of municipal solid waste. In addition, examples of successful building projects using recycled products are given, and the challenges and prospects of this approach, as well as its significance for sustainable development and environmental responsibility in the construction industry, are revealed.
**Keywords:** secondary raw materials, environment, waste, recycling, construction, municipal solid waste, environmental safety, energy efficiency, environmental responsibility

**Please cite this article as:** Muzalev S.V., Nikiforova E.V., Petrova O.A., Antonova O.V., Melnikova L.A. Recycling of municipal solid waste in construction. Construction Materials and Products. 2023. 6 (5). 7. DOI: 10.58224/2618-7183-2023-6-5-7

## 1. INTRODUCTION

Municipal solid waste (MSW) management is among the most urgent issues of today worldwide [1]. This problem is preceded by such factors as increasing urbanization [2], high population growth, and increased consumption [3], resulting in rising volumes of MSW and more. However, through innovative approaches in MSW recycling, it can be transformed into valuable resources for both the industry and the population [4]. The present study examines a promising area of application of MSW recycling – construction.

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Received June 23, 2023; Received in revised form September 5, 2023; Accepted October 12, 2023

Construction is the leading industry that involves a considerable amount of natural resources and produces large volumes of waste. In light of growing environmental awareness, increasing consumption, and the need for more sustainable development, the availability of MSW recycling products opens new horizons for sustainable design and construction [5].

Positive factors of recycled waste include the reduction of negative impact on the environment and the population [6]; minimization of consumption of primary raw materials [7]; reduction of waste [8]; improvement in energy consumption and reduction of costs for construction materials [9]; development of the circular economy.

The present article discloses the advantages and disadvantages of using MSW recycling products, the existing applications of recycled MSW in construction, the prospects of these products, and the experience in using secondary raw materials. The use of MSW recycling products is a step towards sustainable development, in which waste is transformed into resources and provides for more environmentally friendly and efficient construction projects [10].

## 2. METHODS AND MATERIALS

Research on the application of MSW recycling products has been conducted by many scientists, among which are I.N. Rykova and S.V. Shkodinsky [11], I.M. Potravny and D. Baakh [12], G.G. Lunev and Yu.M. Prokhotsky [13], E. Beccaloni, L. Bonadonna, F. Di Maria, C. Cini, E. Confalonieri, and G. La Rosa [14], M.N. Tolmachev [15], S.V. Klyuev [16, 17], R.S. Fediuk [18], N. Makul [19, 20], etc.

The general issues of sustainable and environmentally friendly development are covered in the works by S.V. Muzalev, S.N. Kukushkin, O.A. Grazhdankina, and A.V. Nikolaenko [21], T. Stepanova and O. Schneider [22], etc.

A striking example of approaches to sustainable development and minimization of negative environmental impact is the use of recycled MSW in construction. This approach reduces the amount of waste and the use of raw materials in construction, which undoubtedly attracts the attention not only of the population but also of construction companies.

To further consider this topic, we need to note the principal differences in the definitions of MSW and construction waste. MSW refers to "waste generated in residential premises during the consumption process by both natural and legal persons, as well as goods that have lost their consumer properties during their use for personal and domestic needs" [23].

"Waste generated during demolition, disassembly, reconstruction, renovation (including capital) or construction of buildings, structures, industrial facilities, roads, and engineering and other communications" (as per GOST R 57678-2017. National standard of the Russian Federation. Resource saving. Waste management. Elimination of construction waste (approved and brought into effect by the Order of Rosstandart № 1163-st of September 19, 2017) URL: https://files.stroyinf.ru/Data/652/65223.pdf) is classified by the Federal Waste Classification Catalogue as "construction and repair waste" (code 80000000000) (as per the Federal Waste Classification Catalogue, approved by the Order of Rosatrodniknadzor № 242 of May 22, 2017, as amended on November 2, 2018. URL: https://db.wastebase.ru/wastebase.aspx). This type also includes waste generated by ongoing construction in residential buildings, which in turn prevents the inclusion of this waste in the concept of MSW. Fig. 1 lists the main types of construction waste.


**Fig. 1**. Main types of construction waste.

For comprehensive research of the examined topic, we conducted a study of publications, including scientific research and information on the existing waste recycling projects, as well as the use of secondary raw materials in construction. The study utilized the methods of analysis, synthesis, systematization, and induction.

## 3. RESULTS AND DISCUSSION

Today, the world generates 2.1 billion tons of waste annually, of which 30-40% is not managed in an environmentally friendly way (according to ALBA Group: Facts and figures and facts on the closed-loop recycling in Germany. – Mode of access: /www.alba.info/en/alba-group/press/press-kit/figures-and-facts-on-the). The approach is popular in countries, which have made significant progress in using recycled MSW. Among the most successful are Germany, China, Sweden, etc. Importantly, waste management and recycling in Europe are controlled at the legislative level. The main documents governing MSW recycling in Europe are indicated in Fig. 2.

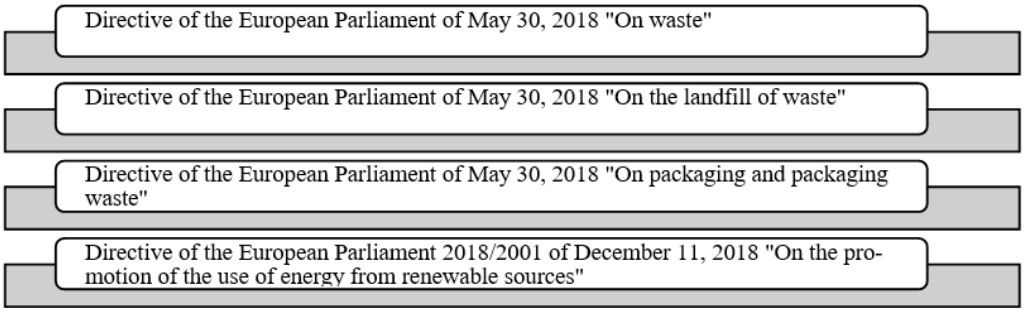


**Fig. 2**. The main documents regulating the issues of processing and disposal of MSW in Europe.

The experience of some countries is examined in more detail in Table 1.

**Table 1**. Secondary use of MSW.

| Country | Secondary use of MSW |
|---|---|
| Germany | Germany uses the Dual System (Duales System Holding GmbH & Co), which involves the creation of additional waste collection lines (along with public containers, waste collection containers for manufacturers are installed) [19]. The system is based on the Green Dot icon (der Grune Punkt). The Green Dot is the label of MSW products that provides and guarantees reception and recycling.<br>Germany recycles more than 90% of household waste, total recycling of various materials reaches > 80%, and secondary materials are used to produce 68% of the paper, 94% of the glass, and 45% of the steel (according to ALBA Group: Figures and facts on the closed-loop recycling in Germany. – Mode of access: /www.alba.info/en/alba-group/press/press-kit/figures-and-facts-on-the).<br>Recycling plastic bottles saves energy equal to that used to provide heat to approximately 2 million German residents for at least 3 months [11].<br>"In 2019, the first residential building in Germany was constructed from recycled materials in Hannover using a variety of secondary raw materials that architects used in the process of creative solution" [13].<br>The CRCLR House project is an example of using recycled MSW in construction, as it involved the construction of a multi-story house based on waste and straw on the site of a former brewery.<br>The German company Büscher built a full-fledged house with 75% of the recycled construction waste. Load-bearing and non-load-bearing elements of internal walls are made of 100% recycled aggregates. |
| Netherlands | The Netherlands is moving towards a circular economy. The waste management system is identical to that in Europe.<br>Experts of the state distinguish the nine Re levels of circularity: refuse, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover.<br>In Amsterdam, the Circular Cities subprogram promotes the attainment of the energy necessary for the city's functioning from renewable sources.<br>In addition, the principle of smart design provides for the construction of new types of houses. "Houses are built in a 'modular and flexible' way, providing the possibility of remodeling dwellings without radical reconstruction of the building" [24]. |
| Sweden | Sweden has a circular economy based on renewable resources. This country ranks first among European countries in terms of waste recycling (it recycles 99% of its waste), and even has an economic benefit from importing waste for recycling from other countries.<br>The country has a special label called Miljönär: "Any company, organization, enterprise, or private person whose activity is focused on reducing the volume of waste" (according to the resource: "By 2030 road construction will use up to 40% of secondary raw materials" // Vedomosti. 14.06.2022 URL: https://www.vedomosti.ru/press_releases/2022/06/14/k-2030-godu-pri-stroitelstve-dorog-budet-ispolzovatsya-do-40-vtorsirya).<br>Due to the increased threat of climate change, Sweden uses waste as fuel for buses and residential heating. "Waste is burned in low carbon waste incinerators, and food waste is used to produce organic biogas fuel" [25].<br>Sweden divides waste into fractions, that is, the debris that remains after burning is used as fuel in generating stations, then mixed with wood sawdust and burned again, which provides energy for heating and hot water supply.<br>"In total, all hazardous waste constitutes no more than 3%" [24]. |
| Denmark | There is a Danish model of waste management, which includes the following aspects:<br>- state legal regulation, social control, and planning;<br>- regulated roles of responsibility and competence from the state, as well as regional and local authorities, to management companies for waste collection, treatment and disposal;<br>- complete coverage of the waste management process with strict observance of the rules and principles corresponding to the motto "polluter pays". |

As the experience of these countries shows, MSW recycling and reuse, both in construction and in other spheres, positively affects not only the living conditions and quality of life of the population but also significantly minimizes the negative impact on the environment. The development of the circular economy does not do without waste-to-energy processes. The analysis of experience in dealing with MSW allows us to highlight the main advantages of the circular economy (Fig. 3).

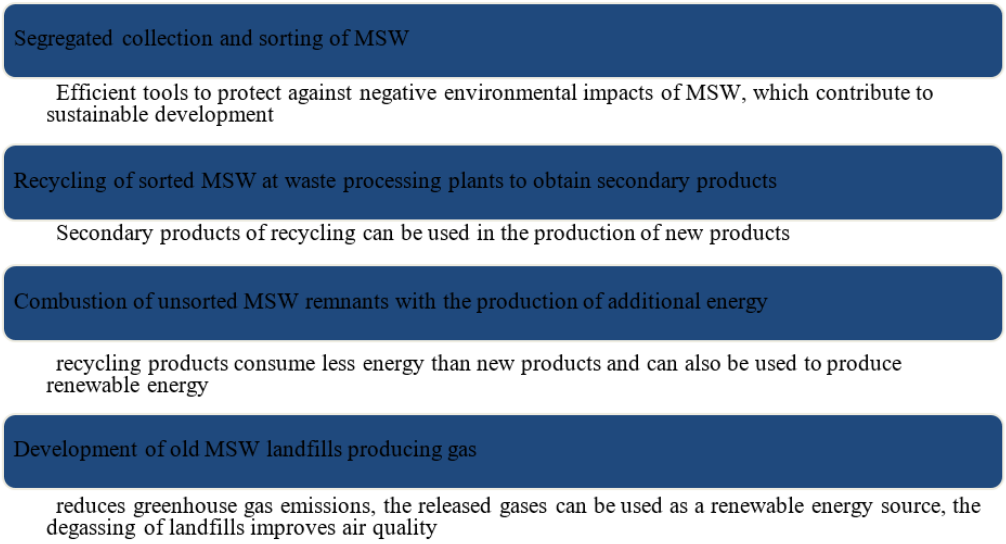


**Fig. 3**. Benefits of the Circular Economy.

Next, let us consider the experience of Russia with MSW processing and subsequent recycling.

"In Russia, 70 million tons of MSW are thrown away annually, the area of unauthorized landfills is 20 thousand ha" (according to the Ministry of Natural Resources and Ecology of the Russian Federation. URL: https://www.mnr.gov.ru). The problem is clearly evidenced by the fact that Russian companies process only 4% of MSW, and in a few years, the area of landfills will almost double.

The monitoring data of the Russian Environmental Operator (REO) for 2022 and the first half of 2023 are presented in Fig. 4.

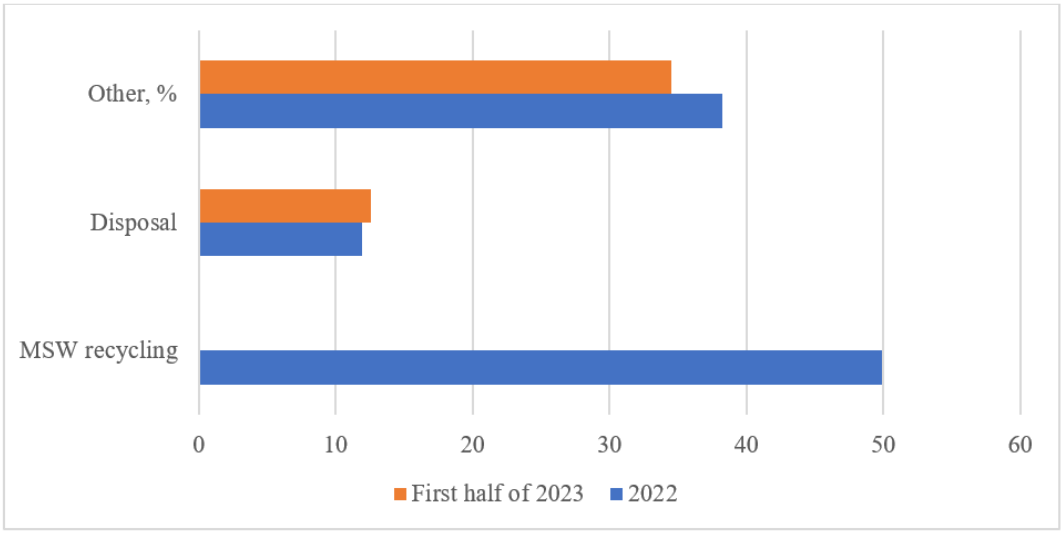


**Fig. 4**. Volumes of processing and disposal of MSW in Russia for 2022 and the first half of 2023 (compiled by the authors on the materials of "Level of processing and disposal of MSW in Russia in the first half of 2023" // Vedomosti. 14.07.2023. URL: https://www.vedomosti.ru/press_releases/2023/07/14/uroven-obrabotki-i-utilizatsii-tko-v-rossii-po-itogam-pervogo-polugodiya-2023-goda-sostavil-529-i-126).

The main normative legal act regulating the field of waste management is the Federal Law of June 24, 1998 89-FZ "On production and consumption waste".

In Russia, the use of MSW recycling products is a new direction only starting to develop. Recently, there has been increased attention to the issues of MSW management and recycling, yet there are several problems that considerably hinder the development of the field. They include:

- Insufficient infrastructure. Most landfills do not comply with environmental requirements, which poses a threat to the environment and public health;
- Low recycling efficiency. Russia does not have a developed recycling industry, and the equipment and technologies used by the majority of enterprises do not meet contemporary standards;
- Insufficient funding due to the fact that such aspects as modern equipment, personnel training, and the development of infrastructure require large investments rarely allocated for this area;
- The lack of environmental awareness among the population. Compared to European countries, the level of environmental awareness in Russia is low. Citizens lack the motivation to sort waste, which entails the lack of support for waste collection and management.

Despite these major constraints, there are some successful directions in recycling in Russia (Fig. 5).

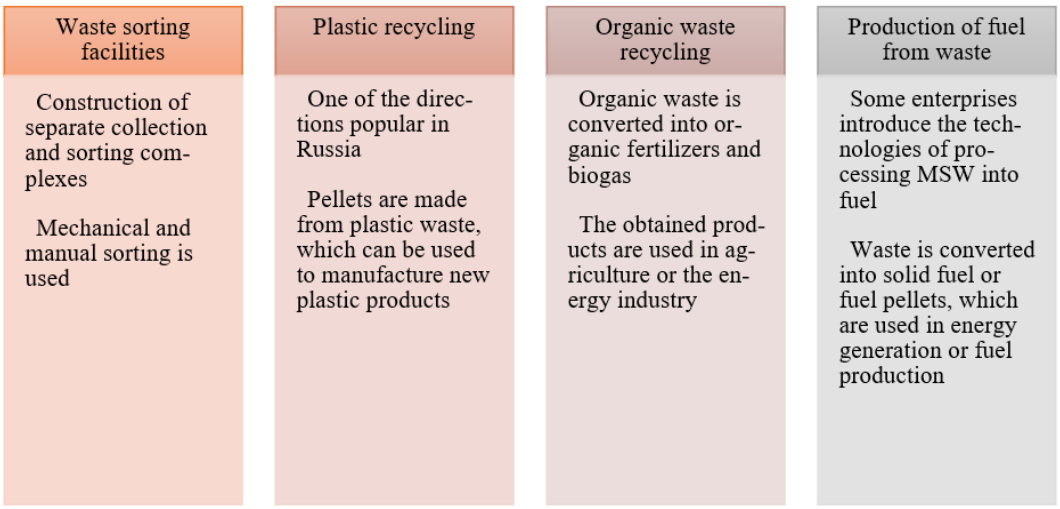


**Fig. 5**. Developing areas of MSW recycling in Russia.

"In Russia, the target indicators for the development of the MSW treatment industry focus on increasing the share of waste processing by incinerating non-utilized waste remnants with the production of energy to 24% by 2026. At the same time, the goal is to increase the level of waste recycling into secondary raw materials and composting up to 24%. In this case, the share of disposal of such waste will decrease from 93% to 36% by 2026" [12].

The development of the circular economy in Russia is facilitated by state programs, for example, the program "Application of secondary resources and secondary raw materials from waste in industrial production", the national project "Ecology", etc.

"Among the national development goals of the country for the future. it is planned to create a sustainable system of MSW management providing 100% sorting of waste and reducing the amount of waste sent to landfills in half" (according to the Decree of the President of the Russian Federation of №474 July 21, 2020 "On the national development goals of the Russian Federation until 2030". URL: http://www.kremlin.ru/events/president/news/63728).

As for the application of MSW recycling in construction, in 2018 the "Strategy for the development of the industry for the treatment, utilization, and decontamination of waste from production and consumption until 2030" was adopted (according to the Decree of the Government of the Russian Federation №84-p of January 25, 2018 (as amended on October 13, 2022) URL: http://static.government.ru/media/files/y8PMkQGZLfbY7jhn6QMruaKoferAowzJ.pdf). At the heart of measures under this Strategy are the 3R principles of circular economy (reduce, reuse, recycle). "As part of the plan of measures for the implementation of the Strategy, a Federal Scheme for the Management of Construction and Demolition Waste (CDW) is being developed using the best available

technologies, taking into account, inter alia, the projected growth of demolition waste, and allows methodical formation of the full organizational and technological chain of waste management – from formation to complete utilization" (according to the Ministry of Natural Resources and Ecology of the Russian Federation. URL: https://www.mnr.gov.ru).

A promising material in this respect is recycled plastic. Plastic waste collected from households and production can be used in the production of asphalt cement mixtures after sorting and separating the target fraction. Adding recycled plastic as a filler in cement mixtures increases such key properties as strength, fracture resistance, abrasion, heat resistance, rigidity, and load-bearing capacity of cement sheets [26]. Plastic recycled materials can also be used in the production of modified gypsum and plaster mixtures with increased mechanical characteristics [27].

Awareness of the promise of using recycled secondary raw materials in construction is also shown by Russia's chief body in the system of MSW management – the Russian Environmental Operator (REO). In its program "Application of Secondary Resources, Secondary Raw Materials from Waste in Construction and Housing and Utilities for 2022-2030", the REO plans to increase the share of recycled MSW and construction waste use in road construction to 40%. As the head of the REO, Denis Butsayev notes that "Foreign experience shows that up to 80-90% of the resources spent on road construction can be secondary raw materials" (electronic resource "By 2030 road construction will use up to 40% of secondary raw materials" // Vedomosti, June 14, 2022. URL: https://www.vedomosti.ru/press_releases/2022/06/14/k-2030-godu-pri-stroitelstve-dorog-budet-ispolzovatsya-do-40-vtorsirya).

To give an example, plastic is used as a secondary raw material in road construction in India. As of today, there are over 30 thousand km of roads built with recycled plastic waste.

A positive example of MSW being applied in construction is cement plants using MSW as fuel. Such plants substitute a major part of fuel (natural gas and coal) with sorted MSW. One such cement plant (LafargeHolcim) is successfully operating in Kaluga Oblast, Russia. Experts say that in 2019, it processed over 50 thousand t of MSW, which saved the enterprise 11.5% of the natural gas consumed by it regularly. The high-temperature technology (2,000°C) involves safe disposal of the waste with the formation of bottom ash, which is converted into a semi-finished clinker when entering into a chemical reaction with the raw material mix. This semi-finished clinker is used in the production of conventional construction cement. "That is, there is zero ash output, as compared to waste incinerators, which create 15-20% of bottom ash after incineration" [12].

The importance of realizing secondary raw material recycling projects in all areas of industrial production owes to:

- the creation of new productions and jobs;
- saving natural resources;
- reduction of the cost of works performed.

An illustrative example of the application of secondary raw materials is the construction of roads based on recycled tires, which are used as an asphalt concrete modifier based on rubber crumbs. This technology has been used in the construction of up to 15 million $km^2$ of roads in Russia (the Central Ring Road, M11, M4).

The use of secondary raw materials in the construction industry is not limited to producing construction materials. To some degree, the waste itself can serve as a building material. For example, a study by E.A. Sukhinina "Construction of buildings from secondary raw materials, taking into account the requirements of environmental standards" offers a classification of construction materials based on secondary raw materials (Fig. 6).

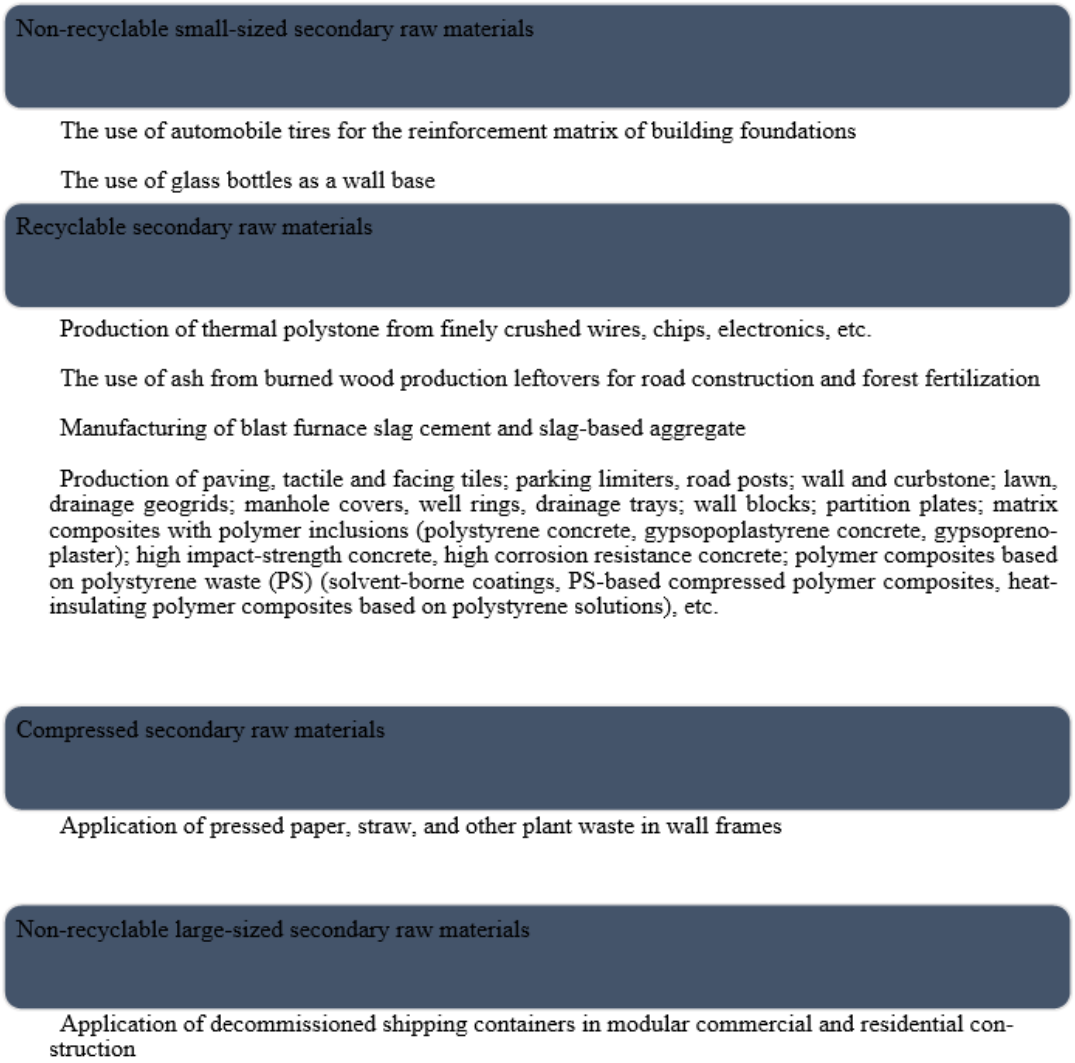


**Fig. 6**. Classification of building materials based on recycled materials (compiled by the authors according to [24]).

The products of MSW recycling include construction materials, plastics, glass, paper, and more. Table 2 presents some possible ways to apply recycled MSW in construction.

**Table 2**. Possible ways to use recycled MSW in construction.

| Material | Methods of reuse |
|---|---|
| Construction waste | **Concrete waste recycling.** Crushing and sorting concrete produces gravel and rubble, which are used in the production of new concrete. This method minimizes the consumption of natural raw materials and reduces the amount of waste.<br>**Asphalt waste recycling.** Old asphalt can be recycled to produce new asphalt mixtures, thus saving on oil products used in the production of asphalt.<br>**Metal waste recycling.** Metal structures not in use are recycled to produce new metal products.<br>**Wood waste recycling.** Wood waste is recycled into chips and wood slabs used as insulation, veneer materials, etc.<br>**Glass waste recycling.** This waste can be recycled into fiberglass and used in the production of double-glazed units, glass blocks, etc. |
| Municipal waste | **Plastic waste recycling.** Such waste is used to make plastic boards, drainage systems, pipes, etc. This method allows for minimizing the use of petroleum products and reducing the impact on the environment.<br>**Paper waste.** Cardboard, paper, and packaging material are recycled into cellulosic fibers used for the production of wall insulation or substrates for flooring.<br>**Organic waste.** Converted into organic fertilizers (by composting) and biogas (anaerobic processing). |
| Commercial waste | **Industrial waste**. This type of waste is formed in various industries, for example, steel leftovers can be used in the production of construction materials.<br>**Waste from mining operations**. Wastes such as sludge, tailing, or sand and gravel can be used to create embankments or ground mixtures.<br>**Metal processing waste**. Steel and aluminum waste, which forms chips or scraps, can be reshaped into new metal products.<br>**Chemical industry waste**. Chemical solutions, dust, etc. can be used in the production of construction materials or additives. |
| Special waste | **Medical waste**. Waste from the construction or renovation of medical facilities requires special processing and disposal per the existing standards.<br>**Electronic waste**. Electronic waste contains valuable components that can be recycled, but can also contain hazardous substances that require special disposal. |

As demonstrated in Table 2, there is a decent number of ways MSW can be reused in construction. Fig. 7 reflects data on the content of waste per 1 $m^3$ (according to the resource Plotnost stroitelnykh otkhodov [Density of construction waste]. URL: https://www.google.com/search?q).

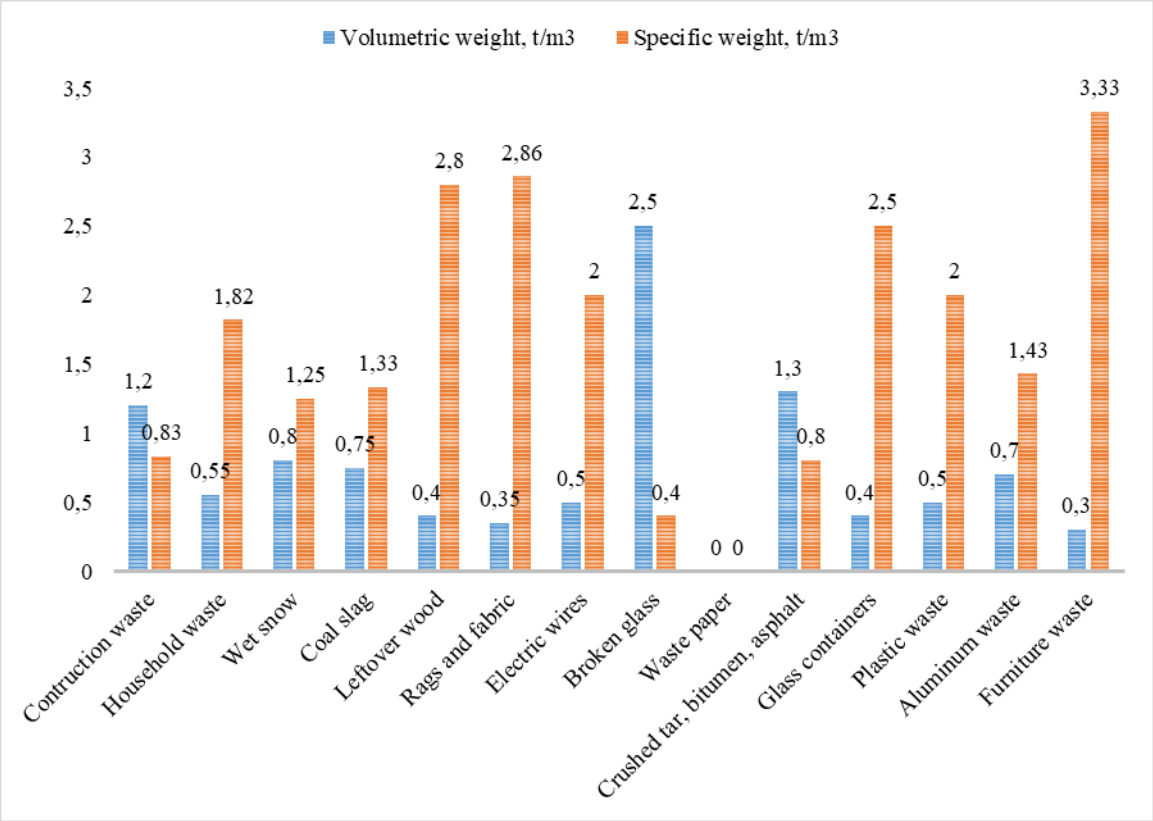


**Fig. 7**. Weight of 1 $m^3$ of waste.

The reuse of waste is a key direction in circular policy. Circular economic policy is often compared with green policy. The principles of the latter, when observed, improve the environmental and socio-economic condition of the country. Green construction is commonly understood as a modern construction policy that uses energy and material resources throughout the processes of construction, exploitation, and disposal, while increased attention is paid to the internal quality and comfort of the building. "Green construction is oriented on ecological standards that facilitate the transition from traditional to sustainable building design" [28].

The advantages of green construction are described in Fig. 8.

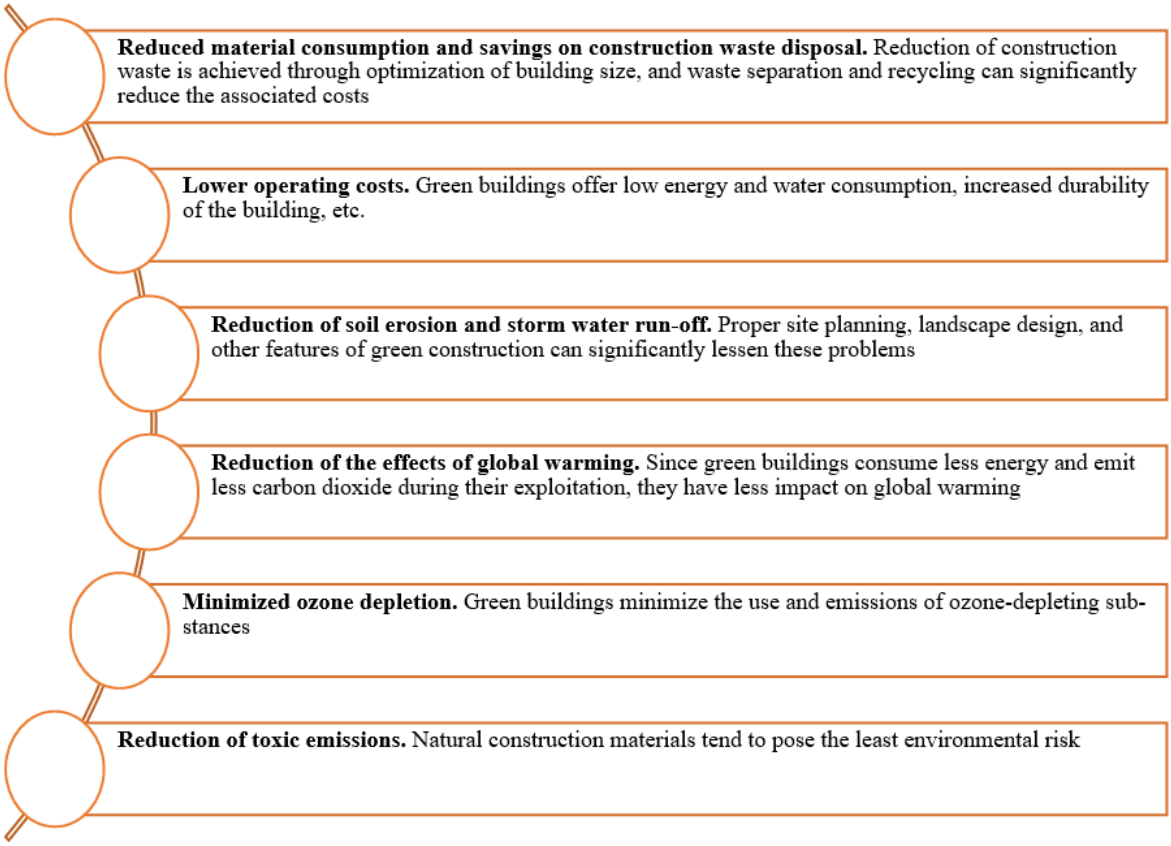


**Fig. 8**. Benefits of green construction (compiled by the authors based on [29]).

This leads us to the conclusion that MSW recycling serves as an instrument of circular economy and green construction, given that its primary principles include minimization of environmental impact, reduction of construction waste, and improvement of the life quality of the population.

## 4. CONCLUSIONS

1. The use of MSW recycling products in construction is an efficient method of waste use, as well as a method to minimize negative impact on the environment and human health. This method allows the manufacturing of construction materials and products that can be used in various construction projects.
2. MSW recycling products have several advantages, including reduction of greenhouse gas emissions, reduction of waste volumes, saving of natural raw materials, energy efficiency, environmental friendliness, etc. All these benefits affect the social, economic, and environmental aspects of life of the population and the state.
3. Analysis of experience shows that the transition to a circular economy has a positive effect on the well-being of the nation and the people. Examples of Germany, Sweden, the Netherlands, and other countries demonstrate that waste recycling can lead to zero consumption.
4. Positive effects of the use and application of recycled products can be achieved under several conditions: the development of an efficient waste collection and sorting system, the development of recycling technologies, the establishment of quality standards for secondary raw materials, the adoption of the green construction technology, and support from the government and business.

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