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# ROAD INVESTMENTS CONDUCTED ON THE PRINCIPLES OF A CIRCULAR ECONOMY AND THEIR IMPACT ON FUNDING FOR ROAD REPAIRS AND ONGOING MAINTENANCE

# INWESTYCJE DROGOWE PROWADZONE NA ZASADACH GOSPODARKI W OBIEGU ZAMKNIĘTYM ORAZ ICH WPŁYW NA FINANSOWANIE REMONTÓW I BIEŻĄCEGO UTRZYMANIA DRÓG

**STRESZCZENIE.** Inwestycje drogowe prowadzone na zasadach Circular Economy (gospodarki o obiegu zamkniętym) mają na celu wprowadzenie zrównoważonych praktyk i minimalizację negatywnego wpływu infrastruktury drogowej na środowisko. Jednym z głównych elementów inwestycji drogowych prowadzonych na zasadach Circular Economy jest zastosowanie materiałów z recyklingu. Materiałem coraz powszechniej stosowanym w budownictwie drogowym jest sfrezowany beton asfaltowy oraz skruszone stare warstwy konstrukcyjne, które po odpowiedniej obróbce mogą być ponownie wykorzystane. Przedmiotem badań było określenie wpływu prowadzenia inwestycji na zasadach Circular Economy na finansowanie remontów i bieżącego utrzymania dróg na przykładzie Płocka – polskiego miasta średniej wielkości. W 2011 r. współautor artykułu zaproponował władzom miasta wprowadzenie zasad zagospodarowania materiałów rozbiórkowych pozyskiwanych z inwestycji realizowanych w pasach drogowych ulic miejskich, co z powodzeniem wdrożono w połowie 2011 r. Wprowadzone regulacje dotyczyły nawierzchni: asfaltowych, kamiennych, z żelbetowych płyt drogowych, z trylinki, z kostki betonowej, ale również krawężników, obrzeży, oporników, a także elementów podbudowy. Program odzyskiwania materiałów rozbiórkowych dał w krótkim czasie duże efekty, przede wszystkim w aspekcie ochrony środowiska, gdyż przed 2011 r. wszystkie materiały rozbiórkowe trafiały na wysypisko odpadów komunalnych, a obecnie ilości materiałów tam przekazywanych równe są zeru. Badania oparte o dane z ostatnich 10 lat, zestawiono z wydatkami ponoszonymi przez zarząd dróg na bieżące utrzymanie i remonty dróg. Celem badań była w konsekwencji odpowiedź na pytanie czy gospodarka drogowa oparta o recykling, może przyczynić się do obniżenia kosztów ponoszonych na utrzymanie i bieżące remonty dróg.

**SŁOWA KLUCZOWE:** gospodarka cyrkularna, odzysk materii, budowa dróg, asfalt z odzysku, łagodzenie klimatu.

**ABSTRACT.** Investments conducted on the principles of Circular Economy aim to introduce sustainable practices and minimize the negative impact of road infrastructure on the environment. One of the main elements of road investments conducted on the principles of Circular Economy is the use of recycled materials. An increasingly common material in road construction is milled asphalt concrete and crushed old construction layers which, after appropriate processing, can be reused. The research focused on determining the impact of Circular Economy-based investments on the funding of road repairs and ongoing maintenance, using the example of Płock, a medium-sized Polish city. In 2011, the co-author of the paper proposed to the city authorities the implementation of regulations regarding the utilization of demolition materials obtained from road investments in urban street lanes, which was successfully implemented in mid-2011. The introduced regulations applied to surfaces such as asphalt, stone, concrete road plates, trachyte, and concrete blocks, as well as curbs, edges, and elements of the substructure. The demolition material recovery program yielded significant results in a short time, primarily in terms of environmental protection. Before 2011, all demolition materials were sent to municipal landfills, and currently, the quantities sent there equal zero. The research, based on data from the last 10 years, was compared with the expenditures incurred by the road management for ongoing maintenance and road repairs. The aim of the research was, consequently, to answer the question of whether a road economy based on recycling can contribute to reducing the costs of road maintenance and ongoing repairs.

**KEYWORDS:** circular economy, material recovery, road construction, recycled asphalt, climate mitigation.

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## 1. INTRODUCTION

Road investments conducted under the principles of Circular Economy and climate change mitigation focus on implementing sustainable construction and operational practices to minimize the negative impact on the natural environment and reduce greenhouse gas emissions. One of the primary elements of road investments guided by the principles of a closed-loop economy is the utilization of recycled materials. The appropriate processing and utilization of such construction materials, along with their recycling, help reduce the extraction of natural resources, decrease the amount of waste stored in landfills, and mitigate their adverse environmental effects. Various recycled materials can be employed in road construction. For example, asphalt mixes can be enriched with recycled materials such as crushed stone, reclaimed asphalt pavement, slag, or concrete aggregates. These materials can undergo suitable processing and be added to the traditional asphalt mix, thereby reducing the consumption of new raw materials and limiting construction waste. Concrete can also be produced using recycled materials. This is achievable by incorporating components like crushed waste concrete, slag, or fly ash from power plants. Adding these materials to a new concrete mix reduces the need for new components and simultaneously utilizes construction waste. Recycled materials can also be used for stabilizing the subbase of roads built on weak soils [1, 2].

## 2. ROAD INVESTMENTS IN POLAND AND WORLDWIDE BASED ON CIRCULAR ECONOMY AND CLIMATE CHANGE MITIGATION PRINCIPLES

The utilization of recycled materials in road investments is becoming increasingly popular worldwide. Many countries are prioritizing sustainable road infrastructure and are developing regulations, standards, and initiatives that promote the use of recycled materials as a standard practice in road construction. Pioneering countries in the use of recycled materials in road construction include China, the Netherlands, Germany, France, Sweden, the United States, Canada, Japan, Australia, Iran, Jordan, and New Zealand, where recycled asphalt pavements are extensively researched and applied [3, 4, 5, 6]. In the United Kingdom, there are numerous programs and initiatives aimed at increasing the use of recycled materials in road construction. The Recycled Aggregate Quality Protocol project which establishes standards and guidelines for the use of recycled materials in road construction may serve as an example [7].

Efforts to utilize recycling in road construction are also underway in Poland, where programs promoting sustainable practices in the road sector exist. However, significant steps towards effective waste management were taken only in 2019 when the Council of Ministers approved documents related to environmental policy for 2030 and a "roadmap" for the transition to a closed-loop economy. In Poland, asphalt recycling is increasingly used, especially in road repairs. This process involves milling the existing asphalt surface and using the obtained material to produce a new asphalt mix. One of the main materials used in road construction is concrete which, when crushed, can be used as aggregate in new concrete mixes, reducing the consumption of new raw materials. In Poland, there are programs supporting the use of recycling in road construction, such as the Government Local Investment Fund which provides financial support to local governments for infrastructure investments, including the use of recycled materials. It is worth noting that recycling practices in road construction in Poland are still evolving and developing. There is growing environmental awareness and commitment to introducing sustainable solutions in the road sector [8].

During the construction, reconstruction, repairs, or routine maintenance of roads, recycled materials such as asphalt and concrete rubble can be used. The process was undoubtedly facilitated by the Regulation of the Minister of Climate and Environment of December 23, 2021, specifying detailed conditions for losing the waste status concerning asphalt destruct [11], which clearly indicates that material obtained from cold milling of asphalt layers, crushing of slabs cut from the asphalt surface, or blocks obtained from these slabs can be reused. The reuse of materials from dismantled or reconstructed roads reduces the consumption of natural resources and the amount of waste. Road investments should also consider efficient resource management, such as energy, water, and construction materials. Road investments may also foresee the use of innovative materials and technologies that are eco-friendly and resistant to wear [13, 14, 16].

In addition to using recycled asphalt, investments may involve the use of intelligent road materials, such as photocatalytic surfaces that reduce air pollution, and the use of materials with extended lifespans that require less frequent repairs. It is essential to consider an economic approach to waste by minimizing the generation of construction waste and thoughtfully using those that will arise. Road investments should include long-term planning and monitoring of their environmental impact. Defining specific indicators, such as the reduction of $CO_2$ emissions, increased public transport usage, or decreased consumption of natural resources, allows for evaluating the effectiveness of investments and identifying areas requiring further action [15, 17].

Road investments aligned with the principles of a closed-loop economy also consider rainwater retention. This may involve the use of special systems for collecting and storing rainwater which can be used for watering green areas along roads or for industrial purposes [12]. Investments can focus on increasing roadside greenery, such as trees or lawns. Roadside green belts not only enhance aesthetics but also contribute to improving air quality, absorbing $CO_2$, reducing noise, and enhancing the microclimate around roads. During the implementation of road investments, particular attention should be paid to the protection of natural areas affected by road construction. Restoring biodiversity, creating green areas, and protecting ecosystems can help offset the impact of investments on the environment.

Road investments have a significant impact on climate change mitigation. The transportation sector is one of the main sources of greenhouse gas emissions, such as carbon dioxide ($CO_2$) and nitrogen oxides (NO). According to the GUS [2022] yearbook, the combustion of fuels in the road transport sector was the largest source of nitrogen oxide emissions in 2020, accounting for 34% of the total emissions of this pollutant in Poland [9]. Taking this into account, investments can support the integration of various means of transport, such as cars, bicycles, pedestrians, and public transport. The construction of bike paths, sidewalks, and bicycle parking spaces, as well as providing convenient transfers between different modes of transport, can encourage the use of more environmentally friendly means of transportation. Investments can also focus on optimizing urban logistics. The use of intelligent transport management systems, as well as electromobile delivery vehicles, can lead to a reduction in road traffic and, consequently, emissions.

Furthermore, road investments can be directed towards improving infrastructure for pedestrians, such as sidewalks or bicycle paths. Prioritizing pedestrians and cyclists as primary means of transportation can ultimately lead to a reduction in air pollution. Investments in new lines and the reconstruction of existing rail transport infrastructure can also contribute to reducing $CO_2$ emissions, as well as promoting the use of this type of transport as an alternative to cars.

## 3. PŁOCK PRINCIPLES OF MANAGING DEMOLITION MATERIALS AND THEIR IMPACT ON ROAD REPAIR AND MAINTENANCE FINANCING

The research aimed to determine the impact of using recycled materials obtained from road repairs and reconstructions on the financing of road repairs and ongoing maintenance, with a focus on the city of Płock. In 2011, one of the co-authors of the paper (then the director of the Municipal Road Administration – Piotr Gryszpanowicz) proposed to the city authorities the implementation of principles for managing demolition materials obtained from investments in the road lanes of city streets, which was successfully implemented in mid-2011. The Municipal Road Administration (MZD) in Płock, at that time, was responsible for managing approximately ~300 km of public roads, of which around ~250 km had road surfaces, and about ~40 km were unregulated, dirt, or temporarily hardened roads. The administration also maintained approximately ~50 km of non-public roads with varying standards. All of this resulted in significant annual expenditures on road works.

The introduced regulations specifically concerned surfaces: asphalt, stone, concrete road slabs, trachyte, concrete blocks, as well as curbs, edges, and understructure elements. The program for recovering demolition materials yielded substantial results in a short time, primarily in terms of waste recycling. Before 2011, all demolition materials were sent to municipal landfills, whereas currently, the amounts of materials sent there equal zero. Table 1 shows the quantities of demolition materials obtained during investment works in Płock, suitable for reintegration within repair and ongoing road maintenance works.

Thanks to the introduced regulations, in less than 10 years, a significant amount of demolition material has been obtained. In addition to a large quantity of 50×50×7 concrete tiles, MON concrete slabs, trilith-type blocks,

Table 1. Demolition materials reused during renovation works in Płock from 2012 to 2021

| Year | Concrete tiles 50x50x7 [pcs.] | Concrete slabs MON [pcs.] | Interlocking concrete pavers [pcs.] | Concrete paving blocks [$m^2$] | Concrete edging and curbstones [pcs.] | Crushed concrete [$m^3$] | **Crushed concrete** [t] | Crushed asphalt [$m^3$] | **Crushed asphalt** [t] |
|---|---|---|---|---|---|---|---|---|---|
| **2012** | 2942 | 1721 | - | 818 | 354 | 820 | **1640** | 6306 | **12 612** |
| **2013** | | | | | | | | | |
| **2014** | 2871 | 170 | 36 | 1641 | 942 | 1658 | **3316** | 10 480 | **20 960** |
| **2015** | 10 068 | 366 | 220 | 637 | 1417 | 490 | **980** | 4418 | **8836** |
| **2016** | 2624 | 241 | 182 | 309 | 143 | 2719 | **5438** | 3395 | **6790** |
| **2017** | 3146 | 366 | 240 | 1245 | 202 | 3783 | **7566** | 2336 | **4672** |
| **2018** | 4746 | 162 | 288 | 1631 | 263 | 3688 | **7376** | 6125 | **12 250** |
| **2019** | 4766 | 7 | 23 | 2520 | 14 | 711 | **1422** | 1212 | **2424** |
| **2020** | 2432 | 144 | 180 | 1899 | 31 | 1063 | **2126** | 614 | **1228** |
| **2021** | 726 | 15 | - | 221 | - | 873 | **1746** | 1228 | **2456** |
| **Sum** | **34321** | **3192** | **1169** | **10921** | **3366** | **15 805** | **31 610** | **36 114** | **72 228** |

curbstones, and curbs, 31.610 tons of crushed concrete and 72.228 tons of asphalt millings were obtained. The recovered material was used in Płock to solidify dirt roads. The number of repairs and maintenance work increased while maintaining the same level of financial expenditure. The recovered crushed concrete was used in the sub-layers of non-public roads, as well as sidewalks, bike paths, and parking lots. Due to meeting local needs, since 2019, the Municipal Roads Administration in Płock has also been given the opportunity to sell material from demolitions when the material could not be used for tasks related to the road management's activities. Table 2 shows the quantity of demolition materials sold by the Municipal Roads Administration through tender procedures conducted from 2019 to 2023. The scale of the quantity of demolition materials intended for sale varies from year to year, as it depends on the available material from demolitions, which is closely related to the number of investments and planned repairs in the city.

Applied legal solutions have brought significant economic benefits to the city of Płock in a short period. Research based on data from the last 10 years, juxtaposed with the expenses incurred by the road management for ongoing maintenance and road repairs (see Table 3) in previous years, leaves no doubt and leads to one fundamental conclusion – road management based on recycling undeniably contributes to reducing costs for maintenance and ongoing road repairs.

In Płock, materials that do not require advanced technologies are mainly reused in projects related to ongoing maintenance or road repairs. At the stage of acceptance for storage, the road management ensures proper cleaning and sorting of materials. In the case of concrete elements that are not suitable for reuse, they must be crushed so that, in the future, they can be used as aggregate to harden road surfaces or as a subbase layer. Although this solution,

Table 2. Materials from Demolitions Sold by the Municipal Road Management in Płock in the Years 2019–2023

| Year | 2019 | | 2020 | | 2021 | | 2022 | | 2023 (half a year) | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Unit** | Quantity [t] | Price [PLN] | Quantity [t] | Price [PLN] | Quantity [t] | Price [PLN] | Quantity [t] | Price [PLN] | Quantity [t] | Price [PLN] |
| **Crushed asphalt** | 6000 | 394 215 | - | - | 000 | 61 500 | 4000 | 250 920 | - | - |
| **Concrete aggregate** | 2500 | 62 730 | 4000 | 98 400 | 2000 | 50 430 | 8500 | 219 555 | 8 200 | 257 562 |
| **Sum** | 8500 | **456 945** | 4000 | **98 400** | 3000 | **111 930** | 12 500 | **470 475** | 8 200 | **257 562** |

Table 3. Area of paved roads in the context of repair and ongoing maintenance works and their costs incurred by the Municipal Road Management in Płock in the years 2012–2022

| Year | Road surface stabilization with gravel | | Road stabilization using crushed material | |
|---|---|---|---|---|
| | **Area** [m$^2$] | **Costs** [PLN] | **Area** [m$^2$] | **Costs** [PLN] |
| **2012** | 15 703.55 | 510 939.93 | - | - |
| **2013** | 28 300.64 | 1 279 913.89 | - | - |
| **2014** | 13 714.00 | 552 149.51 | - | - |
| **2015** | 2357.04 | 77 210.44 | 22 630.90 | 318 795.60 |
| **2016** | 9937.47 | 314 270.72 | 20 980.97 | 382 452.75 |
| **2017** | 8826.15 | 435 245.93 | 13 529.45 | 273 107.60 |
| **2018** | 6551.14 | 336 248.08 | 30 550.46 | 668 761.96 |
| **2019** | - | - | 2478.95 | 101 300.64 |
| **2020** | 11 991.92 | 127 830.55 | 13 196.25 | 62 316.82 |
| **2021** | 1774.56 | 75 710.57 | 2739.19 | 82 409.36 |
| **2022** | 3061.06 | 340 301.27 | 670.00 | 30 447.10 |
| **Sum** | 102 217.53 | **4 049 820.89** | 106 776.17 | **1 919 591.83** |

successfully implemented in Płock, represents the simplest form of reusing recyclable materials obtained during investment projects, the analysis of data shows significant financial savings. As a result, there has been an increase in the number of repairs and maintenance work conducted while maintaining the same level of financial expenditure.

Thanks to the implemented program for recovering materials from demolitions in just 10 years, it was possible to harden approximately 30 km of dirt roads within the city limits of Płock without increasing annual expenditures for road repairs and maintenance. Due to the high quality of the material, properly crushed and sifted, high-quality concrete and asphalt rubble were obtained. The savings made from not purchasing material were entirely used to cover the costs of incorporating the materials properly.

To better illustrate the scale of the benefits of having one's own material that can be used for road hardening, a simulation was conducted covering data from 2015 to 2022. This is a representative period during which no additional material purchases for road hardening were made. The simulation was based on data regarding financial expenditures for road investments in individual years. Taking into account the cost of hardening 1m2 over a specified time range, the simulation calculated the area that would be strengthened, assuming that the contractor has their own recycled material or, in the absence of recycled materials, uses the contractor's material (Table 4).

As the analysis of the data for the specified period shows: approximately 44,500 m$^2$ of roads were hardened with concrete aggregate, and just under 107,000 m$^2$ with asphalt rubble. In a similar period, considering the need to purchase material on the market and taking into account the indicators of rising prices, only slightly over 23,000 m$^2$ of roads would have been hardened with concrete aggregate, and just under 29,000 m$^2$ with asphalt rubble. Translating these data into percentage indicators, from 2015 to 2022, the road management, if forced to purchase material for road hardening, would have completed only 52% of roads with a concrete aggregate surface and 27% of roads with an asphalt rubble surface. With the same financial expenditures, the necessity to purchase material would have resulted in the completion of no more than 50% of investments related to incorporating asphalt rubble and no more than 90% (2017–2022) and 50% (2015–2016) of projects utilizing concrete aggregate (Fig. 1).

The analysis of expenditures incurred by the road management for the current maintenance and repairs of roads, including revenues from the sale of recycled materials for the years 2019-2022, also presents interesting insights.

The large number of road investments, especially in the years 2012–2022, resulted in the road management having significant quantities of construction materials, which, since 2019, could no longer be fully utilized within its administration area. The surfacing of the majority of dirt roads in the city over 10 years, as well as the very high demand for concrete and asphalt debris in the surrounding

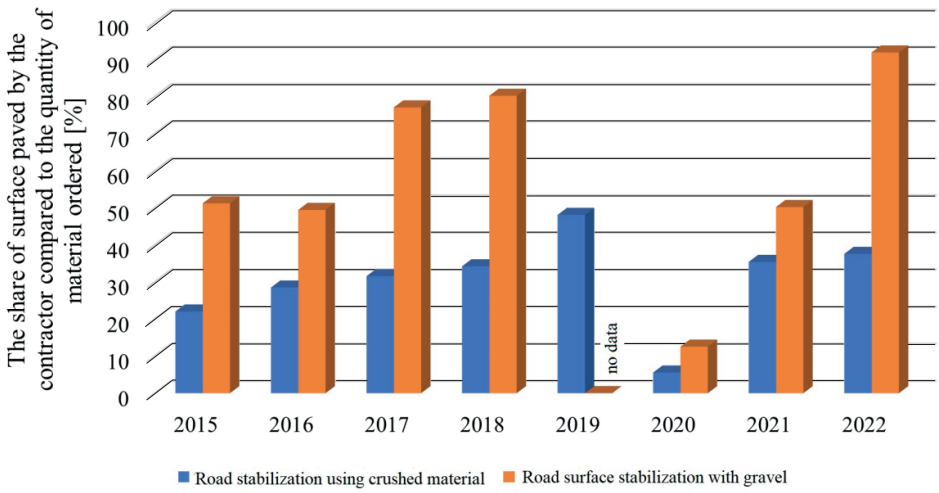


Fig. 1. Percentage share of the surface area of pavements constructed with the ordering party's material in relation to the simulated quantity of material obtained by the contractor

Table 4. Simulation of the area of paved roads with the same financial expenditures, assuming that the contractor has or does not have the material, in the years 2015-2022

| Year | Road surface stabilization with gravel | | Road stabilization using crushed material | |
|---|---|---|---|---|
| | provided by the contractor [m²] | purchased by the contractor [m²] | provided by the contractor [m²] | purchased by the contractor [m²] |
| **2015** | 2357.04 | 1206.41 | 22 630.90 | 4981.18 |
| **2016** | 9937.47 | 4910.48 | 20 980.97 | 5975.82 |
| **2017** | 8826.15 | 6800.72 | 13 529.45 | 4267.31 |
| **2018** | 6551.14 | 5253.88 | 30 550.46 | 10 449.41 |
| **2019** | – | – | 2 478.95 | 1191.77 |
| **2020** | 11991.92 | 1503.89 | 13 196.25 | 733.14 |
| **2021** | 1774.56 | 890.71 | 2 739.19 | 969.52 |
| **2022** | 3061.06 | 2812.41 | 670.00 | 251.63 |
| **Sum** | 44 499.34 | 23 378.50 | 106 776.17 | 28 819.78 |

municipalities, led to the decision to gradually sell surplus stockpiled material. Analyzing the specified period, there is a clear surplus of income from the sale of recycling materials over the amounts spent on road surfacing in the city (Table 5). The changes in the classification of roads in Płock based on the type of surface from 2012 to 2021 are presented in Table 6 and Fig. 2.

By the end of 2022, approximately 90% of all roads in Płock consisted of hard surfaces. Data indicates that over the years 2012–2021, the share of roads with hard surfaces increased, while the proportion of dirt roads decreased accordingly.

Table 5. Expenditures incurred by the road management for road hardening, including revenues from the sale of recycled materials, in the years 2019–2022

| Year | Total expenses on road surfacing [PLN] | Income from sales [PLN] |
|---|---|---|
| **2019** | 101 300.64 | 456 945.00 PLN |
| **2020** | 190 147.37 | 98 400.00 PLN |
| **2021** | 158 119.93 | 111 930.00 PLN |
| **2022** | 370 748.37 | 470 475.00 PLN |
| **Sum** | **820 316.31** | **1 137 750.00 PLN** |

Table 6. Classification of roads in Płock based on the type of surface from 2012 to 2021

| Year | Total roads | | Including: hard-surface roads | | Including: unpaved roads | |
|---|---|---|---|---|---|---|
| | length [km] | area [thou. m²] | length [km] | area [thou. m²] | length [km] | area [thou. m²] |
| **2012** | 281.10 | 1855.40 | 238.80 | 1500.30 | 42.30 | 355.10 |
| **2013** | 281.10 | 1867.70 | 243.70 | 1538.80 | 37.40 | 328.90 |
| **2014** | 281.10 | 1867.70 | 253.80 | 1592.20 | 27.30 | 275.50 |
| **2015** | 281.10 | 1874.20 | 260.50 | 1639.90 | 20.60 | 234.30 |
| **2016** | 282.90 | 1911.00 | 265.20 | 1690.30 | 17.70 | 220.70 |
| **2017** | 282.90 | 1911.00 | 268.10 | 1701.40 | 14.80 | 209.60 |
| **2018** | 282.90 | 1911.00 | 269.10 | 1708.30 | 13.80 | 202.70 |
| **2019** | 287.80 | 2320.00 | 274.40 | 2118.90 | 13.40 | 201.10 |
| **2020** | 288.10 | 2322.20 | 274.70 | 2121.10 | 13.40 | 201.10 |
| **2021** | 288.10 | 2320.70 | 275.20 | 2118.20 | 12.90 | 202.50 |

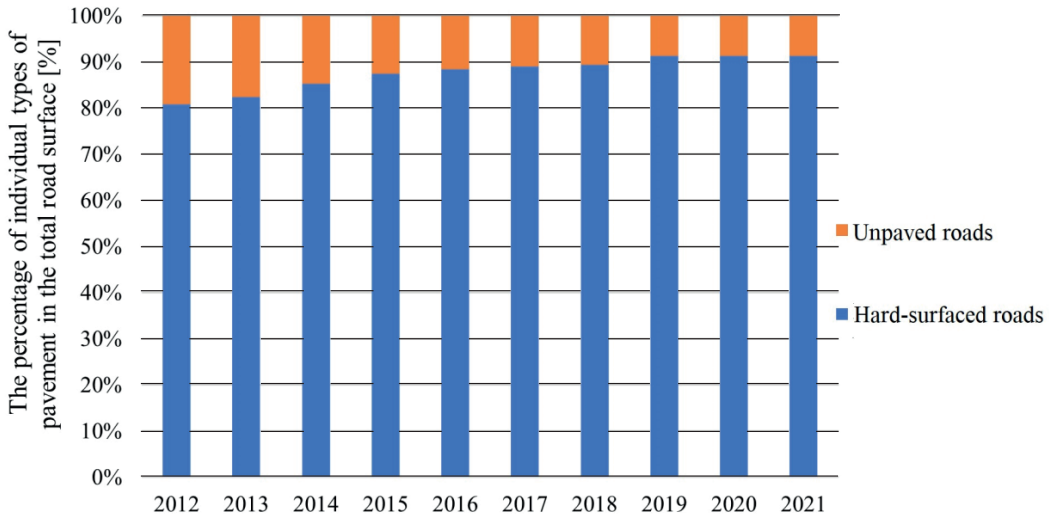


Fig. 2. Percentage share of the surface area of different road surfaces in the total road area in Płock

## 4. SUMMARY

Circular Economy principles involve extending the life cycle and reusing resources. The use of recycled materials in road construction aligns with this concept, as waste is transformed into valuable resources and reintroduced into the production process. However, it's important to note that the application of recycled materials in road construction can vary depending on local regulations, resource availability, and technology. The use of recycled materials in the construction, renovation, or ongoing maintenance of roads has many benefits:

- Using recycled materials helps reduce the extraction and consumption of new natural resources, such as sand or gravel.
- Utilizing recycled materials as raw materials in the road construction process reduces the amount of waste deposited in landfills, contributing to sustainable waste management.
- Recycled materials are cheaper than new resources, which can contribute to reducing road construction costs.
- The production of new resources, such as asphalt or concrete, involves the emission of carbon dioxide ($CO_2$) associated with the extraction, production, and transportation processes. Using recycled materials reduces the demand for new resources, thereby reducing $CO_2$ emissions associated with their production.
- Recycled materials, such as concrete or asphalt debris, often require less energy for processing compared to the production of new resources.
- Using recycled materials in road construction represents responsible management of construction debris, which, instead of ending up in landfills, is

processed and reused, reducing the negative impact of road investments on the natural environment.

The example of Płock clearly demonstrates that implementing actions in transportation construction in line with the principles of the Circular Economy not only brings ecological benefits but also significant financial savings. The reuse of materials does not generate costs related to disposal, transport to neutralization sites, or storage. Additionally, it can generate financial profits from the sale of demolition materials obtained during reconstructions and renovations.

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