

CIRCULAR MATERIAL USE IN LANDSCAPE DESIGN

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Abstract. The aim of the article is to highlight trends in landscape and environmental improvement by including new environmental and landscape elements made from recycled materials. To achieve this objective, a number of objectives have been defined: to present a recycled tyre pellet material for use in outdoor landscaping, to look at the tyre recycling process and how this material is obtained, to look at and analyse market trends and products for this material, how this material fits into the circular economy, to propose new ways of using this material in environmental and landscape landscaping. The methods used in the research are literature analysis, research of examples of good practice in Europe, constructive criticism and analysis, public surveys and grapho-analytical compilation of the obtained data. An essential part of the research is the conducted experiment, as the result of that recycled tyre granules were used in outdoor furniture collection. The selected research topic is actual because it is necessary to think about the wider use of recycled tyre materials, to increase the use of recycled material in various outdoor environmental products, to create demand in this sector; as well as introduce more people to this material - in a different way than usual.

Keywords: tires, recycling, recycled tyre granules, circular design, circular economy, product design, and landscape

Introduction

Tires as we know them today were introduced about 70 years ago. The external characteristics of the tires have not changed significantly since their introduction, but the structure of the tires has improved considerably. Many components are added to improve tire performance, longevity, wear resistance, and more. These properties are useful both during tire operation on the road and also contribute to the efficiency and further use of recycled tire materials in various products [1]. Car tires contain several valuable materials such as rubber (75%), steel (15%), textile fibers (10%). Tires that are no longer usable and need to be recycled are called end-of-life tires (ELT). In Europe, approximately 50% of all used tires are recycled to recover their valuable materials. The pure rubber in the tires is processed into granules, which can further be used in various industries, such as sports, construction, product design, etc. [2]. The purpose of this article is to highlight landscaping and environmental improvement trends, offer recycled tire granule materials for use in outdoor landscaping, review the tire recycling process and how this material is obtained, review and analyse market trends and products for this material, and how this material fits in circulation economy, to offer new ways to use this material in environmental improvement and landscape. Nowadays, outdoor furniture of various designs and materi-

als can be observed in the outdoor environment. Next to the classic outdoor furniture, more common are non-standard design solutions, and more sustainable choice of materials [3]. The use of recyclable materials in products is not only a trend, it is important to do so in order to reduce as much as possible unnecessary waste into nature. It is relevant to come up with new uses for worn-out materials, giving them a new life. Since many materials that end up in waste have properties beneficial to the outdoor environment, various recycled materials are often used in outdoor landscaping (Fig. 1). It is more and more common to think about how to make modern cities greener and more pleasant for people [4]. It is relevant to use various greenery pots, to integrate them into city streets and squares [5]. Outdoor furniture is also supplemented with places for such decorative greenery, thus ensuring that this piece of furniture fulfils several functions at once (Fig. 2, 3). In order to provide the furniture with the widest possible use, simple, well-integrated shapes are thought of. Unusual furniture design is often used, but there is always a consideration of how well this product will fit into the environment given how many different styles are found in the outdoor environment. When studying recycled tire granule material and products already made from them, it was concluded that this material has many positive properties - longevity, it is suitable for outdoor conditions, withstands frost, rain, abrasive weather



Fig. 1. Paving of recycled tire granules in front of a public building [*]



Fig. 2. Decorative plants integrated into the urban environment [*]



Fig. 3. Outdoor furniture with an integrated place for decorative greenery [*]



Fig. 4. Recycled tire granules in outdoor furniture collection with user [*]



Fig. 5. Visualization of products in an urban environment [*]



Fig. 6. Offer of colour variations of the collection [*]

conditions, is difficult to damage mechanically and it can be recycled repeatedly, as well as using binders, it is possible to make elements of different shapes from it. In the experimental part, with her work, the author wants to show a wider use of recycled tire granules, increase the use of recycled material in various outdoor environmental products, create demand in this industry; as well as to introduce more people to this material - in a different way, as in tires (Fig. 4). The style of the developed furniture is designed in such a way that it is as easy as possible to integrate it into urban environments of different styles, but if necessary, the developed collection can be expanded - the rubber granules can be offered in other colours, as well as the wooden seat can be painted and offered in additional shades (Fig. 5., 6.). It is also possible to expand the composition of the collection. Keeping the existing style of the collection, it is possible to offer a coffee table made from recycled tire rubber granules, variations in the size of greenery boxes, variations in the length of the benches, offering benches with a backrest. All this furniture should be designed in such a way that it can be used both separately and can be combined with each other and complement each other so that it can be more easily integrated into the outdoor environment and the overall landscape.

Methodology

In the literature analysis section, articles and statistics from the publications and data sheets of The European Tire & Rubber Manufacturers Association (ETRMA) were reviewed, data and information from the European Environment Agency were used, scientific articles from the books of scientific collections "Tire waste and recycling" (2021) and "Waste" (2019). A number of companies in Europe engaged in tire recycling, production of recycled tire granules, as well as companies producing various products from this material have been reviewed and analysed. The observations examine the products of these companies, because of which recommendations are given in the field of design and recommendations for further research. In the conducted experiment, a solution for a circular design object from recycled tire granules is proposed. The descriptive method is used for structuring the work and creating content.

I Tire recycling (relevance of the topic)

The European Union (EU) adopted three directives during the millennium to ensure that the largest amount of tires are diverted from landfills and recycled in a sustainable way [6]. The Landfill Directive (1999) was the first to be adopted, banning the landfilling of whole car and truck tires from 2003 and tire by-products from 2006. Thanks to this directive, end-of-life tires were defined as 'waste'. The overall aim of the directive was to divert the majority of tires away from landfills, thereby using the material for recycling or energy recovery [7].

Shortly after, the End-of-Life Vehicles Directive (2000) was adopted, which required end-of-life vehicles to be disposed of with the tires already removed to ensure that end-of-life tires do not end up in landfills [8].

Third, the Waste Incineration Directive (2000) was adopted. The aim of the directive is to reduce dioxin emissions by 90% by 2005. This directive controlled the use of tires for energy recovery and inadvertently directed tires towards this type of recycling [9].

Thanks to these directives, the possibilities of tire recycling and the reuse of their materials in new products were thought of. A waste tire management system is needed so that waste tires can be collected and sent for recycling. In general, three end-of-life tire management models have been developed

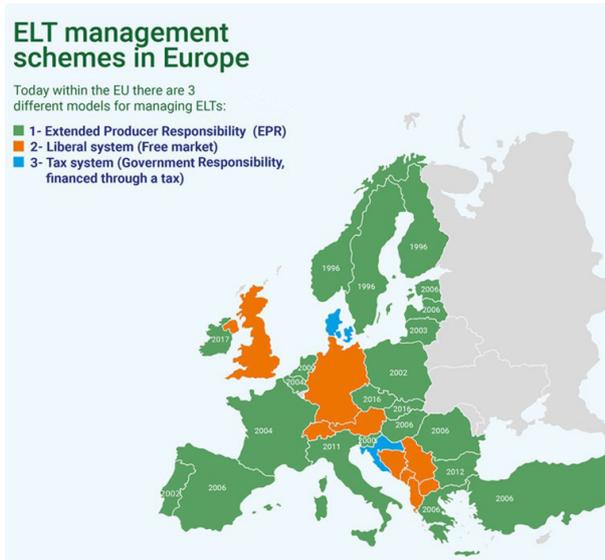


Fig. 7. Waste tire management models in Europe [10]

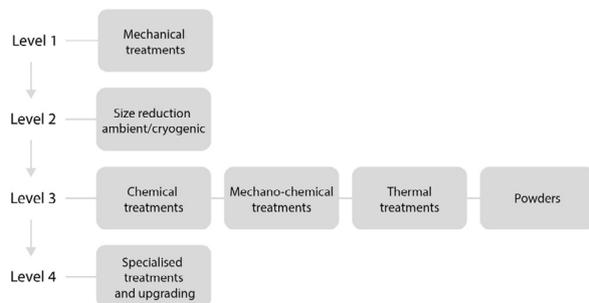


Fig. 8. Tire recycling levels [*]

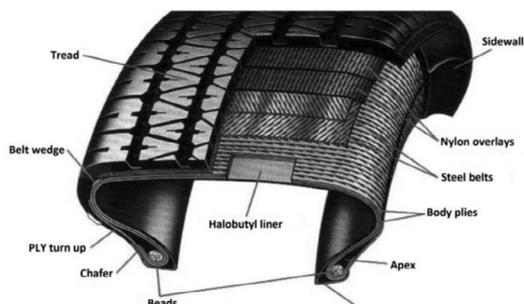


Fig. 9. Typical tire section [1]

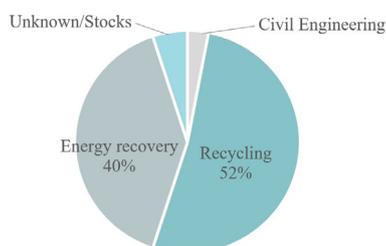


Fig. 10. Processing of used tires in 2019

in Europe:

1) Extended Producer Responsibility (EPR) - EPR is the producer's full or partial operational and/or financial responsibility for the product, which is extended to the stage of the product's life cycle after consumption. In other words, under this system, the original manufacturer has a duty of care to ensure that waste from its products is disposed of in a responsible and environmentally sound manner. This led to the

creation of non-profit companies funded by tire manufacturers, which aim to manage the collection and recovery of ELTs using the most economical solutions.

2) Free market system - according to this system, legal acts determine the goals to be achieved, but do not specify the responsible parties. In this way, all operators of the recovery chain enter into contracts under free market conditions and act in accordance with the law. This can be supported by voluntary cooperation between companies to promote best practice.

3) Tax system - according to the tax system, each country is responsible for ELT management. It is financed by a tax collected from tire manufacturers and then passed on to consumers.

In Europe, the Extended Producer Responsibility (EPR) system is the most widely used (Fig. 7) [10].

Before being sent for processing, the tires are sorted into categories - car tires, truck tires, etc., and then they are sorted again by size. Partially worn tires that are still fit for road use or export are diverted from recycling and integrated back into the market. Retreadable tires are directed to tire retreading facilities. Tires that cannot be further used or renewed are sent for recycling, before which they are further sorted.

Before processing, the tires are cleaned of debris such as glass, stones or various objects. Tires obtained from stock or other long-term storage must be washed before handling.

In total, there are four levels of tire recycling, which become progressively more complex (Fig. 8). Recycled tire granules are obtained as a result of the first and second levels, this material also accounts for 75% of the demand for materials obtained as a result of processing, so these two levels are examined more closely.

Level 1

Wire Stripping - A mechanical procedure that removes the rubber-coated steel coil wires by cutting or tearing the rubber parts that secure the wires to the tire casing (Fig. 9).

Tire sidewall removal - a mechanical cutting procedure that releases the tread strips from the carcass (Fig. 9).

Shredding and chipping - used for whole car or truck tires. Shredding is a process that uses different technologies to break up the tire. The process results in shredded tire material ranging in size from 50 to 300 mm and irregularly shaped. Shredding is usually a secondary crushing process that results in irregularly shaped material in the range of 10 to 50 mm.

Level 2

Ambient grinding - this process uses whole or pre-treated car or truck tires in the form of shredded, chips, sidewalls or treads. This process is a multi-stage technology that results in the sequential separation of rubber, metals and textile fiber.

At the beginning of the process, previously unremoved metals are magnetically separated from the rubber. The rubber material is then passed through one or more successive granulators. In order to sift out the last remnants of impurity and divide the granules into size fractions, the material passes through several sieves and screening equipment. In the last phase, textile fiber residues are removed with air separators.

Cryogenic processing - this process usually uses pre-treated tires as raw material, most often wood chips or granules obtained from ambient grinding. Cryogenic processing takes place at very low temperatures so that the rubber remains brittle. At the beginning of the process, the material is placed in a freezing chamber, with the help of liquid nitrogen it is cooled to a temperature where the rubber loses its elasticity. As a result, the rubber remains brittle and can be broken to obtain smooth and regularly shaped granules of the required size. Due to the fragility of the material, textile fibers and met-

al are easily separated in the mill. To remove the last traces of impurities, the material is passed through magnetic and sieving equipment [11].

Both of the mentioned methods can be used repeatedly to obtain finer fractions of better quality granules. Often both of these technologies are combined to take advantage of each technology and reduce the cost of the overall granulation process [12].

In Europe in 2019, 95% of all used tires were collected and recycled. Data analysis shows that approximately 1.95 million tons or 52% of used tires were processed using material recovery (Fig. 10). This figure includes 1.36 million tonnes of tires sent to the granulation process; 476,000 tons of used tires were incorporated into cement; 112,954 or 3% tons were used in civil engineering. 1.43 million tons or 40% of tire diverted energy for recovery. The amount of used tires in storage or unknown and awaiting recycling was almost half less than the previous year, reaching 165,000 tons or 5% [13].

II Circular design

A circular economy is an economic system that opposes a linear open-ended system (produce, consume, dispose). It aims to achieve sustainable development while creating environmental quality, economic prosperity and social equity for the benefit of current and future generations [14]. The system aims to return to nature what comes from nature through the life cycle of the product (Fig. 11).

The European Community (EU) aims to double the use of recycled materials as a share of the total amount of material used in the economy between 2020 and 2030, as set out in the Circular Economy Action Plan. Increasing the use of secondary materials would reduce the extraction of primary raw materials and the associated environmental impact. In 2021, recycled materials accounted for 11.7% of material used, an increase of less than 1% since 2010. These data show slow progress to double the rate of recycling materials by 2030. For the progress to be faster, there must be a greater demand for circular materials in the market [15].

Due to the lack of demand and market for waste tire granules in Europe, some of the waste tires are incinerated for energy recovery, which is a wasteful use of resources (Fig. 12). Statistically, in Europe on average, one tire is mechanically recycled for every tire burned [2].

Tires are not an easy product to renew, their recyclability is affected by the possibilities of current technologies, as well as market demand in this direction. At the moment, tires belong to the category of products for which complete circulation is not possible, but they are suitable for an "open loop" life scenario, as a result of which it is possible to produce other, no less important products. The four "R" scheme is used for tire recycling, which includes reuse, retreating, recycling, recovery [16].

The Reuse process involves the sale of partially worn tires for continued use, as well as export to countries with fewer restrictions on the use of tires on the road.

Recovery process turns tire waste into fuel. Tires, like coal,

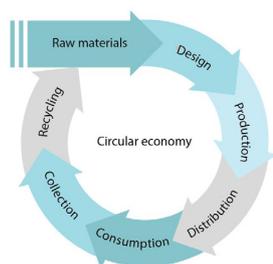


Fig. 11. Circular economy scheme [16]

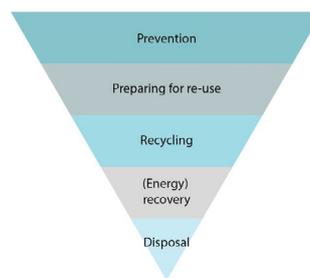


Fig. 12. Waste hierarchy [16]

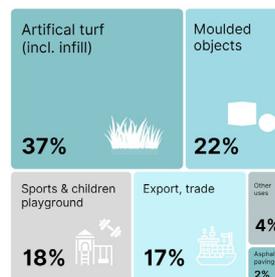


Fig. 13. Segmentation diagram of the recycled tire granule market [16]

have a high calorific value, making them useful as fuel. For example, the use of tire-derived fuel in cement kilns helps reduce harmful emissions, and wire embedded in rubber can help improve the quality of cement.

As a result of recycling, tire waste is turned into raw material that will be reintegrated into the economic flow. The recycling of used tires into rubber granules is a common and productive way of recycling tires, it is widely used in various sports field surfaces, children's playground surfaces, in the production of road curbs, in road construction, as well as in the production of various everyday products [2] (Fig. 13). Using pyrolysis, it is possible to obtain gases, oils, carbon coal and steel from tires, which can be used as new resources that are re-entered into commerce [17].

Retreating remanufactures the tire casing to reduce production energy and resources needed to produce new tires.

Some of the examples of good practice in Europe were investigated - companies producing recycled tire granules from waste tires, as well as companies producing products from recycled tire granule material.

Companies engaged in the production of products from recycled tire granules:

- **Rubrig** (Latvia) – the company offers various types of outdoor rubber tiles, coverings with 2D graphics, rubber 3D shapes [18];
- **Kraiburg** (Germany) – the company uses recycled tire granule material as sound and vibration absorption material in specific products, offers various types of rubber covering tiles, rubber 3D forms, delimiting rubber borders [19];
- **Eco paving** (United Kingdom) – the company offers various types of laid rubber coverings for outdoor environments [20];
- **Ecoprodev** (Portugal) – the company offers rubber covering tiles, curbs, rubber carpets, greenery boxes of various sizes [21].

Companies that produce recycled tire granules from used tires:

- **Tire recycling solutions** (Switzerland) – rubber powder is produced from used tires, which can be used in the production of new products (tires, asphalt production, production of molded rubber products) [22].
- **Ecopneus** (Italy) – the company deals with the collection and processing of used tires into granules, this product

is further sold as raw material for the production of new products [23].

- **Genan** (Denmark) – Genan is one of the world's largest tire recycling companies. Because of tire recycling, the company offers rubber granules of various fractions and colours, rubber powders, as well as recycled steel and textile fibers [24].
- **Eco Green Equipment** (UK) – The company provides tire recycling solutions including tire shredders and granulators to transform tires into valuable materials [25].
- **Granuband** (Netherlands) – the company deals with tire recycling and produces rubber granules for various applications, including filling artificial sports fields and various industrial applications [26].

Benefits of tire recycling:

- The tire recycling process reduces waste - tire recycling reduces the number of old tires in landfills and illegal dumping sites, including helping to prevent the release of dangerous chemicals;
- Conservation of resources - saves natural resources and energy for the production of new rubber products;
- Reduction of carbon footprint – the lifetime of rubber products increases, which reduces the production of new rubber products, which contributes to the mitigation of climate change.
- Noise reduction in the urban environment – the use of recycled tire granules in highway and railway barriers is common, they reduce noise pollution in urban areas, which benefits the urban environment and society;
- Water management - these same recycled granules are used in storm water management systems, helping to filter runoff that helps prevent flooding or soil erosion;
- Safer environment - contributes to the general well-being of society, for example, using this material for the surfaces of playgrounds, as well as sports fields to absorb shocks, reducing the risk of injuries;
- Resource efficiency - tire recycling reduces the generation of new waste;
- Improving the urban environment – by including rubber mulch in landscaping and green areas in the urban environment, which helps retain moisture in vegetation, prevent weeds from growing, and create breathable and water-permeable coverings;
- Sustainable construction – recycled tire granules can be used as filler for various building materials;
- Marine ecosystems – creating artificial reefs from this material, which help to create habitats, helping to solve biological diversity and ecological balance;
- Cost savings – using recycled tire granule material in new products will reduce their overall costs, as this material will be cheaper than new rubber material;
- Promotion of the circular economy - including this material in the production of new products.

III Experiment and its results

Nowadays products made from recycled materials are becoming more and more relevant (Fig. 14). Both buyers and producers pay more attention to how environmentally friendly the product is, what resources were used in its production, whether it will be possible to recycle it.

In the conducted experiment (as part of the bachelor's thesis), recycled tire rubber material was chosen to be used in the outdoor furniture collection (Fig. 15). The offered collection products can be used both in public places - parks, near various buildings, bus stops, city squares, and also in private places - house yards, gardens, terraces. The main task of benches and decorative greenery boxes is to show that

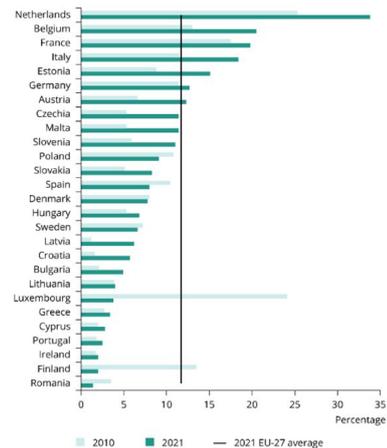


Fig. 14. Use of recycled materials in Europe in 2010 and 2021 [12]



Fig. 15. Recycled tire granules in outdoor furniture collection [*]

the material of recycled tire granules can be used not only industrially or as a covering material, but it can also be used to create various outdoor furniture, thus functionally and aesthetically complementing the surrounding environment and landscape.

As part of the work, a survey was conducted in which 76 respondents took part, the purpose of which was to find out the public's views on the necessity of tire recycling and the use of recycled materials in various products. To the survey question, "Do you think it is important to think about tire recycling and reuse of this product?" 76% said that it is definitely important to think about it (Fig. 16).

There are many potential places to place such furniture, according to the survey data, it can be concluded that people would like to see this type of product placed in public places (Fig. 17). This product could definitely conquer the landscaping market, where the main buyers would be city governments and public building owners.

The base of the bench and the greenery box are made from pressed recycled tire rubber granules, which are treated with a polyurethane binder. The products use granules in the size of 0.8-2.5 mm fractions.

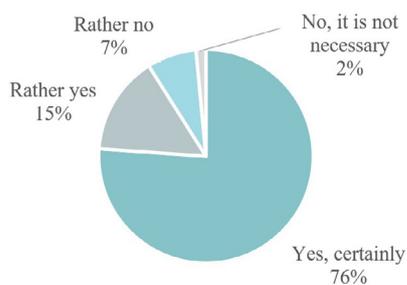


Fig. 16. Respondents' answers to the question "Do you think it is important to

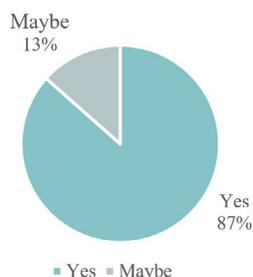


Fig. 17. Respondents' answers to the question "Would you like to see this type of product in parks, squares, near public buildings?"

Rubber shapes are made by pressing recycled tire granule and polyurethane binder mass in aluminium moulds at a temperature of 125°C. Such compressed rubber forms are suitable for outdoor environments - they are resistant to moisture and adverse weather conditions. They are suitable for use in both cold and hot weather conditions, and also have high resistance to mechanical damage and are long-lasting. Such compressed granules can last for an average of 10-15 years, after their service life they can be re-ground, recycled and used as a repeated raw material.

During the materials research stage, tests were carried out with a sample of pressed recycled tire granule material. The resistance of pressed rubber granules to heat, cold and moisture was tested. To verify the heat resistance of the granules, the sample was heated and its surface temperature was measured after heating with a light cloth pressed to the surface to ensure that no stains were formed from the hot granules (Fig. 18).

The test confirmed that when the surface of the sample was heated to 41.3°C and a light cloth was pressed against it, no stains were formed, which means that this type of material is safe for use in the hot season when the material could heat up in the sun.

In order to verify the cold resistance of compressed recycled tire rubber granules, a compressed granule sample was left in the snow at -6°C for 12h. After testing, the granules could be observed to be frozen and covered with snow, but no damage was found (Fig. 19).

To observe the moisture resistance of the pressed recycled tire rubber sample, water was poured onto the sample (Fig. 20). Initially, the water remained on the surface of the rubber, but after a short time it could be observed that it slowly seeped through the rubber shape. After the test, it was concluded that the rubber granules conduct water well and act like a sponge. The absorbed water slowly flowed through the sample, as moisture could be observed underneath for a long time after the test.

The ability of pressed granules to absorb moisture was examined. A compressed rubber granule sample was weighed and placed in water, its weight was recorded at various time intervals.

After the test, it could be concluded that the weight of the



Fig. 18. Heat resistance testing process

Fig. 19. Cold resistance testing process

Fig. 20. Moisture resistance testing process

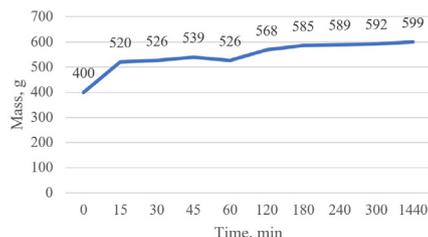


Fig. 21. Weight of pellets immersed in water versus time

rubber granule shape increased by 200g within 24 hours (Fig. 21). This factor could be influenced by the density of the compressed granules, but it can be concluded that the granules can absorb and retain water.

After the tests, it can be concluded that this type of pressed granules are well suited for various outdoor conditions, they are flexible - they do not deform when freezing and thawing. Each product of the collection is not only aesthetically attractive, but also functional. When creating a collection of outdoor furniture, it is important to pay attention to the basic functions of each product, as well as to make them easy to read for the user. The bench fulfils its main function as a seat, its shape is a simple horizontal rectangular shape, which will ensure that this bench will be easily placed and included in any type of environment, and its height corresponds to the basic principles of seating ergonomics. The rectangular shape is designed in a suitable length so that two to three people can sit on it freely.

The greenery box is designed so that it is convenient to plant and care for decorative plants, as well as to be stable and serve well in an outdoor environment. Its shape, like that of the bench, is rectangular, but to ensure easier planting and care of plants, this shape is placed in a vertical direction, which is 24 cm higher than the seat of the bench (Fig. 22).

The shapes of the elements of the collection are consistent with each other, their sizes are designed in such a way that it is possible to place the products of the collection both together as one element and separately.

After the conducted experiment, it can be concluded that by properly using recycled tire granule material and potentially combining it with other materials already known to the public, it is possible to obtain functional, designer outdoor furniture that gives an aesthetic design to the green-blue landscape. Aesthetic design is one of the three main functions to ensure a unified spatial system in the urban environment [4]. It is also important to use new technologies in landscaping, thus developing the urban environment and offering new solutions for its improvement. The use of recycled tire granule material in outdoor landscaping facilities can serve as a new technological solution, while at the same time introducing people to this material more widely and promoting demand in the production industry of this material [3].

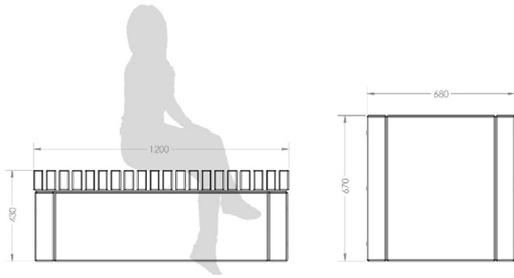


Fig. 22. Product main dimensions with user [*]

This experiment demonstrates that there is potential for wider use of this material, which would potentially create greater demand for the material by encouraging tire recycling processes to recover valuable materials, thus diverting them from recycling to energy recovery, a more inefficient use of this resource.

Conclusions and recommendations

- The study of urban environments and landscape realities emphasizes the relevance of utilizing recycled materials in modern environmental and landscape beautification projects;
- Historically, pneumatic rubber tires have been produced since 1888, however, the recycling of rubber tires was not addressed as an issue until 1999, when the first “Landfill Directive” was adopted. During this period of time, environmental pollution from used tires is assessed and used tires are considered “waste” for the first time.
- In accordance with the first three directives, recommendations are given on how to combat waste rubber tire pollution in Europe. Thanks to the Landfill Directive (1999), tire recycling possibilities and their involvement in the circular economy were thought about.
- Tires can be included in the circular economy using the Four R scheme (Reuse, Retreating, Recycling, Recovery), which is also used for the management of used tires in Europe.
- In Europe, most of the tires produced are recycled, but only ~50% of them are recycled to recover valuable materials. In order to promote the recycling of materials, the market needs more demand for this material;
- In order to promote the demand for the material, an extended market analysis should be carried out on the use of the specific material, as well as on the products in which this material could potentially be used most successfully. The article discusses new ways of using the material.
- In percentage terms, the majority of the market segment where recycled tire granule material is used is made up of artificial grass infill, pressed objects of various shapes and coverings of sports and playgrounds.
- While the European product offering from this material is currently uniform and narrow, there is potential for wider applications.
- Exploring new ways to use the material, potentially combining it with other known materials, can result in functional and aesthetically pleasing outdoor furniture that enhances green-blue landscapes.
- The use of recycled tire granule material in outdoor environmental improvement facilities can serve as a new technological solution, while at the same time making people more familiar with this material and promoting demand in the production sector of this material.
- In the education of an architect and a landscape archi-

tect, it is important to think about competencies such as circular economy and circular design, to ensure that the future urban environment is greener and more pleasant for people, as well as that the use of sustainable materials is thought about in this sphere.

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Kopsavilkums

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