ISSN: 2594 - 2905

# SUSTAINABLE REVALORIZATION OF CARPET WASTE UNDER AN APPROACH BASED ON CIRCULAR ECONOMY PRINCIPLES

SUSTAINABLE REVALORIZATION OF CARPET WASTE UNDER AN APPROACH BASED ON CIRCULAR ECONOMY PRINCIPLES

Flores Velázquez Roberto[1], Lara Ruíz Nadia[2], Hernández Jaimes Belem Gabriela[3]https://doi.org/10.61117/ipsumtec.v8i2.380

[1] Autonomous University of the State of Morelos,roberto.flores@uaem.mx , https://orcid.org/0000-0001-6908-9822.
[2] Autonomous University of the State of Morelos,nadia.lara@uaem.mx , https://orcid.org/0000-0001-6167-9000.
[3]Autonomous University of the State of Morelos,belem.hernandez@uaem.mx , https://orcid.org/0000-0002-3866-3593.

***Abstract*** -- Sustainable disposal of industrial waste has become a global priority in order to reduce its harmful effect on the environment. In particular, the carpet industry generates large amounts of waste, although this has not been fully verified worldwide, and only certain countries, such as the United States and the United Kingdom, have implemented measures to combat this problem. In the best-case scenario, this waste ends up in landfills, where it undergoes natural degradation, and the by-products produced are treated correctly. However, in most situations, it is dumped into the environment in garbage dumps, contributing to air, soil, and water pollution, as well as being a waste of resources. For this reason, options for revaluing this waste have been explored, and the circular economy provides a sustainable response that not only reduces the impact on the environment but also produces economic and social benefits. This document investigates how the valuation of carpet waste can turn a problem into an opportunity, highlighting its relevance to sustainability. It analyzes some processes for measuring circularity using globally established and accepted procedures, such as the Hellen MacArthur Foundation's Material Circularity Index and the Circular Economy Toolkit. Finally, it analyzes the contribution of these processes to the Sustainable Development Goals (SDGs).

***Keywords:*** carpet waste, circular economy, circularity index, sustainable development goals, revaluation.

***Abstract*** -- Sustainable disposal of industrial waste has become a global priority to reduce its environmental harm. In particular, the carpet industry generates a large amount of waste, although it is not fully verified worldwide, and only certain countries, such as the United States and the United Kingdom, have implemented measures to combat this problem. At best, this waste ends up in landfills, undergoing natural degradation, and the by-products produced are adequately treated. However, in most situations, it is dumped into the environment, contributing to environmental pollution of air, soil, and water and being a waste of resources. For the aforementioned reasons, options have been explored to revalue this waste, and the circular economy provides a sustainable response that reduces the effect on the environment and produces economic and social advantages. This paper investigates how the valorization of carpet waste can turn a problem into an opportunity, highlighting its relevance for sustainability. Some processes are analyzed to measure their circularity using established and globally accepted procedures, such as the Materials Circularity Index of the Hellen MacArthur Foundation and the Circular Economy Toolkit. Finally, an analysis is made of these processes' contribution to the Sustainable Development Goals (SDG).

***Key words –*** carpet waste, circular economy, circularity index, sustainable development goals, revaluation.

## INTRODUCTION

Carpets represent a significant challenge in waste management due to their volume and complex composition. However, their recycling and reuse can contribute to a circular economy. This involves recovering valuable materials, innovating in transformation processes, and adopting policies such as extended producer responsibility (EPR), which obliges manufacturers to manage the entire life cycle of their products by promoting industrial sustainability.

The circular economy is a management model that aims to decouple economic growth from the consumption of finite resources. Instead of following the traditional linear model of "extract, manufacture, and dispose," the circular economy proposes a closed loop where materials are reused, recycled, and regenerated. This approach not only conserves valuable resources but also reduces waste and minimizes environmental impact [1]. This model is based on ecological and philosophical principles that consider natural systems as a model. For example, in nature, the waste of one organism becomes a resource for others, generating a continuous cycle of regeneration. This paradigm has been adapted for resource management in industry, promoting a more efficient and sustainable use of materials.

Carpets are everyday products that, at the end of their useful life, present significant challenges for final disposal, as they are composed of a combination of synthetic fibers such as nylon, polypropylene, fiberglass, rubber, and natural fibers, adhesives, and persistent inorganic fillers that make recycling difficult. Figure 1 shows the characteristic components of carpets. Nylon, in particular, is highly valued for its ability to be recycled and converted into new textile yarns. Polypropylene, used in the base of carpets, can be transformed into new plastic products, while fiberglass is reused in insulating materials. Natural fibers, such as wool, can be used as compost or reused, and rubber and latex can be recycled or used to generate energy.

In the United Kingdom, for example, approximately $4\times10^{11}$ g of carpet waste is generated annually, a significant proportion of which ends up in landfills (either sanitary landfills or open dumps), generating greenhouse gas emissions as the materials slowly decompose (Bird, 2014). As a result, some countries have begun to ban the disposal of carpets in landfills, as is the case in the United Kingdom, where this measure will come into force in 2025 [3].

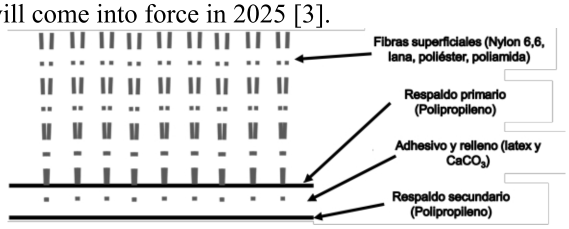



**Figure 1.** *Components of carpet.*
**Source:** *adapted from Cunningham and Miller* [4]

In the United States, more than $1.4\times10^{9}m^{2}$ has been discarded since 1954, and the approximate composition is $33\times10^{12}$g of nylon 6,6, $16\times10^{12}$g of polypropylene, $5.5\times10^{12}$g of polyethylene, and $47\times10^{12}$g of adhesive and filler. Of this, 89% of the carpet is sent to landfills, 6% is incinerated, and less than 5% is recycled [4]. Furthermore, only 20% of the recycled material is recycled into carpet in a closed loop, and the remaining 80% is recycled into other less valuable products, meaning that only 1% of carpet waste in the United States is recycled into carpet.

## DEVELOPMENT

This study began with a general review of options for the recovery and reuse of carpet waste, as well as a description of some practical examples of how this waste can be reused.

Next, several processes reported in the literature were selected to evaluate their circularity, as described below.

### *Material Circularity Index*

To evaluate the circularity index of the carpet waste recovery process, the *Material Circularity* Index (MCI) was used, which was determined using the Microsoft Excel program developed by the Ellen MacArthur Foundation. According to this methodology, the MCI value ranges from 0 (highly linear) to 1 (highly circular) and involves analyzing the flow of primary and recycled materials, end-of-life recyclability, and durability.

### *Circular Economy Toolkit*

The *Circular Economy* Toolkit (CET) assesses the type of company and/or product. To carry out the assessment, it is necessary to answer 33 questions focused on the characteristics of the process based on seven sub-areas:

1. Design, manufacturing, and distribution
2. Use
3. Repair and maintenance
4. Reuse and distribution
5. Remanufacturing and reconditioning
6. Product as a service
7. Recycling

Three areas are also taken into account:

1. Material reduction
2. Material Optimization
3. Industrial Symbiosis

Each question is answered based on the information obtained from the production process being evaluated.

The type of responses varies according to the subarea, allowing conclusions to be drawn that will provide a schematic diagram of the potential for improvement in the corresponding areas. The questionnaire is answered online as shown in Figure 2 [5]. The tool classifies areas for improvement by establishing a color-coded analysis framework, defined as follows:

• Green: represents high potential for improvement.
• Yellow: represents medium potential for improvement.
• Gray: represents low potential for improvement.

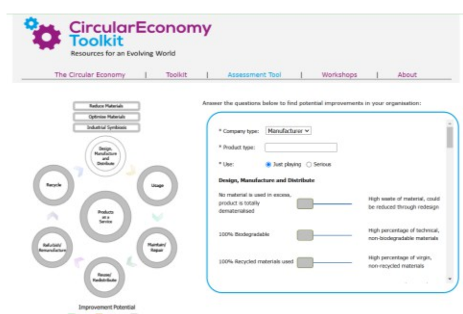



**Figure 2.** *Online Circular Economy Toolkit.*
**Source:** *Circulareconomytoolkit.org* [5].

## DISCUSSION AND ANALYSIS OF RESULTS

### *Carpet waste recovery and revaluation processes*

The sustainable disposal of carpet waste poses a significant challenge due to its complex composition and high volume of generation. Currently, there are recovery processes and revalorization strategies through which it is possible to transform this waste into valuable resources, thus contributing to the circular economy and reducing its environmental impact. Table 1 describes traditional recovery processes, such as mechanical separation, chemical recycling, and pyrolysis, along with revalorization options, which include mechanical and chemical recycling, direct reuse, and energy production. These strategies make it possible to recover useful materials, such as synthetic fibers and inorganic fillers, and encourage innovation in industrial, construction, and animal welfare applications, demonstrating the potential of carpet waste as a secondary raw material in a circular economy model.

### *Practical examples of carpet waste reuse*

One of the most interesting aspects of carpet waste recovery is its reuse in practical applications that transform waste into valuable resources. By reusing carpet waste, the amount of waste that ends up in landfills is reduced, thereby reducing pollution and the extraction of natural resources. It also contributes to energy efficiency in construction and other sectors. Table 2 highlights how the reuse of carpet waste through the circular economy not only reduces environmental impact but also generates economic, social, and technical benefits in various applications.

### *Circularity Index Analysis*

To analyze the feasibility of using the Ellen MacArthur Foundation's MCI to quantify the circularity of carpet waste recovery processes, three studies reported in the literature with different applications of this waste in the preparation of composite materials were taken as a reference.Gowayed et al. [20] manufactured composites using polypropylene recovered from carpet waste and a polyethylene matrix. The samples were compression molded with a fiber volume fraction of up to 25% carpet waste, significantly increasing the mechanical properties compared to pure polyethylene. Figure 3 shows the circularity analysis of the process, which yields an MCI of 0.17. In addition, the authors concluded that this application of carpet waste is not very viable due to the costs incurred by the mechanical separation of propylene from carpet waste.

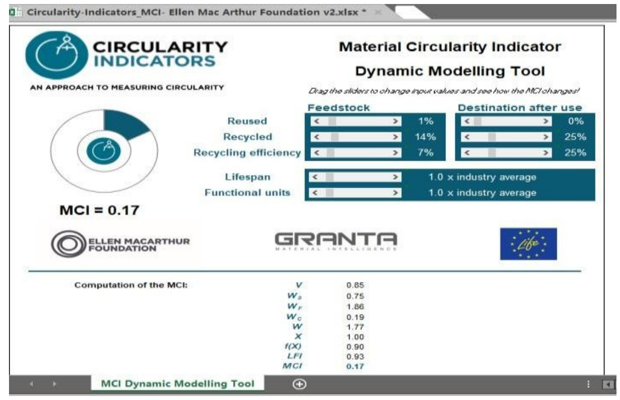



**Figure 3.** *MCI for the manufacture of composites from propylene recovered from carpets and polyethylene.*
**Source:** *own elaboration* (2025).

Kiziltas and Gardner [21] investigated the preparation of composite materials from microcrystalline cellulose and recycled nylon from carpet waste for use in the automotive industry. The composite samples were injection molded. Different mechanical properties were studied, and it was found that the best formulation was with a 30% weight content of cellulose filler, significantly increasing the flexural modulus, tensile strength, and tensile modulus without significant changes in flexural strength. Figure 4 shows the circularity analysis of the process, with an MCI of 0.30.

**Table 1.** *Recovery processes and options for revaluing carpet waste to promote the circular economy.*

| Recovery processes | Description | Revaluation Options |
|---|---|---|
| **Mechanical separation** | Carpets are shredded and their components (fibers, fillings, etc.) are separated by screening or centrifugation. | **Mechanical recycling**: Synthetic fibers are reused in the automotive industry, and inorganic fillers are used in construction materials. |
| **Chemical recycling** | Processes such as depolymerization recover nylon in its original form for reuse. | **Chemical recycling**: Materials are broken down into basic components to create new chemicals or fuels. |
| **Pyrolysis** | A thermal process that breaks down materials in the absence of oxygen, recovering energy and useful materials. | **Energy production**: Waste is used as fuel in energy generation processes. |
| **Direct reuse** | Carpet waste is directly incorporated into new products.<br>products, such as construction<br>materials construction materials. | **Reuse**: Carpets are reconditioned for less demanding applications, such as surfaces for horses or fillings for furniture. |

**Source:** *own elaboration* (2025)

**Table 2.** *Applications and benefits of reusing carpet waste through the circular economy to reduce environmental impact.*

| Application | Benefits and Properties | Environmental Impact and Relevance | References |
|---|---|---|---|
| **Equestrian surfaces** | • Improves horse welfare.<br>• Reduces dust in stables.<br>• Excellent cushioning, durability, and anti-slip properties. | • Reduces improper waste disposal.<br>• Promotes the reuse of materials in specific environments. | [6, 7] |
| **Building materials** | • Improved thermal and acoustic properties.<br>• Thermal conductivity: 0.035 to 0.049 W/m·K.<br>• Superior noise absorption across a wide frequency spectrum. | • Extends the service life of materials.<br>• Contributes to energy efficiency in buildings.<br>• Reduces the need for new insulating materials. | [8, 9, 10, 11, 12, 13] |
| **Concrete production** | • Improves mechanical properties and durability.<br>• Increases compressive, tensile, and flexural strength.<br>• Reduces chloride ion permeability and improves resistance to freeze-thaw cycles. | • Contributes to the development of sustainable building materials.<br>• Reduces the use of natural resources in concrete production. | [14, 15, 16] |
| **Fillers for furniture** | • Use as filling in sofas and mattresses.<br>• Wood reinforcement plywood, improving the modulus of rupture and elasticity. | • Reduces the volume of waste sent to landfills.<br>• Promotes reuse in furniture manufacturing. | [17, 18] |
| **Automotive industry** | • Manufacture of automotive components (interior panels, floor mats, pedal supports). | • Reduces dependence on virgin materials in the automotive industry.<br>• Encourages innovation in the use of recycled materials. | [19] |

| | | | |
|---|---|---|---|
| | • Takes advantage of the mechanical and strength properties of synthetic fibers. | | |

**Source:** *own elaboration* (2025)

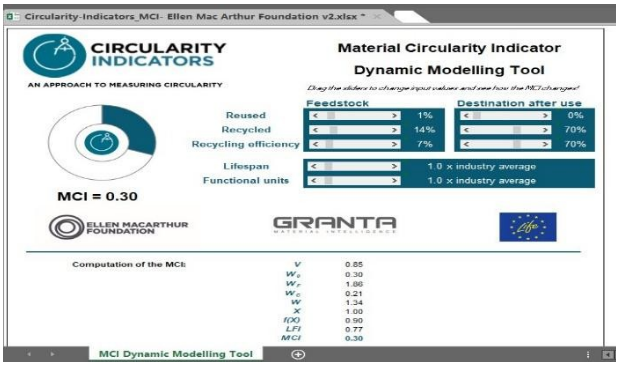



**Figure 4.** *MCI for the manufacture of composites from nylon recovered from carpets and microcrystalline cellulose*.
**Source:** *own elaboration* (2025).

Xantos et al. [22] developed a method for manufacturing a structural composite using carpet waste composite in a low-density polyethylene matrix. The carpet waste had an approximate composition of 63 to 65% by weight calcium carbonate, 15 to 18% by weight polypropylene, and 12 to 15% by weight SBR. The manufacturing process consisted of a combination of extrusion and injection molding to fill a mold cavity. The flexural strength and flexural modulus of the composite improved when the aforementioned carpet waste was added, which was attributed to the high calcium carbonate content. Figure 5 shows the circularity analysis of the process, which yielded an MCI of 0.35.

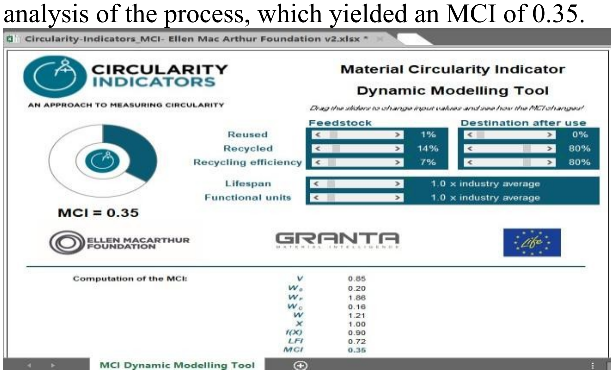



**Figure 5.** *CCI for the manufacture of carpet waste and polyethylene composites*.
**Source:** *own elaboration* (2025).

***Circular Economy Toolkit***

The CET is applied in companies where the process has been established on a commercial scale. Currently, processes that reuse carpet waste do not operate on a commercial scale, so the use of this toolkit is not feasible. However, it is feasible to analyze the wool carpet manufacturing process.

in order to identify areas of opportunity to improve the process and make it more sustainable based on the principles of the circular economy. Figure 6 shows a flow chart of the manufacture of a wool carpet. A detailed description of the process can be found in [23].

Evaluating the circularity of the finished wool carpet product with the CET yielded the results shown in Figure 7. There is **HIGH POTENTIAL FOR IMPROVEMENT** in the following areas:

**1. Material reduction**, as the company consumes a large amount of virgin raw materials with 12% waste. This waste can be reused as virgin material as it does not contain contaminants because it is pre-consumer;

**2. Material optimization**, as considerable amounts of waste are generated. In the case of wool, it is sent to landfills and dumps, or in the worst case, it is illegally dumped in the open air;

**3. Industrial symbiosis**, as waste can be used as raw material by another company. For example, wool waste is used to fertilize pastures, which are then used to feed sheep, thus closing the cycle.

**4. Maintenance/repair,** as wool is very durable, resistant to friction, and maintains a good appearance for a long time.

**5. Remanufacturing/restoration**: new trends require manufacturers to maintain carpets. The innovation of modular carpets makes it easier to repair damaged areas of the carpet, avoiding the need to replace the entire carpet.

**6. Product recycling**, as areas of opportunity must be explored to improve the low recycling rates of carpets after their useful life.

**7. Product-as-a-service stage**, as carpet manufacturers and companies offer the product and maintenance service on a rental basis for constant renewal to prevent obsolescence.

ISSN: 2594 - 2905

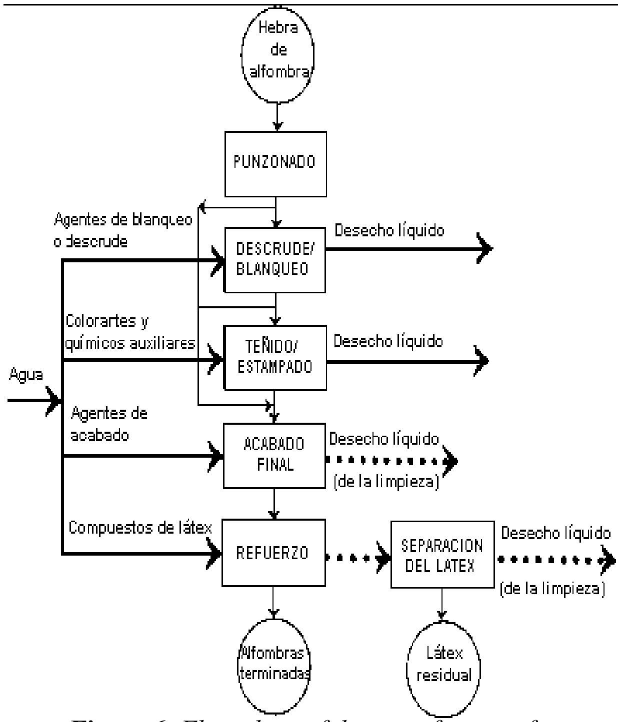
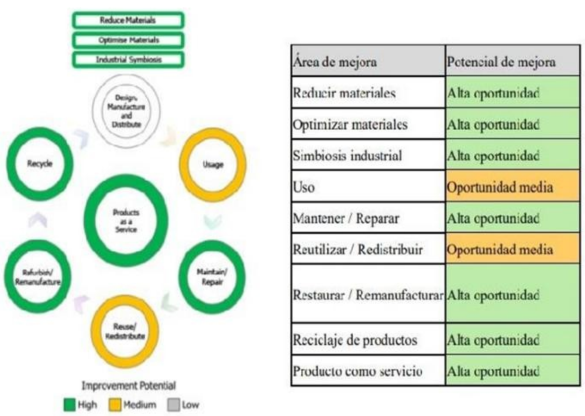



**Figure 6.** *Flow chart of the manufacture of a wool carpet.*
**Source**: *Juárez Gómez, O.* [23]




| Área de mejora | Potencial de mejora |
|---|---|
| Reducir materiales | Alta oportunidad |
| Optimizar materiales | Alta oportunidad |
| Simbiosis industrial | Alta oportunidad |
| Uso | Oportunidad media |
| Mantener / Reparar | Alta oportunidad |
| Reutilizar / Redistribuir | Oportunidad media |
| Restaurar / Remanufacturar | Alta oportunidad |
| Reciclaje de productos | Alta oportunidad |
| Producto como servicio | Alta oportunidad |

**Figure 7.** *CET results for the manufacture of wool carpets.*
**Source:** *Own elaboration.*

On the other hand, there is **MEDIUM POTENTIAL FOR IMPROVEMENT** in the areas of:
**1. use**, since consumption depends on the polymer selected for manufacturing.
**2. reuse/redistribution**, given that the second-hand market is not formal and requires greater infrastructure.

***Impact on the Sustainable Development Goals (SDGs)***
The Sustainable Development Goals (SDGs) are a set of 17 global goals established by the United Nations in 2015 to address the world's main social, economic, and environmental challenges. These goals seek to eradicate poverty, protect the planet, and ensure peace and prosperity for all people. Each SDG has specific targets and concrete actions to achieve them by 2030. The recovery of carpet waste is aligned with several of these goals, especially those related to environmental sustainability, the development of circular economies, and technological innovation, as indicated in Table 4.

**Table 4.** *Impact of carpet waste recovery and recovery processes on the Sustainable Development Goals.*

| SDGs | Impact of carpet waste recovery |
|---|---|
| **SDG 12: Responsible production and consumption** | Promotes recycling and reuse, reduces resource waste, and decreases raw material extraction. |
| **SDG 13: Climate action** | Prevents methane emissions in landfills and reduces the carbon footprint by using recycled materials. |
| **SDG 11: Sustainable cities and sustainable communities** | Reduces solid waste in landfills and promote local circular economies. |
| **SDG 9: Industry, innovation, and infrastructure** | Promotes innovation in recycling and sustainable product design . |
| **SDG 8: Decent work and economic growth** | Generate employment in recycling and sustainable manufacturing, and reduce costs by leveraging existing resources . |
| **SDG 15: Life on land** | Reduces extraction of natural resources and minimizes the environmental impact of waste on ecosystems. |

**Source:** *Own elaboration.*

## CONCLUSIONS

The revaluation of carpet waste represents a step toward sustainability through the application of circular economy principles, reducing environmental impact and generating economic and social benefits. This study shows that, despite the complex composition of carpets, there are various recovery and revaluation strategies that allow this waste to be recycled in different applications. Mechanical separation, chemical recycling, pyrolysis, and direct reuse are processes that minimize the amount of waste that ends up in landfills and promote innovation in industrial, construction, and animal welfare applications. On the other hand, the LCA shows that carpet waste recovery processes have potential for improvement in terms of circularity, as there are viable applications that contribute to sustainability. Likewise, the CET identified areas of opportunity in the manufacture of wool carpets, highlighting the need to reduce the consumption of virgin raw materials and improve recycling rates. Finally, this work indicates the importance of aligning waste recovery efforts with the Sustainable Development Goals. In particular, with regard to responsible production and consumption, climate action, sustainable cities and communities, industrial innovation, decent work, economic growth, and life on land.

Future lines of research similar to that developed in this study include the evaluation of the circular economy in the clothing industry, and in the upholstery and interior components of the automotive industry. In the case of the clothing industry, a significant waste of resources has been detected, leading to an environmental impact, and some areas of opportunity include eliminating unwanted substances and microfibers, encouraging greater use of clothing, improving the recycling sector, and making resources more efficient through the use of renewable sources. In the automotive sector, textiles are used in seats, roof linings, door panels, carpets, and insulation. Applying the circular economy would involve designing these components to facilitate their disassembly and recycling at the end of the vehicle's useful life, as well as using recycled or bio-based materials in their manufacture, contributing to the sustainability of the industry.

## BIBLIOGRAPHY

[1] Bocken, N. M. P., De Pauw, I., Bakker, C., & Van Der Grinten, B. (2016). Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering, 33(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

[2] Zeb-Khan, A. (2023, November 30). Carpet Recycling UK reports 81% landfill diversion in the UK in 2021. Carpet Recycling UK. Retrieved from: https://carpetrecyclinguk.com/carpet-recycling-uk-reports-81-landfill-diversion-in-the-uk-in-2021/.

[3] DEFRA (2014). Department for Environment, Food & Rural Affairs. Annual Waste Management Report.

[4] Cunningham, P. R., & Miller, S. A. (2022). A material flow analysis of carpet in the United States: Where should the carpet go? Journal of Cleaner Production, 368, 133243. https://doi.org/10.1016/j.jclepro.2022.133243

[5] Circular Economy Toolkit, Circulareconomytoolkit.org. Retrieved from: http://www.circulareconomytoolkit.org.

[6] Kumar, J., Jaiswal, B., Kumar, K., Kumar, K., & Verma, R. K. (2023). Reuse of waste carpet into a sustainable composite. In CRC Press eBooks (pp. 230–243). https://doi.org/10.1201/9781003291961-17

[7] Souza, B., Van Der Heijden, R., & Benoît, J. (2023). Strength and Deformation Behavior of Equestrian Riding Surfaces Improved with Recycled Geosynthetics. Geotechnical Testing Journal,

[8] Ayed, R., Bouadila, S., Skouri, S., Boquera, L., Cabeza, L. F., & Lazaar, M. (2023). Recycling textile waste to enhance building thermal insulation and reduce carbon emissions: Experimentation and Model-Based Dynamic Assessment. Buildings, 13(2), 535. https://doi.org/10.3390/buildings13020535

[9] Di Schio, E. R., Ballerini, V., & Valdiserri, P. (2024). Thermal characterization of textile waste materials for reuse in the energy refurbishing of buildings. WSEAS Transactions on Environment and Development, 20, 478–

[10] Jailani, M. E. A., & Isa, M. H. M. (2021). The application of textile waste as a sound insulation building material. In Advances in Civil Engineering Materials (pp. 109–115). Springer Singapore.

[11] Karmakar, S., Majumdar, A., & Butola, B. S. (2024). A sustainable recycling process and its life cycle assessment for valorising post-consumer textile materials for thermal insulation applications. Waste Management & Research the Journal for a Sustainable Circular Economy. https://doi.org/10.1177/0734242x241270933

[12] Siltumens, K., Grinfelde, I., Znots, G., Golubovs, R., & Brencis, R. (2024). Use of shredded textile waste as material for sound absorption. Engineering for Rural Development. https://doi.org/10.22616/erdev.2024.23.tf190

[13] Rubino, C., Liuzzi, S., & Martellotta, F. (2024). Exploring the potential of recycled textile panels to improve sound insulation in buildings. Proceedings of the 10th Convention of the European Acoustics Association Forum Acusticum 2023.

[14] Haigh, R., Sandanayake, M., Joseph, P., Yaghoubi, E., & Vrcelj, Z. (2024). The mechanical and microstructural performance of waste textile and cardboard materials in concrete. Structural Concrete, 25(5), 4033–4047. https://doi.org/10.1002/suco.202301148

[15] Idrees, M., Saeed, F., Farooq, Z., Köksal, F., & Shi, J. (2023). Production of waste carpet fiber-reinforced concrete as sustainable material. Journal of Building Engineering, 77, 107499. https://doi.org/10.1016/j.jobe.2023.107499

[16] Simon, A., Tripathi, A., Surehali, S., & Neithalath, N. (2023). Carpet fiber recycling in regular-use concrete mixtures and associated life cycle analysis. Waste Management Bulletin, 1(3),

[17] Bartoszuk, K., & Kowaluk, G. (2024). Utilization of Fibrous Mat Residues from Upholstered Furniture as Sustainable Fillers in Plywood Production. Materials, 17(16), 4080. https://doi.org/10.3390/ma17164080

[18] Mancosh, D., Przybylinski, J. P., & Murdock, D. E. (2007). Carpet waste composite. https://patents.google.com/patent/US8278365B2/en

[19] García-Arrieta, S., Elizetxea, C., Calle, A., Ollo, O., Múgica, M., Goikuria, E., Sarlin, E., & García, M. (2022). Recycled fibers integration in automotive components

manufactured by injection. Journal of Composite Materials. https://doi.org/10.23967/r.matcomp.2022.07.049

[20] Gowayed, Y. A., Vaidyanathan, R., & El-Halwagi, M. (1995). Synthesis of Composite Materials from Waste Fabrics and Plastics. Journal of Elastomers & Plastics, 27(1), 79–90. https://doi.org/10.1177/009524439502700106

[21] Kiziltas, A., & Gardner, D. J. (2012). Utilization of carpet waste as a matrix in natural filled engineering thermoplastic composites for automotive applications. Advanced Engineered Wood Composite (AEWC) Center, University of Maine: Orono, ME, USA.

[22] Xanthos, M., Dey, S. K., Mitra, S., Yilmazer, U., & Feng, C. (2002). Prototypes for building applications based on thermoplastic composites containing mixed waste plastics. Polymer Composites, 23(2), 153–163. https://doi.org/10.1002/pc.10421

[23] Juárez Gómez, O. (2024). Revaluation of carpet waste based on the principles of the circular economy. [Bachelor's thesis]. Autonomous University of the State of Morelos. Faculty of Chemical Sciences and Engineering, Mexico.

**Table of Contribution Roles**

| Role | Author(s) |
|---|---|
| Conceptualization | Roberto Flores Velázquez |
| Data curation | Nadia Lara Ruíz |
| Methodology | Belem Gabriela Hernández Jaimes |
| Project management | Roberto Flores Velázquez |
| Resources | Nadia Lara Ruíz, Belem Gabriela Hernández Jaimes |
| Supervision | Roberto Flores Velázquez |
| Validation | Roberto Flores Velázquez, Nadia Lara Ruíz, Belem Gabriela Hernández Jaimes |
| Editorial (original draft) | Roberto Flores Velázquez, Nadia Lara Ruíz, Belem Gabriela Hernández Jaimes |
| Writing (revision and editing) | Roberto Flores Velázquez, Nadia Lara Ruiz |