International Journal of Research in Industrial Engineering

www.riejournal.com

Int. J. Res. Ind. Eng. Vol. 13, No. 2 (2024) 188–206.

Paper Type: Research Paper

Application of Circular Economy for Sustainable Waste Management in the Carpet Industry

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Citation:

Received: 15 November 2023 *Revised: 16 Januray 2024* *Accepted: 28 Februray 2024*	Parvaresh, F., & Amini, M. H. (2024). Application of circular economy for sustainable waste management in the carpet industry. *International journal of research in industrial engineering*, *13*(2), 188-206.

Abstract

In today's modern world, the linear economy is no longer responsive, and there is a crucial need for a fundamental shift in people's mindset toward properly using raw materials and products. This article explores the 9R framework as a model for implementing the circular economy in the flooring industry. The framework delves into maximizing material value while minimizing waste and environmental degradation. This research aims to identify the role of the circular economy in the flooring industry across various countries. The article also examines successful strategies proposed to achieve the goals and benefits of this approach, presenting the results within the framework of the 9R model. The results of this research indicate that effective steps have been taken in Iran towards the sustainable production of carpets, which serve as the primary flooring in the country. Among the most important of these, we can highlight the growing trend of using raw materials appropriately in producing this product, along with interesting innovations related to its usage transformation. However, for the complete implementation of all principles of the circular economy in Iran, there are significant obstacles, among which one of the most important is the high cost of establishing recycling units. Therefore, the government must encourage large production units capable of operating in the recycling sector by providing supportive packages. In general, within the scope of this research and its results, it is concluded that designing carpets with a long lifespan and recyclability, along with educating customers on the proper use of products and promoting the repair and reuse of second-hand products, can lead to a more flourishing and sustainable economy in this industry.

Keywords: Circular economy, Sustainability, Flooring, Carpet, Waste reduction.

1 | Introduction

The linear process in product production involves using raw materials obtained from the earth or any other source, converting them into the desired product, and then discarding them as waste after consumption. The

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https://doi.org/10.22105/riej.2024.426147.1405

'take characterizes the linear economy, make, consume, and throw away' model. This approach has led to the overexploitation of natural resources and the accumulation of waste that pollutes the environment. Today, the linear economy is recognized as an ineffective strategy for addressing climate change and ensuring sustainability. In contrast to this process, another approach called the circular economy is introduced, which strives to minimize the use of raw materials at each output unit and recycle waste as much as possible so that it can be reused as input for production [1].

The concept of circular economy is rooted in various schools of thought and theories that challenge the current ruling economic system, characterized by the excessive consumption of natural resources. In recent years, the circular economy has gained increasing attention worldwide. Economists often view this economic model as a potential driver for countries with high capacities to achieve multiple goals simultaneously, including resource efficiency, waste reduction, and job creation. Many environmentalists also endorse the circular economy as a means of conserving resources and minimizing environmental impact. They believe transitioning from a linear to a circular model can help address environmental challenges [2]. In this regard, new technologies and artificial intelligence have proven very effective. For example, studies have shown that integrating machine learning within industrial circular economy models enhances resource recycling capabilities and product quality and paves the way for a sustainable trajectory in future industrial development [3].

Today, various production sectors, including the textile industry and construction and service providers like logistics and transportation, have embraced the circular economy concept. The flooring industry is an example of a sector seeking to take advantage of this concept. However, inadequate comprehensive studies focus on implementing circular economy principles within the flooring sector. In addition, Lifecycle Assessment (LCA) studies, circular business models, material innovation, and recycling technologies have identified research gaps. The flooring industry is an example of a sector seeking to take advantage of this concept. However, inadequate comprehensive studies focus on implementing circular economy principles within the flooring sector. Other important research areas that require attention in this field include studies on Life Cycle Assessment (LCA), circular business models, material innovation, and recycling technologies. In this research, we introduce the 9R framework for achieving the circular economy and examine the implementation of circular economy principles in the flooring production and consumption cycle in Iran and other countries. We also present relevant successful solutions within the aforementioned structure.

2 | Methodology

Various frameworks have been proposed to implement the circular economy, with one of the most recent being the 9R structure, which will be discussed in this research. In this section, the research methodology employed in this study is explained first. Subsequently, while referring to the principles and structure of the 9R framework within the context of the circular economy, the studies conducted to implement these principles regarding sustainable flooring production in Iran and other countries are explored.

2.1 | Research Method

This literature review encompasses domestic and foreign research on sustainable flooring production, explores the principles of achieving a circular economy in this field, and examines information gathered from interviews with relevant officials and managers. Additionally, it includes limited data published by flooring production and after-sales service websites and centers. So, the overall stages of conducting this research have been as follows:

I. Collecting and reviewing research published in reputable scientific journals and websites.

II. Conducting interviews with relevant officials and managers to better understand the subject and the intended scope.

III. Identifying successful companies in sustainable flooring production and recognizing their solutions.

IV. Explaining and interpreting the findings, followed by a summary of the conducted research.

2.2 | Principles of Circular Economy

The circular economy is founded on three core principles: eliminating waste and pollution, promoting the circulation of products and materials at their maximum value, and encouraging natural reproduction [4].

The first principle of the circular economy is to eliminate waste and pollution. Currently, the economies of most countries, including Iran, operate within a linear waste management system. After use, numerous products in the market often end up in landfills or incinerators due to their limited capacity for easy reuse, recycling, or conversion into compost. However, given the limited resources on our planet, this system may not be efficient in the long run. Moreover, the swift advancement of industries such as metal electroplating, mining operations, fertilizer production, tanning, and batteries has substantially increased environmental pollution [5]. Consequently, the significance of the first principle of the circular economy becomes evident.

The second circular economy principle involves circulating products and materials at their highest value. Consequently, less waste is generated, and the intrinsic value of products and materials is preserved. In essence, according to this principle, waste production is considered a flaw in the design, and the primary criterion for any product design is the reintroduction of materials into the economic cycle at the end of their use.

The third principle of the circular economy is the regeneration of nature. By moving from a waste-producing linear economy to a circular economy, natural processes are supported, with more space provisions for the environment to flourish. As the economy shifts from linear to circular, the focus shifts from extraction to regeneration. The circular economy is a systemic solution that can tackle global challenges such as climate change, biodiversity loss, and pollution.

2.3 | The Relationship between Circular Economy and Sustainability

The results of implementing the circular economy show that this economic model is more sustainable than the traditional linear economy for various reasons, including a reduction in the use of resources. In this context, sustainability refers to a development that meets the needs of the present generation without limiting the ability of future generations to meet their own needs [6]. Sustainability entails aligning present and future needs with the responsible management of resources, strategic investments, technological advancements, and effective governance [7].

Sustainability involves considering and integrating economic, cultural, social, and environmental aspects when designing a system [8]. The overall success of an organization is significantly influenced by the performance of its sustainable supply chain [9]. Organizations should enhance their capabilities in developing new products to achieve sustainable growth and ensure long-term survival [10]. It is necessary to mention that the discussion of sustainability is not only raised in production systems but can also be exemplified in service systems such as banks [11], as well as industries like the tourism industry [12]. Various methods have been proposed to assess the sustainability of companies. For instance, among these methods, one can refer to Data Envelopment Analysis (DEA) presented by Chen et al. [13] for evaluating the sustainable operational performance of electronic industry groups in China.

2.4 | The 9R Framework in the Circular Economy

The 9R framework explores how materials can be utilized at their highest value while minimizing waste and environmental degradation. *Table A1* presents the elements of the 9R framework with a brief explanation for each [4], [14].

It is essential to note that despite extensive efforts in waste management, employing various principles of the 9R framework, there may still be residual waste that requires disposal. In this regard, selecting a suitable landfill site is introduced as a fundamental issue in waste management, and various studies have been

conducted on this matter. Among them, we can refer to the research undertaken by Bozorgpanah and Qasemi [15] regarding the Freshkill landfill center. Freshkill, spanning an area of 890 hectares, stands as the largest landfill in the world, situated in New York City. In this facility, sanitary landfilling is adopted as a valuable solution for solid waste management. The advantages of utilizing this center, beyond producing methane gas for heating and income generation, include the reduction of greenhouse gas emissions, marking significant environmental and economic success. Indeed, various studies have been conducted in recent years regarding the proper selection of landfill sites, among which the research conducted by Kabgani [16] can be mentioned. This study utilized a two-stage Multi-Attribute Decision Making (MADM) method to rank proposed options for landfill sites, considering diverse economic, technical, and social criteria.

2.5 | Circular Economy in the Flooring Production and Use

Considering the circular economy concept, this section examines the common practices of sustainable flooring production and use, both domestically and internationally. *Fig. A1* provides a view of this review.

2.5.1 | Domestic flooring production regarding the circular economy

Carpet is the most commonly used flooring in Iranian homes and serves as a cultural commodity. To introduce sustainable carpet production, we will start by discussing the yarns used in the texture of this flooring type. In the following, *Fig. A2* depicts and introduces the yarns:

Warp thread: the warp thread is placed along the length of the carpet and plays a decisive role in creating strength in the carpet.

Weft thread: the weft threads are perpendicular to the warp threads and parallel to each other across the carpet width. The weft threads' main role is to connect the carpet warp threads and, on the one hand, hold the carpet warp root.

Pile yarn: this type of thread in handwoven carpets is the same colored thread that the master weaver, by tying the warp threads, places on the axis perpendicular to the direction of the carpet threads.

However, in machine carpets, such threads stand between the warp and weft threads in a U shape and are secured with an adhesive or glue after being woven. Various types of carpets exist, typically categorized into two main groups: machine-made and handwoven. The details of these categories will be discussed further.

Machine carpet

Machine-made carpets can be classified based on their weaving process, which involves three categories of threads: warp, weft, and pile threads, each playing a crucial role in determining the carpet's texture. In Iran, the pile yarn for machine-made carpets is primarily crafted from acrylic, polypropylene, or polyester fibers. Accordingly, machine-made carpets are classified into three categories acrylic, polypropylene, or polyester, each with distinct characteristics.

I. Acrylic carpets, known for utilizing acrylic yarn as the primary pile material, constitute approximately 80% of Iranian carpets. Acrylic fibers are made of petroleum and polymer materials and are warm, light, and very similar to natural wool threads; thus, these fibers have been used as a good option for carpet weaving. However, acrylic fibers are imported, and one of their disadvantages is their recycling problems. Although modern technologies enable the recycling acrylic carpets, the process is not cost-effective. In addition, experts believe that it will be better to limit the weaving capacity of acrylic carpets in Iran for several reasons. First, acrylic fibers cost more than other synthetic alternatives, placing a significant financial burden on the consumer. Second, acrylic fibers have more destructive environmental effects than other synthetic fibers. Third, the very intense smoke generation of acrylic during a fire is dangerous for commercial and office environments; therefore, some countries have imposed import bans on it. Nevertheless, despite the various drawbacks, acrylic carpets are one of Iran's most popular and best-selling categories of machine-made carpets [17].

II. Polypropylene carpets gained prominence in Iran during the early seventies when machine-made carpets began incorporating this fiber type as the primary pile yarn. A carpet woven with polypropylene yarn exhibits a comparable appearance to acrylic carpets, yet it distinguishes itself by being recyclable. Recycling polypropylene carpets diminishes reliance on oil and gas resources, alleviating pressure on primary materials and contributing significantly to environmental preservation. Moreover, the ease of domestic polypropylene fiber production contributes to the affordability of carpets, making them a more economical choice than acrylic carpets.

III. Polyester carpets, distinguished by using polyester fibers often referred to as artificial silk in the pile yarn of machine-made carpets, radiate a unique beauty and boast high recyclability. Today, most polyester carpets are completely pure polyester, which makes them easy to recycle. *Table A2* outlines the distinctive characteristics of acrylic, polypropylene, and polyester carpets to facilitate a comprehensive comparison.

Machine carpets reusing and recycling old machine carpets may be reused and recycled in various ways. Carpet restoration is a way to increase the carpet life. Carpet restoration is a specialized service aimed at repairing and restoring carpets to a usable condition. Also, the restored carpet usage can be changed. Carpet usage change refers to utilizing the carpet or its components for purposes different from their previous use. It can be used in different ways, such as a traditional pillowcase, a bedspread for outdoor beds, and a mattress pad. For example, the carpet panel of Imam Redha's Shrine (peace be upon him) is a blessed piece of carpet prepared by Astan Quds Radhavi and presented as a valuable artistic and religious work. In this holy place, when the sahn carpets become worn out or aged, many people request to take a part of these carpets home due to the perceived blessings they hold. Therefore, Astan Quds Radhavi has made it possible in its factories for sections of the carpets to be cut and framed in good condition, particularly the carpet flowers. *Fig. A3* shows an example of Imam Redha's Shrine carpets [18].

Despite having many advantages in machine carpet recycling, Iran has not effectively utilized them. So, thousands of tons of used carpets in Iran go to landfills or are burned yearly, while this high capacity can be used better. Currently, only a handful of factories in Iran produce recyclable machine-made carpets, and these factories could change less than 10% of the raw materials of machine-made carpets to recyclable ones. Hence, manufacturers of machine-made carpets should implement strategies to produce recyclable carpets to prevent the creation of unhealthy products containing hazardous substances. They should also strive to adhere to global standards. Significantly, the recycling process for machine-made carpets varies depending on the type of pile yarn used. The acrylic, polyester, cotton, or jute fibers are entirely separate in this type of carpet. This implies that these materials are not combined; they are utilized in a pure and distinct form within the carpet components. Therefore, nylon and polyester polymers can be turned into carpet yarn again during melt-spinning. Also, other fibers can be made into thick threads or cobwebs with the wool spinning system or used in the texture of underlays. These fibers can even be used in the non-woven industry or felt blankets. Polyester carpets are recyclable, and at present, the majority of carpets produced in Iran belong to the polyester category.

Unfortunately, Iran encounters several challenges in carpet recycling, even with easily recyclable polyester carpets. However, there has been a shift in perspective among factory owners due to increased knowledge and awareness of recycling's importance. Consequently, today, many are buying used and depreciated carpets to recycle them.

Handwoven carpet

The handwoven carpet is distinctive in Iran due to its unique cultural, economic, and social significance. The handwoven carpet is woven on a specific weaving machine called 'Dar'. Handwoven carpets are made of natural fibers such as silk, cotton, jute, wool, and the like, as natural colors. Hence, handwoven carpets pose no environmental harm after depreciation and disposal. Some farmers have even conducted experiments, discovering that burying handwoven carpets under trees enhances their growth.

Of course, one can also use old handwoven carpets in other areas of the house or sell them at a lower price because some people are always looking for affordable handwoven carpets. However, efforts should be made to increase the handwoven carpet's lifespan by better maintenance. Generally, the value of handwoven carpets

increases with their extended lifespan. Handwoven carpet restoration is a specialization capable of increasing the carpets' useful life. In addition, since the handwoven carpet is considered a work of art, it can be easily changed, and a part of it can be used for other purposes, including picture carpets, traditional pillowcases, and the like. For example, the forty-piece carpet, globally known as a collage carpet, is created by assembling pieces of several different damaged or worn-out carpets. This type of carpet, exemplified in *Fig. A4*, is currently in high demand among enthusiasts of modern decorations. An advantage of collage carpets is that old carpets (damaged for various reasons, including fire or decay, and cannot be restored and used as carpets) are reused by putting together healthy pieces of these carpets and producing various carpets and artistic products. Upcycled carpet products are in high demand, especially abroad. These carpets have leather linings, giving them increased strength and resistance.

2.5.2 | International flooring production and attention to the circular economy

The European Carpet and Rug Association (ECRA) approach is centered on unlocking the full potential to establish a circular economy in carpets and flooring by 2030, aligning with sustainable development goals. Achieving this necessitates economic growth in this market, increased awareness, and environmental protection. Thus, the carpet industry in Europe is needed to implement initiatives. One of these initiatives involved prohibiting the use of raw materials that generate volatile organic compounds (VOCs) in the manufacturing of carpets and floors. Accordingly, to prevent environmental problems, research has been conducted to find materials, health standards, and effective recycling in the textile industry [19].

So far, European and American countries made efforts to follow the sustainability principles regarding flooring. In these countries, the industry strategy for implementing circular economy principles includes three stages [20]:

I. Ensure that carpets and floorings are recycled as best as possible at the end of their life.

II. Establish a common Europe-wide approach to material use and design, facilitating efficient recycling and material reuse.

III. Promote investments in the carpet industry culture that encourage the utilization of the most advanced materials, the production of the most sustainable products, and the adoption of the most efficient production methods available.

Numerous international health institutes and European organizations are actively exploring solutions to mitigate the risks associated with carpets and flooring products, prioritizing human health and environmental concerns. Among these institutions, the Austrian OEKO-TEX standard institute [21] stands out as a notable contributor to these efforts. This institute has extensively researched carpets and flooring to establish a standard. Attaining this standard and displaying its emblem on carpets signifies that the carpet is fully sustainable and health-conscious, with its production process free from harmful chemicals detrimental to both humans and the environment.

In the USA, numerous research and operational institutes have been established to innovate Eco-friendly products and improve their recyclability. These institutes also affect waste. For example, the new laws enacted by the state of California stipulate that companies failing to comply with the necessary legal approvals cannot sell their products in this state, either directly or indirectly, through other stores and distributors. In these countries, some non-profit organizations even actively promote circular economy principles. Cradle to Cradle (C2C) Products Innovation Institute is involved in making industries interested in following circular economy principles. This institute evaluates products and materials based on sustainability principles and awards industry certificates. C2C certificate assesses products in five indicators [22]:

I. Material health: check the chemical composition of the product.

II. Reusing materials: evaluate how to recycle or compost the product at the end of its life.

III. Renewable energies and carbon management: investigate the product effect on climate change and the amount of energy consumption in its production.

IV. Water monitoring: check the amount of water resources consumed during the product's life cycle.

V. Social fairness: assess the product's social impact.

The C2C certificate is given to a product with a favorable rating per each indicator while the product demonstrates continuous environmental and social performance improvement. The institution experts believe that this policy implementation leads to collecting the worn and torn carpets and rugs in the interest of the consumer and not only does not inflict any losses to the factory owners but also increases their profits. Many companies are actively implementing circular economy principles. *Table A3* depicts information about some noted companies, followed by their activities.

I. Bentley Mills, a prominent commercial carpets and flooring manufacturer, has achieved C2C certification, signifying its commitment to sustainable and environmentally friendly practices. The company actively seeks suppliers that reduce the need for primary and natural resources by providing recycled materials. In the production of its products, in addition to the quality and long life, this company also considers the end of the life of the products and tries to make it easier to recycle or reuse them. It also invests in technologies and methods that reduce water consumption, energy consumption, and greenhouse gas emissions. In fact, by focusing on all these aspects, this company is always trying to find new ways to conserve resources and reduce waste [23].

II. Shaw Carpet Company is considered one of the largest flooring manufacturers in the world, and it realizes the benefits of recycling and steps on the path of sustainable production. This company has found a solution to get used carpets, and whenever the customer wants to replace his carpet, Shaw Carpet Company will receive it. If the carpet is a product of the same company, it will be replaced with a new one. If the consumer does not intend to replace it, the company offers to buy it back. These carpets are transported to a central depot where they undergo sorting based on fiber type before being directed to the recycling department. Recycled yarns are included in the carpet production process to produce new carpets [24].

III. Big yarn company has also followed sustainability measures in carpet production. The company uses a yarn with 75% recycled content, which is very effective. This new recycled yarn (Eqocycle) is mainly based on post-industrial waste and supports carpet manufacturers in reducing the ecological footprint of their final products. By minimizing waste, reusing materials, saving energy, and reducing carbon emissions, Eqocycle has provided a circular economy solution in its product [25].

IV. The Italian luxury carpet company uses econyl yarn to produce carpets. Aquafil Group manufactures this innovative and environmentally friendly artificial yarn. This yarn comes from recycled nylon fishing nets, plastic waste, and other industrial waste. The company's approach encompasses conscious and sustainable design, utilization of green energy, and incorporation of natural and reusable raw materials [26].

V. Mohawk Industries is committed to sustainability and prioritizes the circular economy approach. This collection ensures that the manufactured carpets, known for their durability and longevity, can be effortlessly recycled at the end of their life cycle. In terms of waste reduction, this collection has invested in advanced technologies and equipment in carpet production, which enables the optimal use of materials and waste reduction. Mohawk also has recycling programs to ensure the generated waste is properly recycled or repurposed. Meanwhile, these industries focus on using recycled materials in their carpet production and have developed innovative processes to incorporate recycled content into their products without compromising quality. In this regard, Mohawk offers a wide range of eco-friendly carpet options made from recycled materials. These carpets are designed to be durable and long-lasting and contribute more to the circular economy by increasing the product life cycle and recyclability [27].

VI. Tarkett is another company that has implemented various initiatives to promote the circular economy in its flooring products. The company uses recycled and renewable materials in its flooring production and has developed innovative processes to incorporate recycled content (such as recycled PVC) into its products. By implementing strict environmental standards and social responsibility throughout its supply chain and production processes, using renewable materials, and reducing waste, Tarkett has taken valuable steps in conserving resources, the health and well-being of customers, and preserving the environment [28].

VII. Ege Carpet Company operates in sustainable carpets production. This company uses 100% regenerated and renewable yarns in carpet production. The yarn used in this company's carpets comes from regenerated nylon threads. It should be noted that nylon products at their end-of-life cycles and those discarded in nature or industrial areas, or the remaining waste from other production processes, are first converted into nylon chips and then regenerated as nylon thread, which can be used in the Ege carpets production process. Of course, these carpets' nylon threads, if worn out, can be separated from their colored pigments and used again and again in new carpets, which creates an economic cycle [29].

3 | Results and Discussion

This section first examines the implementation of the circular economy in sustainable flooring production in Iran and other countries. The results of these investigations are then presented within a 9R framework and discussed.

3.1 | A Review of Domestic Literature on the Circular Economy Implementation in Sustainable Flooring

Olfat and Mazroui Nasrabadi [17] examined various models for measuring the stability of the machine carpet supply chain. They studied models such as the triple bottom line model, the breaking down boundaries model, and the Global Reporting Initiative (GRI) method. This research examined the level of Iranian carpet manufacturers' attention to different dimensions of sustainability using the Analytic Hierarchy Process (AHP). The research findings show that the economic factor had the most weight (0.525), which indicated that producers consider the profit value as the main influential, followed by the social factor (0.314) and the environmental factor (0.161), respectively. These results indicated that these producers do not care for non-material factors, especially environmental factors. Radnia [30] examined the impact of Iranian handwoven carpets on job creation, foreign exchange income, and the environmental sustainability of their production. This article underscores the seamless compatibility of handwoven carpets with nature, emphasizing their adherence to the principles of the circular economy.

Momeni et al. [31] identified handwoven Iranian carpets as a key non-oil export item for the country, underscoring the necessity of adhering to sustainability principles to augment production. For example, dyeing is the key influential factor in carpet production. Therefore, plants such as chamomile, grape leaves, beets, onion skins, mulberry leaves, fig leaves, walnut skins, sumac, and saffron should be used, and chemical dyeing should be avoided.

The space required for the sustainable production of handwoven carpets and the consideration of various economic, social, and environmental aspects in the production of this type of carpet was investigated by Mazroui Nasrabadi and Jafari [32]. The results showed that the raw materials with the least waste produced and less energy consumed are preferred to achieve a green supply chain in the handwoven carpet industry. For example, it is better to use Iranian spring wool fibers or completely ripe and white cotton fibers, and the silk used in the carpet texture should not be tangled or short. To make the fibers durable and the color last, it is better to dye them, using the traditional method in copper pots and with natural materials so that the consumer's health is less harmed. Also, dyeing wastes should be transferred to a special place to be recycled and used again. In the spinning stage, devices with low depreciation should be used, and measures should be taken to minimize the devices' depreciation and prevent energy loss and air pollution. Finishing and washing operations should be done in a flat place using alkaline materials so as not to damage the strength of the carpet. Warehouses should be properly ventilated with anti-willow materials should be used. Also, the factories must have proper ventilation to not endanger the employees' health, and people must wear special masks during dyeing. In fact, in this research, efforts have been made to pay attention to various aspects of sustainability, particularly focusing on employee satisfaction as one of the crucial elements of social sustainability in handwoven carpet production. Today, successful organizations view their employees as the primary customers within the organization, recognizing them as a powerful tool for promoting macro-level management and achieving organizational goals. These organizations strive to deliver high-quality services to

customers and tailor their plans according to employees' needs and preferences. This strategic approach is crucial to establishing a sustainable industry [33].

The key factors affecting the sustainable development of the machine-made carpet industry in Iran were identified by Jandaghi et al. [34]. They collected information, interviewed carpet experts, and identified various effective factors in three economic, social, and environmental dimensions. They analyzed the aforementioned factors across four distinct scenarios: prosperity, scenarios involving passive actors, disaster, and anachronistic worlds. In the prosperity scenario, improvements in the business environment, coupled with the removal of sanctions, create favorable conditions for Iran to participate in international organizations. This, in turn, amplifies attention to the carpet industry. In the lazy actors' scenario, the business environment is strengthened by reforms, with the sanctions removed to some extent. In this scenario, Iran prioritizes its oil economy, with minimal attention directed towards other economic sectors. In a disaster scenario, the business environment will significantly shrink, disabling companies from adopting the new technology and losing their connection with the international markets. Finally, in the anachronistic world scenario, which is very similar to the disaster scenario, the cost of production will considerably increase, and the purchasing power of people will decrease. This research concluded that achieving a prosperous scenario depends on the efforts of the government, people, and carpet producers. *Table A4* presents a summary of the reviewed domestic literature.

3.2|A Review of Foreign Literature on the Circular Economy Implementation in Sustainable Flooring

Agrawal et al. [35] investigated two companies, Desso and Interface, which are active in carpets. By launching a leasing business, these two companies provided solutions to follow the circular economy. They received a monthly fee from the customer for maintenance, cleaning, and worn carpet tile replacement, and at the end of the lease, they kept the ownership of the carpets for themselves. These companies believed the leasing model could increase the motivation to invest in durable, recyclable carpet production. In this regard, the interface company tried to produce sustainable products by collecting and using second-hand carpets, but in this way, the company faced problems that needed to be solved. But Desso launched its collection system to recover used carpet tiles. The company partnered with Aquafil, Europe's largest yarn producer, to set up a recycling plant to turn used materials into new yarn and valuable by-products for other industries. Then, they signed a contract with an asset management company called Dell to implement their leasing program so that they could collect products more quickly. The research results show that achieving a successful circular business model may require the cooperation of an ecosystem consisting of several different companies.

Liang et al. [36] examined polyurethane, a material extensively employed in carpet production. Being a versatile polymer, similar to other plastics, polyurethane is derived from fossil fuels, and its production process not only generates greenhouse gases but also raises various health and environmental concerns associated with its disposal through burial or burning. Notably, the research indicates that industrial post-consumer waste is managed in three ways: burial, incineration, and recycling, with shares of 58%, 12%, and 30%, respectively. However, burying waste like polyurethane risks human health and the environment. Burning these materials also causes big environmental pollution. Therefore, governments should adopt policies to remove these concerns through recycling. They also should follow the circular economy principles, which have been successfully implemented in several countries. As an illustration, numerous European countries have implemented bans on burying urban solid waste, including polyurethane. However, this issue is notably prevalent in Africa, where a lack of fundamental infrastructure for waste management further compounds the situation. Studies have shown that polyester, polyethene, and polypropylene are the most commonly occurring plastics in both freshwaters and coastal areas in African countries. Therefore, it is crucial to find effective solutions to remove plastic pollution and prevent plastic leakage into the environment in these countries [37].

Khoo et al. [38] examined the activity of interface companies as one of the largest carpet producers in the circular economy. The company pursued sustainability goals without sacrificing commercial objectives. To reduce environmental impact and dependence on oil derivatives, it turned to exploring diverse methods for

sourcing raw materials, with discarded fishing nets being one of the potential sources. In developing countries, fishermen often discard their used nets on the beaches or waters. This marine debris can remain for centuries, harming marine life and communities whose livelihoods heavily depend on fishing and causing problems for divers and other harbor users. With this in mind, Interface joined its yarn manufacturer, Aquafil, and the Zoological Society of London (ZSL) in 2012 to launch a program to recycle fishing nets, a model that brings significant benefits to local people. Working with local communities in the Philippines and Cameroon, the program encouraged people to sell fishing nets instead of throwing them away, thereby preventing beach and ocean pollution. The collected nets are cleaned, packed, and handed over to Aquafil. Using advanced regeneration technology, Aquafil transforms these nets into Econyl, a 100% recycled nylon yarn. After collection, the nets are thoroughly cleaned before being packed and delivered to Aquafil. Aquafil transforms these nets into Econyl, a 100% recycled nylon yarn using advanced regeneration technology. This product could be used in carpet production. In general, by purchasing yarn produced from depreciable fishing nets, Interface could use its market power to encourage the production of more sustainable materials and production processes that reduce energy consumption, waste, and pollutant emissions. The circular economy performance of an industrial symbiotic network in innovative cement mortar production, reinforced by synthetic fibers recycled from artificial grass carpets, was investigated by Marinelli et al. [39]. The worn and torn artificial grass carpets contain recyclable materials, including plastic particles that can be used in concrete production. This concrete production is an effective solution to prevent waste and increase the cooperation between the companies.

Furthermore, Marinelli et al. [40] conducted a study on developing an effective inter-industry network, focusing on exchanging materials and by-products. This network was specifically designed to produce cement mortar reinforced with synthetic fibers recycled from artificial grass carpets. Artificial grass includes synthetic fibers, including polyethene and polypropylene (12.5%), rubber (34.5%), silica sand (50.5%), and bituminous membrane (2.5%), which can be used in industry. Artificial fibers extracted from artificial grass are used as cement reinforcement. Silica sand is known as aggregate and is removed for construction purposes. Bituminous membrane is widely used in road asphalt, and existing rubber is used for children's playgrounds in parks. Therefore, the components of depreciable artificial grass carpets are not being discarded, creating an industrial symbiosis.

Lama et al. [41] adopted the newly developed resource pressure method to assess the environmental sustainability of various carpet designs and circular strategies. The resource pressure method refers to an approach that uses the amount of natural resources consumed and the pressure exerted on these natural resources to evaluate the environmental effects of a product or substance. The resource pressure method enables researchers to assess the effectiveness of circular strategies in reducing primary resource consumption and the corresponding environmental impacts. This study evaluated the ecological sustainability of various carpet designs in collaboration with a Swiss textile company. This evaluation considered the environmental effects, the circular economy improvement, and sustainability separated for two types of carpets (woven and tufted) in scenarios followed by the amount of profit and sustainability in these scenarios calculations. The research findings show that the carpet circular design can significantly reduce resource pressure. *Table A5* presents a summary of reviewed foreign literature in this field.

3.3 | Discussion

The previous section discussed the circular economy implementation in sustainable flooring production activities in Iran and other countries. In this section, the results of these investigations are expressed in a 9R framework (*Table A6*). It is worth mentioning that the 9R framework has been utilized to examine the implementation of circular economy in various industries, such as pharmaceuticals [42], automotive [43], and food [44] sectors.

Considering the obtained results, it is evident that the global adoption of the circular economy in sustainable flooring production is on the rise, garnering attention from various perspectives. In the case of Iran, although

different approaches have been used so far in implementing circular principles in the carpet and flooring industry, these approaches have mostly focused on maintaining and extending the product's lifespan. Recently, there has been a discourse on the post-consumer usage transformation of flooring materials like carpets. Efforts have been undertaken to minimize their disposal as much as possible. Regarding products such as carpets, there has been discussion about their change in use after depreciation, and efforts have been made to minimize their transformation into waste. However, a significant challenge lies in the recycling of these products. To explain this, we should note that over 80% of machine-made carpets in Iran are woven from acrylic fibers, posing considerable difficulty in recycling.

Furthermore, around 85% of machine carpet weaving units in Iran are classified as small and medium-sized, with an annual production output of less than one million square meters. Despite this, the high cost associated with establishing a machine carpet recycling unit poses a significant challenge. The economic feasibility for small and medium-sized industrial units becomes impractical due to these expenses, presenting a notable obstacle to recycling these products.

4 | Conclusion

Today, major carpet and flooring manufacturing companies worldwide have embraced the circular economy approach. They strive to demonstrate to their customers that their products are environmentally friendly by offering sustainable products and obtaining relevant certifications. In the present study, while introducing the 9R framework as a comprehensive structure for achieving the benefits of a circular economy, the sustainable production of flooring, particularly carpets, in Iran and other countries is investigated.

Within the scope of this research, and based on the results obtained from the examination of studies conducted in this field and information gathered from interviews with relevant managers and experts, it can be concluded that significant strides have been taken towards sustainable carpet production in Iran. Among the most important steps taken in this direction are the appropriate utilization of raw materials, extending the product's useful life, and transforming its usage. However, achieving the full implementation of all circular economy principles in Iran faces substantial obstacles. One of these obstacles is the high cost of establishing recycling units. Therefore, the government must encourage large-scale production units capable of entering the recycling sector by providing support packages. By doing so, they can enter the field and take effective steps in waste management for this product through recycling.

Furthermore, efforts should be made to properly educate consumers, raising awareness about the importance of sustainable products. This matter will empower customers to abstain from purchasing environmentally harmful products and understand the correct usage of the products they acquire. On the other hand, enacting legislation and vigilant oversight to ensure the effective implementation of these laws plays a crucial role in achieving a circular economy that enhances profitability and fosters resource and environmental conservation. In fact, by designing products with a long lifespan and the possibility of recycling, as well as promoting the repair and reuse of second-hand products, we can create a more sustainable and prosperous economy in the country.

One of the suggestions that can be of interest to enthusiasts in this field for future studies is the use of Operations Research (OR) methods and simulation for designing and analyzing sustainability in flooring production systems, which has not received sufficient attention until now. Examining various circular business models to select the best model for achieving goals and the benefits of a circular economy is another suggestion that provides a good foundation for further development and research in this area. Finally, giving more attention to industrial symbiosis as a collaborative and mutually beneficial relationship among different industries or organizations is another suggestion for future studies. Efforts should be made to transform the waste or by-products of each organization into raw materials or energy sources for the same organization or other organizations, creating a closed-loop system as much as possible.

Acknowledgments

The authors would like to acknowledge the anonymous reviewers whose constructive comments and suggestions helped refine this manuscript.

Author Contributions

The authors confirm their contribution to the paper as follows:

Conceptualization, Fereshteh.Parvaresh., and Mohamad Hosein Amini.; Methodology, Fereshteh.Parvaresh.; Software, Fereshteh.Parvaresh., and Mohamad Hosein Amini.; Validation, Fereshteh.Parvaresh.; formal analysis, Fereshteh.Parvaresh., and Mohamad Hosein Amini.; investigation, Fereshteh.Parvaresh., and Mohamad Hosein Amini.; resources, Fereshteh.Parvaresh., and Mohamad Hosein Amini.; data maintenance, Fereshteh.Parvaresh., and Mohamad Hosein Amini.; writing-creating the initial design, Fereshteh.Parvaresh., and Mohamad Hosein Amini.; writing-reviewing and editing, Fereshteh.Parvaresh.; visualization, Fereshteh.Parvaresh., and Mohamad Hosein Amini.; monitoring, Fereshteh.Parvaresh., and Mohamad Hosein Amini..; project management, Fereshteh.Parvaresh.; funding procurement, Fereshteh.Parvaresh., and Mohamad Hosein Amini. All authors have read and agreed to the published version of the manuscript.

Funding

This research received funding.

Conflicts of Interest

The authors declare no conflict of interest.

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Appendix

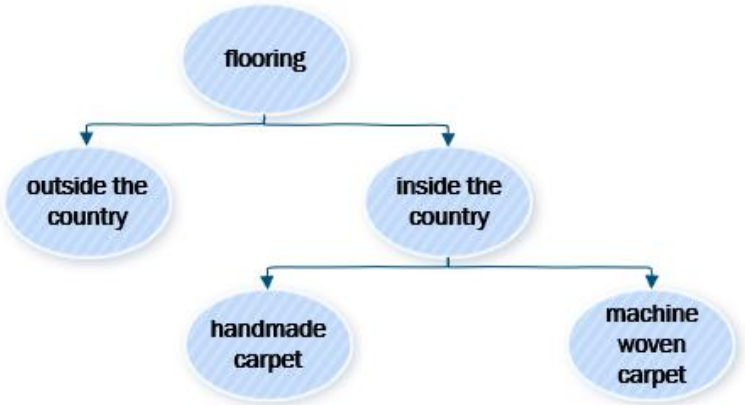

Fig. A1. Reviewed literature considering sustainable flooring.

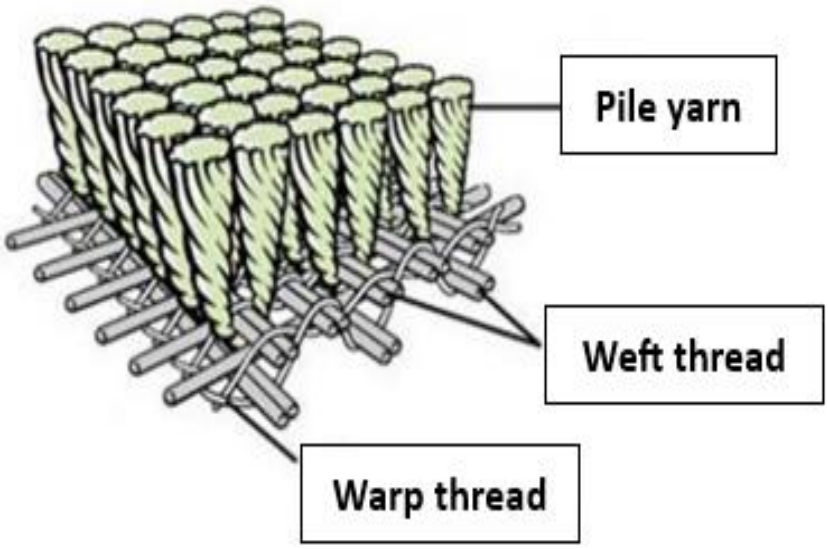

Fig. A2. Types of yarn in carpet production.

Fig. A3. Carpet frame of Imam Redha's Shrine (PBUH).

Fig. A4. Carpet frame of Imam Redha's Shrine (pbuh).

Table A1. The 9R framework elements.

R0	Refuse	Refraining from buying unnecessary goods or products that generate much waste.
R1	Rethink	To reconsider consumption patterns and consciously make decisions to reduce waste production.
R2	Reduce	Use fewer resources and produce less waste. For example, this involves purchasing products that last longer, are unpackaged, and have minimal packaging.
R3	Reuse	Reuse products and materials instead of discarding them to extend their lifespan.
R4	Repair	Repair damaged products instead of discarding them.
R5	Refurbish	Update an old product using sustainable methods and materials, such as renovating and retrofitting an old building.
R6	Remanufacture	Separate a product component, check and clean it, repair or replace parts, and reassemble. Remanufacturing is an industrial process through which an obsolete product can be remade.
R7	Repurpose	Find new uses for items no longer suitable for their original purpose. In practice, individuals or businesses strive to discover a new purpose, giving it a second life rather than discarding a product.
R8	Recycle	A process in which recycled materials, such as plastic, paper, metal, etc., are transformed into usable materials through chemical, physical, and mechanical methods.
R9	Recover	Extract valuable resources from waste without pre-processing, such as burning waste oils that cannot be refined for car reuse to generate energy.

Table A2. Characteristics of acrylic, polypropylene, and polyester carpets.

Type of Carpet	Advantages	Disadvantages
Acrylic carpet	It absorbs little grease, moisture, willow, dust, and pollution.	It is difficult to clean dirt and oil stains from it.
	It is more heat, light, and abrasion resistant than natural fibers such as wool and cotton.	It is flammable.
	Due to its ability to absorb a lot of color, it has a wide range of colors.	Thread tissue is toxic and unsuitable for the cycle of nature.
	Heat insulated	It can only be washed with industrial carpet shampoos.
Polypropylene carpet	It has great resistance to tension.	It is weak against heat and sunlight.
	It has a low density.	It melts at 165 degrees Celsius.
	It is compatible with human skin and anti-allergic.	It absorbs dirt quickly, and it is difficult to remove oily stains from it.
	It absorbs very little moisture and dries quickly after washing.	The poor reversibility of this type of fiber causes the carpet to become rigid over time due to wear and tear.
Polyester carpet	It has high color acceptability, better color and glaze, and impressive beauty, which makes it more diverse in design and color.	Due to washing, it is sensitive to alcohol-containing detergents and loses its original color over time.
	Due to the lack of fluff, it is more suitable for people with allergies.	It is delicate and very thin and has a shorter lifespan.
	It absorbs little moisture.	It does not tolerate a lot of washing and loses its original state.
	It is affordable	It melts when exposed to hot objects.

Table A3. Foreign companies active in sustainable flooring production.

Company Name	Company Website	Company Main Products
Bentley mills [23]	https://www.bentleymills.com/	Types of carpets used in homes and offices
Shaw floors [24]	https://shawfloors.com/	Types of carpets, and more tiles carpet
Beaulieu international group [25]	https://www.bigyarns.com/	All kinds of yarns, car carpets
Luxury carpet studio [26]	https://www.luxurycarpet.it	All kinds of carpets and rugs for home, commercial, and office use
Mohawk industries [27]	https://www.mohawkflooring.com/	A wide variety of carpets and rugs
Tarkett group [28]	https://professionals.tarkett.com	Types of carpets, and more tiles carpet, used in commercial places and airplanes
Ege carpets [29]	https://blog.egecarpets.com	Types of roll carpets with a wide variety

Table A4. Review of domestic literature on the implementation of circular economy in flooring.

Article	Objective
Olfat & Mazroui Nasrabadi [17]	Investigate different methods and models for measuring sustainability in the machine-made carpets supply chain.
Radnia [30]	Emphasize the importance of Iranian handwoven carpets in job creation and foreign exchange income and align its production with environmental protection.
Momeni et al. [31]	Investigate the importance of handwoven carpet export and emphasize its sustainable production, using plant materials in dyeing.
Mazroui Nasrabadi & jafari [32]	Attention must be paid to various sustainability aspects (economic, social, and environmental) in the production of handwoven carpets, and the space required for the sustainable production of this product must be investigated.
Jandaghi et al. [34]	Investigate the factors affecting the carpet industry's sustainable development according to the scenarios predicted for the future of this industry.

Table A5. Review of foreign literature on the circular economy implementation in flooring.

Article	Target
Agrawal et al. [35]	Examine the solutions of carpet leasing companies and emphasize the usefulness of circular business models consisting of an ecosystem of several different companies.
Liang et al. [36]	Examine polyurethane as one of the most widely used materials in carpet production and emphasize the importance of its recycling.
Khoo et al. [38]	Investigate the solution of Interface company in using fishing nets in the carpet industry.
Marinelli et al. [39]	Investigate the production of reinforced concrete using synthetic fibers recycled from artificial grass carpets and emphasize the importance of the industrial symbiosis approach.
Marinelli et al. [40]	Investigate an efficient network between industries based on the industrial symbiosis approach for using different components of artificial grass waste based on the materials exchange and by-products.
Lama et al. [41]	Adopt the resource pressure method to evaluate the sustainability of different carpet designs and determine the effectiveness of circular strategies in reducing the consumption of primary resources and environmental effects.

Table A6. The results of circular economy implementation in sustainable flooring production.

R0	Refuse	- People's attention to the environmental harmful effects, the difficulty in recycling carpets, including acrylic carpets, and consumers' tendency to avoid buying products lacking green labels (indicating environmentally friendly production).
R1	Rethink	- People's attitudes are changing to replace modern and less colorful carpets with healthier fibers rather than opting for bright and potentially unhealthy options, including acrylic carpets. - Considering various carpet characteristics, such as moisture absorption, cleanability, softness, and aesthetics, and selecting the appropriate carpet for different areas of the house (e.g., living room, bedroom, kitchen). - Establishing laws by the government to implement various sustainability principles and increasing consumer awareness to enable informed choices of flooring compatible with circular economy principles.
R2	Reduce	- Trying to produce a carpet that consumes the least raw material and puts less pressure on primary resources. - Learning from manufacturing companies such as Big Yarn, Interface, and Diso about yarns that can be recycled and do not generate waste. - Observing the principles of carpet maintenance and washing it properly to increase the life and longevity of the carpet.
R3	Reuse	- Using second-hand carpets for spaces less important than reception, such as rooms and kitchens. - Utilizing cyberspace to sell vintage floor coverings. - Donating old floor coverings to charitable organizations.
R4	Repair	- Specialized in repairing handwoven and machine-made carpets and floor coverings. This includes removing damaged parts from tile carpets and replacing them with new ones.
R5	Refurbish	- Dyeing worn and faded nylon and wool carpets using new stable colors.
R6	Remanufacture	- Creating a carpet collage (or a forty-piece carpet) by assembling and connecting pieces from several damaged carpets through gluing and sewing.
R7	Repurpose	- Transforming second-hand carpets by repurposing them into carpet panels, traditional pillowcases, bedspreads for outdoor beds, and similar items. - Utilizing worn-out flooring, especially new materials, as animal bedding.
R8	Recover	- Burning carpets, rugs, and other discarded floor coverings to generate energy.
R9	Recycle	- Recycling polyester and polypropylene fibers from used carpets for use in the construction and textile industries. - Recycling nylon fishing nets and other plastic waste and turning them into Econyl yarn for carpet production. - Using synthetic fibers recycled from artificial grass carpets as cement reinforcement.