Key Engineering Materials
ISSN: 1662-9795, Vol. 919, pp 218-226
doi:10.4028/p-0ods3h

Submitted: 2021-07-27
Accepted: 2021-12-13
Online: 2022-05-11

Circularity Performances of the Production of a Cement Mortar Reinforced with Recycled Synthetic Fibers

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Keywords: fiber-reinforced concrete, sustainable construction material, supply chain, industrial symbiosis, circular economy.

Abstract. Forced by environmental implications and by legislation requirements, the cement sector is moving towards more circular economy practices, with the primary aim to enhance the sector sustainability. This commitment translates into product technology innovation, but also into innovative development perspectives for the industries involved in the supply chain. Moreover, dealing with recycled materials can modify the interaction among stakeholders from a conventional supply chain to an industrial symbiosis approach, where companies mutually exchange products and by-products into circular interactions. The purpose of this article is to investigate the circularity performances deriving from the production of a cement mortar reinforced with recycled synthetic fibers coming from artificial turf carpets. From the collection of artificial turf carpets at the end-of-life stage it is possible to recover several materials: plastic fibers used in the cement mortar, and in addition, silica sand, rubber, and bituminous membrane. The production of the innovative reinforced cement mortar leads to the connection between industries belonging to different sectors and consequently to uneven economic and environmental implications. Starting from the available literature, this study aims at evaluating the circularity potential of the unusual interactions among companies to support the development of an effective strategy, reducing environmental and economic pressures.

Introduction

The signs of unsustainability in the construction sector are numerous, from the raw materials scarcity and the biodiversity degradation and loss [1], up to the environmental impacts linked to the building industry responsible for emitting about 35% of the total greenhouse gases (GHGs) globally [2]. In order to face this critical context, in recent years, technological innovation and circular economy (CE) strategies are spreading inside the construction sector-related products, services and works, led also by legislation requirements, such as the European Green Deal and the CE Action Plan [3]. The CE principles and practices provide a wide set of solutions to improve the sustainability of the construction industry. One of the main goals of circular business models is to take advantage of the embedded value in materials for as long as possible, for example using secondary materials. In fact, the use of recycled content in the manufacturing of construction materials reduces the demand of raw materials as well as the amount of waste landfilled [4].

However, some barriers hinder the implementation of this circular path, namely an insufficient supply of recovered materials or the lack of market demand, the price and quality of secondary materials, the lack of technical information and contractor awareness can be identified [5].

So, it appears evident that the implementation of most of the circular strategies involves several firms along the value chain and requires coordination of the materials exchange and the logistics among these different firms, demanding a systemic innovation of the construction industry value chain [6]. Such business model innovation strategies include the establishment of key partnerships or networks for secondary material supply, allowing access to sufficient volumes and quality of secondary materials, and recycling [7].

The material reuse business model impacts the value creation for the partners involved in the network: the use of secondary materials can allow cost savings if the price is steady (but it can also imply high costs due to logistics or labor); the recovery and reuse innovative processes can promote employment creation; it results in the reduction of the overall life cycle costs related to the value chain; the reduced environmental impacts can improve the corporate image [8].

To generalize, the transition of the construction industry towards circularity involves the creation of industrial symbiosis (IS) networks, providing the supporting framework for the transition towards circularity [9]. According to one of the first definitions of the IS concept, and the most cited one, IS engages "*traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity*" [10]. The geographic proximity allows the use of local infrastructure and the reduction of logistics cost, but exchanges along a supply chain (depending also by the type and value of the waste or by-product stream) can make synergies and exchanges advantageous over long distances [11].

The implementation of IS in the construction industry to improve its sustainability and circularity is suggested and analyzed by some scholars [12,13] demonstrating several advantages that are also main drivers for the emergence of IS [14]. Yu et al. [15] found that IS in the construction industry presents some peculiar characteristics including the presence of an industrial actor involved in the materials recycling who usually initiates arranging the connections and the need for a high up-cycling efficiency, depending on the innovation of recycling technologies and the incoming waste quality (Fig. 1).

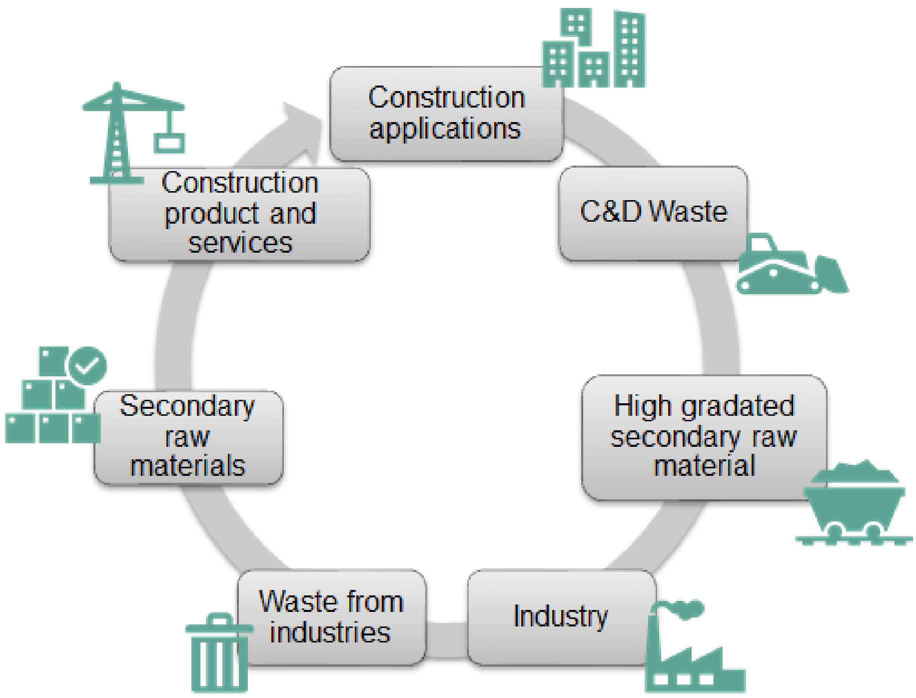

Fig. 1. Circularity in the construction sector.

This paper analyses the potential circularity performances of emerging links deriving from the production of a cement mortar reinforced with recycled synthetic fibers coming from artificial turf carpets.

The production of the innovative cementitious material is one of the main objectives of the project IMPReSA Betonplast, funded by the Emilia Romagna Region focusing on the development of innovative construction materials including non-recyclable plastic particles acting as reinforcement. The ambition of the present study is to contribute to the project by investigating the potential environmental and economic barriers to the development of such materials along the entire supply chain. The overall aim is to design an efficient network between industries based on the exchange of materials and by-products, according to the industrial symbiosis approach. The optimization of the materials cycle increases resource efficiency, reducing waste and pollution, and brings about economic benefits.

Case Study

The project IMPReSA Betonplast aims at the development of innovative "eco-friendly" construction materials, promoting the use of non-recyclable plastics in substitution of natural origin aggregates. In this context, one of the selected secondary materials are synthetic fibers retrieved from artificial turf carpets of soccer pitches at the end-of-life stage. Those fibers are included in a cementitious conglomerate for structural and restoration purposes.

From artificial turf carpets at the end-of-life stage, however, it is possible to recover additional raw materials in different percentages to use as by-products. The recoverable materials are as follows: synthetic fibers (12.5%) composed of polythene (PE) and polypropylene (PP), rubber (34.5%), silica sand (50.5%) and bituminous membrane (2.5%) (Fig.2).

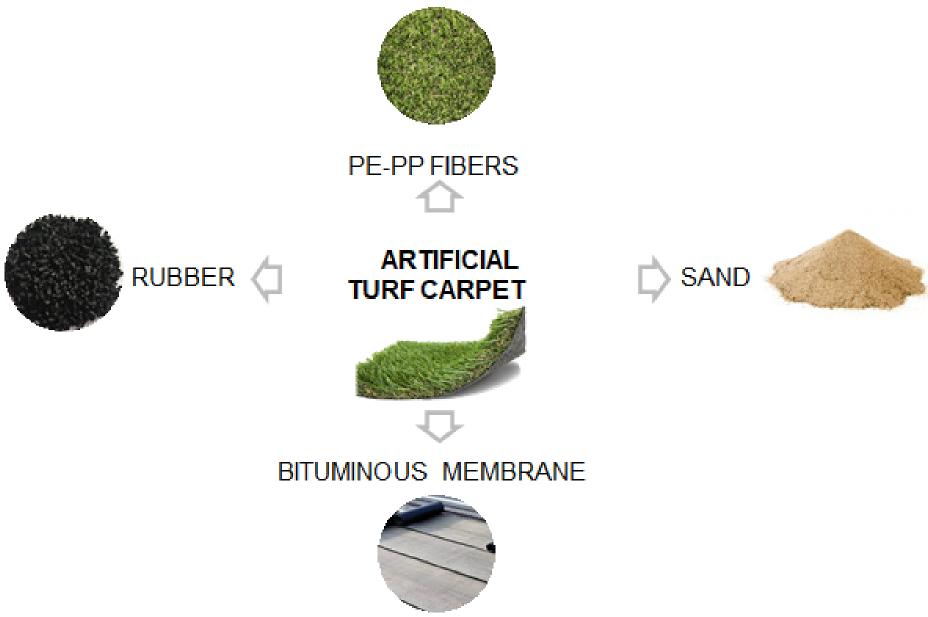

Fig. 2. Recoverable secondary raw materials from artificial turf carpets.

Secondary Raw Materials

Sand, gravel and rock, commonly known as aggregates, are mined world-wide for construction uses and account for the largest volume of solid material extracted globally [16]. Aggregates are relevant in terms of their contribution to economic progress and also the impact they have on the environment. Not only does extraction of aggregates alter the landscape, but they also affect groundwater reserves and the cultural assets of a region [17]. Decreasing the impacts of sand mining and transitioning toward a less ecologically destructive, and more resource-efficient circular economy in the construction sector are global priorities [18].

To reduce the environmental problems related to the extensive use of those natural resources in the construction sector and especially in the concrete production, one of the viable solutions is the use of recycled materials [19]. Indeed, in recent years several studies have been conducted related to green concrete, namely concrete made from different types of eco-friendly materials, derived from agriculture, municipal, electronic, industry, construction, and demolition waste [20, 21]. Beyond these promising solutions, the prospect of recovering sand and other aggregates already extracted and their re-use in the most cost-effective way possible, is interesting both from the environmental and economic point of view [22].

Bituminous materials are one of the oldest and most widely used construction materials. Their components are obtained from finite resources, nevertheless these materials have long been known as sustainable products due to their capacity to extend their serviceable lives through reclaim, reuse and/or the recycling processes [23]. Recycling bituminous mixtures to produce urban roads is a promising solution to reduce the environmental burden due to conventional hot mix asphalts [24].

The rubber is produced by shredding or grinding old tires into small pieces. In recent years, recycled rubber, also called tire crumb, is used to surface some running tracks and water parks and it is also used to reduce the risk of injuries on playgrounds [25].

The possibility to recover various secondary raw materials, lead to several potential circularity interactions among different companies, depending on the use of the recovered materials and on legislation, environmental and economic related issues.

Building up an Efficient Network

Considering the secondary materials and their potential uses, we designed a circular industrial network that involves 6 companies, as shown in Fig. 3.

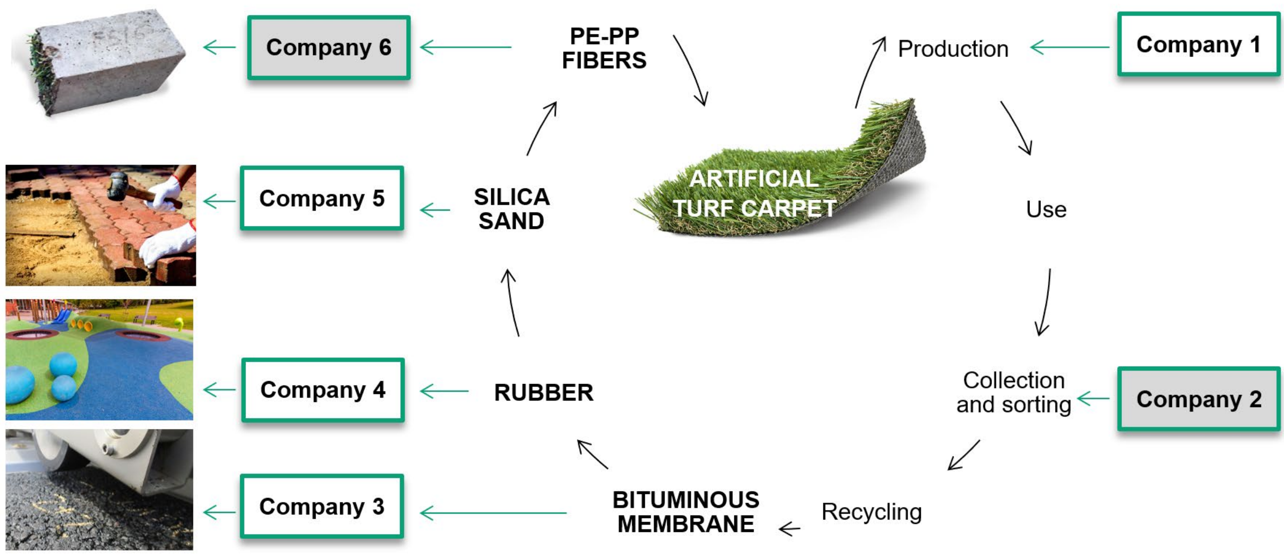

Fig. 3. Schematic diagram showing the closed loop supply chain.

The symbiotic network is based on the external exchanges approach [26] where Company 2, the one that collects the artificial turf carpets, sends the recovered materials wastes to other companies, which will use them in their production processes and Company 6 aims to use PE-PP fibers as reinforcement in a cementitious matrix, to innovate and make greener on of their flagship products. The other firms inside the boundaries are Company 3, that could adopt the bituminous membrane scraps for road asphalt mixtures; Company 4, that could recycle the rubber to produce playground surfaces and Company 5, that uses the silica sand in general construction activities.

Finally, Company 1 is the producer of the artificial turf carpets, starting from recovered sand and rubber.

Enablers and Barriers Analysis

In order to evaluate the circularity performance of the emerging network, the factors that facilitate and support (enablers) and those that hinders or obstructs (barriers) the development of exchanges between the involved companies are identified.

According to Henrique et al. [27], who present a collection of key factors recently retrieved from the literature, the identified enablers and barriers could be grouped on the basis of the following dimensions: social; economic; policy; management; technological; geographical and intermediaries.

The enablers and barriers relevant for the case under study are listed in Table 1 and Table 2.

Table 1. Key enablers evaluation. Adapted to the case under study from Henrique et al. [27].

Dimension	Nr	Key enabler	Yes/Not
Social	S1	Trust environment	Y
	S2	Environmental awareness	N
	S3	Spontaneous and self-organized approach	Y
	S4	Internal and external network of the relation between companies	N
	S5	Community Awareness & Education Activities Programs	N
Economic	E1	Operational cost reduction	Y
	E2	New business opportunities	Y
	E3	Identification of saving in the waste management	Y
	E4	National funding	Y
	E5	Private contribution	N
Policy	P1	Promotion of the industrial policy	Y
	P2	Environmental tax policy	Y
	P3	Promotion of network and waste market	N
	P4	Promotion of framework for CE	Y
Management	M1	Promotion of protocols and formal agreements	N
	M2	Diversification of the traditional business approach	Y
	M3	Promotion of spontaneous negotiation “one-to-one negotiations”	Y
Technological	T1	Facilities that allow the technological viability of synergy	Y
	T2	Improving the process, incorporation of technologies	Y
	T3	Network Promotion	Y
	T4	Digitization of the industry through the transition to I4.0	N
Geographical	G1	Geographical proximity	Y
	G2	Strategic position	Y
	G3	Logistic networks	Y
Intermediares	I1	Involvement of R&D institution and universities	Y
	I2	Government involvement	N
	I3	Anchor companies’ involvement	Y
	I4	Regional and national entities promoting synergies	Y

Table 2. Key barriers evaluation. Adapted to the case under study from Henrique et al. [27].

Dimension	Nr	Key Barrier	Yes/Not
Social	S1	Social Inertia	Y
	S2	Lack of trust environment	N
	S3	Conflicts of interest	N
	S4	Lack of knowledge in industrial sustainability	N
Economic	E1	Lower, unclear or inexistence economic benefits	Y
	E2	Instability in demand factors	Y
	E3	Low costs associated with waste disposal	N
	E4	Lack of financing funds (private or public)	N
	E5	Market immaturity	N
Policy	P1	Existence of regulation and framework	Y
	P2	High complicate bureaucratic procedures	Y
	P3	Uncertainty in the approach of the future policy	N
Management	M1	Limited resources	N
	M2	Implementation unviability	N
	M3	Lack of protocols and formal agreements	Y
Technological	T1	Lack of knowledge or nonexistence (commercially) of reliable material recovery technologies	N
	T2	Lack of investment	N
	T3	Integration problem	N
	T4	Lack of quality materials	Y
Geographical	G1	Long distances between the involved companies	N
	G2	Lack of infrastructure	N
Intermediares	I1	Lack of intermediaries	N
	12	Poor communications	N
	I3	Lack of participative network	Y

The results of the analysis are illustrated in Fig. 4, with evidence of the enablers and barriers with the highest prevalence in each dimension.

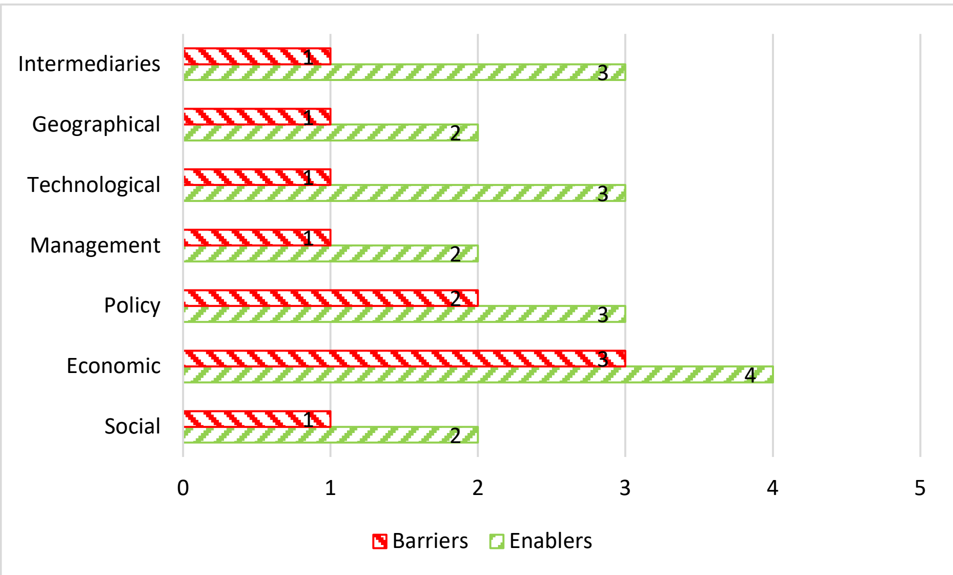

Fig. 4. Key barriers and enablers analysis

The economic dimension is the one with the greatest incidence in general terms. It is a facilitating factor when considering potential savings in resources and new revenues through the sale of the recovered materials as resources and of new products. As a barrier, the economic dimension is affected by the collection and transportation costs, the instability in demand factors, which ends up directly affecting the supply chain and by the potential lack of buyers, considering that the market itself could be inadequately prepared for the incorporation of innovative and unusual products.

The policy dimension is supported by several plans and policies that allow the implementation of the CE in industrial activities, both at national and regional level. Through article 18 of the law entered into force in 2016 [28], it has become mandatory to include a minimum recycled content in several construction products, e.g., concrete and cement mortars. In the last year (2020), the Ministry of Development signed the Transition Plan 4.0 which encourages circular technological innovations [29].

The geographical dimension is mainly an enabler factor. The company involved in the recovery activities is located in a strategic position in the center of an industrial site and the other selected companies are characterized by a geographical proximity, located at an average distance of 150 km [30], well connected by a network of roads.

Regarding the social dimension, the relation between companies and other involved stakeholders, and the sharing of information could promote trust between the involved industrial parts and the end-users (clients), increasing the social acceptability of products containing secondary raw materials and the awareness of concepts such as environment and industrial ecology.

In reference to the intermediary dimension, the involvement of several universities will promote the sharing of knowledge in order to consolidate the innovative products, and especially the CE practices with a consequent promotion of the initiative and of the incoming network.

The technological dimension is mainly an enabler. Apart from some adaptation of the production plants to the innovative industrial processes, the technology improvement will allow better control of production processes, data availability, wastes and resources.

Finally, the difficulty to unhinge existing value chains in favor of new ones could mine the management dimension. Nevertheless, between the involved companies there is the awareness that new business approaches produce economic and environmental benefits, therefore negotiations will be promoted to optimize operational costs and resource efficiency.

Conclusions

The starting concept of the present research is the consciousness that the environmental impacts linked to the construction structures are mainly related to the production of construction materials, including raw material extractions, transports and all the related manufacturing stages coming from the construction industry sector.

It is evident that, to reach sustainable construction structures, among other aspects, it is necessary to coordinate the materials exchange and the logistics among firms, through a systemic innovation of the construction industry value chain. That means, to stimulate a circular business model, taking advantage of the embedded value in materials for as long as possible, and implementing the application of CE principles and practices.

Within this view, the study analyses the potential circularity performances of emerging links deriving from the production of a cement mortar reinforced with recycled synthetic fibers coming from artificial turf carpets. Taking into account the secondary raw materials to recover and the facilitating and hindering factors, we built up a network between industries based on the exchange of materials and by-products, according to the industrial symbiosis approach.

Acknowledgments

The research has been co-funded by the European Regional Development Fund (ERDF) - ROP of the Emilia-Romagna Region (IT) and the Development and Cohesion Fund (FSC), within the framework of the “Progetto IMPReSA, Impiego di Materiali Plastici da Riciclo per malte e calcestruzzi Strutturali Alleggeriti” (CUP E81F18000310009-POR-FESR 2014/2020 - asse 1.2.2-strategic industrial research projects).

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