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INNOVATIVE USE OF SCRAP AND WASTE DERIVING FROM THE STONE AND THE CONSTRUCTION SECTOR FOR THE MANUFACTURING OF BRICKS. REVIEW OF THE INTERNATIONAL SCENARIO AND ANALYSIS OF AN ITALIAN CASE STUDY

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Abstract

The construction sector has evolved a lot over the last few years promoting the design and manufacturing of innovative and environmentally sustainable materials and products. In accordance with European and national guidelines, with a growing awareness of environmental issues several experiences are showing the interest of companies to qualify their products as green and environmentally sustainable. In the European context many directives have been introduced which, among their themes, speak of circular economy, reduction of the use of resources, better efficiency of production, etc. At the same time, initiatives related to the GPP were activated in the Italian context, that foresee an increase of the recycled content in building materials. Especially the brick manufacturing industry is very sensitive to the issue of the waste recovery and many experiences show that is possible to obtain optimum products with weighted material mixes (virgin raw materials and secondary raw materials). This procedure also contributes to a gradual recovery of waste otherwise disposed of in landfills. In the international scenario there are many studies about the reuse of waste and scraps in the bricks material mixes; the studies mainly derive from heterogeneous sectors as, for example: fly ash from coal plants, scraps and waste from the natural stone extraction, ceramic production residue, aggregates from demolition, waste oil, slag from steel mills, sawmill sludge and dust, glass powdered, recycled plastic, textile fibers, etc. The analysis of many experiences highlighted two key issues: the importance of cross-sectorial exchanges as a condition for enabling strategies of circular economy and the high intrinsic value of the material scrap. Particular attention has been paid to the Catalyst case study, a company that has developed different types of bricks, produced almost entirely with secondary raw material.

Key words: bricks, circular economy, reuse, scraps, sustainable production, waste

Received: March, 2018; Revised final: July, 2018; Accepted: September, 2018; Published in final edited form: October 2018

1. Introduction

The construction sector represents a very impactful industry, both from the point of view of energy consumption and use of natural resources. Therefore, every innovation developed within the construction sector (production of materials and/or

semi-finished products with recycled content, rather than design solutions with environmental attention) represents a good outcome from the point of view of sustainability. The need to promote sustainable lifestyles is therefore representing an ethical and social choice no longer postponed (EC Communications, 2011a; 2014; 2015; SPREAD, 2012).

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In this regard the report Signals 2017 (EEA, 2017) of the European Environment Agency shows that energy efficiency and the use of natural resources are the only viable perspective to accelerate process of shared sustainability. The improvement of natural resource efficiency is also at the heart of the UNEP International resource panel, the UN Program for the environment, indeed in the report *Resource Efficiency: Potential and Economic Implications* (UNEP, 2017) two fundamental aspects emerge: the first is that the efficient use of resources can contribute to economic growth and job creation; the second aspect is that it can offset the costs that the GDP of the world should support to hold the global warming within the limit of +2 (UNEP, 2017) respecting the limits set by the Paris agreement.

The importance of intervening to improve the use of natural resources is annually remembered by Global Footprint Network. In the report on Earth Overshoot day (Global Footprint Network, 2017) is underlined the day of the year in which the world's population runs out of their resources. In this year, the Earth Overshoot day coincided with the August 2nd, in a significant advance of the day reported in 2016 and in 2015 and forecasts say that in 2030 this day could fall at the end of June.

Compared to these premises it is clear that it is essential to promote initiatives aimed at the enhancement of waste recovery (both pre-consumer and post-consumer) especially in heterogeneous contexts and in cross-sectorial reality (Migliore et al., 2015). This type of approach presupposes a revision of manufacturing processes capable of overcoming the "linear" vision of the process in favor of a "systemic" logics (Cutaia et al., 2015). Waste cannot be seen only as the output of a process, this would represent a reductive view, rather we should try to see in waste, resources to be exploited (Mihajlov and Stevanovic-Carapina, 2015).

In accordance with these principles, many studies have been conducted and some were translated into real productive cases with marketing of sustainable products with recycled content. The paper will consider some experiences that intended to convey towards the manufacturing of bricks, different types of scraps and/or waste (to add and/or replace the typical mixture of materials), with the aim of highlight potential and good practices replicable in other contexts. Finally, a case study concerning the company Catalyst of Carrara, which has developed highly innovative patented products, will be analyzed. These products have been designed with the objective of contributing systematically both to the reduction of waste disposed on the territory and enhancing scrap/waste.

2. Innovative bricks production

2.1. Scraps and waste concerning the building sector

In 2014, according to Eurostat statistics, the total waste production by the economic activities and

domestic waste in the EU-28 accounted for 2.503 billion tons.

This quantity represents the highest amount registered in the EU-28 over the period 2004-2014. A large part of the total waste generated is related to demographic and economic dimension of the EU, but it appears that the construction sector accounted for 34.7% of the total in the 2014, followed by mining (28.2%), manufacturing activities (10.2%), water and waste services (9.1%) and household activities (8.3%); the remaining 9.5% of waste was generated by other economic activities (Eurostat, 2014). It is a fact that cannot be overlooked because it highlights the potential derived from strategic interventions for environmental improvement in the supply chain in general.

The European Commission has estimated that if in the construction sector were applied systematically environmental improvements and new management procedures, we could have a positive impact on 42% of final energy consumption, on 35% of our emissions of greenhouse gases and on over 50% of mined materials, it would also save up to 30% water (EC Communication, 2011b).

The EEA (European Environmental Agency), within its report (EEA, 2012), reported that adding the impacts due to building products, in their whole lifetime, to those generated during the use of residential buildings, buildings are responsible for 31% of the contribution to global warming, the 20% of the causes of acidification, 21% is their contribution to tropospheric ozone precursors emissions and, 22% is their part of the consumption of material resources. On the basis of all these considerations this research work aims to highlight what it can be obtained by giving value to scrap materials, referring mainly to the production of brick.

2.2. The use of waste and scraps as secondary raw materials in the bricks production

The experiences carried out nationally and internationally on the recovery of waste as secondary raw material for the production of bricks for the building industry, are numerous and heterogeneous.

Considering the types of scrap/wastes that are already used it is possible to list the following: scraps from quarries (kaolin, basalt, etc), blast furnace slag, sawmill sludge, dust and waste glass, cotton waste, paper production scraps, etc.; each retrieval of material give origin to products/materials that have higher performances and/or that are environmentally more sustainable (considerable materials are many more, but the study has focused the attention to those that have led to the production of materials that are also innovative, from the point of view of the performance, of the production process and of application system, compared to traditional production).

A study (El-Mahllawy, 2008) on the ability to reuse scraps of kaolin quarries, blast furnace slag and scraps from basalt quarries, pointed out that not only

this scrap could entirely replace the virgin raw materials, but it can improve the resistance in acidic environment of bricks products. In this case it was particularly interesting the aspect related to the renewed and enhanced product: the scrap/waste recovered not only contributed to an environmental improvement (impact avoided disposal in landfill and the reduced consumption of virgin raw materials), but it has also fostered a remarkable process of up-cycling. The scraps arising from the stone industry has been proved as useful in the mixtures for the manufacturing of bricks in other circumstances.

In one study it has been showed the ability to retrieve both the sawmill sludge (from stone industry) and the glass dust and waste, in sizes ranging from 25 to 75% of the original mixture (Turgut, 2008) for the production of bricks. Another study underlined the possibility to recover the quarries dusts mixed with waste from the working of aluminum and generic ash (Shakir Alaa et al., 2013). Referring the attention to the stone sector in the Italian context, emerges an interesting research (Corcione et al., 2018) project that integrates the use of waste deriving from the Lecce stone extraction/processing and the use of 3D printing of building components. In this case the waste is used to produce slabs for buildings facades. Other studies (Van Wijk et al., 2015) were conducted on this theme and these shows how many possible developments are possible, and above all how these can foster environmental improvement and the development of forms of circular economy. In other cases, the waste from C&D was recovered as secondary raw material with excellent results, a study (Seco et al., 2018) conducted in Spain established that concrete waste could be used to substitute up to 50% of the clay whereas ceramic wastes could only substitute a maximum of 30% of the clay.

The waste that can be used for the production of bricks, as shown, comes from different production sectors, a study conducted in Belgium (Nabil et al. 2018) showed that the waste foundry sand from Belgaum foundry industry is useful as secondary raw material in the percentage up to 50% in clay bodies to produce bricks. Even the waste of cotton processing and the waste from the paper mill can be reused to produce bricks (Rajput et al., 2012) and it has been shown that this type of wastes can be used to replace the 90% of the quantity of material brick making (the remaining 10% is compensated with the use of cement).

Even the agriculture sector can provide useful waste for the production of bricks mixture: rice straw (Kung-Yuh et al., 2009) can be used in the production of bricks helping to reduce the thermal conductivity of brick. Other studies have highlighted possible mixtures to be obtained by adding expanded polystyrene (Ling and Teo, 2011) or sand (Lertsatitthanakorn et al., 2009). Similarly, to the above-described experiences, it is possible to trace significant proposals within projects financed at Community level from the Life programme. A study conducted in Spain (LIFE, 2005) showed that the

sludge from wastewater treatment can become a good component for mixture of bricks and quantifies the percentage between 1 and 2.5% of the total weight. The proposed production system also promotes a significant reduction of energy consumption, because, the sludge does not require treatments, the combustion for the firing of bricks, frees them from all organic substances that could cause problems. Another very interesting project Life (LIFE, 2008) that is working on the reduction of energy consumption in manufacturing phase has been developed in Germany. In this case the waste types treated as secondary raw material are the sawmill sludge from stone sector, which allow a reduction in firing temperature and therefore a considerable gain in terms of energy consumption and emissions.

Reported cases give the idea of the multiplicity of initiatives that can be activated within the supply chain of brick manufacturing, and it is possible to point out how scrap materials and waste - coming from areas completely unrelated to the supply chain of brick and more generally to the construction sector - can become valuable resources for the production of excellent quality products (this study is part of a research developed in the context of the valorization of pre-consumer waste financed by the Fondazione Fratelli Confalonieri di Milano). All these falls within the Community directives on environmental sustainability and represents an evolution of the productions toward increasingly sustainable production systems.

3. Case studies

3.1. Catalyst case study

Based on the assumptions made, a case study has been selected that has been able to tackle different environmental aspects, leading to production of different types of bricks. The bricks have the added value of being produced almost entirely with secondary raw material and they are manufactured using a production system with a reduced environmental impact.

The case study of this company has been selected because it has received several mentions, including that of the European Union in the framework of eco-innovation proposals suitable for the Horizon2020 projects and that of the 2016 SAIE (an important Italian event related to the construction sector) that reward the processes that leads to the zero impact.

The Catalyst company has developed two types of bricks very innovative for their characteristics, the first type is the "Carrara-block ®" the second one is the "Ri-block ®". The first type of brick, "Carrara-block ®" is very interesting because it combines and solves two very important environmental issues: the first one is linked to the large quantity of waste deriving from the extraction of marble throughout the territory (the Catalyst company works in the Apuan district, a territory characterized by the presence of the

marble quarries and the enormous environmental impact caused by the chain that goes from the extraction to the processing of stone); the second one is connected to significant reduction in energy consumption (compared to traditional bricks manufacturing) because this type of bricks is obtained by pressing and not by firing. The production system (Fig. 1) starts from taking the scraps from the marble producers (the scraps currently are stored in permanent landfills, and although some quantities are retrieved, it's never an up-cycling processes); scraps are transported in machining centers where they are crushed, screened and chemically tested; than they are mixed with binder elements (white cement and water in very small quantities) and finally are compacted with high compression presses. After a period of curing, the product is ready to use.

From an environmental perspective the benefits associated with this type of bricks are:

- *Control of the use of natural resources.* The brick is made using almost completely recycled material (75% recycled deriving from the waste of local companies related to the extraction/processing of stone and 25% cement binder).

- *Reduction of impacts generated by the waste deriving from stone sector.* With a production and a systematic use of this brick, Apuan territory may benefit from the decrease of waste production (the waste became secondary raw material) and especially could reduce the growth of landfills. If we refer to the quantities of material extracted (over 3 million tons according to Massa-Carrara ISR data) and to the quantity of waste material (variable percentage from 35 to 75%), it evident that at present the environmental impact linked to the lithic sector is decidedly too high. The marble, the main product of the stone sector, increases its ecological footprint by almost three times, because it assume in its global cost what is necessary to manage and/or dispose waste (Table 1).

- *Reduction of emissions.* The production of "Carrara-block®" doesn't include combustion or firing, so in terms of issue, it impacts less in percentage than the traditional brick manufacturing.

- *Improved performance.* The brick product, not being subject to shrink, can be laid with a reduced use of adhesives and mortars (reducing the consumption of raw materials), also less use of bedding mortar provides greater resistance of masonry.

- *Recyclability.* At the end of the lifecycle of the building, "Carrara-block®" is 100% recyclable, because it can be crushed and re-manufactured again.

The second type of product is the "Ri-block®", that is produced from construction and demolition waste and is able to manage two environmental issues: the first one is related to the management of C&D waste (discussed in section 2.1) and the second, as in the case of "Carrara-block®", is connected to the avoidance of significant energy consumption required for traditional bricks firing, because this type of brick is obtained by pressing and not by firing. The manufacturing system (Fig. 2) proceeds by taking the C&D waste from yards and/or construction and demolition waste storage sites, carries it in machining centers where it is crushed, screened and chemical tested, then is mixed with binder elements (cement and water in very small quantities) and finally is compacted with high compression presses.

An interesting aspect of this brick is that its manufacturing can be realized directly on site, because the presses (Fig. 3) are transportable. This aspect makes the material very interesting because it can contribute to the almost total decrease of the impacts related to transportation (raw materials first and finished products at the end). This production system can be extremely efficient even to deal with emergencies related to natural disasters such as earthquakes.

Referring the attention to one of the latest earthquakes that occurred in Italy, it can be estimated that for each 100 tons (about half the quantity of material that may constitute an apartment) disposed of into the nearest storage site, it is released into the atmosphere 1 ton of CO_{2eq}, it should be noted that government sources affirm that the total rubbles are almost 2,500 million tons.

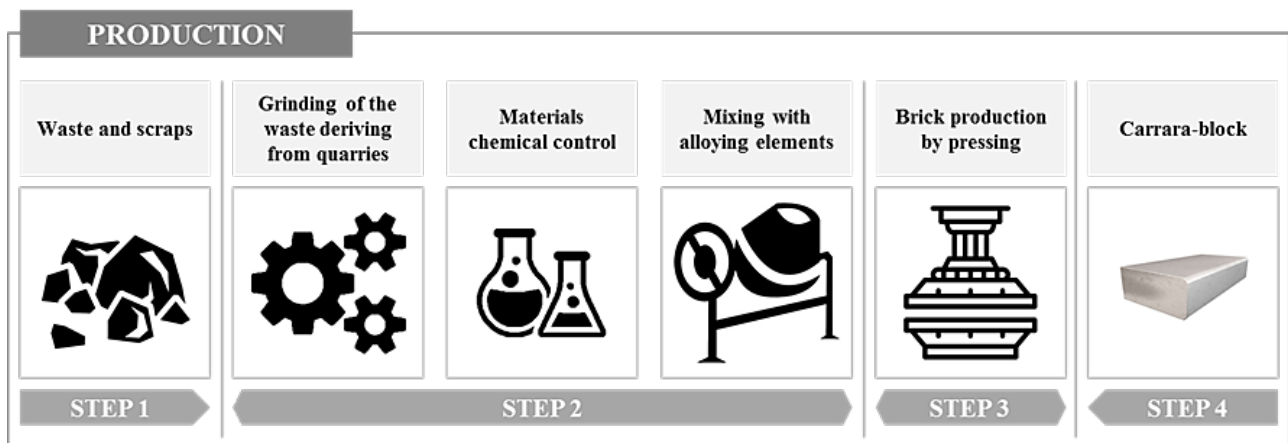


Fig. 1. Production of the "Carrara-block®"

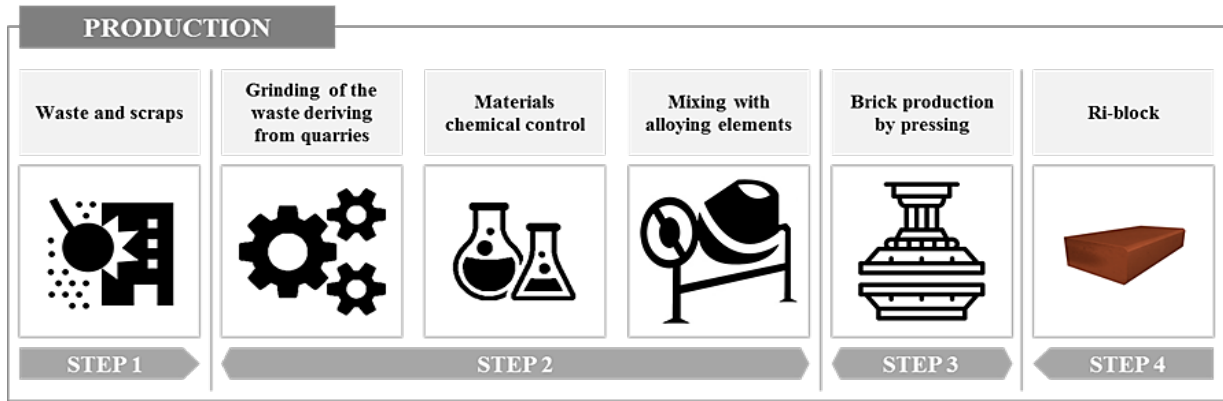


Fig. 2. Production of the “Ri-block®”

Table 1. Comparison between impact generated from transport and disposal of waste and forecast scenarios (Data from Sima Pro 8.3 and Ecoinvent 3.3)

	[u.m]	[f.u.] Iton	Impact allocation (forecast scenarios)					
			0% recycled *		30% recycled **		50% recycled ***	
TRANSPORT	kgCO ₂ eq	0.158	0.158 kgCO ₂ eq	0%	0.110 kgCO ₂ eq	-30%	0.079 kgCO ₂ eq	-50%
	MJ eq	0.027	0.027 MJ eq	0%	0.018 MJ eq	-30%	0.013 MJ eq	-50%
LANDFILL	kgCO ₂ eq	5.073	5.073 kgCO ₂ eq	0%	3.551 kgCO ₂ eq	-30%	2.536 kgCO ₂ eq	-50%
	MJ eq	0.166	0.166 MJ eq	0%	0.116 MJ eq	-30%	0.083 MJ eq	-50%

Note: * this scenario describes the current situation in which 100% of the impacts are allocated to the only product; ** this scenario describes the possibility to recycle 30% of waste and to be able to relocate with mass criterion the impacts generated by transport and landfill on a bigger quantity of products; *** this scenario describes the possibility to recycle 50% of waste and to be able to relocate with mass criterion the impacts generated by transport and landfill on a bigger quantity of products.

From an environmental perspective the benefits associated with this type of bricks manufacturing are:

- *Control of the use of natural resources.* The brick is made using almost entirely waste material deriving from construction and demolition and can be produced and used directly on site. An interesting aspect that emerges is the ability to use the press directly in areas affected by the earthquake, avoiding the high costs of disposal of rubble and the cost and the impacts deriving from the transport (Table 2).

- *Reduce of the impacts generated by the construction sector.* With a production and a systematic use of “Ri-block®”, the incidence of generated impacts by construction and demolition waste would decline significantly. The entire construction sector would benefit and landfills would be resized.

- *Reduction of emissions.* The production of “Ri-block®” doesn't include combustion or firing, so in terms of issue, it impacts less than the traditional brick manufacturing.

- *Improved performance.* The brick product, not being subject to shrink can be laid with a reduced use of adhesives and mortars (less raw materials), also reduced use of bedding mortar provides greater resistance of masonry.

- *Recyclability.* At the end of the lifecycle of the building, “Ri-block®” is 100% recyclable, because can be crushed and re-product again.

The last three characteristics are identical for the two products, because they have the same

production process. Another aspect that should not be overlooked is that both bricks examined in this study, despite the presence of recycled and the type of production process, can be considered of excellent quality from the performance point of view. Table 3 shows the values related to the specific performance of Catalyst bricks compared with bricks with similar characteristics and emerged that in no case the bricks with recycled content is lower.

3.2. Building product and CAM (minimum environmental criteria) in Italy

The bricks produced by Catalyst are just one of the initiatives undertaken at EU and globally level to promote virtuous cycles and examples of circular economy, also because it agrees with what is expressed within the CAM (Environmental Minimum Criteria) launched by the Italian Government (Ministry of the Environment, 2017). The CAM's are environmental requirements defined for the various phases of the purchasing process in the general framework of GPP “Green Public Procurement”, in order to identify the best products, design solutions or services from an environmental point of view along the life cycle, taking into account the availability of market.

The CAM's are defined in the scope of the provisions of the Plan for Sustainability in consumption in the field of public administration and shall be adopted by Decree of the Minister of the Environment, Land and Sea Protection.






Fig. 3. High compression press used for the production of the “Ri-block®”

Table 2. Impact generated from transport and disposal of C&D waste that can be avoided with a system of recycling like the one proposed by the Catalyst

	[u.m]	[f.u.] 1 ton	Quantity [ton]	Distance [km]	Total impact 0% recycled *
TRANSPORT	KgCO ₂ eq	0.158	2.500.000 t	30 km	11.850.000 KgCO ₂ eq
	MJ eq	0.027	2.500.000 t	30 km	2.025.000,00 MJ eq
LANDFILL	KgCO ₂ eq	5.073	2.500.000 t	-	12.682.500 KgCO ₂ eq
	MJ eq	0.166	2.500.000 t	-	415.000 MJ eq

Note: * this scenario describes the current situation

Table 3. Comparison between typical bricks and bricks made with recycled material

				
		medium bricks	Carrara-block®	Ri-block®
STRUCTURAL CHARACTERISTICS		*	**	**
Average Compressive Strength	N/mm ²	46.80	48.76	52.10
Water absorption	%	8.5	3.3	6.6
THERMAL CHARACTERISTICS				
Thermal resistance	m ² K/W	0.32	0.072	0.081
Thermal conductivity	W/mK	0.72	0.76	0.62

Note: * data from comparison with similar products; ** data from Laboratorio Sigma s.r.l. (RINA Iso 9001/2008)

Their systematic and uniform application, allows to disseminate environmental technologies and environmentally preferable products, and produces a leverage effect on the market, causing virtuous economic operators to adapt to the new requirements of public administration. In Italy, the effectiveness of CAM's was secured thanks to art. 18 of l. 221/2015 and, later, in art. 34 on “Energy and Environmental Sustainability Criteria” of Legislative Decree 56 (2016) (in Italian).

This requirement ensures that national public procurement policy is effective not only with the aim of reducing environmental impacts, but with the objective of promoting more sustainable and circular models of production and consumption and in

spreading the “green” jobs. In addition to the enhancement of environmental quality and respect for social policy, the application of the Minimum Environmental Criteria also responds to the need of the public administration to rationalize their consumption and reduce, where possible, the expenses.

Referring to the attention to the construction industry for Public Administrations (as featured in the “National Action Plans on Green Public Procurement (PANGPP)” released in November 2017) is required the use of products with recycled content of at least 30% of the total of its weight; it also provides that waste (non-hazardous) resulting from construction and demolition waste must be recycled or reused for at

least 70% by 2020 (Ministry of the Environment, 2017). This is an important signal intended to sensitize companies to innovate in a sustainable manner and to take into account the value of scraps/waste as secondary raw material.

4. Conclusions

The aim of the paper was to highlight the actual weaknesses of sustainability management practices within the construction industry which could be improved by starting with small initiatives that, if conducted in a systematic manner and on a global scale, could lead to radical changes. As reported by several sources the construction sector is responsible for 37% of the whole of the waste produced in the Europe Community and efforts to reduce these impacts would lead to perceptible improvements, both at the local scale (production of waste landfills, etc.) and at the global scale (emissions etc.).

The presented experiences want to give an idea of what is now ongoing to face the environmental issues with the objective to highlight that the waste cannot be seen only as a problem but we should look at these as to new resources to compensate the fact that natural resources are declining at a planetary scale. The selected case study is fully in line with the theme of sustainability, because is able to address several aspects that can promote environmental improvements (reduction of waste and their enhancement, product and process innovation, etc.); but especially wants to demonstrate that also and especially in a small scale, it is possible to activate virtuous processes that, if well managed can lead to excellent results (the data deriving from the environmental assessments on the induced impacts demonstrate what has just been said).

Specifically, considered the Apuan industrial district, the inclusion of the Catalyst, in the stone sector supply chain, brings benefits not only to the territory (other destination of waste and consequent valorization), but also to the stone sector that could become more environmentally sustainable if all waste products would be classified as by-products of processing and therefore not as a problem but as an additional resource.

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