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Characteristics of Waste Generated in Dimension Stone Processing

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Abstract: Natural dimension stone processing generates large volumes of stone waste, which have a significant impact on the environment, as well as on the efficiency and profitability of the stone-processing plant. The article presents the characteristics of waste produced as a result of natural dimension stone processing and the structure of the waste production process. Solid stone scraps and sludge were distinguished. On the basis of the performed analyses, it was shown that stone waste constitutes 10–35% in relation to the quantity of the processed stone material, with the quantity of sludge being even threefold greater than the volume of solid scraps. According to the circular economy principles, the aim should be to reduce the amount of waste generated by reducing primary resources in favour of secondary material. Reducing the volume of stone waste is possible through rational planning of stone production while at the same time maximising the efficiency of stone material usage and introducing the most modern processing machines. This significant volume of stone waste encourages efforts to find solutions for both its management and reduction. This paper reviews the utility potential of stone waste. Sensible use of waste is important to increase the profitability and productivity of processing plants while incentivising environmental protection.

Keywords: stone waste; waste generation; waste recycling; industrial waste treatment; sustainable manufacturing; dimension natural stone processing

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1. Introduction

Natural stone owes its popularity to its availability, performance, and decorative qualities. An accelerating trend towards the use of natural stone is also related to a wide variety of stones which may serve various purposes, for example, for use in window sills, work surfaces, cladding, or floor tiles. As a natural material, stone has unique physical and mechanical properties, and therefore, it is widely appreciated in construction. Some construction products made of natural stone and their parameters are standardised, e.g., in EN 1341 or EN 1469 [1]. The growing interest in natural stone entails increased production, which requires a number of processing machines and tools. It is important to select and use stone-processing machinery which would be adjusted to the manufacturing of particular natural stone products having defined properties and parameters of a final element.

Stones are processed with various devices, which give them proper shape and dimensions, as well as surface texture. Natural stone processing technology comprises a number of actions aimed at delivering stone products for various applications. However, apart from practical products, stone processing generates significant quantities of stone waste. This waste, as well as its efficient management, represents a great environmental problem in many countries [2–7]. The volume of generated stone waste largely depends on the amount of the processed material (and the efficiency of the processing plant), on the type and size of the generated waste, the type and geological properties of the stone, the type of machinery used for stone processing [4], as well as on the applied technology of dimension natural stone processing, the degree to which the block of stone is used in order to produce the final product and the needs of the clients. In order to identify its potential applications, it is important to identify the volume of stone waste generated, as well as its character [7]. However, this task is sometimes difficult, particularly when different types of natural stone are supplied to processing plants.

Issues related to stone waste have already been discussed in the literature [2,4,7]. However, these works discuss the problem from a general perspective or with specific examples and do not directly indicate to what extent the volume of generated stone waste depends on the technology used and type of waste. Meanwhile, it is important to know and understand the production processes of natural stone products, which, consequently, lead to the generation of different types of stone waste. Knowledge of the share of such waste in the total volume of processed stone material indicates the scale of the problem and the need to find a method of reusing it. This article characterises the process of generating stone wastes and indicates their types and quantities, as well as their potential application.

2. Stone Wastes as a by-Product of Natural Dimension Stone Processing

2.1. Definition of Stone Wastes

Waste is generated in any company and should be understood as any substance or object which its owner disposes of, intends to dispose of, or is obliged to dispose of [8]. Depending on the specific nature of a company, the type and volume of waste differ. According to the European Parliament and European Commission Directive 2008/98/EC of 19 November 2008 on waste [8], each economic entity is obliged to have an adequate waste management policy. Economic activity should result in a possibly limited waste generation. If this is impossible, waste should be recovered, then recycled, or if no other option is available, stored in dedicated sites. Stone wastes that are recovered and reused should be understood as scraps.

Mining wastes are a characteristic type of waste. They comprise by-products generated during the exploration and mining stages, as well as in physical and chemical processing and treatment of minerals. Careddu [2], Kaźmierczak et al. [5,9], Yurdakul [7], Tayebi-Khorami et al. [10], and Woźniak and Pactwa [11] note that these wastes pose significant problems despite their vast potential for further use. Moreover, they seem impossible to be completely eliminated. Therefore, it is important to explore different solutions to reduce and manage them [12]. A reduction in waste is possible by following the circular economy rule, which promotes a drastic reduction in primary resources in favour of secondary material flowing through internal cycles. Lèbre et al. [13] emphasise that it is unreasonable to believe that mining is becoming an unnecessary economic sector. The growing demand for mineral resources will continue to render mining processes indispensable. However, proper management of Earth's resources and adoption of the circular economy rule is the basis for reducing the amount of waste generated in mineral mining and processing.

Stone wastes generated as a result of natural stone processing in stonemasonry companies represent a special type of mining waste. Stone wastes are typically large and medium-size fragments, as well as small parts of stone produced in stone processing, or ready stone products which do not meet the quality standards. According to the European Commission Decision of 18 December 2014 amending Decision 2000/532/EC on waste registers in accordance with European Parliament and EC Directive 2008/98/EC [14], wastes generated in natural stone processing are classified as wastes from stone cutting and sawing (code 01 04 13). Importantly, these wastes are not classified as dangerous wastes.

The waste from natural dimension stone processing becomes a serious problem because the amount of waste generated reaches enormous volumes, which makes it practically impossible to neutralise this waste properly [15]. Additionally, the stone processing technologies and types of stone products make it difficult to limit the volume of waste produced in stonemasonry companies. Production may be more effective and economic and may result in a smaller quantity of waste, if some part of the waste is reused into other stone products or if stones are processed with the use of innovative technologies. However, the most significant reductions in natural stone wastes may be achieved through proper organisation of the processing plants and increased awareness of the management staff [6].

Mitchell et al. [16] and Shamrai et al. [17] observe numerous benefits of rational stone waste management, the most significant of which are the potential revenue from the sale of stone waste, thus becoming an additional income for the company, and also a rational use of natural resources. The benefits also include a decreased amount of material lost in extraction and processing, lower costs of waste storage, transportation, and disposal, as well as increased social responsibility of the company.

2.2. Structure of Stone Waste Production in Processing Plants

Stonemasonry companies process natural stone supplied in the form of raw blocks or pre-processed elements requiring further treatment. The fundamental stage in producing a stone element is its processing, which consists of cutting, milling, or providing the desired texture to its surface. Usually, various types of stone (e.g., granite, sandstone, marble, limestone, etc.) are processed in stonemasonry companies, and various stone products are manufactured. Much less often, stonemasonry companies specialise in the manufacturing of one product (serial production) or in processing one type of natural stone. Stonemasonry companies that process one type of stone most often are plants located near mines extracting this particular stone type.

Except for the finished stone product, the processing of natural dimension stone results in solid scraps (Figure 1a) and sludge (Figure 1b). Depending on the particular process, technology involved and type of natural stone (e.g., granite, sandstone), the size and type of waste are different (Figure 2).

(**a**) (**b**)

Figure 1. Stone waste: (**a**) crushed slabs (different waste size); (**b**) sludge.

Solid scraps are produced in the process of cutting off larger parts of natural stone or giving the texture of stone surfaces without the use of water. Solid scraps have various sizes, from a few millimetres to several hundred centimetres [4]. The most common type of solid scrap includes offcuts, i.e., rough-edged stone cut off the stone block in order to achieve regular surfaces of the stone block (Figure 3). The length and width of the offcuts are usually equal to the size of the stone block being worked on (e.g., 2.5 × 1.5 m). However, the thickness of this waste is from several to several dozen cm. It should be noted that the sizes of these scraps depend on the quality of the processed stone block (regular and equal shape of the stone block), which is influenced by the adopted mining technology. Therefore, a properly selected dimension stone mining technology may significantly reduce the size of the produced stone waste.

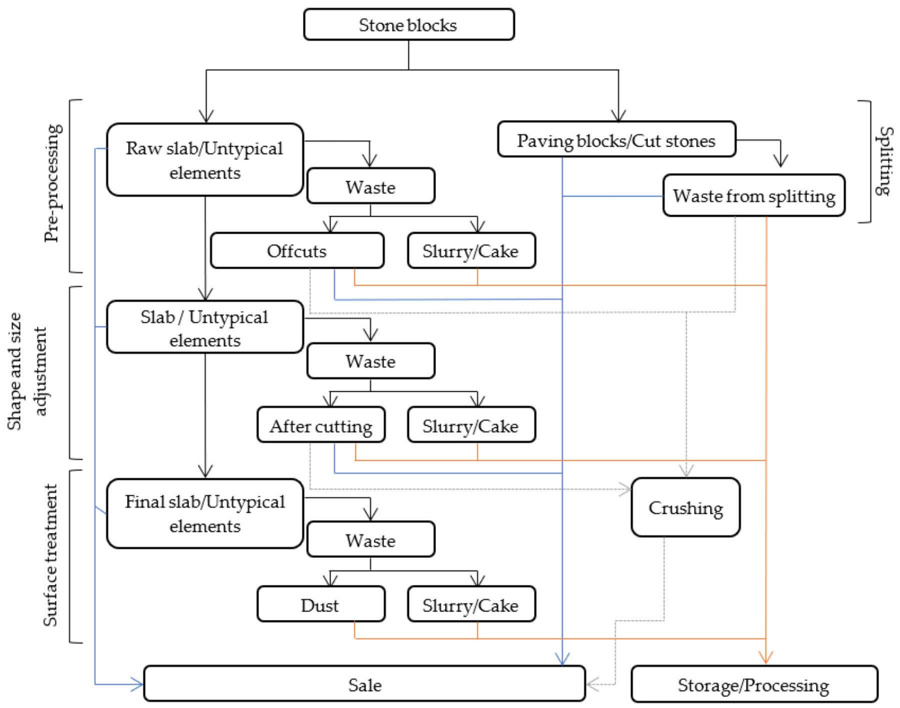

Figure 2. General diagram representing waste production in the processing of natural stone.

Figure 3. Offcuts (2.5 m long, 1.5 m wide, 0–0.1 m thick).

Depending on the pre-processing technology employed, a valvestone can be formed in this process. Valvestone is the lower part of the cut stone block that remains in the block cutting machines for safety reasons. The size of this type of scrap is similar to the size of the offcuts.

Other scraps include stone fragments cut or split (in the process of giving the stone element its desired size and shape, and when split stone elements are produced) or dust, generated as a result of texturising the stone by an impact action (e.g., pointing, chiselling) or by flame treatment. The dimensions of scraps produced after cutting or splitting are from several to several dozen centimetres, while dust waste is usually up to 1 mm.

Stone sludge is produced by using water as a medium for cooling and removing fine stone particles from underneath the processing tool. They are a mixture of ground rock mass with water and may additionally contain some small quantities of abrasive material (particles of the synthetic diamond). The majority of grains in sludge are smaller than 100 µm and rarely larger than 150 µm [4]. Importantly, stone sludge represents the greatest volume of processing-related wastes. While the volume of solid scraps may be reduced by rational stone material handling, a reduction in the volume of sludge is difficult without alternating the employed stone-processing technology.

The above-mentioned wastes are accompanied by wastes from damaged stone blocks or final stone products. These include materials with inherent defects (fractures, voids, etc.) and secondary defects (e.g., defects resulting from the manufacturing process). Such materials are frequently reprocessed or sold at discount prices. Table 1 contains a detailed characteristic of wastes generated in the processing of natural stone.

Table 1. Characteristics of waste from the processing of natural stone.

Type of Waste	Definition of Waste	Description of Waste Source
	SOLID STONE SCRAPS	
Damaged stone blocks	Stone blocks that have significant defects or have been damaged and are characterised by different sizes and irregular shapes.	Stone blocks that have insufficient material quality or have been damaged during transport or unsuccessfully divided into smaller parts.
Damaged final stone products	Final stone products with inherent and secondary defects.	During the processing operation, fractures or defects in the final stone products may occur (secondary defects) or primary defects are revealed.
Offcuts	The first and last slab of a stone block cut in a head saw, having one surface smooth and one surface raw/split.	Offcuts occur when a stone block with uneven surfaces is cut. The basic operation behind cutting a stone block is to approximate its shape to a cube. Offcuts are due to the technology employed in natural stone processing.
Valvestones	Lower part of the cut stone block	Waste is generated after cutting a stone block due to safety reasons and in order not to damage the cut raw slabs. This waste is generated as a result of using certain stone block cutting technologies (e.g., disc saw) and is less and less frequent.
Waste from splitting	Parts of the split material outside the size standard of the product (e.g., paving stone).	When splitting natural stone into smaller-size elements (e.g., in the production of paving stone), oversize rock parts of the desired element are split off.
Waste from cutting	Parts of rock material which are smaller in volume than offcuts and have a minimum of 3 smooth surfaces.	Waste is produced as part of the size and shape adjustment. Rock material is produced as a result of cutting off the oversize parts of natural stone. The quantity of this waste depends on the volume of the cutoff stone parts and on the planned cutting locations.
Dust	Fine fraction rock and abrasive material.	As stone is processed, fine fractions of rock material and spalls are split/chipped off the rock. In addition, depending on the surface treatment technology used, this type of waste may include abrasive material (e.g., sand being the product of sandblasting).
	STONE SLUDGE	
Slurry/Cake	A mixture of water, ground fine rock, and particles of the cutting tool.	This type of waste is generated at each stage of stone processing. Stone is abraded by the processing elements and subsequently mixed with water. This type of waste additionally comprises small amounts of particles from the working tools.

2.3. Analysis of Stone Waste Production

Analysing the volume and type of the produced stone materials is an important parameter in selecting proper machinery for a processing plant, as well as the basis for the adoption of a production management strategy with a view to reducing the volume of waste produced. The machinery is selected on the basis of numerous other factors, the most important of which is the type of stone products. Table 2 shows types of processed natural stone, types of stone products, and machinery used in 10 plants in which the scale and type of processing-related stone waste were analysed. The plants process various types of rocks (granites, sandstones, marbles, etc.) and produce various elements (stone slabs, paving blocks, untypical and formed elements, etc.).

The volumes of natural stone waste produced in stonemasonry companies vary. Table 3 shows the analysis of the volume and type of stone wastes (scraps). The volume of stone wastes (scraps) was analysed based on data obtained from processing plants on the flow of semi-finished products in the individual stages of stone processing, as well as on the author's own observations. The volume of stone wastes generated at individual stages was estimated from the differences in the volume of stone elements before and after the processing stage. The same basis was used to identify the masses of processed stone and semi-finished products. The volume and mass of sludge were determined from measurements (weighing) conducted by the processing plants. The volume of solid stone scraps was calculated from the difference in initial weight and volume of processed dimension natural stone, finished stone products, and sludge.

The analyses demonstrated that the volumes of stone wastes (scraps) are between 10% and 35% in relation to the quantity of the processed stone material. Interestingly, the greatest volume of waste is produced at the pre-processing stage. This phenomenon is related to the greatest amount of work involved and to the amount of processed natural stone, as well as to the type of machinery employed. In the complete stone processing cycle, the volume of sludge is in all analysed plants more than the volume of solid wastes (solid scraps) (up to three times more). Solid wastes (solid scraps) are generated in the pre-processing and, to a lower extent, in the shape and size adjustment processes. They are characterised by larger fragments of natural stone, which can be processed again, thus significantly reducing the volume of stone waste produced. Stone sludge is a much more significant problem because it is a fine material and cannot be reprocessed. Therefore, it is necessary to use it in other industrial sectors.

Table 2. Types of stone products and machinery used in plants in which the scale and type of stone waste were analysed.

	Processing Plant 1	Processing Plant 2	Processing Plant 3	Processing Plant 4	Processing Plant 5	Processing Plant 6	Processing Plant 7	Processing Plant 8	Processing Plant 9	Processing Plant 10
Type of natural stone	granite, limestone, marble	granite, marble	granite, sandstone	granite, gneiss, marble, sandstone, limestone, onyx	sandstone	granite	sandstone, limestone, marble	granite, sandstone, limestone, marble	sandstone	granite, sandstone
Production	cladding slabs, stairs, window sills, paving blocks	raw slabs stairs, window sills, paving blocks, curbs	cladding slabs, stairs, window sills, curbs	raw slabs	raw slabs, cladding slabs, formed elements, untypical elements	raw slabs, paving blocks, curbs	raw slabs, cladding slabs, stairs, window sills, formed elements	raw slabs, cladding slabs, stairs, window sills, formed elements, curbs	raw slabs, cladding slabs, formed elements	raw slabs
Pre-processing	gang saw, disc saw, multi-wire diamond saw	gang saw, disc saw	gang saw	multi-wire diamond saw	gang saw	gang saw, multi-wire diamond saw, stone splitting machine	gang saw, multi-wire diamond saw	gang saw, multi-wire diamond saw	multi-wire diamond saw	gang saw
Shape and size adjustment	table saw	table saw	table saw	-	table saw	-	table saw	table saw	table saw	-
Surface treatment	abrasive-polishing line, side grinder, thermal burner, graining machine, sandblaster	abrasive-polishing line, side grinder, thermal burner	abrasive-polishing line, side grinder, graining machine, sandblaster	abrasive-polishing line, thermal burner	abrasive-polishing line	-	abrasive-polishing line	abrasive-polishing line, graining machine	abrasive-polishing line	abrasive-polishing line, sandblaster

Table 3. Average volume of stone waste produced per month in each of the processing stages.

		Processing Plant 1			**Processing Plant 2**			**Processing Plant 3**			**Processing Plant 4**			**Processing Plant 5**		
Quantity of rock material to be processed, m^3		268.00			244.88			175.25			291.67			179.79		
		Quantity of stone waste		Loss of stone material	Quantity of stone waste		Loss of stone material	Quantity of stone waste		Loss of stone material	Quantity of stone waste		Loss of stone material	Quantity of stone waste		Loss of stone material
		m^3	Mg	%	m^3	Mg	%	m^3	Mg	%	m^3	Mg	%	m^3	Mg	%
Pre-processing	Stone sludge *	22.35	211.50	8.34	19.15	181.72	7.82	38.51	182.00	21.98	42.00	112.14	14.40	8.55	23.00	4.76
	Solid stone scraps	8.45	82.30	3.15	8.76	71.18	3.58	14.39	68.00	8.21	16.80	44.86	5.76	9.18	24.70	5.11
Shape and size adjustment	Stone sludge *	1.91	6.00	0.71	0.08	0.30	0.03	1.54	5.00	0.88	-	-	0.00	1.49	4.00	0.83
	Solid stone scraps	5.09	16.00	1.90	0.42	1.50	0.17	2.46	8.00	1.40	-	-	0.00	3.79	10.20	2.11
Surface treatment	Stone sludge *	5.10	15.60	1.90	0.60	10.70	0.25	4.10	17.20	2.34	18.90	50.46	6.48	2.96	8.50	1.65
	Solid stone scraps	2.80	11.40	1.04	0.70	11.00	0.29	1.10	10.60	0.63	2.10	5.61	0.72	-	-	0.00
Total	**Stone sludge ***	**29.36**	**233.10**	**10.96**	**19.83**	**192.72**	**8.10**	**44.15**	**204.20**	**25.19**	**60.90**	**162.60**	**20.88**	**13.00**	**35.50**	**7.23**
	Solid stone scraps	**16.34**	**109.70**	**6.10**	**9.88**	**83.68**	**4.03**	**17.95**	**86.60**	**10.24**	**18.90**	**50.46**	**6.48**	**12.97**	**34.90**	**7.22**
	Total volume	**45.70**	**342.80**	**17.06**	**29.71**	**276.40**	**12.13**	**62.10**	**290.80**	**35.43**	**79.80**	**213.06**	**27.36**	**25.97**	**70.40**	**14.45**
		Processing plant 6			Processing plant 7			Processing plant 8			Processing plant 9			Processing plant 10		
Quantity of rock material to be processed, m^3		330.00			259.75			360.00			86.48			250.60		
		Quantity of stone waste		Loss of stone material	Quantity of stone waste		Loss of stone material	Quantity of stone waste		Loss of stone material	Quantity of stone waste		Loss of stone material	Quantity of stone waste		Loss of stone material
		m^3	Mg	%	m^3	Mg	%	m^3	Mg	%	m^3	Mg	%	m^3	Mg	%
Pre-processing	Stone sludge *	18.74	51.54	5.68	28.71	73.21	11.05	41.49	112.02	11.53	5.79	15.63	6.70	15.82	43.82	6.31
	Solid stone scraps	18.70	51.43	5.67	16.34	41.67	6.29	21.44	57.89	5.96	3.10	8.37	3.58	8.50	23.55	3.39
Shape and size adjustment	Stone sludge *	-	-	0.00	2.12	5.41	0.82	5.67	15.31	1.58	2.70	7.29	3.12	-	-	0.00
	Solid stone scraps	-	-	0.00	5.40	13.77	2.08	7.60	20.52	2.11	3.44	9.29	3.98	-	-	0.00
Surface treatment	Stone sludge *	-	-	0.00	4.59	11.70	1.77	8.01	21.62	2.22	2.90	7.84	3.36	9.33	25.86	3.72
	Solid stone scraps	-	-	0.00	-	-	0.00	1.33	3.60	0.37	-	-	0.00	0.57	1.57	0.23
Total	**Stone sludge ***	**18.74**	**51.54**	**5.68**	**35.42**	**90.32**	**13.64**	**55.17**	**148.95**	**15.32**	**11.39**	**30.77**	**13.18**	**25.15**	**69.68**	**10.04**
	Solid stone scraps	**18.70**	**51.43**	**5.67**	**21.74**	**55.44**	**8.37**	**30.37**	**82.01**	**8.44**	**6.54**	**17.66**	**7.56**	**9.07**	**25.11**	**3.62**
	Total volume	**37.44**	**102.97**	**11.35**	**57.16**	**145.76**	**22.01**	**85.54**	**230.97**	**23.76**	**17.93**	**48.42**	**20.74**	**34.22**	**94.79**	**13.66**

* The volume of stone sludge was determined on the basis of the dried volume of hydrated grated stone material.

3. The Use of Waste from the Processing of Natural Stone

Natural stone wastes from stonemasonry plants constitute a substantial part of all waste produced there and are a significant environmental problem, as they are not biodegradable [18]. The efficient production management in processing plants and the resulting rational stone waste management require the planning and designing of stone elements to be performed in such a way that the processed material is fully used as various stone products. It is also important to introduce technical solutions to reduce waste. Such an approach will affect a reduction in stone scrap production. Still, the generated stone scraps should continue to be properly processed. Although reusing waste is socially and environmentally important, it should also be economically profitable and technically feasible [16].

Generally, stone wastes from processing plants are environmentally neutral. However, according to Simsek et al. [19], Rizzo et al. [20], Nasserdine et al. [21], and Luodes et al. [22], they may also have a negative environmental impact. Therefore, the European Parliament and EC Directive 2008/98/EC of 19 November 2008 on waste [8] encourages other applications of stone wastes. Although stone wastes are generally stored in waste disposal facilities or in post-mining excavations, the literature on the subject mentions numerous proposals for their application (Table 4).

Table 4. Literature research on the possibilities of application of stone scraps.

Application of Stone Scrap	Type of Stone Scrap	Material	References
Building materials (mortar/concrete/brick)	powder/fine aggregate	granite	[23–33]
		marble	[34–55]
		limestone	[56–61]
	powder/fine aggregate	basalt	[62–65]
	coarse/fine aggregate	sandstone	[66–71]
	powder	mix/unidentified	[72–77]
Ceramic materials	fine grained waste/powder	granite	[78–80]
		marble	[81–85]
	powder	gneiss	[86–88]
		serpentinite	[89,90]
		mix/unidentified	[91,92]
Stabilised clay soil	powder	marble	[93]
		limestone	[94–97]
		mix/unidentified	[98,99]
Fertilisation	unidentified	marble	[100]
		basalt	[101,102]
	powder	gneiss	[103–106]
Various composite materials	powder	granite	[107]
		marble	[108–111]
		sandstone	[112]
		basalt	[113,114]
Other applications	powder	granite	[115]
		marble	[116–119]

In processing plants, various types and volumes of natural stone (e.g., granite, sandstone, limestone, marble) are often processed, which indicates the variety of stone waste and the different physical and chemical properties of these materials. The literature has repeatedly described both the possibilities of using stone scrap for the production of construction materials and their physicomechanical parameters. The largest number of studies showing the possibilities of using stone waste concerns granite and marble because of their widespread use in architecture and civil engineering. In addition, the largest number of studies were related to the use of stone powder.

The analysis of the literature on the subject indicates the possibilities of using stone scrap in the construction industry, which is concerned with the selection of various mixtures with the use of stone waste (most often from the processing of granite and marble) to produce mortar, concrete, or bricks. These works reveal that the use of up to 35% of the volume of stone waste material for the production of Portland cement does not affect the quality parameters of this product [26]. Ghannam et al. [24] and Prošek et al. [46] indicate that using stone waste can increase the strength parameters of concrete. Additionally, the use of fine stone waste can be a good solution for the production of ceramic products. Luiz et al. [92] and Munir et al. [83,84] emphasise that the inclusion of 15% of ornamental stone waste in the production of ceramic products does not affect the properties of these products.

Saygili [93], Ibrahim et al. [94], Ogila [95], Pastor et al. [96], Sabat and Muni [97], Igwe and Adepehin [98], and Sivrikaya et al. [99] have shown that the application of stone scrap to stabilise clay soils is beneficial and, at the same time, improves geotechnical properties and reduces soil swelling. The use of fine rock material for fertiliser production, used in agriculture, as well as in the reclamation process, can have a positive impact on the growth of vegetation and improve soil properties [100,102–105].

Stone scraps can also be used to produce various composite materials. Karimi et al. [107] propose to use granite waste for the production of ecological stone composite based on acrylonitrile–butadiene–styrene (ABS), while Conde-Vázquez et al. [112] indicate the possibility of using sandstone waste for the production of artificial arenite using cement polymerisation. Kurańska et al. [113] point to the possibility of applying stone waste to the production of highly efficient porous polyurethane composites. Basalt waste can also be used as admixtures for gypsum composites [114]. The use of fine marble waste is possible to produce various other composite materials: geopolymer hybrid composite materials [108,111], composite materials with the structure of unsaturated polyester [110], or composite materials produced from waste PET [109].

Other applications of stone scrap do not represent a large-scale use. However, more research should be conducted into the possibilities of their usefulness. Alves et al. [115] point to the use of granite waste for rock wool production. Agrawal et al. [116], Marras, and Careddu [117] propose to use marble waste in the rubber industry, whereas Özkaya et al. [119] have conducted a study on the possibility of applying waste marble powder as an adhesive filler in the manufacturing of laminated veneer lumber (LVL). Navar et al. [118] have tested the possibility of using waste marble powder as a potential alternative to current commercial calcium carbonate sorbents for capturing CO_2.

The reprocessing and reusing of stone scraps increase productivity and profitability while reducing the final production costs. In addition, it simultaneously limits the threat to the environment, reduces the number of non-biodegradable waste deposition sites, and offers alternative raw materials for various industrial activities. Table 5 shows general methods for using scraps generated in the processing of natural stone.

Table 5. Different applications of scrap from dimension natural stone processing (own work based on Shamrai et al. [17] and Shirazi [120]).

Type of Stone Scrap	Different Applications of Scrap from Dimension Natural Stone Processing
Small stone waste (including sludge)	Asphalt and concrete production Brick manufacturing Construction fill Production of synthetic aggregate Media for biofiltration systems or soil remediation Mineral content for soil Tire mixtures production
Waste in the form of aggregates	Construction fill Construction mixture ingredient For road filling For reclamation in landscaping and decorative use Media for biofiltration systems
Larger stone pieces and paving	Fill for gabion retaining walls and foundations For reclamation in landscaping and decorative use
Damaged blocks or slabs	Use as a foundation filler Production of aggregates For cutting tiles of small size Production of paving stones or tiles

4. Conclusions

Production processes should be planned to maximise resource usage and environmental protection while balancing costs. One of the cost-intensive factors in the production process is energy. Energy efficiency is an important optimisation issue and should be understood as the amount of energy used to obtain a product. This issue has been addressed in many works on mining [121,122]. In the context of natural stone processing, this issue is also important because such processes require high energy input. The generated stone waste, which generally represents a loss of raw material, also affects the number of production costs. In addition, stone wastes produced in stone processing pose significant problems, which considerably affect the environment, as well as the production efficiency and profitability.

The produced stone waste, i.e., solid scraps and sludge, comprises 10–35% of the quantity of the processed natural stone, solid scraps accounting for almost threefold greater quantities. Most of this waste is generated in the first stage of stone processing. A reduction in the quantity of stone waste is possible if the production of stone elements is rationally planned in order to use the material with maximum efficiency and if companies decide to introduce modern machinery, which is now designed with a view to reducing stone waste. In addition to the need to reduce stone scrap, it is necessary to search for its usage. The use of scrap, once its potential has been discovered, is now considered to be an activity that can contribute to product diversification, reduce final costs, and provide alternative raw materials for a variety of industrial sectors [79].

Based on the analysis conducted in the article, the following two important research areas can be identified that should be developed with a view to waste reduction or reprocessing:

- Research efforts to find or improve a technology that reduces the volume of waste produced or the development of a waste-free technology;
- Research efforts to find possibilities of stone waste application.

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