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Analysis of sustainable concrete obtained from the by-products of an industrial process and recycled aggregates from construction and demolition waste

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Abstract

The excessive exploitation of natural resources for construction is producing an extreme impact on air pollution and global warming. In response to the extreme climate changes and the lack of primary resources that social-economic systems are experiencing all over the world, international and local governments are supporting the development of the culture of sustainable manufacturing, following the principles of the circular economy. In this context, the present study supports the research on the design of sustainable and cross-industry value chains. This paper investigates the characteristics of sustainable concrete obtained from industrial waste and recycled aggregates from construction and demolition waste. The industrial waste adopted in this study is the by-product of an industrial production process. The aim was to investigate the characteristics of such a by-product as a recycled additive for sustainable concrete and to assess its eco-compatible safety performance. The results suggest that the by-products adopted in this research provide an interesting alternative to the use of primary resources, e.g. the fine sand, in the concrete mixture. However, the optimal amount of by-products depends on the characteristics of the waste material in the mixture. The eco-compatibility test was performed to investigate the leaching behavior of the proposed sustainable concrete. The present research promotes the adoption of a cross-industry and circular approach towards sustainability, showing that the use of industrial waste to produce sustainable concrete allows benefits for all the stakeholders involved in the value chain and for society.

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1. Introduction

The culture of environmental sustainability is reaching both developed and developing countries as a response of international and local governments to the extreme climate changes and to the lack of primary resources that social-economic systems are experiencing all over the world. The rising global population and the increasing lifestyle standard levels are among the main causes of the excessive exploitation of natural resources, producing an extreme impact on air pollution and global warming. However, technological progress and economic growth are possible and environmentally sustainable when the consumption of primary resources is limited. In this context, sustainable development practices support technical and economic progress with no impact on the natural resources for future generations. The use of recycled materials or renewable resources in industrial applications are examples of sustainable practices. In 2011, the European (EU) Commission estimated that the global use of primary natural resources will quadruple by 2050 [1]. The over-exploitation of natural resources is also the cause of the increased production of solid waste. The global annual production of solid waste is expected to increase by 70% in 2050, due to the increasing urbanization and population growth [2]. These data endorse the importance of finding alternative resources for sustainable development, which might be retrieved from the downstream products of the industrial processes [3]. The European Union promotes the adoption of sustainable policies for waste management and sustainable development. The European Green Deal (EGD) is a set of policy initiatives endorsed by the EU Commission to boost sustainable growth and support a circular economy-based model [4–6]. Specifically, the EGD includes the Circular Economy Action Plan (CEAP), which promotes the efficient use of natural resources and the adoption of a sustainable approach along the entire life cycle of products [7]. The targets of the CEAP are the sectors that use the most resources and where the potential for circularity is high. These sectors include electronics and Information and Communication Technologies (ICT), batteries and vehicles, and construction. The revision of the energy performance of the European Buildings Directive is among the initiatives of the EU Commission announced for the fourth quarter of 2021. Construction processes require high consumptions of energy, which result in intensive gas emissions in the atmosphere and the production of large quantities of solid waste . The high potential for circularity in the construction processes makes the building industry a critical target area of the European CEAP, i.e. circular economy-based systems promote the reuse, recovery, and recycling of waste materials in a closed-loop system which produces lower pollution and reduces carbon emissions. Almost half of the non-renewable resources used in the human economy are for building construction, infrastructure, and industrial construction. The high environmental impact of these activities and the natural resource scarcity are triggering a widespread interest of construction practitioners and international research teams on second-generation building materials. Sustainable building, also known as “green building”, supports the use of recovered or recycled materials obtained from renewable energy sources, with low environmental impact. Sustainable building practices also require construction companies to avoid the use of potentially harmful materials that may create unsafe conditions for the people or cause damage to the environment during their life cycle. However, green buildings are usually more expensive than conventional buildings, because of the additional costs due to more expensive, but also more efficient, construction systems. More research and higher knowledge on the benefits of sustainable building are necessary to increase the interest of construction stakeholders and to improve cleaner production policies in the construction industry.

Nomenclature

BPC	By-Product Contribute
BPC_x	By-Product Contribute, with x percentage of by-products in the mixture
CDW	Construction and Demolition Waste
COD	Chemical Oxygen Demand

Still, the increasing interest of the EU manufacturing industry in sustainable value chains and production processes confirms an ongoing shift in values in industry and society toward a long-term sustainable production. Synergic and holistic approaches are necessary to create such values and go beyond the limits of single industries and value chains. This paper proposes a study on the use of waste materials from different industries, i.e. industrial waste and Construction and Demolition Waste (CDW), to produce sustainable concrete for construction. Specifically, the industrial waste analyzed in this research is the by-products of an industrial process. The aim is to investigate the characteristics of such by-products as recycled additives for sustainable concrete and to assess the eco-compatibility of the proposed product. The findings in this paper support the research on the design of sustainable value chains, promoting the adoption of a cross-industry approach towards sustainability.

Circular economy systems improve the "take-make-dispose" model of industrial linear economy-based systems, building economic, natural, and social value through the transition to renewable energy sources [5]. A production system based on a circular economy model regenerates the primary resources by keeping materials and products in use, and designing waste and pollution flows out of the system. This approach allows higher productivity because products and equipment remain in the production system for longer. In a circular economy system, the by-products of primary processes, e.g. energy and production waste, become inputs to secondary processes. In 2014, the EU Commission published the European Zero Waste Program (EZWP), which includes a set of objectives for improving waste management in industrial processes and encouraging the redesign of resource life cycles so that products and materials are reused until their end-of-life [8]. It was estimated that waste reuse could satisfy from 10% to 40% of the EU demand for raw materials, leading to a 40% reduction in gas emissions by 2030. CDW is the largest waste stream in the European Union. In 2018, the EU construction industry generated about 372 million tons of CDW, corresponding to an increase of nearly 8% compared to 2016 [9]. Recent studies proposed the use of CDW as recycled aggregates for secondary applications. Road and geotechnical applications offer interesting opportunities for using recycled aggregates from CDW. Specifically, recycled aggregates with a minimum of 50% of concrete content are usually applicable for earthworks, filling, and road sub-bases [10]. In the last years, many researchers have investigated the replacement of conventional fine aggregates for concrete, with industrial waste. Some studies focused on the use of industrial waste obtained from manufacturing processes, e.g. powdered soda-lime waste glass [11], plastic waste [12], aluminum waste [13] and foundry waste [3]. However, the use of waste materials as inputs for production processes is economically attractive when production costs are lower than the cost of using primary resources, and market uptake is guaranteed. Besides the economic drivers, the quality of building materials and products is essential for the success of circular economy solutions in construction. The transition to a circular economy-based model for sustainable building saves primary resources, reduces waste production, and produces lower greenhouse gas emissions during the lifetime of construction products and processes. In this context, the present research investigates the application of a circular economy model to produce a recycled additive for sustainable concrete, obtained from the by-products of an industrial process. A by-product is a secondary product derived from a production process, in addition to the principal product. The Italian environmental legislation, i.e. the Environmental Consolidated Act, specifies the responsibilities of the producers of byproducts [14]. Specifically, producers should ensure that their by-products are adopted as inputs of secondary production processes, with no impact on public health and the environment. For this reason, the present research includes the eco-compatibility assessment for the sustainable concrete obtained from the combination of CDW and the investigated by-products.

2. Materials and methods

The industrial waste materials adopted in this study are the by-products obtained from the production processes of an Italian company leader in the production of concrete-based products for construction, such as floor stickers, fillers, pre-mixed mortars, plasters, and putties. The main production processes performed in the company production plant consist in preparing a specific mixture of primary materials and packing the final product in paper bags. The primary materials adopted in the production processes are mainly macro-components (about 85% of the final product), like cement, natural hydrated lime, calcium sulfate, calcium carbonate, and sand. The remaining 15% of the mixture consists of micro-components, such as powder resins and hydrated lime, which provide specific technical performance to the final product. The size of the particles in the by-products is between 0.06 mm and 1 mm. In this study, such by-products were combined with the recycled aggregates from CDW to produce sustainable concrete for the construction of road sub-bases. The CDW adopted in this research are recycled aggregates from crushed demolition materials, with particle sizes between 0 and 70 mm, which are destinated for disposal. Two main conditions determine the generation of the by-products of the production processes investigated in this study. The first condition refers to primary materials that do not pass the acceptance test during production processes. Such materials become by-products of the production process as they do not meet the requirements of production protocols. The second condition refers to the non-compliance of the final product with the quality control requirements. This condition occurs when the final product does not pass the company compliance testing, which is required for CE marking. The by-products in this study consist of a mixture of concrete-based powders containing Portland cement (in variable percentages between 50% and 75%) and other aggregates such as calcium carbonate, siliceous aggregates, and traces of organic substances. Table 1 shows the tons of by-products generated in the production plants of the company involved in this study.

Table 1. Amount of by-product and total industrial waste for disposal produced in the production plants of the company involved in this study, from 2010 to 2015.

	2010	2011	2012	2013	2014	2015
By-product [tons]	87	36	19	2	65	8
Total industrial waste for disposal [tons]	1675	1640	1515	1298	1509	1484
Incidence	5.2%	2.2%	1.3%	0.2%	4.3%	0.5%

The average production of by-products obtained from the company production plants is 36t per year. Sensible variations were registered from 2010 to 2015. Such variations reflect the fluctuations of the construction market. The average incidence of the by-products over the total production of industrial waste for disposal produced in the company production plants is about 2.3%. The composition of the materials in the by-products may create some hazardous inherent conditions that require further investigations, as specified in the EU Regulation 1272/2008 [15]. The hazardous component in the by-products is Chromium VI (< 0.0002%), which is present in the Portland cement. Consequently, the by-products may cause eye irritation, skin damage, allergic reactions, and respiratory hypersensitivity. However, the total amount of Chromium VI in the by-products is lower than the threshold limit value set by the EU legislation. The company collects such by-products as special waste materials destined for disposal. The sustainable concrete investigated in this study is obtained by the combination of the by-products introduced in above, with CDW materials. The by-products are adopted to complete the grading curve of the building material used in the construction of road sub-bases from CDW. The European Standard EN 13242:2013 defines the requirements for the aggregates used in civil engineering work and road construction [16]. The Standard also requires collecting the aggregates in batches, aiming to ensure the homogeneity of the materials. Each batch is tested to ensure the conformity and the eco-compatibility of the final product. The conformity test aims to verify the geometrical properties of the aggregates in the concrete. The testing modalities are in the EU Standard EN 933-1:2012 [17]. Specifically, the test consists of dividing and separating the material into several particle size classifications of decreasing sizes, using a series of sieves. The aperture sizes and the number of sieves are selected by the nature of the sample and the accuracy required. The mass of the particles retained on the various sieves is related to the initial mass of the material. The EU Standard also requires reporting the cumulative percentages passing each sieve in numerical or graphical form. The Italian legislation specifies the acceptance limits for the materials used in road sub-bases. Specifically, a percentage limit value is set for the particles retained in each sieve [18]. Such limits are in Table 2. In this study, the conformity test was performed to analyze the geometrical properties of the recycled aggregates obtained from CDW. The results permitted identifying the maximum percentage of by-products to add to the recycled aggregates in the sustainable concrete. The eco-compatibility test verified the environmental compatibility of the sustainable concrete. The aim was to assess the leaching behavior of the concrete and to ensure compliance with specific reference values. The EU Standard EN 12457-2 defines the modalities for testing the leaching of granular waste materials [19]. The leaching limit values for the hazardous components in the waste materials are in the Italian Ministerial Order n.88 of 5 February 1998 [20]. A sample of the sustainable concrete obtained from recycled aggregates and by-products was tested, aiming to ensure compliance with the leaching limit values in the EU Standard and to define the optimal amount of by-products in the sustainable concrete mixture.

Table 2. Acceptance limit values for the grain materials intended for use in road sub-bases [17,18].

Parameter	Limit for road sub-bases
Passing sieve 63 mm	100%
Passing sieve 40 mm	Not present
Passing sieve 20 mm	Not present
Passing sieve10 mm	Not present
Passing sieve 4 mm	≤ 60%
Passing sieve 2 mm	Not present
Passing sieve 1 mm	Not present
Passing sieve 0.5 mm	Not present
Passing sieve 0.063 mm	≤ 15%
Maximum diameter	63 mm
Material passing sieve 0.5 to the material passing sieve 0.063 ratio	>1.5

3. Results

The results of the conformity test are in the following Table 3 and Figure 1. Specifically, Figure 1 shows the grading curve of the recycled aggregates from CDW investigated in this study. Detailed data for the grading curve are in Table 3. The curve in Figure 1 provides a graphic description of the composition of the recycled aggregates, based on the particle size. Specifically, the points in Figure 1 refer to the diameter of the particles in the recycled aggregates (horizontal axis) and the percentage of fine material (vertical axis) retained on each sieve [17]. The mass of the sample used in the test was 9011g. The passing material at sieve 0.063 was 4.2%. The ratio of the material passing at sieve 0.5 to the material passing at sieve 0.063 was 2.2. The by-products investigated in this study would replace the fraction of medium-fine sands in the concrete , i.e. the by-product grain size is between 0.06 mm and 1 mm. The squared points in Figure 1 show the position of the by-products in the grading curve of the recycled aggregates from CDW. The cumulative weight percentage of the equivalent fraction in the recycled aggregates ranges between 4.2% (mesh sieve 0.075 mm) and 15.9% (mesh sieve 2 mm) (Table 3). Consequently, the maximum weight percentage of by-products in the sustainable concrete for road sub-bases is 11.7%. Two eco-compatibility tests (Test A, Test B) were performed on two samples (Sample A, Sample B) of sustainable concrete obtained from the combination of the by-products introduced in Section 2 with the recycled aggregates adopted in this study. Table 4 shows the characteristics of the samples adopted for testing. Percentage values refer to the weight fraction of the components in the sample. Sample A refers to the mixture of sustainable concrete in which the by-products replaced 20% of the sample weight. Recycled aggregates from CDW made up the remaining 80% of the sample. Sample B refers to the sustainable concrete from CDW, with no by-products in the mixture. The comparison of the results from the two eco-compatibility tests provides insights into the impact of the by-products on the sustainable concrete in Sample A. The results of the eco-compatibility tests are in Table 5. The results of the eco-compatibility test for Sample A show that 5 out of 21 parameters exceeded the leaching limit values in the EN Standard. Such parameters refer to the concentrations of sulfates, total chromium, selenium, Chemical Oxygen Demand (COD), and pH. Specifically, the leaching value for sulfates was more than three times higher than its threshold limit value. These results show that the sustainable concrete in Sample A did not meet the requirements of the eco-compatibility test. Conversely, the sustainable concrete in Sample B met the requirements of the eco-compatibility test, i.e. all the parameters investigated in test B were within the leaching limit values. The sulfates value in test B was relatively high (237 mg/l < 250 mg/l), while medium values were for selenium, total chromium, COD, and pH. These results suggest that the optimal amount of by-products in the mixture is lower than 20% of the weight of the sustainable concrete.

Table 3. Results of the conformity test: detail data for the grading curve of recycled aggregates from CDW.

Mesh sieve [mm]	Passing material, cumulative weight percentage [%]	Retained material, partial weight percentage [%]	Retained material, cumulative weight percentage [%]
80	100.0	0.0	0.0
63	95.7	4.3	4.3
50	82.5	13.3	17.6
40	61.5	21.0	38.6
31.5	49.4	12.0	50.6
25	42.3	7.1	57.7
20	35.5	6.8	64.5
16	31.7	3.9	68.4
14	29.9	1.8	70.2
12.5	28.6	1.4	71.6
10	25.9	2.7	74.3
8	23.5	2.4	76.7
6.3	21.6	1.9	78.6
5	20.1	1.5	80.1
4	18.7	1.4	81.5
2	15.9	2.8	84.3
1	13.3	2.6	86.9
0.5	9.2	4.1	91.0
0.25	6.8	2.4	93.4
0.125	4.9	1.9	95.3
0.075	4.2	0.7	96.0
0.063	4.2	0.0	96.0

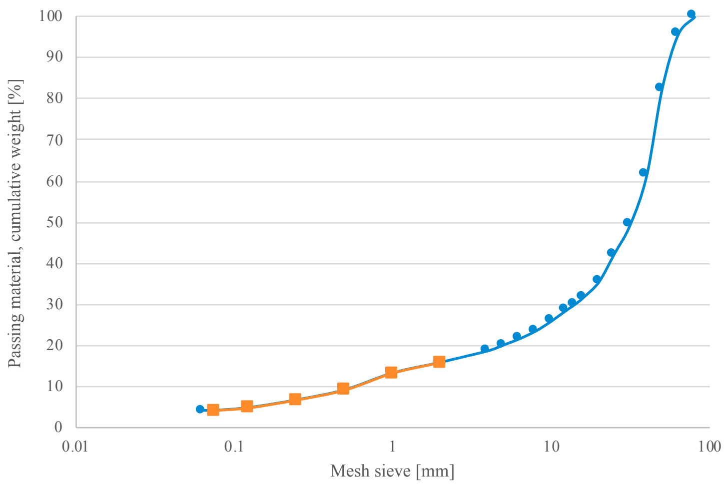

Fig. 1. Grading curve of the recycled aggregates investigated in the conformity test (squared points on the orange curve section refer to the fraction of recycled aggregates with particles between 0.075 mm and 2 mm).

Table 4. Composition of the sustainable concrete samples adopted for the eco-compatibility tests.

Eco-compatibility test	Sample	Weight percentage of by-product [%]	Weight percentage of recycled aggregates [%]
A	Sample A	20	80
B	Sample B	0	100

Table 5. Results of the eco-compatibility tests for the sustainable concrete samples. Bold values refer to the parameters exceeding the limit values in the Ministerial Order 88 of 2 February 1998 [20].

Parameter	Unit of measurement	Leaching limit (LL) value	Measurement uncertainty	Results for Sample A	Results for Sample B
Nitrates	mg/l NO3	50		< 0.1	45
Fluorides	mg/l F	1.5		< 0.1	< 0.1
Sulphates	mg/l SO4	250	± 39.9	798.5	237.0
Chlorides	mg/l Cl	100	± 0.3	5.3	12.9
Cyanides	mg/l Cn	0.05	± 0.0	0.01	< 0.01
Barium	mg/l Ba	1	± 0.019	0.372	0.04
Copper	mg/l Cu	0.05	± 0.0	0.06	0.003
Zinc	mg/l Zn	3		< 0.005	< 0.005
Beryllium	mg/l Be	0.01		< 0.001	< 0.001
Cobalt	mg/l Co	0.25		< 0.005	< 0.005
Nickel	mg/l Ni	0.01	± 0.0	0.001	< 0.004
Vanadium	mg/l V	0.25	± 0.0	0.073	0.027
Arsenic	mg/l As	0.05		< 0.001	0.001
Cadmium	mg/l Cd	0.005		< 0.001	< 0.001
Total chromium	mg/l Cr	0.05	± 0.011	0.224	0.022
Lead	mg/l Pb	0.05		< 0.03	< 0.03
Selenium	mg/l Se	0.01	± 0.001	0.019	0.003
Mercury	mg/l Hg	0.001		< 0.001	< 0.001
Asbestos	mg/l	30		< 0.1	< 0.1
COD	mg/l	30	± 1.8	36	23.9
pH	-	5.5<>12	± 0.0	12.6	9.5

Equation 1 shows the formulation for the By-Product Contribute (BPC) to the sustainable concrete, where x is the percentage of by-products in the mixture, BP_A is the reference value for a specific parameter in Sample A, and BP_B is the reference value for the same parameter in Sample B. This formulation allows to compute the BPC to the sustainable concrete containing the 20% of by-products, as in Equation (2). BPC_20 values were computed for each parameter in the eco-compatibility test. Table 6 shows the BPC_20 values for the critical parameters that caused the failure of the eco-compatibility test of Sample A, i.e. sulfates, total chromium, selenium, and COD. This research did not include the analysis of BPC_20 values for the pH, i.e. pH is a logarithmic value and multiple factors are responsible for its variation. Proportionally, BPC_100 refers to the content of by-products in the sustainable concrete containing 100% of by-products. The BPC_100 values for each parameter that caused the failure of the eco-compatibility test of Sample A are in Table 6. The maximum weight percentage (X) of each by-product parameter in the mixture for the sustainable concrete is in Equation (3), where Y is the weight percentage of recycled aggregates from CDW in the sustainable concrete and LL is the leaching limit value of the by-product parameter [20]. Given the relationship between X and Y in Equation 4, the formulation for the weight percentages of each critical parameter is in Equation 5. The X values for the parameters that caused the failure of the eco-compatibility test of Sample A are in Table 7. These results confirm that sulfates were the most discriminating parameter for the adoption of the by-products in the mixture for sustainable concrete. 0.5% is the maximum weight percentage of by-products in the mixture for the eco-compatibility test. Higher percentages of by-products in the mixture would cause the failure of the eco-compatibility test of the sustainable concrete.

$$BPC\_x = BP\_A - (100\% - x)BP\_B \quad (1)$$

$$BPC\_20 = BP\_A - 80\%\, BP\_B \quad (2)$$

$$(BPC\_100 \cdot X) + (BP\_B \cdot Y) \leq LL \quad (3)$$

$$X + Y = 1 \quad (4)$$

$$X \leq (LL - BP\_B)/(BPC\_100 - BP\_B\,) \quad (5)$$

Table 6. Values of the BPC20 and BPC100 for the parameters that caused the failure of the eco-compatibility test of Sample A.

Parameter	BPA [mg/l]	BPB [mg/l]	BPC20 [mg/l]	BPC100 [mg/l]
Sulfates	798.5	237.0	608.4	3042.0
Total Chromium	0.224	0.022	0.2064	1.032
Selenium	0.019	0.00	0.0166	0.083
COD	36.0	23.9	16.9	84.4

Table 7. LL and X values for the critical parameters that caused the failure of the eco-compatibility test of Sample A.

Parameter	LL [mg/l]	X	X% [%]
Sulfates	250	0.005	0.5
Total Chromium	0.05	0.027	2.7
Selenium	0.01	0.090	9.0
COD	30	0.010	1.0

4. Discussion

The by-products investigated in this study were obtained from the waste materials of the industrial processes of an Italian company leader in the production of concrete-based products. The company management has defined two intended uses for such by-products. The first aims to recover the industrial waste by adding a limited amount of by-products (about 1%) to the primary materials in the production processes. Such quantity does not affect the quality performance of the final product. The internal use of the by-products is an interesting option for the manufacturer of construction products. The company can benefit from low-cost waste management solutions, e.g. reduced waste transport, while ensuring the performance of the final product. However, other solutions are necessary for the remaining quantity of by-products that could not be absorbed by the production processes. The second intended use is related to the transfer of the by-products to other companies, e.g. the manufacturers of building materials for road sub-bases, for testing purposes. The transfer option allows economic and environmental benefits for both companies. The by-product producer benefits from reduced waste production and lower cost for disposal. The manufacturer of building materials replaces the primary resources for road sub-bases with cheaper materials. Furthermore, the partial replacement of the primary resources in the sustainable concrete allows for multiple environmental benefits, in terms of reduced extraction of natural resources and reduced industrial waste disposal. The analysis of the particles in the by-products and the results of the conformity test of the recycled aggregates from CDW showed that the by-products could replace the fraction of fine components, e.g. the fine sands, in the mixture for sustainable concrete. Sand and gravel are the most extracted primary materials for building. The over-extraction of these materials and the resulting lowering of the riverbeds are among the main causes of the reduction of the groundwater table and coastal erosion. The environmental concerns associated with sand mining operations are causing a growing interest of researchers and social systems in the implications of the policies that govern sand extraction. The government restrictions on sand extraction from the riverbeds are determining a significant increase in the price of sand for concrete. The rising cost of primary construction materials has increased the prices of buildings and constructions in the last decades. The reuse of industrial waste for the development of sustainable concrete and the creation of a supply chain for these products offer a valid contribution to the application of the management policies for reducing the extraction of primary resources. However, the transfer of the by-products to other companies for commercial purposes requires the co-existence of two conditions, i.e. the presence of market demand and the by-product availability in such quantity as to satisfy the market demand. The latter condition is a constraint of the first. Today, both these two conditions are not present. Low quantities of by-products do not create market demand. Such materials are considered industrial waste for disposal. Still, the increasing interest of social systems and governments in sustainable building and the spreading of the culture of sustainability support the creation of a market demand for sustainable concrete obtained from secondary resources, e.g. industrial waste. These resources must be accompanied by documented data reporting the waste composition and the physical, chemical, toxicological, and ecotoxicological properties. Further documentation is required to regulate the waste transfer, reporting the delivery unit, e.g. 25 kg bags or big bags, and modalities. The by-product producer involved in this study bore the cost of delivery. The receiver, i.e. the manufacturers of building materials, signed a declaration of liability for the use of the by-products. Finally, the results in Section 3 allowed to define the maximum weight percentage of by-products for the sustainable concrete mixture. Specifically, the analysis of the aggregates grading curve in the conformity test revealed that the maximum weight percentage of by-products in the sustainable concrete for road sub-bases is 11.7%. Such value should not exceed 0.5% to ensure the eco-compatible safety performance of sustainable concrete. The eco-compatibility test revealed that sulfates, total chromium, selenium, and COD caused the failure of test A. Sulfates and chromium are naturally present in concrete materials. High COD values may be due to the presence of organic additives in the by-products. These findings are limited to the products and materials investigated in this research. The variable composition of the recycled aggregates from CDW should be considered when estimating the maximum weight percentage of the by-products in the sustainable concrete mixture. Also, the inherent characteristics of the by-products depend on the characteristics of the industrial processes from which such materials are obtained.

5. Conclusions

This paper investigated the use of recycled aggregates from Construction and Demolition Waste (CDW) and the by-products of an industrial process, to produce sustainable concrete for road sub-bases. The aim was to define the optimal composition of the waste materials in the concrete mixture, i.e. the amount of by-products and recycled aggregates, and to assess the eco-compatibility of the sustainable concrete. The results suggest that the by-products adopted in this research provide an interesting alternative to the use of fine sand in the concrete mixture, i.e. the particles in the by-products completed the grading curve of the recycled aggregates from CDW. However, the optimal amount of by-products in the mixture depends on the characteristics of the CDW material. The weight percentage values obtained should be considered as reference values for future research. Also, this study was limited to the analysis of one sample of recycled aggregates. Future developments of this research include the analysis of multiple samples of recycled aggregates from CDW. The eco-compatibility test provided detailed information about the leaching behavior of the proposed sustainable concrete. The results reveal that a limited percentage of by-products (0.5%) should be included in the concrete mixture because of the leaching behavior of the sulfates in the concrete. This information should appear in the documentation required for product commercialization. The by-product supplier should provide the same documentation to the companies who are interested in producing sustainable concrete. The lack of documented information and data regarding the origins and composition of waste materials can create doubts and concerns about their quality. The use of traceability systems and Building Information Modeling (BIM) for material inventories supports the creation of confidence and trust among the stakeholders in the supply chain of recycled and regenerated products. These systems collect data and information on construction materials during their whole life cycle. Material passports also provide information on the environmental impact of built-in materials, supporting the assessment of the recycling potential of existing buildings before their demolition. Similarly, Digital Product Passport will electronically register, process and share product-related information amongst supply chain businesses, authorities and consumers. These two tools are expected to improve efficiencies in terms of information transfer, but also increase transparency, both for supply chain businesses and for the public. In this context, the technologies of the Industry 4.0 and smart manufacturing approaches play a critical role to ensure the effectiveness of such digital tools. Finally, the circular approach to waste management proposed in this study extends the life-cycle of waste materials, as the by-products of industrial processes and CDW. However, the receiver, i.e. the sustainable concrete manufacturer, is responsible for the proper use of such waste materials. More studies are necessary to define the legislative aspects and the regulatory procedures governing the supply chain of the proposed sustainable concrete. However, the present research provides evidence of the benefits of circular economy models for the development of cross-industry and sustainable value chains.

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