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Substitution of Aggregates in Concrete and Mortar with Coltan Mining Waste: Mechanical, Environmental, and Economic Impact Case Study

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Abstract

The mining process involves drilling and excavation, resulting in the production of waste rock and tailings. The waste materials are then removed and stored in designated areas. This study aims to evaluate the mechanical strength and the environmental and economic impact of using Coltan Mining Waste (CMW) as a substitute for aggregates in concrete and mortar production. To achieve this, the CMW needs to be characterised. The Dreux Gorisse method was primarily used to produce concrete with a strength of 20 MPa at 28 days. The mortars, on the other hand, were formulated according to the NF P 18-452 standard. The environmental impact of using CMW as substitutes for natural aggregates in the production of concrete and mortar was analysed using SimaPro software. The results showed that mortars and concrete made with CMW have comparable compressive strengths to the reference mortar and concrete; reduce the negative impact on ecosystem quality, human health, resources, and climate change. It has also been shown that the substitution of aggregates by CMW reduces the cost of concrete and mortar as a function of the distance from the aggregate footprint.

Keywords

Aggregate, Coltan Mining Waste, Concrete, Mortar, Mechanical Strength, Life Cycle Analysis

1. Introduction

The construction industry is confronted with a growing imperative to reconcile its expanding material demands with environmental sustainability. As traditional construction materials continue to strain global resources, alternative approaches are urgently sought to mitigate environmental impacts. An effective way to produce sustainable concrete and mortar is by utilizing waste minerals. This approach can turn a potential environmental concern into a valuable resource, which aligns with the concept of a circular economy. To fully evaluate this approach, a comprehensive analysis through the lens of Life Cycle Analysis (LCA) is necessary.

The extraction, processing, and utilization of minerals in the construction sector contribute significantly to greenhouse gas emissions, resource depletion, and environmental degradation. Waste minerals, often considered byproducts or residues of mining operations, present an untapped opportunity to address these challenges. Integrating these waste minerals into concrete and mortar formulations not only decreases reliance on virgin materials but also diverts potentially harmful substances from entering landfills or causing ecological harm.

Utilizing natural resources has improved living standards and quality of life. This activity increased as the Industrial Revolution progressed [1].

Using mining exploitation waste has been a popular topic in the last decade, particularly at the building and civil engineering levels [2] [3] [4] [5] [6]. The reuse of tailings contributes to minimising greenhouse gas emissions by encouraging the conservation of natural resources, which reduces the usage of construction materials. The waste minerals in focus encompass a spectrum of byproducts, such as slag, fly ash, and quarry residues, originating from mining and mineral processing activities. Each of these waste minerals brings unique characteristics to the construction materials, influencing not only their mechanical properties but also their environmental performance.

The impact of the mining industry, particularly tailings, has a major effect on water bodies and human settlements in the surrounding area or further afield due to the flow of the river. The use of tailings to replace cementitious materials has been reported in several studies [7] [8] [9]. Even though the use of waste in certain construction materials has been the subject of several studies, life cycle analysis of the materials derived from this waste is imperative in order to understand the environmental impact of this substitution of natural materials by waste in construction materials [10] [11]. This scientific article studies the strength and life cycle assessment of concrete and mortar from the total substitution of aggregates by coltan waste. Life Cycle Analysis is a systematic methodology that quantifies the environmental impacts of a material or product across its entire life cycle, from raw material extraction and processing to manufacturing, construction, use, and end-of-life disposal. By applying LCA to construction materials incorporating waste minerals, we intend to provide a comprehensive understanding of the environmental footprint associated with these innovative solutions. Throughout this research, environmental performance follows the LCA methodology established by the ISO 14040 standard [12]. SimaPro software [13] will be used to analyse the environmental impact of the materials studied. In addition to the compressive strengths of mortars and concretes made from coltan waste, this study assesses the environmental impact of using coltan waste in mortar and concrete in the east of the Democratic Republic of Congo. The system has a functional unit (FU) of 1 m^3. It will also be necessary to present the characteristics of the materials used, in particular conventional aggregates, aggregates derived from coltan waste, the dosage of conventional concrete, the dosage of concrete derived from mining waste, the dosage of conventional mortar and the dosage of the various mortars derived from coltan waste.

2. Materials and Experimental Methods

2.1. Materials

2.1.1. Cement

The cement used was a CPJ-CEMII 42.5 cement with a density of 3.1 g/cm^3, the chemical properties of which are presented in Table 1.

2.1.2. Water

The water used in the study is tap water of Goma. The water used is potable by the standard NF EN 1008 [14] which specifies that the mixture must be made with drinking water free from impurities.

2.1.3. Aggregates

1) Origin

To produce conventional concrete and mortar, conventional aggregates consisted of rolled sand (SN) and crushed gravel (GN) from the quarry. Coltan mine waste rock came from Coltan extraction during mining operations, five samples (GS4, GS1, GS5, GS3, SS4) were taken. Coltan waste rock in the form of sand comes from coltan processing, three samples (SR1, SR2, SR3) were taken. Coltan Mining waste was collected from stopes in the 4731-mining perimeter, specifically at Gakombe (GS1, SR1), Dédé Bibatama (GS4, SR2, SS4) and Luwowo (GS5, SR3) in the Masisi area region in DRC. Figure 1 shows images of aggregates used in this study.

2) Chemical composition

Table 2 presents the chemical composition of materials, using XRF analysis.

The XRF results show that the chemical composition of the Coltan Mining waste is composed of pozzolanic materials (SiO_2, Al_2O_3 and Fe_2O_3) with small amounts of CaO, MgO and other compounds. The combined weight of pozzolanic

Table 1. Chemical composition of cement used.

Composition	SiO_2	TiO_2	Al_2O_3	TFe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Others
Mass%	23.5	0.31	5.0	3.57	0.2	2.43	57.1	0.24	0.49	0.18	4.0	2.96

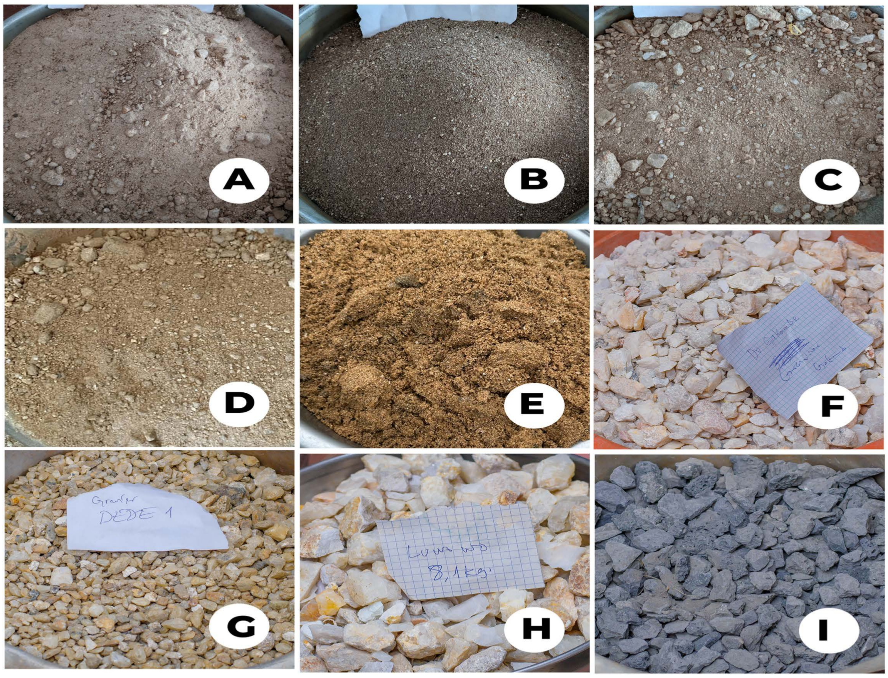


Figure 1. pictures of the used aggregates (A) SR1 (B) SR2 (C) SR3 (D) SS4 (E) SN (F) GS1 (G) GS4 (H) GS5 (I) GN.

Table 2. Chemical composition of aggregates.

	SR2	SR1	SR3	GS1	GS5	GN	SN	GS4	SS4
SiO_2	48.8	59.49	54.71	73.24	70.06	40.24	76.16	49.07	49.07
TiO_2	0.21	0.35	0.38	0.25	0.02	2.64	0.46	1.34	1.34
$Al2O_3$	27.21	22.6	25.65	13.95	15.69	14.7	10.64	24.18	24.18
Fe_2O_3	2.07	1.86	6.37	2	0.82	12.75	3.61	7.5	7.5
MnO	0.07	0.11	0.08	0.1	0.05	0.25	0.05	0.52	0.52
MgO	0.19	0.48	0.22	0.3	0.03	4.06	0.5	1.33	1.33
CaO	0.41	0.67	0.28	0.84	0.18	11.91	1.06	1.9	1.9
Na_2O	0.4	0.29	0.73	0.4	0.15	5.18	0.82	0.26	0.26
K_2O	6.92	4.49	1.53	3.99	4.23	4.78	4.44	2.09	2.09
P_2O_5	0.1	0.15	0.1	0.11	0.59	1.42	0.2	0.38	0.38
LOI	7.55	5.47	8.35	2.76	3.68	0.97	1.64	9.56	9.56
SUM	93.92	95.93	98.38	97.95	95.51	98.88	99.58	98.12	98,12
Others	1.72% Rb_2O; 0.14% Nb_2O_5; 0.18% Cs_2O; 0.48% Ta_2O_5; 3.21% F	0.64% Rb_2O; 0.78% SnO_2; 0.32% Ta_2O_5; 1.01% F	0.26% Rb_2O; 0.24% Ta_2O_5 0.34% F	0.68% Rb_2O; 0.14% Nb_2O_5; 0.24% Cs_2O; 0.24% Ba; 0.58% Ta_2O_5	0.91% Rb_2O 0.19% Nb_2O_5; 0.72% Ta_2O_5; 2.37% F	0.20% SO_3; 0.32% SrO; 0.20% BaO	-	0.29% Rb_2O, 0.49% F	0.29% Rb_2O 0.49% F

materials is between 78.08% and 89.19% of the weight of Coltan waste. They are considerably higher than the recommended value (70%) given in ASTM C618-19

[15]. As it happens, these pozzolanic materials may react chemically with the free lime in the cement to form bonded compounds, thereby strengthening the concrete matrix. This can lead to an increase in the long-term strength of the concrete so that due to the slower reaction of the pozzolans, the short-term strength (e.g. 7 days) is slightly reduced. However, this initial reduction is often offset by a longer-term improvement.

3) Density

The densities of natural gravel and sand, coltan tailings, and coltan waste rock are shown in Table 3.

The absolute density of coltan tailings, coltan waste rock, and conventional aggregates is between 2 g/cm^3 and 3 g/cm^3. Consequently, in terms of density classification, the coltan tailings and mine waste rock studied in this study are classified as conventional aggregates. However, the different specific densities of coltan tailings obtained remain lower than the specific density of gold mine tailings obtained by Benarchid *et al.* [16] and Taha *et al.* [17].

4) Particle size distribution

The particle size analysis was carried out respectively on natural aggregates and mine tailings (waste rock and tailings) using the dry method, by the standard. Figure 2 shows the particle size composition of the coltan tailings and the conventional materials used.

Table 3. Density of materials.

Coltan Mine Waste Rock	SR2	SS3	SR1	SR3	SN	GS4	GS1	GS5	GN
Bulk density (Kg/m^3)	1170	1300	1340	1240	1360	1310	1300	1400	1250
Absolute density (Kg/m^3)	2610	2400	2500	2490	2530	2480	2470	2500	2510

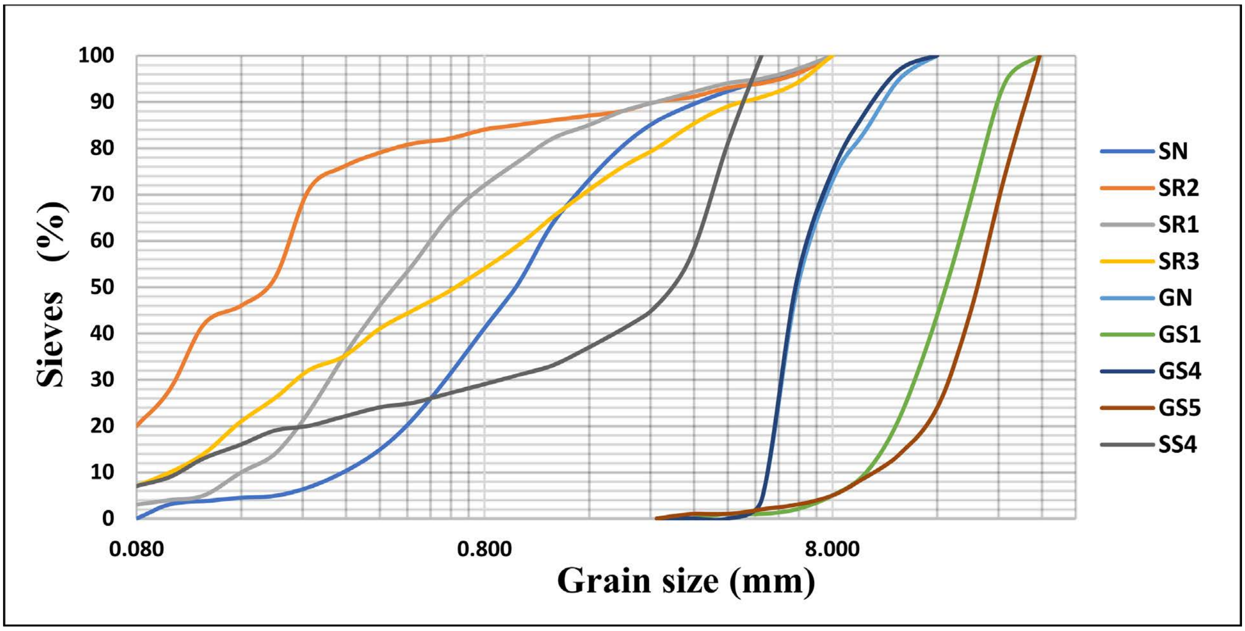


Figure 2. Granulometric composition of aggregates.

The granulometric composition shows that:

- SR1, SR2, SR3, and SS3 have a higher proportion of fine particles than conventional sand (washed sand). This particle size distribution is directly linked to the processing procedure for the mineral mined (Coltan). The concavity of SR1 and SR2 reflects the predominance of fine particles in coltan tailings. The concavity of the SS3 particle size curve expresses the presence of coarse particles in this waste rock despite the presence of several fine particles of less than 0.08 mm. This particle size distribution is mainly due to the semi-industrial operation of the mine. SR3 has a varied particle size distribution due to the separation method used in cassiterite mining.
- GS1, GS4, and GS5 are similar in particle size to conventional gravel. D_{max} (max diameter of aggregates) of GS1, GS4, and GS5 is 25 mm, 16 mm, and 25 mm respectively. D_{max} of natural gravel is 25 mm.

The fineness modulus of sand, a geometric characteristic of sand, is an important parameter in the formulation of concrete. It is used to determine the aggregate dosage, but also to predict the workability of cementitious materials. For example, if the sand used in concrete is predominantly fine, the water content needs to be increased, whereas concrete made with coarse sand loses its workability. Table 4 shows the fineness modulus of fine aggregates.

According to Table 4, the SR2 tailing is fine with a Fineness Modulus of less than 2.2; the SR3 and SR1 residues are good sands for concrete with a Fineness Modulus of between 2.2 and 2.8; the SS4 waste rock and the Conventional Sand are coarse sands with a Fineness Modulus of more than 2.8.

5) Los Angeles test

Impact resistance of aggregate packs on gravel-like waste rock and conventional gravel using the Los Angeles test by NF EN 1097-2 [18] gave the different Los Angeles coefficients presented in Table 5.

Table 4. Fineness modulus of fine aggregates.

Materials	MF
SR1	2.25
SR2	1.26
SR3	2.58
SS4	3.55
SN	3.1

Table 5. Los Angeles test.

	GS1	GS4	GS5	GN
Initial mass	5000	5000	5000	5000
Passage 1.6 mm	2194	2210	2330	756
LA	44	44	47	15

The impact strengths of coltan waste rock obtained from the Los Angeles test range from 44% to 50% and are all lower than those obtained on conventional gravel (15%).

2.2. Experimental Method

2.2.1. Composition of Concrete and Mortar

The concrete was formulated using the Dreux-Gorisse method [19]. The concrete preparation process involved mixing the sand with the coarse aggregates to achieve greater homogeneity. The cement was then added after the mixing water had been introduced. After 3 minutes of continuous mixing, the mixture was covered with a damp towel to prevent evaporation. Finally, the fresh concrete was left to stand for a further 3 minutes and mixed again for 2 minutes. The formulation of plastic cement mortar was guided by two reasons, namely the acceptable resistance that this mortar offers and its common use in construction. The cement/aggregate ratio is typically 1:3 (by mass); the quantity of water used for mixing is required to obtain a plastic consistency (flow time of between 20 and 30 seconds) following standard NF P 18-452 [20]. The mortars were prepared following standard NF EN 1015 [21]. This standard specifies a procedure for making test mortars from dry constituents and water. Mixing was carried out using a mixer complying with NF EN 1015-2 [22]. Five mortars were made, including one control mortar (M0) and four mortars with Coltan Mining Waste. The freshly made mortars were then placed in 4 × 4 × 16 cm moulds (filled in two layers, 60 shocks each), then stored in a damp cabinet at 20˚C ± 2˚C and 95% humidity.

The purpose of formulating mortars and concretes is to determine the optimum quantities of cement, sand and water for mortars and the optimum quantities of water, cement, sand, and gravel for concrete. The target strength is 20 MPa and the target consistency is 7 cm in the Abrahams cone slump. The water and cement dosages were determined using the Bolomey formula and the Dreux Gorisse abacus, which gives the cement dosage as a function of the Abrahams cone slump and the W/C ratio. **Tables 6-8** show the concrete dosage per cubic meter, the nature of the aggregates per concrete and the mortar dosage per cubic meter.

2.2.2. Characterisation of Concrete and Mortar

The slump of the fresh concrete was measured under standard NFP 18-451 [23];

Table 6. Dosage of various constituents per cubic meter of concrete.

	B_0	B_1	B_2	B_3	B_4
Mass of cement (kg)	362.50	400	444	400	444
The volume of water (l)	212.06	206.45	215.49	206.45	215.49
Total mass of sand (kg)	696.32	643.09	690.89	683.22	837.14
Total mass of gravel (kg)	1036.23	1058.96	984.72	1028.95	820.60

the workability of fresh mortar was assessed using the maniabilimeter following standard NF P 18-452 [20] with a flow time of 23 ± 2 seconds. The concrete and the mortar were poured into steel moulds of conventional dimensions (cylinder of 11 cm × 22 cm for the concrete, prismatic of 4 cm × 4 cm × 16 cm for the mortar). The mould was removed after around 24 hours, and the concrete and the mortar specimens were cured in a wet environment at room temperature. Compressive strengths were measured by crushing the concrete and mortar specimens at 28 days using a hydraulic press (**Figure 3**) under standards NF EN 12390-3 [24]. The density of the mortar and concrete was determined at 28 days following the NF EN 12390-7 standard [25].

Table 7. Concrete's nature of aggregates.

concrete	Sand	Gravel
B0 (Reference concrete)	SN	GN
B1	SR1	GS1
B2	SR2	GS4
B3	SR3	GS5
B4	SS4	GS4

Table 8. Dosage of various constituents per cubic meter of Mortar.

Mortars	Type of sand	Cement (Kg)	Fine aggregates (Kg)	W (l)	W/C
M0	Conventionnel	350	1050	273	0.78
M1	SR1	350	1050	315	0.9
M2	SR2	350	1050	350	1
M3	SR3	350	1050	280	0.8
M4	SS4	350	1050	420	1.2

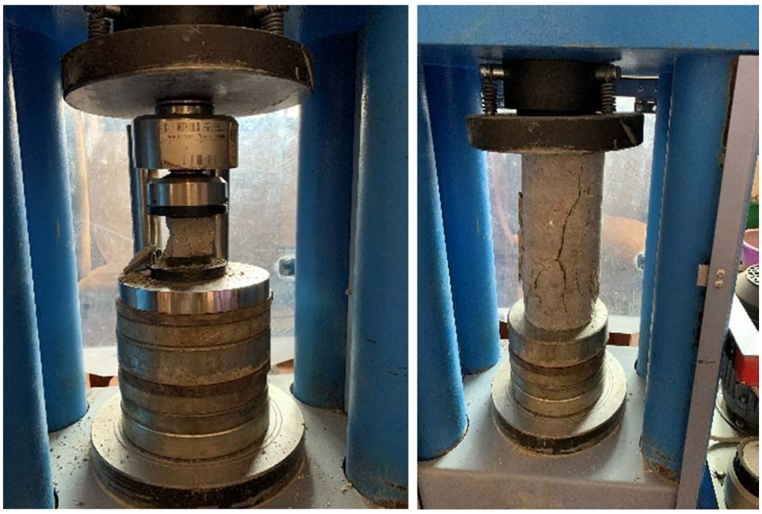


Figure 3. Compression tests on Mortar and concrete specimens.

2.2.3. Life Cycle Assessment

Life Cycle Assessment (LCA) is a systematic and comprehensive methodology for evaluating the environmental impacts of a product, service or process throughout its life cycle, from the extraction of raw materials to the end of its life. LCA aims to take a holistic view of the various phases, quantify the associated environmental pressures and identify opportunities for improvement. LCA has been applied to construction systems to assess their contribution to the environmental burden [26].

The impact of the mining industry, particularly tailings, has a major effect on water bodies and human settlements in the surrounding area or further afield due to river flow. The use of mine tailings in construction materials has been reported in several studies [7] [8] [9], however, the LCA of the reuse of coltan waste has not been investigated [10] [11]. Thus, the environmental performance of this study will enable a proper assessment of the optimisation possibilities and potential positive environmental impacts of incorporating coltan mine waste into cement (mortar and concrete). The environmental performance follows the LCA methodology established by the ISO 14040 standard [12].

SimaPro software [13] was used to analyse the environmental impact of the mixes presented in **Table 6** and **Table 8**. This study aimed to assess the impact of using coltan waste produced in the mining industry in the east of the Democratic Republic of Congo in a cementitious matrix to replace conventional aggregates. The system has a functional unit (FU) of 1 m^3 of ready-mix concrete and mortar.

1) Description of the system

The system under consideration starts with the extraction and production of the main raw materials, cement, aggregates and water. For cement and aggregates, from their respective quarries to the required product, each undergoes several transformations. The production of raw materials, such as cement manufacturing and transportation, contributes significantly to the overall environmental impact. Similarly, in the case of coarse aggregate production, crushing is the primary source of CO_2 emissions. On the other hand, diesel and electricity contribute almost equally to CO_2 emissions from the production and transport of fine aggregates.

2) Raw materials production

This covers the extraction and production of the main raw materials: cement, aggregates and water. Water is distributed by REGIDESO. The plants were also considered to be supplied by this company.

3) Transport of raw materials to the production site

The raw materials in question are transported to the power station, which is the production site. They are transported from extraction sites for aggregates and production plants or sales outlets for cement. Transport may be by lorry, trailer or other suitable means, depending on the availability of transport infrastructure and the distance to be covered. **Table 9** shows the different distances considered. To assess the impact of quarry distance on the LCA, the distance

Table 9. Distances transportation of raw materials.

ACV	Distance definition	Distance in Km
ACV1	Distance from the first gravel quarry to the concrete/mortar plant	123
	Distance from the first sand quarry to the concrete/mortar plant.	171
	Distance from the mining quarry (coltan Mining Waste) and the concrete/mortar plant	5
	Distance from cement-producing site to concrete/mortar plant.	160
ACV2	Distance from the second gravel quarry to the concrete/mortar plant	61
	Distance from the second sand quarry to the concrete/mortar plant.	85
	Distance from the mining quarry (coltan Mining Waste) and the concrete/mortar plant	5
	Distance from cement-producing site to concrete/mortar plant.	160
ACV3	Distance from the third gravel quarry to the concrete/mortar plant	138
	Distance from the third sand quarry to the concrete/mortar plant.	186
	Distance from the mining quarry (coltan Mining Waste) and the concrete/mortar plant	5
	Distance from cement-producing site to concrete/mortar plant.	160
ACV4	Distance from the fourth gravel quarry to the concrete/mortar plant	149
	Distance from the fourth sand quarry to the concrete/mortar plant.	150
	Distance from the mining quarry (coltan Mining Waste) and the concrete/mortar plant	5
	Distance from cement-producing site to concrete/mortar plant.	160
ACV5	Distance from the fifth gravel quarry to the concrete/mortar plant	28
	Distance from the fifth sand quarry to the concrete/mortar plant.	12
	Distance from the mining quarry (coltan Mining Waste) and the concrete/mortar plant	5
	Distance from cement-producing site to concrete/mortar plant.	160

of five quarries was considered to be variable, as shown in Table 9.

4) Concrete production

Once transported to the production site, the dosed raw materials are mixed in a concrete batching plant or mixer. The mixture must be homogeneous to ensure an even distribution of all the concrete components.

5) Transport to the place of use

Once it has been produced, the concrete is transported to the construction site using truck mixers or concrete pumps, which keep the concrete in motion during transport to prevent segregation. A distance of 20 km has been considered in this study.

6) Impact assessment

Life cycle impact assessment methods aim to link, as far as possible, each result of the life cycle inventory (elementary flow or other intervention) to the corresponding environmental impacts [27]. The IMPACT (Impact Assessment Chemistral) 2002+ is the method used in this study. The IMPACT 2002+ methodology proposes a combination of conventional methods (e.g. CML and

EDIP) and damage-based methods (eco-indicator 99) using a median damage-based approach. Figure 4 shows the IMPACT 2002+ framework as a whole, linking all types of LCI results via 14 median categories to four damage categories as presented in Figure 4.

This diagram establishes the link between the results of the inventory and the environmental damage for the elementary flows. The first point to note is that a flow may contribute to different categories of impact, just as the contribution of certain flows is zero for certain types of damage. IMPACT 2002+ divides the intermediate impacts into four categories of damage:

- Human health, expressed in DALYs (Disability Adjusted Life Years): this is the number of years of life lost as a result of exposure to pollutants and toxic products;
- The quality of ecosystems expressed in PDF·m^2·year (Potentially Disappeared Fraction), which corresponds to the fraction of species that have disappeared from one square meter over one year;

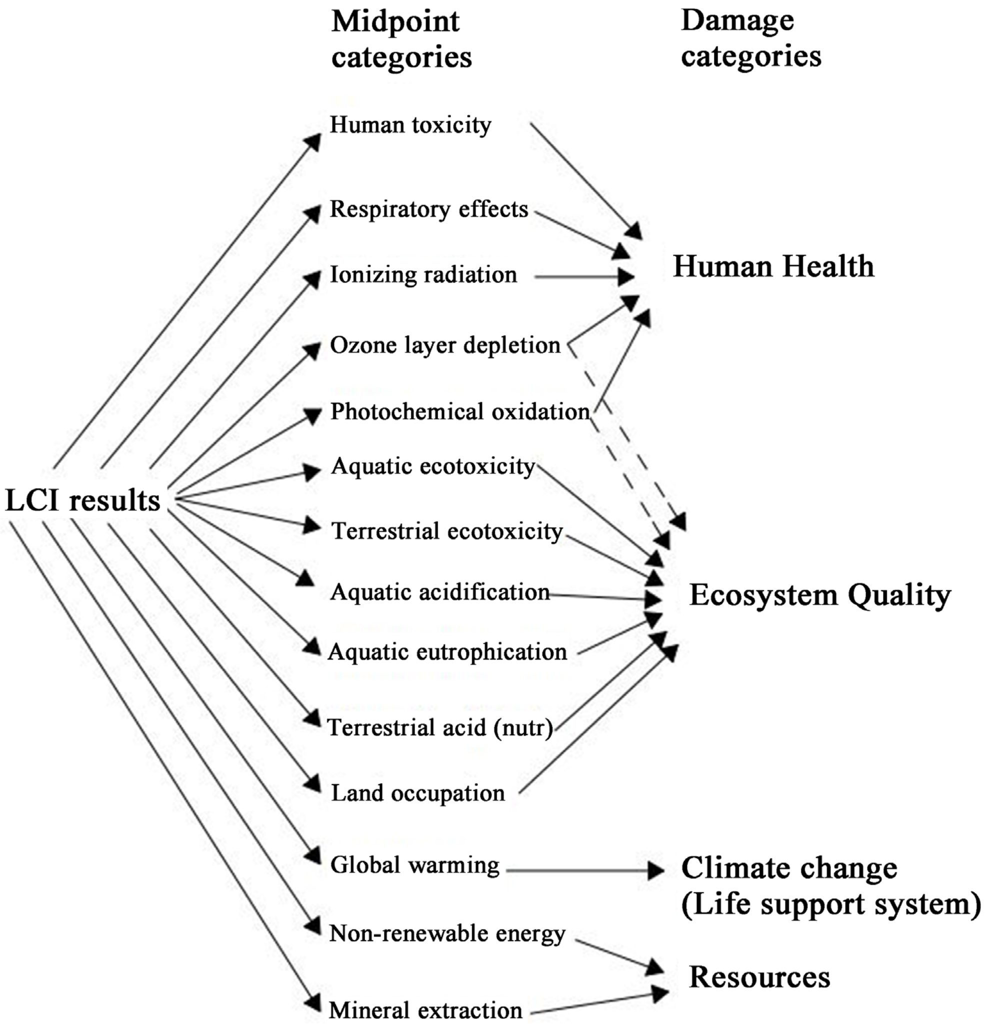


Figure 4. General diagram of the IMPACT 2002+ framework, linking LCI results to damage categories via median categories [27].

- Resources, which include the intermediate categories of non-renewable primary energy consumption and mineral extraction, expressed in MJ (Megajoule of energy used). This category represents the quantity of energy extracted or needed to extract resources, taking into account the decrease in these resources (always more energy for less extraction for non-renewable resources).
- Climate change in kg CO_2 emitted. This is the sum of greenhouse gases (GHGs) expressed as CO_2.

Impact 2002+ makes it possible to aggregate and classify a large amount of inventory data to facilitate analysis, without using unscientific weighting, making it easier to identify and quantify the various environmental impacts.

Life cycle assessment data, like all scientific data, is characterised by uncertainties linked to two main sources:

- The intrinsic statistical dispersion of inventory data generated from sampling, expressed as standard deviation and standard error;
- The accuracy of the model (conformity of the model with reality), resulting from the assumptions made, the limits imposed (system boundaries), the representativeness of the data (use of generic data for certain processes), the allocation rules (for systems generating co-products), the choice of the functional unit or the absence of data, etc.

There are various methods for estimating the uncertainties arising from the development of the model itself. Generally, a sensitivity analysis is used to test the influence of the most important assumptions used in the model, coupled with a Monte Carlo analysis to easily determine the uncertainties resulting from the dispersion of inventory data. Sensitivity analysis also makes it possible to validate the conclusions of the study itself, by incorporating the weight of the initial conjectures, which is of particular interest, especially in LCAs comparing different products. In the following, the various LCAs for mortars and concretes will be established as shown in **Table 9**.

3. Results and Discussion

3.1. Consistency

Figure 5 and **Figure 6** respectively show the maniability test of mortars and the Abrams slump test of concretes as a function of the W/C ratio.

Figure 5 indicates that using Coltan Mining waste as aggregates requires significantly more water for mixing than using reference sand. To attain the desired consistency, mortars based on Coltan Mining Waste M1, M2, M3, and M4 require more water than the reference mortar M0. This is mostly owing to the high fine content of waste rock and coltan tailings. Gonçalves *et al.* [28] and Masika *et al.* [29] reported similar results regarding the occurrence of particles in natural sands.

Furthermore, the reference concrete B0 and the coltan Mining waste concrete, B1, B2, B3, and B4, had the same 7 cm slump for varied W/C ratios, *i.e.* W/C ratios of 1.24, 1.66, 1.78, 1.56, and 1.2 for concrete B0, B1, B2, B3, and B4, respectively.

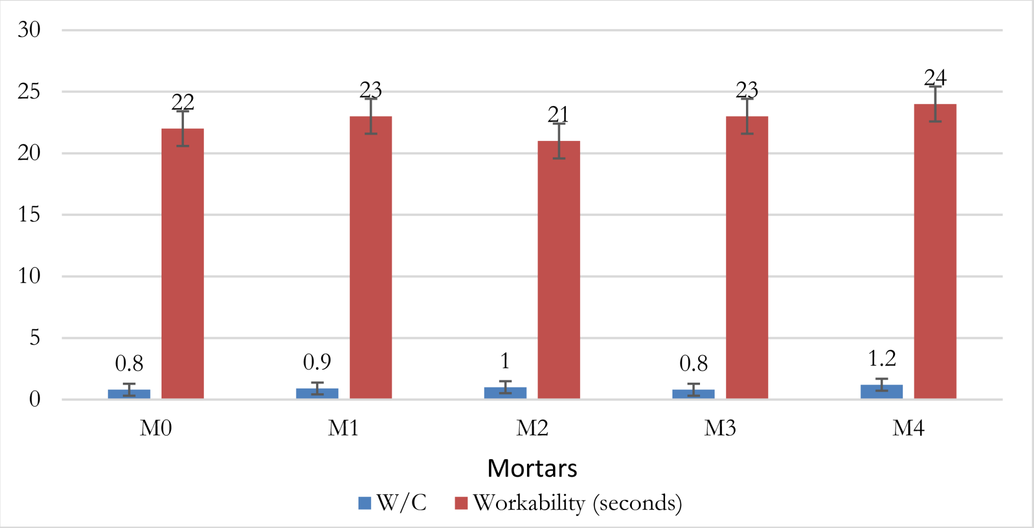


Figure 5. Maniability of mortars (in seconds) as a function of the W/C ratio.

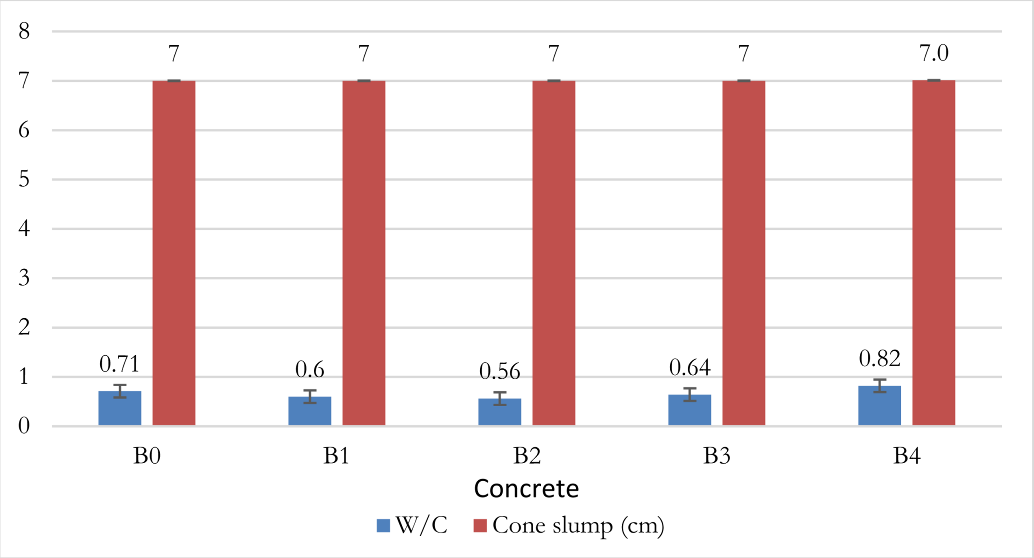


Figure 6. Abrahms slump of concrete (cm) as a function of the W/C.

The greater W/C ratio of coltan waste concretes compared to reference concrete could be attributed to the presence of regular-shaped particles in the coltan Mining wastes used as sand, particularly in B1, B2, and B3 concrete. Similar results related to the shape of flint aggregates by El Machi *et al.*, [30] and Butler *et al.* [31].

3.2. Density

Figure 7 and **Figure 5** show the densities of the mortars and concretes studied respectively.

The difference in density between mortars and concretes based on mine tailings and the reference mortar and concrete illustrated in **Figure 7** and **Figure 8** may be due to disparities in terms of the specific density of aggregates.

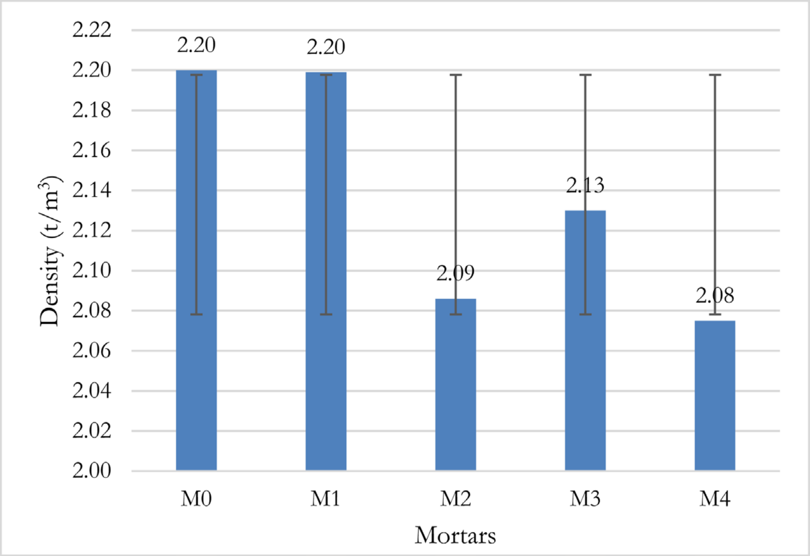


Figure 7. Mortar density (t/m^3).

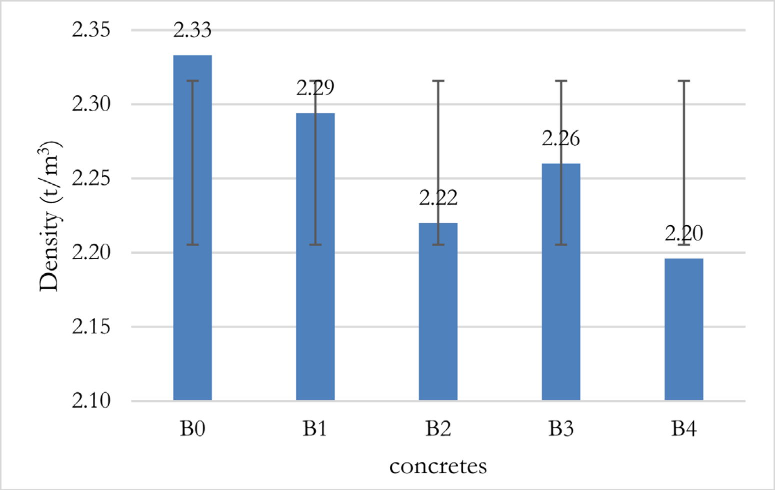


Figure 8. Density of concrete (t/m^3).

3.3. Compressive Strength

Figure 9 and **Figure 10** show the compressive strengths at 28 days of the mortars and concretes studied.

Figure 9 and **Figure 10** illustrate that the total replacement of natural aggregates by coltan Mining Waste in the production of concrete and mortar demonstrates particular performances. Mortars made with coltan residues showed compressive strengths at 28 days similar to the strength of the reference mortar (29 MPa), with a minimum observed of 25 MPa. The concretes obtained using coltan tailings as sand showed strengths greater than or equal to the expected strengths (20 Mpa) at 28 days. These results are similar to the literature such as Atta Kuranchaie *et al.* [32], highlighting that the tailing aggregates can be employed as a replacement in conventional concrete. It can be concluded that the replacement of coarse aggregates with mining aggregates can be used in the

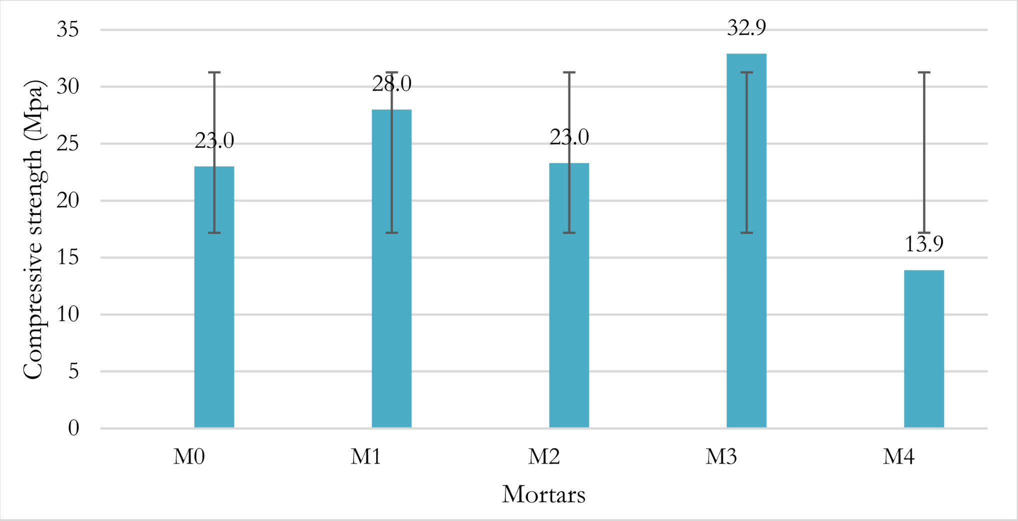


Figure 9. Compressive strength of mortars (Mpa).

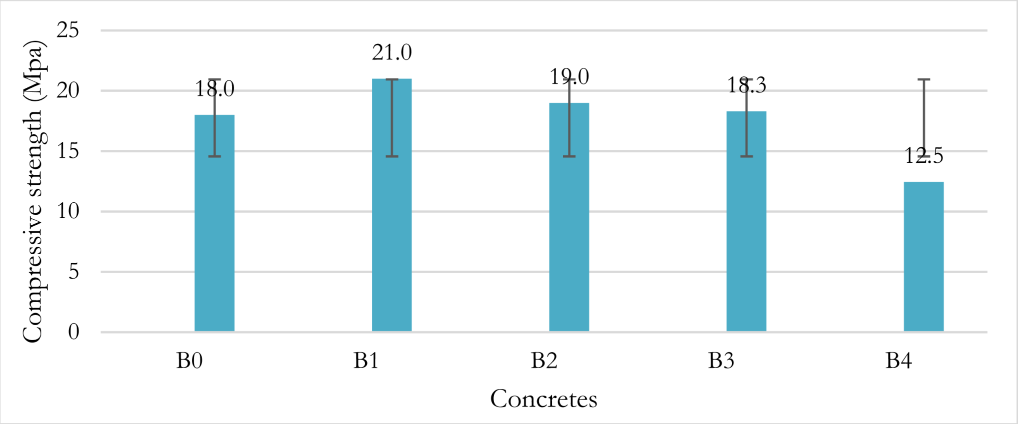


Figure 10. Compressive strength of concrete (Mpa).

mixture. However, for SS4 waste, which has lower strengths in both concrete and mortar, as shown in Figure 9 and Figure 10; this type of material can be used in other structures requiring lower compressive strength, such as pavements, kerbs, floors and cyclopean concrete.

3.4. Environmental and Economic Impact Assessment

1) Environmental impact assessment

The results of the environmental impact analysis using the LCA technique have been summarised in the bar charts shown in Figures 11-20.

The results presented in Figures 11-20 indicate that using Coltan waste as raw materials instead of aggregates in mortar and concrete can significantly reduce the negative impact on ecosystem quality, human health, resources, and climate change. However, in the case of mortar, the cement content of the concrete used is higher than that of the reference concrete, so the influence of substitution on climate change seems less significant. Nevertheless, in the case of quarries far from conventional aggregates, the total substitution of aggregates by coltan

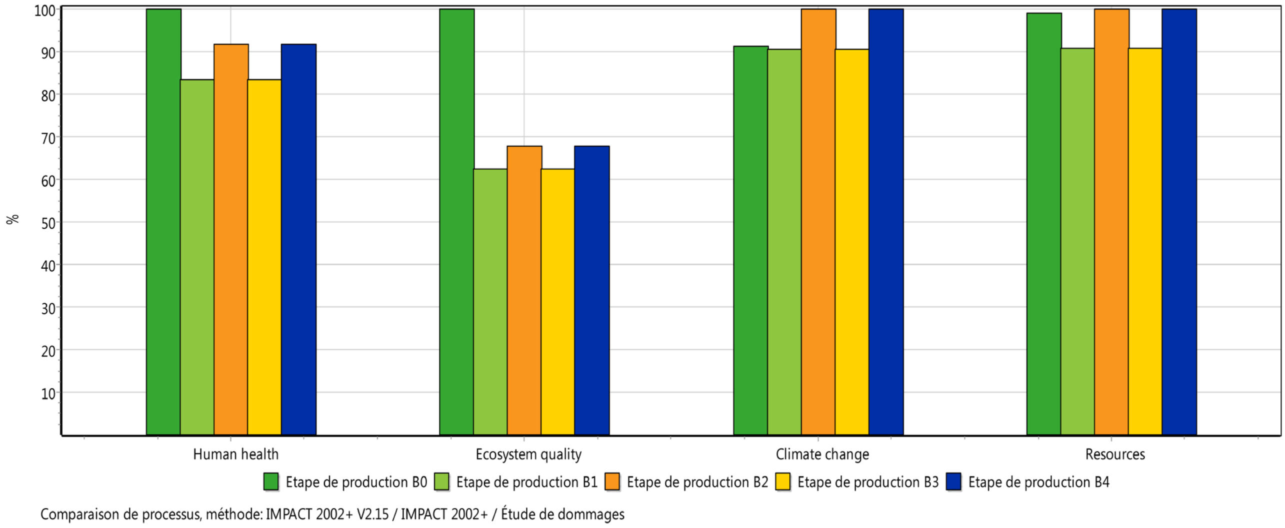


Figure 11. LCA1 of concrete.

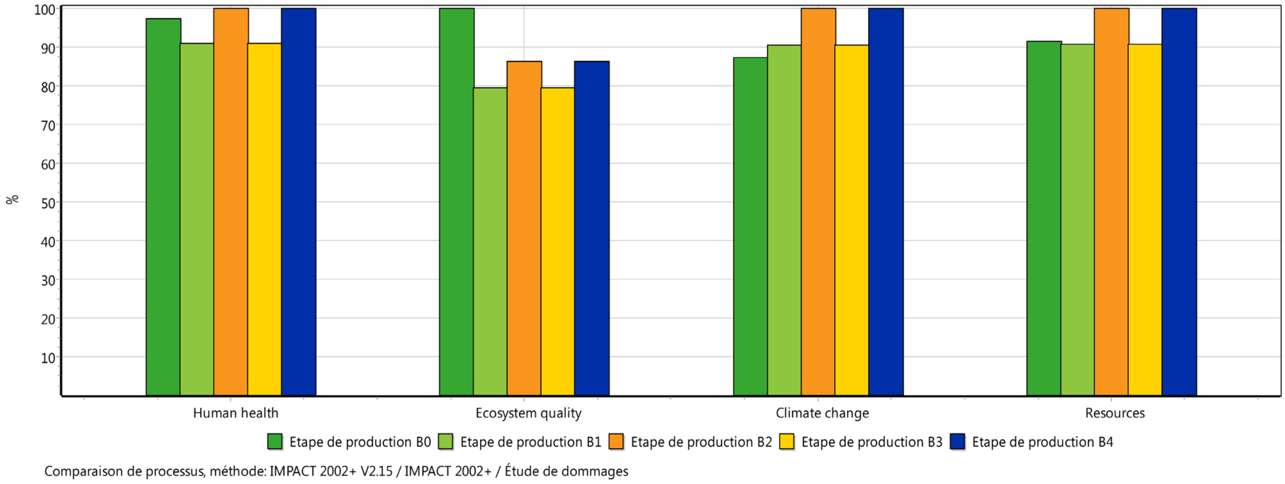


Figure 12. LCA2 for concrete.

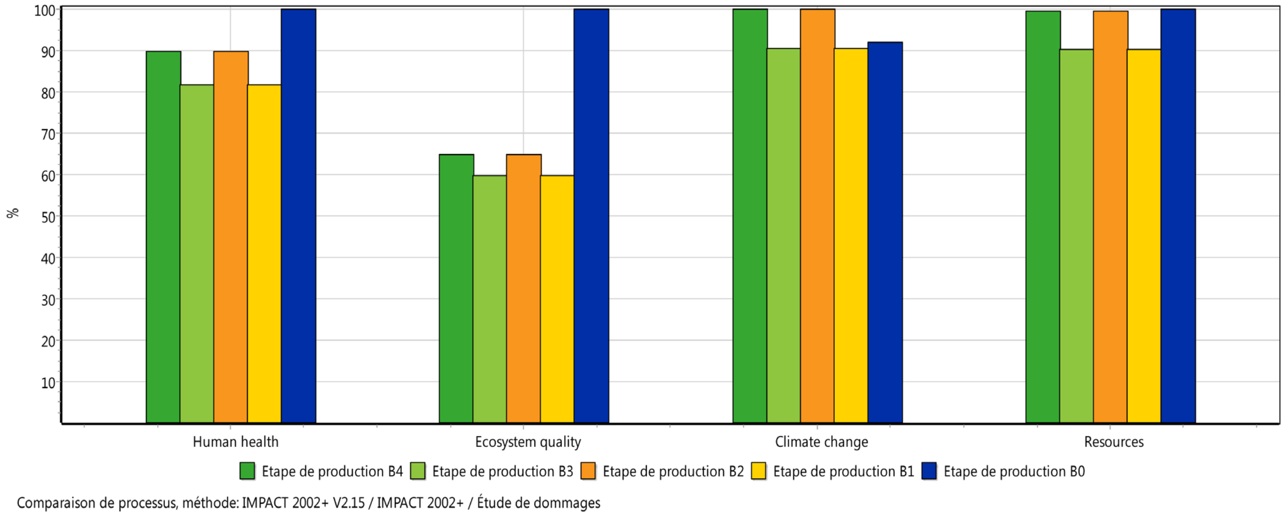
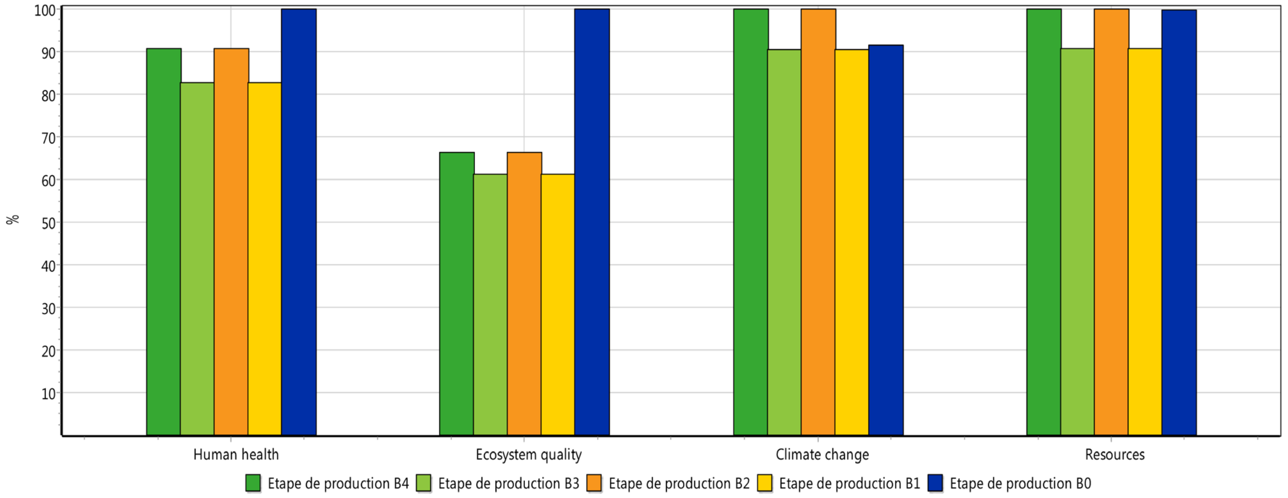
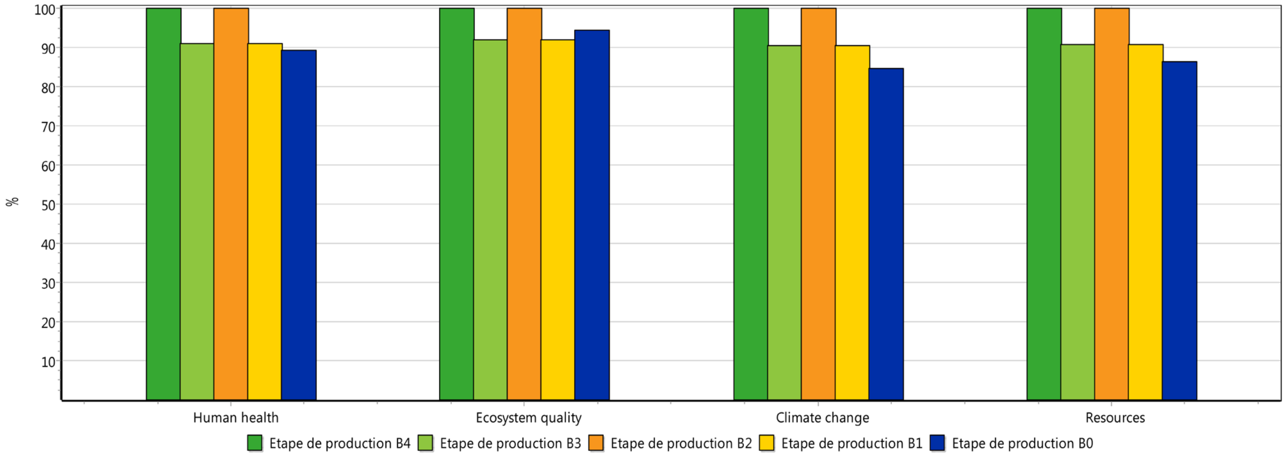


Figure 13. LCA3 for concrete.



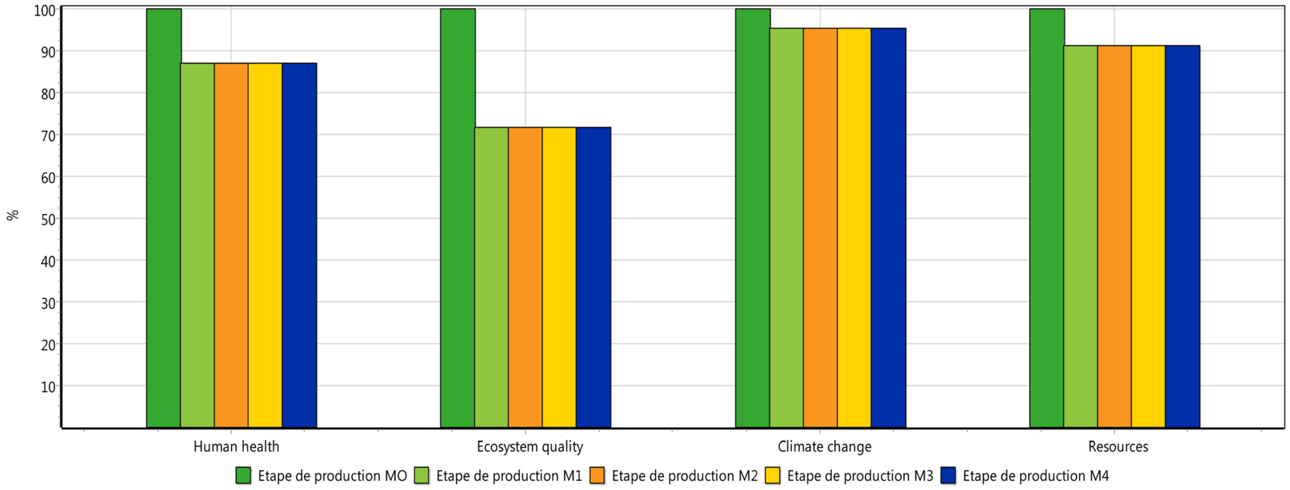
Comparaison de processus, méthode: IMPACT 2002+ V2.15 / IMPACT 2002+ / Étude de dommages

Figure 14. LCA4 for concrete.



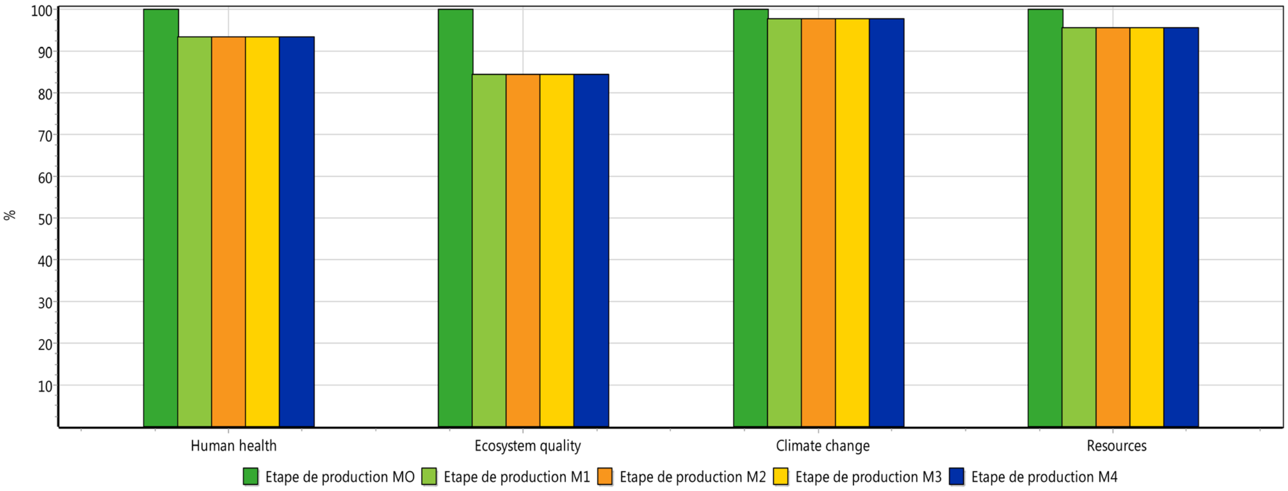
Comparaison de processus, méthode: IMPACT 2002+ V2.15 / IMPACT 2002+ / Étude de dommages

Figure 15. LCA5 for concrete.



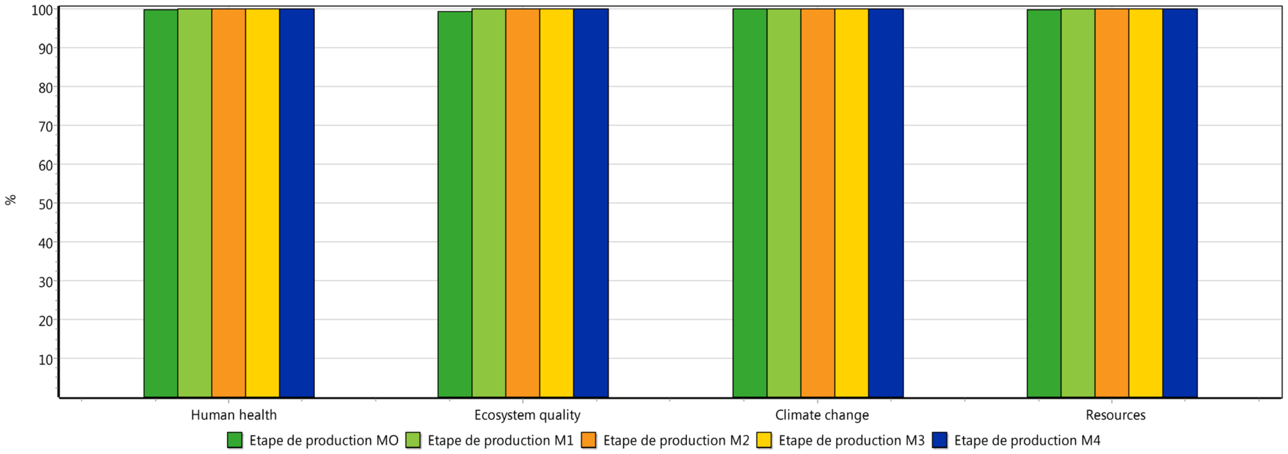
Comparaison de processus, méthode: IMPACT 2002+ V2.15 / IMPACT 2002+ / Étude de dommages

Figure 16. LCA1 of mortars.



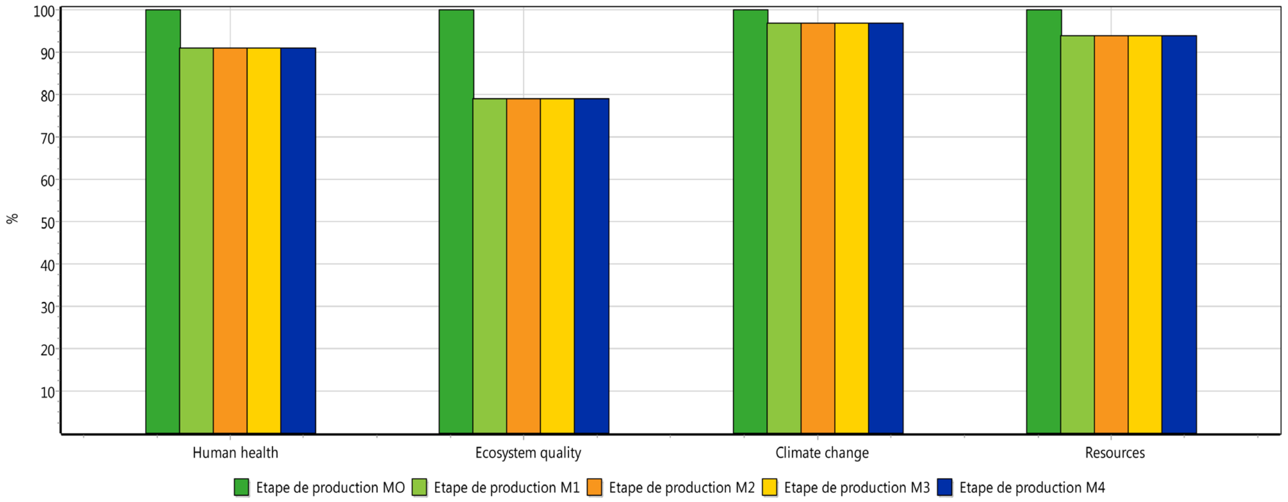
Comparaison de processus, méthode: IMPACT 2002+ V2.15 / IMPACT 2002+ / Étude de dommages

Figure 17. LCA2 of mortars.



Comparaison de processus, méthode: IMPACT 2002+ V2.15 / IMPACT 2002+ / Étude de dommages

Figure 18. LCA3 of mortars.



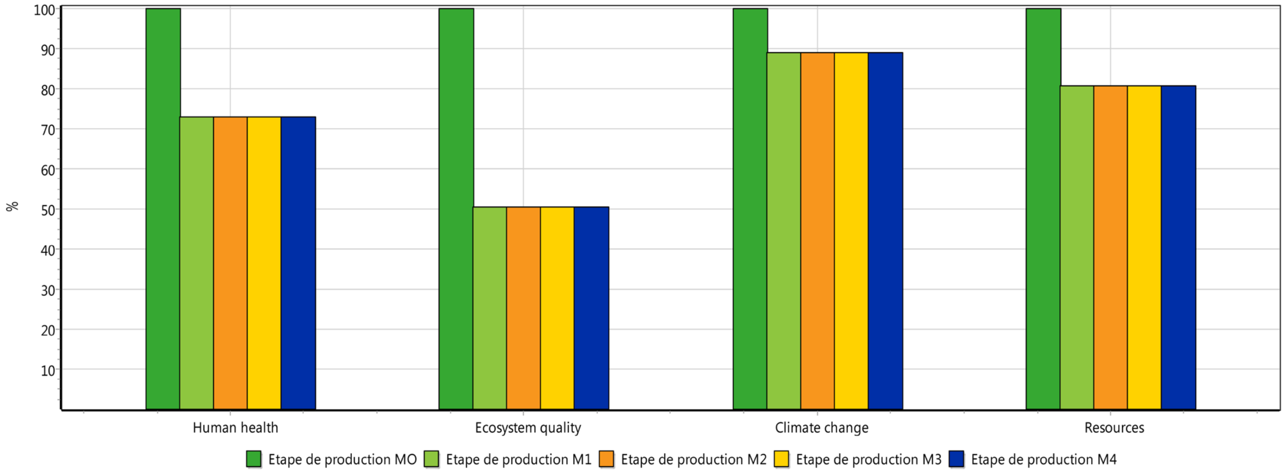
Comparaison de processus, méthode: IMPACT 2002+ V2.15 / IMPACT 2002+ / Étude de dommages

Figure 19. LCA4 of mortars.

emissions in concrete and mortar favours a reduction in the negative impact on climate change, ecosystem quality, human health and resources, regardless of the dosage. These results are in line with those observed by Natividad *et al.* [33] on mining waste. Environmental performance is very sensitive to transport distances.

2) Economic impact assessment

The influence of the total substitution of aggregates by coltan rejects on the cost of mortar and concrete is summarised in the bar charts shown in **Figures 21-30**.



Comparaison de processus, méthode: IMPACT 2002+ V2.15 / IMPACT 2002+ / Étude de dommages

Figure 20. LCA5 of mortars.

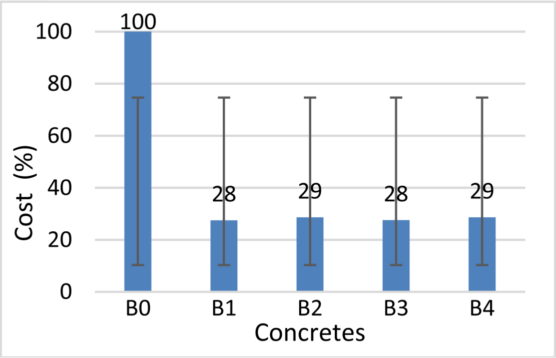


Figure 21. Influence of distance from quarry 1 on the cost of concrete.

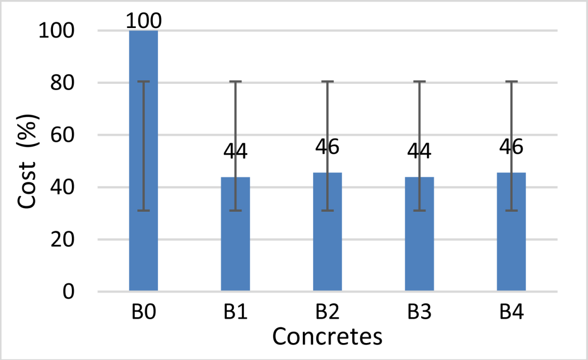


Figure 22. Influence of distance from quarry 2 on concrete costs.

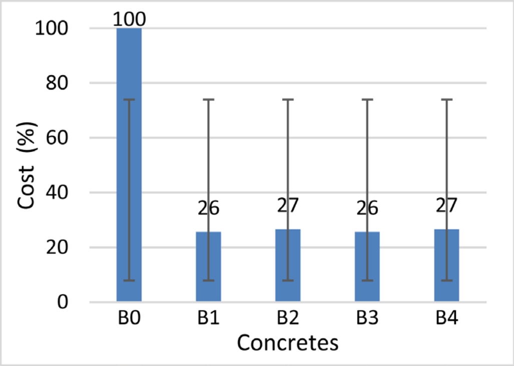


Figure 23. Influence of distance from quarry 3 on the cost of concrete.

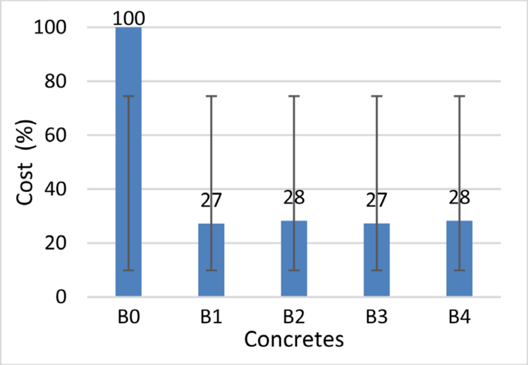


Figure 24. Influence of distance from quarry 4 on concrete costs.

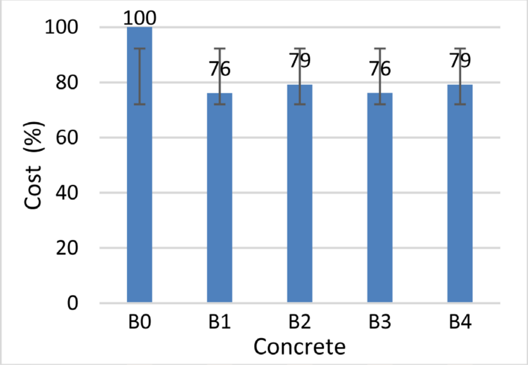


Figure 25. Influence of distance from quarry 5 on the cost of concrete.

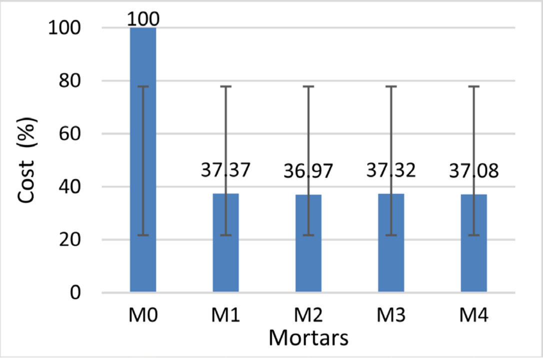


Figure 26. Influence of distance from quarry 1 on the cost of mortar.

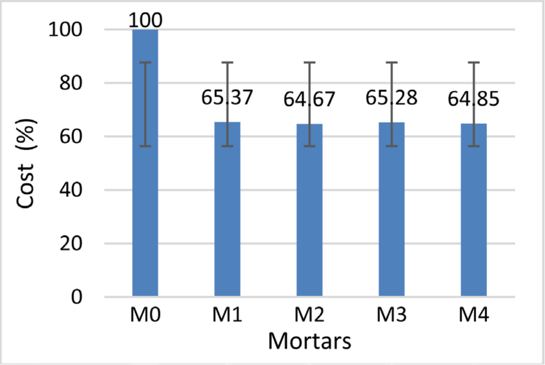


Figure 27. Influence of distance from quarry 2 on the cost of mortar.

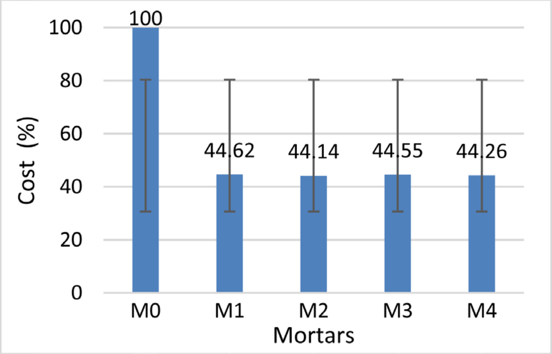


Figure 28. Influence of distance from quarry 3 on the cost of mortar.

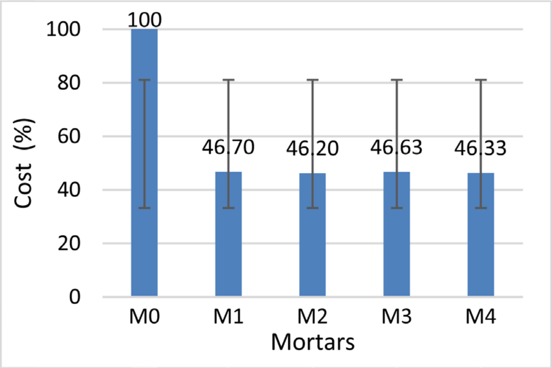


Figure 29. Influence of distance from quarry 4 on mortar costs.

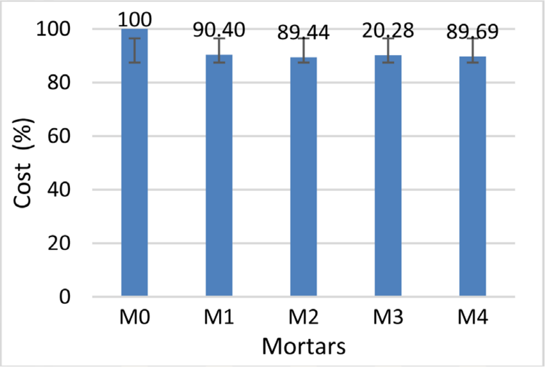


Figure 30. Influence of distance from quarry 5 on mortar costs.

Figures 21-30 show that the distance from the quarries of natural aggregates influences the comparison between the cost of a cubic meter of concrete and mortar. It can be seen that the cost of a cubic meter of concrete varies between 26% and 79% of the cost of the reference concrete, depending on the distance from the quarries from which the conventional aggregates are taken. The cost of mortar made from coltan waste is between 36.97% and 90.4% of the cost of reference mortar, depending on the distance from which the aggregates are taken. This difference is justified by the fact that the distance between the aggregate quarry and the construction site entails transport costs. As natural aggregates are extracted at great distances from coltan discharges, transport costs have a direct impact on the total cost of concrete and reference mortars.

4. Conclusions

Coltan is extracted using open-pit mining operations involving drilling and excavation. During mining, coltan produces overburden, waste rock, and tailings, which are removed and deposited in stockpiles. Geologically heterogeneous, they are composed of rocks with particle sizes similar to clays, sands, gravels, and boulders. This study aimed to assess the mechanical strength and the environmental and economic impact of concretes and mortars produced by the total substitution of aggregates by Coltan mine tailings. To achieve this, it was necessary to characterise the coltan waste so that it could be used as aggregates in mortar and concrete respectively. The Dreux Gorisse method was mainly used to obtain concrete with a strength of 20 MPa at 28 days. The mortars were formulated following standard NF P 18-452.

SimaPro software was used to analyse the environmental impact of the mixes. A functional unit (FU) of 1 m^3 of ready-mix concrete and mortar was used to assess the environmental and economic impacts. The total replacement of natural aggregates by coltan tailings and waste rock in the production of concrete and mortar has demonstrated its particular performance. Mortars made with coltan residues showed compressive strengths at 28 days similar to the strength of the reference mortar (29 MPa), with a minimum observed of 25 MPa. The concretes obtained using coltan tailings as sand showed strengths greater than or equal to the expected strengths (20 Mpa) at 28 days. From an environmental point of view, it was found that total substitution of aggregates by coltan tailings in mortar and concrete significantly reduces the negative impact on ecosystem quality, human health, resources and climate change. In economic terms, substituting coltan mining waste for aggregates makes it possible to obtain concretes costing between 26% and 79% of the cost of reference concretes, while the cost of mortar varies between 36.97% and 90.4% of the cost of reference mortar. Future studies could assess the LCA of cementitious materials derived from coltan waste, taking into account their functional environments as well as their end-of-life.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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