Sustainability (Article)

An experimental and environmental evaluation of mortars with recycled demolition waste from a hospital implosion in Rio de Janeiro

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Supplementary Material 1

This electronic supplementary material includes:

- Details concerning the LCA modelling (p.2);
- Details concerning the data used for aggregates (recycled and natural) modelling (p.3);
- Details concerning the data used for the distance transportation modelling (p.3);
- Details concerning the datasets used in SimaPro 8.3 to model the production process of materials (p.4);
- LCA Results - total impacts of the different scenarios for the mortars and aggregates (natural and recycled) (p.4-10).
- References (p.10).

Life Cycle Assessment – Life Cycle Inventory (LCI)

National data based on Brazilian context was employed for the Portland cement. We modelled in SimaPro the high early strength cement considering 90% of clinker, 5% of crushed limestone and 5% of gypsum. The average thermal energy consumption and electricity used in Brazilian cement plants – for clinker and cement production – was adopted according to Global Cement Database on CO_2 and Energy Information [1] and National Energy Balance [2].

Brazilian data about natural aggregates were based on National Industrial Sand Technical Report [3] that presents the energy sources of extraction and processing of natural aggregates in the country. In this procedure, diesel consumption occurs in the sand quarrying and transport operations from the mining fronts to the processing units. In addition, natural gas consumption occurs mainly for drying process, while crushing, sieving, and some other operations demand electricity.

Data from Borghi et al. [4] were used for the recycled aggregates inventory (Table 1), since they collected primary information and the technological processes similarly to Brazilian practices. Only electricity and transportation distances data were modified according to the Brazilian context. The CDW recycling facilities considered the following stages: crushing, metal separation, sieving and mechanical sorting to remove other residues (e.g. wood, paper, and plastic). Then, considering that the first recycling generates 10% of useless material – in principle – we allocated this impact value on the recycling process.

For the transportation of raw materials (cement, natural sand and recycled aggregates) for mortar production and for the quantification of the avoided impacts (waste concrete to inert landfill and sand mine to mortar production factory), three distances were considered (best, intermediate and worst) as presented in Table 2, similar approach performed by [5, 6].

Data from Ecoinvent v. 3.3 were used to cover cement, steel, water, transportation, energy (electricity, diesel and natural gas), and inert landfill operations (Table 3).

Table S1. Inputs used for aggregates modeling.

Aggregates data					
Inputs	Sorting[1]	Plants powered by electricity[1]	Plants fueled by diesel[2]	Natural aggregates extraction[2]	Natural aggregates production[3]
Electric energy consumption (kWh/t)	-	1.13	-	-	9.50
Diesel consumption (l/t)	0.97	0.25	0.64	0.39	0.41
Natural gas (m^3/t)	-	-	-	-	4.90
Water consumption (l/t)	-	-	1.56	-	0.46
Steel consumption (kg/t)	-	0.02	0.02	-	-
Recovery efficiency	-	99.8%	99.3%	-	-

[1]Hossain et al. (2016)
[2]Borghi et al., (2018)
[3]Geologia et al. (2010)

Table S2. Distance of transportation considered in the modeling.

	Best- Min (km)	Intermediate - Med (km)	Worst - Max (km)
Cement plant to mortar production factory	100	200	400
Sand mine to mortar production factory	50	100	200
Demolition site (on-sorting of CDW waste) to recycling plant	50	100	200
Recycling plant to mortar production factory	50	100	200
Waste concrete to inert landfill [Avoided impact]	60	40	20
Sand mine to mortar production factory [Avoided impact]	50	100	200

Table S3. Ecoinvent v. 3.3 datasets used in the LCA modelling.

Inputs	Datasets
Cement	Clinker production (Clinker {GLO}), Crushed limestone (Limestone, crushed, for mill {GLO}, gypsum (Gypsum, mineral {GLO})
Water	Tap water {GLO}
Steel	Ferromanganese, high coal, 74,5% Mn {GLO}
Transportation	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}
Electricity	Electricity, medium voltage {BR}
Diesel	Diesel, burned in building machine {GLO}
Natural gas	Heat, district or industrial, natural gas {GLO}
Inert landfill	Inert waste treatment of inert waste {GLO}

Table S4. Mortar REF – LCA results.

Impact category	Unit	MORTAR - REF - CPII - Max	MORTAR - REF - CPII - Med	MORTAR - REF - CPII - Min	MORTAR - REF - CPV - Max	MORTAR - REF - CPV - Med	MORTAR - REF - CPV - Min
Abiotic depletion	kg Sb eq	8.37E-06	8.29E-06	8.25E-06	1.04E-05	1.03E-05	1.03E-05
Abiotic depletion (fossil fuels)	MJ	2.40E+03	1.87E+03	1.61E+03	2.66E+03	2.12E+03	1.86E+03
Global warming (GWP100a)	kg CO2 eq	6.19E+02	5.83E+02	5.64E+02	7.65E+02	7.28E+02	7.10E+02
Ozone layer depletion (ODP)	kg CFC-11 eq	2.57E-05	1.89E-05	1.55E-05	2.81E-05	2.13E-05	1.78E-05
Photochemical oxidation	kg C2H4 eq	1.88E-01	1.83E-01	1.80E-01	2.37E-01	2.31E-01	2.28E-01
Acidification	kg SO2 eq	1.29E+00	1.10E+00	1.01E+00	1.51E+00	1.33E+00	1.24E+00
Eutrophication	kg PO4--- eq	1.99E-01	1.61E-01	1.42E-01	2.29E-01	1.92E-01	1.73E-01

Table S5. Mortar M15 – LCA results for diesel recycling plant.

Impact category	Unit	MORTAR - M15 - Diesel - CPII - Max	MORTAR - M15 - Diesel - CPII - Med	MORTAR - M15 - Diesel - CPII - Min	MORTAR - M15 - Diesel - CPV - Max	MORTAR - M15 - Diesel - CPV - Med	MORTAR - M15 - Diesel - CPV - Min
Abiotic depletion	kg Sb eq	8.25E-06	8.17E-06	8.12E-06	1.03E-05	1.02E-05	1.01E-05
Abiotic depletion (fossil fuels)	MJ	2.37E+03	1.82E+03	1.54E+03	2.62E+03	2.07E+03	1.79E+03
Global warming (GWP100a)	kg CO2 eq	6.17E+02	5.79E+02	5.60E+02	7.62E+02	7.24E+02	7.05E+02
Ozone layer depletion (ODP)	kg CFC-11 eq	2.55E-05	1.84E-05	1.48E-05	2.79E-05	2.08E-05	1.72E-05
Photochemical oxidation	kg C2H4 eq	1.88E-01	1.82E-01	1.79E-01	2.37E-01	2.31E-01	2.28E-01
Acidification	kg SO2 eq	1.28E+00	1.09E+00	9.94E-01	1.50E+00	1.31E+00	1.22E+00
Eutrophication	kg PO4--- eq	1.97E-01	1.58E-01	1.39E-01	2.28E-01	1.89E-01	1.69E-01

Table S6. Mortar M15 – LCA results for electricity recycling plant.

Impact category	Unit	MORTAR - M15 - Electricity - CPII - Max	MORTAR - M15 - Electricity - CPII - Med	MORTAR - M15 - Electricity - CPII - Min	MORTAR - M15 - Electricity - CPV - Max	MORTAR - M15 - Electricity - CPV - Med	MORTAR - M15 - Electricity - CPV - Min
Abiotic depletion	kg Sb eq	8.25E-06	8.17E-06	8.12E-06	1.03E-05	1.02E-05	1.01E-05
Abiotic depletion (fossil fuels)	MJ	2.37E+03	1.82E+03	1.54E+03	2.62E+03	2.07E+03	1.79E+03
Global warming (GWP100a)	kg CO2 eq	6.17E+02	5.79E+02	5.60E+02	7.62E+02	7.24E+02	7.05E+02
Ozone layer depletion (ODP)	kg CFC-11 eq	2.55E-05	1.84E-05	1.48E-05	2.79E-05	2.08E-05	1.72E-05
Photochemical oxidation	kg C2H4 eq	1.88E-01	1.82E-01	1.79E-01	2.37E-01	2.31E-01	2.28E-01
Acidification	kg SO2 eq	1.28E+00	1.09E+00	9.94E-01	1.50E+00	1.31E+00	1.22E+00
Eutrophication	kg PO4--- eq	1.97E-01	1.58E-01	1.39E-01	2.28E-01	1.89E-01	1.69E-01

Table S7. Mortar M25 – LCA results for diesel recycling plant.

Impact category	Unit	MORTAR - M25 - Diesel - CPII - Max	MORTAR - M25 - Diesel - CPII - Med	MORTAR - M25 - Diesel - CPII - Min	MORTAR - M25 - Diesel - CPV - Max	MORTAR - M25 - Diesel - CPV - Med	MORTAR - M25 - Diesel - CPV - Min
Abiotic depletion	kg Sb eq	8.13E-06	8.09E-06	8.04E-06	1.02E-05	1.01E-05	1.01E-05
Abiotic depletion (fossil fuels)	MJ	2.05E+03	1.79E+03	1.50E+03	2.60E+03	2.04E+03	1.75E+03
Global warming (GWP100a)	kg CO2 eq	5.95E+02	5.77E+02	5.57E+02	7.61E+02	7.22E+02	7.02E+02
Ozone layer depletion (ODP)	kg CFC-11 eq	2.15E-05	1.81E-05	1.44E-05	2.77E-05	2.05E-05	1.68E-05
Photochemical oxidation	kg C2H4 eq	1.84E-01	1.81E-01	1.78E-01	2.36E-01	2.30E-01	2.27E-01
Acidification	kg SO2 eq	1.17E+00	1.08E+00	9.81E-01	1.50E+00	1.30E+00	1.21E+00
Eutrophication	kg PO4--- eq	1.75E-01	1.57E-01	1.36E-01	2.27E-01	1.87E-01	1.67E-01

Table S8. Mortar M25 – LCA results for electricity recycling plant.

Impact category	Unit	MORTAR - M25 - Electricity - CPII - Max	MORTAR - M25 - Electricity - CPII - Med	MORTAR - M25 - Electricity - CPII - Min	MORTAR - M25 - Electricity - CPV - Max	MORTAR - M25 - Electricity - CPV - Med	MORTAR - M25 - Electricity - CPV - Min
Abiotic depletion	kg Sb eq	8.17E-06	8.09E-06	8.04E-06	1.02E-05	1.01E-05	1.01E-05
Abiotic depletion (fossil fuels)	MJ	2.35E+03	1.79E+03	1.50E+03	2.60E+03	2.04E+03	1.75E+03
Global warming (GWP100a)	kg CO2 eq	6.16E+02	5.77E+02	5.57E+02	7.61E+02	7.22E+02	7.02E+02
Ozone layer depletion (ODP)	kg CFC-11 eq	2.54E-05	1.81E-05	1.44E-05	2.77E-05	2.05E-05	1.68E-05
Photochemical oxidation	kg C2H4 eq	1.87E-01	1.81E-01	1.78E-01	2.36E-01	2.30E-01	2.27E-01
Acidification	kg SO2 eq	1.27E+00	1.08E+00	9.81E-01	1.50E+00	1.30E+00	1.21E+00
Eutrophication	kg PO4--- eq	1.96E-01	1.57E-01	1.36E-01	2.27E-01	1.87E-01	1.67E-01

Table S9. Mortar M50 – LCA results for diesel recycling plant.

Impact category	Unit	MORTAR - M50 - Diesel - CPII - Max	MORTAR - M50 - Diesel - CPII - Med	MORTAR - M50 - Diesel - CPII - Min	MORTAR - M50 - Diesel - CPV - Max	MORTAR - M50 - Diesel - CPV - Med	MORTAR - M50 - Diesel - CPV - Min
Abiotic depletion	kg Sb eq	7.98E-06	7.89E-06	7.84E-06	1.00E-05	9.91E-06	9.86E-06
Abiotic depletion (fossil fuels)	MJ	2.30E+03	1.70E+03	1.39E+03	2.55E+03	1.95E+03	1.65E+03
Global warming (GWP100a)	kg CO2 eq	6.12E+02	5.71E+02	5.50E+02	7.57E+02	7.16E+02	6.95E+02
Ozone layer depletion (ODP)	kg CFC-11 eq	2.50E-05	1.73E-05	1.34E-05	2.74E-05	1.97E-05	1.57E-05
Photochemical oxidation	kg C2H4 eq	1.87E-01	1.80E-01	1.77E-01	2.36E-01	2.29E-01	2.26E-01
Acidification	kg SO2 eq	1.26E+00	1.05E+00	9.48E-01	1.48E+00	1.28E+00	1.17E+00
Eutrophication	kg PO4--- eq	1.94E-01	1.52E-01	1.30E-01	2.25E-01	1.83E-01	1.61E-01

Table S10. Mortar M50 – LCA results for electricity recycling plant.

Impact category	Unit	MORTAR - M50 - Electricity - CPII - Max	MORTAR - M50 - Electricity - CPII - Med	MORTAR - M50 - Electricity - CPII - Min	MORTAR - M50 - Electricity - CPV - Max	MORTAR - M50 - Electricity - CPV - Med	MORTAR - M50 - Electricity - CPV - Min
Abiotic depletion	kg Sb eq	7.93E-06	7.88E-06	7.83E-06	1.00E-05	9.91E-06	9.86E-06
Abiotic depletion (fossil fuels)	MJ	2.00E+03	1.70E+03	1.39E+03	2.55E+03	1.95E+03	1.65E+03
Global warming (GWP100a)	kg CO2 eq	5.91E+02	5.71E+02	5.49E+02	7.57E+02	7.16E+02	6.95E+02
Ozone layer depletion (ODP)	kg CFC-11 eq	2.11E-05	1.73E-05	1.34E-05	2.74E-05	1.97E-05	1.57E-05
Photochemical oxidation	kg C2H4 eq	1.84E-01	1.80E-01	1.77E-01	2.36E-01	2.29E-01	2.26E-01
Acidification	kg SO2 eq	1.15E+00	1.05E+00	9.48E-01	1.48E+00	1.28E+00	1.17E+00
Eutrophication	kg PO4--- eq	1.73E-01	1.52E-01	1.30E-01	2.25E-01	1.83E-01	1.61E-01

Table S11. Natural and recycled aggregates – LCA results.

Impact category	Unit	Natural aggregate - Max	Natural aggregate - Med	Natural aggregate - Min	Recycled aggregate - Diesel - Max	Recycled aggregate - Diesel - Med	Recycled aggregate - Diesel - Min	Recycled aggregate - Electricity - Max	Recycled aggregate - Electricity - Med	Recycled aggregate - Electricity - Min
Abiotic depletion	kg Sb eq	1.65E-10	1.33E-10	1.18E-10	-5.65E-10	-6.19E-10	-6.49E-10	-5.69E-10	-6.23E-10	-6.53E-10
Abiotic depletion (fossil fuels)	MJ	5.94E-01	3.93E-01	2.93E-01	4.48E-01	1.07E-01	-8.31E-02	4.47E-01	1.06E-01	-8.46E-02
Global warming (GWP100a)	kg CO2 eq	4.07E-02	2.69E-02	2.00E-02	3.02E-02	6.68E-03	-6.44E-03	3.01E-02	6.58E-03	-6.54E-03
Ozone layer depletion (ODP)	kg CFC-11 eq	6.78E-09	4.20E-09	2.91E-09	6.00E-09	1.61E-09	-8.45E-10	5.98E-09	1.59E-09	-8.65E-10
Photochemical oxidation	kg C2H4 eq	5.89E-06	3.75E-06	2.68E-06	3.79E-06	1.60E-07	-1.87E-06	3.78E-06	1.43E-07	-1.89E-06
Acidification	kg SO2 eq	1.73E-04	1.05E-04	7.04E-05	1.34E-04	1.73E-05	-4.78E-05	1.33E-04	1.64E-05	-4.86E-05
Eutrophication	kg PO4-- eq	3.42E-05	2.00E-05	1.29E-05	2.84E-05	4.30E-06	-9.15E-06	2.82E-05	4.10E-06	-9.35E-06

Table S12. Natural aggregate – Detailed LCA results.

Impact category	Unit	Total	Diesel	Electricity	Tap water	Natural gas	Transport
Abiotic depletion	kg Sb eq	1.33E-10	7.65E-11	2.02E-11	2.45E-13	4.85E-12	3.15E-11
Abiotic depletion (fossil fuels)	MJ	3.93E-01	3.63E-02	2.27E-02	2.40E-06	1.34E-01	2.01E-01
Global warming (GWP100a)	kg CO2 eq	2.69E-02	2.48E-03	2.28E-03	2.30E-07	8.36E-03	1.38E-02
Ozone layer depletion (ODP)	kg CFC-11 eq	4.20E-09	4.66E-10	1.79E-10	1.37E-14	9.71E-10	2.58E-09
Photochemical oxidation	kg C2H4 eq	3.75E-06	4.60E-07	4.26E-07	4.53E-11	7.26E-07	2.14E-06
Acidification	kg SO2 eq	1.05E-04	1.93E-05	9.12E-06	1.09E-09	7.71E-06	6.85E-05
Eutrophication	kg PO4--- eq	2.00E-05	4.20E-06	8.02E-07	1.13E-10	8.65E-07	1.42E-05

Table S13. Recycled aggregate – diesel recycling plant – Detailed LCA results.

Impact category	Unit	Total	Diesel	Transport	Tap water	Inert landfill [AVOIDED]	Sand [AVOIDED]	Transport [AVOIDED]
Abiotic depletion	kg Sb eq	-6.19E-10	1.54E-11	4.73E-11	9.80E-14	-1.63E-10	-5.07E-10	-1.26E-11
Abiotic depletion (fossil fuels)	MJ	1.07E-01	7.31E-03	3.01E-01	9.61E-07	-7.72E-02	-4.33E-02	-8.02E-02
Global warming (GWP100a)	kg CO2 eq	6.68E-03	4.99E-04	2.07E-02	9.19E-08	-5.26E-03	-3.75E-03	-5.52E-03
Ozone layer depletion (ODP)	kg CFC-11 eq	1.61E-09	9.39E-11	3.87E-09	5.46E-15	-9.91E-10	-3.35E-10	-1.03E-09
Photochemical oxidation	kg C2H4 eq	1.60E-07	9.27E-08	3.21E-06	1.81E-11	-9.78E-07	-1.30E-06	-8.55E-07
Acidification	kg SO2 eq	1.73E-05	3.89E-06	1.03E-04	4.35E-10	-4.10E-05	-2.09E-05	-2.74E-05
Eutrophication	kg PO4--- eq	4.30E-06	8.46E-07	2.12E-05	4.50E-11	-8.92E-06	-3.20E-06	-5.66E-06

Table S14. Recycled aggregate – electricity recycling plant – Detailed LCA results.

Impact category	Unit	Total	Diesel	Electricity	Transport	Inert landfill [AVOIDED]	Sand [AVOIDED]	Transport [AVOIDED]
Abiotic depletion	kg Sb eq	-6.23E-10	1.17E-11	2.13E-13	4.73E-11	-1.63E-10	-5.07E-10	-1.26E-11
Abiotic depletion (fossil fuels)	MJ	1.06E-01	5.55E-03	2.39E-04	3.01E-01	-7.72E-02	-4.33E-02	-8.02E-02
Global warming (GWP100a)	kg CO2 eq	6.58E-03	3.78E-04	2.40E-05	2.07E-02	-5.26E-03	-3.75E-03	-5.52E-03
Ozone layer depletion (ODP)	kg CFC-11 eq	1.59E-09	7.13E-11	1.88E-12	3.87E-09	-9.91E-10	-3.35E-10	-1.03E-09
Photochemical oxidation	kg C2H4 eq	1.43E-07	7.03E-08	4.49E-09	3.21E-06	-9.78E-07	-1.30E-06	-8.55E-07
Acidification	kg SO2 eq	1.64E-05	2.95E-06	9.59E-08	1.03E-04	-4.10E-05	-2.09E-05	-2.74E-05
Eutrophication	kg PO4--- eq	4.10E-06	6.41E-07	8.44E-09	2.12E-05	-8.92E-06	-3.20E-06	-5.66E-06

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