Assessing the impact of selective demolition techniques on C&D waste management

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Abstract. Construction and demolition (C&D) waste is one of the heaviest and most voluminous waste streams generated nowadays in the world. Improper management of C&D waste often results in considerable environmental impacts. This study investigates the potential environmental impacts related to the end-of-life stage of buildings, focusing on how the use of different demolition techniques can influence the performances of the entire system of waste management. The main aim is to investigate if and how the environmental impacts associated to the selective demolition, that may be even higher than the ones associated to traditional techniques, are compensated by the benefits deriving from the waste recovery, reuse and recycling, that selective demolition is expected to maximize. The Life Cycle Assessment methodology is used to analyse and compare different scenarios: a selective demolition scenario for a residential building is compared with a traditional demolition one. Primary site-specific data supplied by demolition companies has been used. Indeed, unexpectedly, the selective demolition scenario results worse than the traditional one. Actions to improve the selective demolition have thus been identified.

1. Introduction

Construction and demolition (C&D) waste is one of the heaviest and most voluminous waste streams generated in the European Union (EU). It accounts for approximately 25% - 30% of all waste generated in the EU [1] and consists of numerous materials, including concrete, bricks, gypsum, wood, glass, metals, plastic, solvents, asbestos and excavated soil. C&D waste arises from activities such as the construction of buildings and civil infrastructure, total or partial demolition of buildings and civil infrastructure, road planning and maintenance.

Composition and quantity can vary considerably according to different factors, as the type of activity that generates the waste (construction or demolition), the characteristics of the yard, and the construction and/or demolition techniques. For example, C&D waste coming from construction activities of new buildings or infrastructure results to be more homogeneous and less contaminated, and consequently more suitable for recovery, than C&D waste coming from demolition activities, especially when traditional non-selective demolition techniques are adopted [1].

This study focuses on how the use of different demolition techniques can influence the performances of the system under analysis in terms of environmental and energetic resources consumption, through a Life Cycle Assessment (LCA) analysis.
2. Selective demolition

Selective demolition is also known as “construction in reverse”, as it is a real process of deconstruction of the activity that has led to the realization of the building. It consists in the selective dismantling of the building components to obtain the separation and sorting of valuable building materials as bricks, windows, tiles.

The practice of selective demolition facilitates the recycling of building materials that can be stripped and removed from the structure, before the demolition work is executed. The goal is to reuse the recovered materials, minimize the burden on municipal landfills and public filling areas by reducing overall waste generation, and thus, benefit the environment [2]. Most of the recovered materials may be sold or recycled depending on the circumstances of the job and the market value of the products to be recycled, allowing savings from waste disposal and landfilling charges and reducing demolition project costs. In technical terms, selective demolition or deconstruction is generally classified into two categories: demolition of structural elements and deconstruction of non-structural elements (also known as soft-stripping).

The main aims of this type of demolition are obtaining mono-material fractions suitable for the treatment in special recycling facilities, that allow the exploitation of waste as secondary raw materials; concretely increasing the level of recyclability of the waste generated on the demolition site whatever it is the original configuration of the building; maximizing the quality of the material obtainable from recycling.

Despite requiring more time and labour to be employed as compared to demolition, deconstruction ensures that the recovered materials are at least recycled to take the form of valuable inputs for other materials, resulting in their longer lifespan. However, in practice, deconstruction is perceived to be more expensive, difficult to apply across the unique characteristics of buildings, and more complex in terms of stakeholders' decisions and planning efforts. As a result, demolition is often preferred over deconstruction by many owners and contractors [3].

3. LCA applied to the selective demolition of a residential building

3.1. Goal and scope

This study aims to analyze the environmental impacts associated to the selective demolition of a residential building. The analysis is intended to be included in a wider project carried out by the AWARE (Assessment on Waste and Resources) research team of the Department of Civil and Environmental Engineering of Politecnico di Milano, in collaboration with Regione Lombardia. Purpose of this project was to evaluate the environmental performance of the non-hazardous C&D waste management system, focusing in particular on the inert fraction, implemented in Lombardy region in the year 2014. The results of this analysis underlined how nowadays the inert fraction of C&D waste gives origin to low quality aggregates, able to be used in substitution just of the natural raw soil (it is intended as the unprocessed material extracted from quarries) [4]. Different possible actions were proposed, to try to improve the overall management system and decrease the associated environmental benefits. Among these ones, the belief that switching from traditional demolition techniques to selective ones could give a significant incentive to the separation of waste at the source and the consequent production of inert C&D waste cleaner and suitable for the recycling in nobler applications, in substitution of natural aggregates, with all the deriving benefits in terms of avoided environmental impacts [4].

This is what the present study wants to investigate, focusing on a real case study, to evaluate the environmental impacts associated to the selective demolition, preceded by a strip-out step, of a residential building, later compared with the impacts associated to a fictitious traditional demolition applied to the same building.

The system boundaries include all the processes involved in the strip out and demolition phases, from the consumptions associated to the use of the mechanical equipment, through the generation of the different waste flows, their storage and subsequent treatments, up to their outlet from the system as
emissions (solid, liquid or gaseous) or as secondary raw materials, as shown in Figure 1. To deal with multi-functionality issues, the chosen approach is the system expansion one, which includes in the analysis also the avoided productions thanks to the recovery of secondary resources. The chosen functional unit is 1 m² of demolished surface, in order to allow the comparison with others literature studies.

![Figure 1. System boundaries of the present LCA analysis.](image)

The LCA analysis was carried out with the SimaPro 8.5 software and the ecoinvent 3.3 database for the background processes, combining two different characterisation methods: one for the environmental impacts evaluation (ILCD 2011 Midpoint) [5] and the other for the energy consumption estimation (CED) [6].

3.2 Inventory data
The present case study aims to analyse the demolition of a residential building located in Milan, via Moscova 33. The demolition works, performed by the Corbat Srl company, started in October 2018 and are expected to be concluded in spring 2019. It is a four-story building, with the presence of an additional basement, of recent construction. The overall surface to demolish is of 7,000 m², for a total volume of 10,000 m³.

The strip-out was already performed by another company, which executed the removal of hazardous components and of all the common equipment/elements such as hydraulic systems, heating/cooling systems, internal glazing, furniture, and so on. Thus Corbat has to deal only with the non-structural selective demolition, which implies the separation of all the construction elements to strip the load-bearing structures, and the structural selective demolition, which means that partitions, substrates, etc. are removed before starting the demolition of the load-bearing parts.

The strip-out took about two months and it was carried out mainly manually; data concerning the amount of waste fractions produced during this preliminary phase and their final destinations were provided by the Ambeco Srl company, which was in charge of the strip-out.

Provided data about the waste streams produced during the demolition phase represent the waste produced up to the completion of the 25% of the overall demolition; thus, the data used in this study are the result of an estimation, done projecting those data up to the end of the demolition phase. For this purpose, data regarding wood, iron, plastic and mixed waste streams were simply multiplied by four to obtain the overall amount of materials produced, while the total mixed inert materials were calculated subtracting the sum of these streams to the total amount of waste estimated by the demolition company, to take into account that part of them, when the data have been provided, were stored in the yard waiting to be sent to treatments. Corbat Srl company provided also data regarding diesel and electric machineries used in the demolition phase.

As regard the waste transportation, which was carried out with Euro 6 diesel trucks, the distances were estimated considering the yard location and the intermediate and final destinations of the different waste streams.
Moreover, to model the baseline scenario, two assumptions were done. The first concerns the selection efficiencies: iron and steel, aluminium, wood and glass, before being sent to recycling, undergo a selection step, thanks to which the different streams are separated from impurities and unwanted particles, which could affect the recycling process itself. In absence of primary data, the efficiencies of selection for the different materials are considered, in the first instance, equal to the efficiencies associated with the selection of waste streams coming from the urban collection [7]. Table 1 reports the considered values.

| Material   | Selection efficiencies (urban collection) |
|------------|------------------------------------------|
| Iron and steel | 94%                                      |
| Aluminium  | 95%                                      |
| Wood       | 90.7%                                    |
| Glass      | 94.7%                                    |

The second main assumption regards a key point for the evaluation of the avoided environmental impacts related to materials recycled: the definition of the substitution factor, which quantify which is the amount of virgin material that could be substituted by a certain amount of recycled product. In fact, as reported in the ISO standard 14044, changes in the intrinsic properties of the substances, due to the recycling activities, must be taken into account. Table 2 shows the different substitution factors chosen for the analysis [5].

| Material   | Secondary product   | Primary product       | Substitution ratio |
|------------|---------------------|-----------------------|--------------------|
| Steel      | Liquid steel        | Liquid steel          | 1:1                |
| Aluminium  | Aluminium scrap     | Al 99.7               | 1:0.70 [8]         |
| Glass      | Packaging glass     | Packaging glass       | 1:1                |
| Wood       | Particle board      | Plywood               | 1:0.6              |

4. Results and discussion

4.1. Baseline scenario

In Table 3, the values that the impact indicators assume in the baseline scenario are reported, underlying the contribution coming from the strip-out phase and the selective demolition one.

Figure 2 and Figure 3 show graphically, to facilitate the interpretation, the impacts associated respectively to the strip-out and the selective demolition phases, pointing out which are the contributions of the single process involved in the study.
Table 3. Impact indicators resulting from the analysis of the baseline scenario.

| Environmental impact categories (ILCD method): | Unit | Total   | Strip out | Selective demolition |
|-----------------------------------------------|------|---------|-----------|----------------------|
| Climate change                                | kg CO₂,eq | 7.86    | -8.27     | 1.61E+01             |
| Ozone depletion                                | kg CFC-11 eq | 1.27E-05 | 2.54E-07  | 1.24E-05             |
| Human toxicity, non-cancer effects             | CTUₘ | 2.00E-05 | 2.10E-06  | 1.79E-05             |
| Human toxicity, cancer effects                 | CTUₘ | 1.64E-04 | 1.35E-05  | 1.50E-04             |
| Particulate matter                             | kg PM₂.₅ eq | 4.91E-02 | 1.23E-02  | 3.68E-02             |
| Photochemical ozone formation                  | kg NMVOC<sub>eq</sub> | 4.68E-01 | 3.99E-03  | 4.64E-01             |
| Acidification                                  | molH⁺,eq | 7.03E-01 | 3.79E-01  | 3.24E-01             |
| Terrestrial eutrophication                     | molN<sub>eq</sub> | 1.81     | -8.06E-02 | 1.89                 |
| Freshwater eutrophication                      | kg P<sub>eq</sub> | -7.78E-02 | -1.04E-02 | -6.74E-02            |
| Marine eutrophication                          | kg N<sub>eq</sub> | 1.85E-01  | -8.05E-03 | 1.93E-01             |
| Freshwater ecotoxicity                         | CTUₜ | 5.12E+03 | 3.56E+02  | 4.77E+03             |
| Water resource depletion                       | m³ water<sub>eq</sub> | 2.14     | 7.75E-02  | 2.06                 |
| Mineral and fossil resource depletion          | kg Sb<sub>eq</sub> | 1.70E-06  | 2.35E-05  | -2.18E-05            |
| Energetic indicator (CED)                      | MJ   | 186.41   | -148.60   | 335.01               |

Figure 2. Impacts associated to the strip-out phase in the baseline scenario.
As clear from Table 3, the impact indicators have almost all positive sign, except for the freshwater eutrophication. This means that the impact associated to the strip-out phase, where most of the material streams enter the recycling chain, are not able to compensate the impacts of the selective demolition phase, that are mainly positive, strongly depending from the use of diesel and electric machinery and from the disposal of plastic and mixed waste in landfill, at least in this baseline scenario.

In the strip-out phase, significant positive contributions come from the disposal in landfill of plasterboard, that nowadays still present several issue concerning the recycling. The main benefits come, instead, from the metals recycling, even if iron and steel recycling presents very big impacts in the category of human toxicity (cancer effects) and freshwater ecotoxicity, mainly due to the disposal of steel scraps from the recycling, linked to the leaching of Chromium VI. The same considerations can be done for iron and steel coming from the selective demolition phase, whose recycling represent the unique significant benefit.

4.2. Ideal scenario
Starting from the baseline scenario, thus the one actually implemented in the reality, an ideal scenario was built, resulting from the combination of several improvement actions.

In this alternative scenario, the selection efficiencies are considered to be the maximum ones (100% for all the fluxes), plasterboard is sent to recycling (instead of disposal in landfill) and plastic and mixed waste undergo an incineration process (again instead of disposal in landfill).

In this way, it is possible to analyse which would be the environmental impacts and the energy resources consumption if all these improvement actions will be implemented in the reality. Results are being processed and they will be presented during the convention.
4.3. Traditional demolition scenario

The baseline scenario is then compared with a fictitious scenario where the same analysed building is supposed to be demolished with traditional techniques. This analysis aims to investigate the differences between selective and traditional demolition, in term of environmental impacts and energetic resources consumption, underlying the strengths and weaknesses of each scenario.

From the responses of some companies of the demolition sector, what arises is that, even if the demolition implemented is not selective, very often iron and steel are separated from the other mixed waste, mainly due to economic reasons, because the revenues for the company associated with the gate fees applied by the plants that withdraw this kind of waste is very remarkable (200 €/t).

In the traditional demolition scenario, this fact was taken into account, but not all the iron and steel were considered to be suitable for the separation and, consequently, for the recycling. The iron and steel fraction that in the baseline scenario are associated with the strip-out phase, indeed, are considered to require a manual intervention for the separation at the demolition site and so it is unfair to suppose that this part of material can be separated during traditional demolition operations. This is why only the iron and steel that in the baseline scenario come from the selective demolition phase are considered to be separated and sent to recycling.

Everything is not iron, in this traditional demolition scenario is supposed to go to constitute the mixed inert materials stream, that in this case has a high presence of impurities which make it suitable only for the substitution of natural raw soil, after checking the compliance with legislation limits. Considering the Circolare Ministeriale 5205/2005, dealing with percentage limits of extraneous fractions in the final aggregates, some legislation limits are not complied (limits on the presence of plasterboard and wood). Thus, to have the possibility to really use this material as secondary raw material, a further more intense selection step is required (whose impacts are estimated and accounted for).

In table 4 the values that the impact indicators assume in the traditional demolition scenario are reported whereas Figure 4 shows the results in a graphic form, underlying the contributions of the different processes involved.

Also for this scenario, what is clear is that most of the impact categories results with a positive sign, except for the freshwater eutrophication and mineral and fossil resource depletion categories. In this scenario, the only benefits come from the iron and steel recycling, even if the impacts associated to this process in the human toxicity (cancer effects) and freshwater ecotoxicity are still very high. As regard the mixed inert materials, what can be seen is that the impacts associated to their recycling increase, due to the changing in the avoided product: while in the baseline scenario, mixed inert coming from the demolition phase are considered sufficiently clean to be used in substitution of natural aggregates, here they are assumed suitable only for the substitution of a less refined product, so the resulting avoided impacts are lower.

In table 4, a comparison between the resulting total values of the impact indicators for the baseline scenario and the traditional demolition one is reported. What can be seen is that the baseline scenario results worse than the traditional one for most of the impact indicators.

Except for the freshwater eutrophication and for the CED indicator, all the other impacts seem to decrease in the fictitious scenario with respect the real one, probably due to the fact that the benefits coming from the recycling of the materials in the strip-out phase are not sufficiently consistent to compensate the impacts coming from the processes of disposal of plasterboard, plastic and mixed waste, that in this second case are treated together with the mixed inert materials, sending them to recycling to produce a secondary raw materials to be used in substitution of the natural raw soil.
**Figure 4.** Contribution analysis of the impacts associated to the traditional fictitious scenario.

**Table 4.** Comparison between indicators resulting from the baseline and the traditional demolition scenarios evaluation.

| Environmental impact categories (ILCD method): | Unit | Traditional scenario | Baseline scenario | Percentage variation |
|-----------------------------------------------|------|----------------------|-------------------|----------------------|
| Climate change                                | kg CO$_2$ eq | 6.97 | 7.86 | 12.89% |
| Ozone depletion                               | kg CFC-11 eq | 1.20E-05 | 1.27E-05 | 5.47% |
| Human toxicity, non-cancer effects            | CTU$_h$ | 9.63E-06 | 2.00E-05 | 107.40% |
| Human toxicity, cancer effects                | CTU$_h$ | 1.50E-04 | 1.64E-04 | 8.75% |
| Particulate matter                            | kg PM$_{2.5}$ eq | 4.39E-02 | 4.91E-02 | 11.67% |
| Photochemical ozone formation                 | kg NMVOC$_{eq}$ | 3.83E-01 | 4.68E-01 | 22.21% |
| Acidification                                 | molH$^+$ eq | 4.45E-01 | 7.03E-01 | 57.82% |
| Terrestrial eutrophication                    | molN$_{eq}$ | 1.53 | 1.81 | 18.40% |
| Freshwater eutrophication                     | kg P$_{eq}$ | -6.76E-02 | -7.78E-02 | -15.07% |
| Marine eutrophication                         | kg N$_{eq}$ | 1.28E-01 | 1.85E-01 | 44.74% |
| Freshwater ecotoxicity                        | CTU$_e$ | 4247.06 | 5124.99 | 20.67% |
| Water resource depletion                      | m$^3$water$_{eq}$ | 8.52E-01 | 2.14 | 151.00% |
| Mineral and fossil resource depletion         | kg Sb$_{eq}$ | -5.47E-05 | 1.70E-06 | 103.11% |
| Energetic indicator (CED)                     | MJ | 309.58 | 186.41 | -39.79% |
5. Conclusions
The present analysis investigated which are the environmental impacts and the energetic resources consumption associated to the end-of-life stage of a residential building, focusing on how the implementation of different demolition techniques can influence the final results.

Despite the theoretical considerations about the benefits that can result from the selective demolition, that allowing the separation of the waste streams at the source maximizes the recycling potential, the results show a different outcome. Limiting the analysis to the presented case study, what arises is that the selective demolition scenario presents higher environmental impacts than the traditional demolition, and that the recycling of some of the waste streams does not compensate the impacts related to the employment of more mechanical equipment and the ones arising from the disposal in landfill of plasterboard, plastic and mixed waste.

The following step would be the analysis of the ideal scenario and its comparison with the traditional demolition one, to check if an optimal selective demolition practice, which implies the recovery of each waste stream (material recycling where possible and energy recovery elsewhere), is able to compensate the generated impacts, resulting in a total improving of the system under analysis.

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