Recycled aggregate production: remark and assessment of the economical advantage of a case study

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ABSTRACT: Recycled aggregate has been used in Italy to produce structural concrete after the related EU (European Union) directives was implemented at national level.
The use of recycled materials in construction has been scholarly proved to be economically advantageous.
This study focuses on mobile and fixed plants in Italy. The former applies only in case of debris recycling, whereas the latter can be competitive only when the recycling operation is complementary to the quarry activity. Production plants and demolition operations have been therefore investigated to show their technical and economic feasibility in different scenarios.
The outcome of this study is herein presented.

1 INTRODUCTION

Two major factors have been found to have considerably influenced the market of recycled aggregates in Europe and Italy: the EU and national regulations and environmental awareness.

The market of recycled aggregate has grown in countries with limited natural resources.

Waste disposal has also been one of the top EU political and environmental priorities. In the complex interaction between human activities and the environment, waste is proved to be one of the most environment-degrading products.

In 1972 the European Commission introduced measures on waste reduction, reuse and recycling.

In 2006, directive 2006/12/EC (European Commission) on waste was issued. It covers the scope of minimizing the waste, prevent hazardous waste, maximize reclamation, reuse, recycling and energy-recovery.

No specific directive refers to management and recycling of construction and demolition debris. However, in 1992 the European Commission listed debris among waste management priorities because of its growing amount.

Only recently, effective environmental policies have been implemented in Italy, even though relevant environmental issues started rising as early as the beginning of the 1970s.

In the 1980s the Government undertook the first significant measures to handle the waste management.

Because of the too many and dated laws on this regard, a new law was issued in 1982 aiming to provide a comprehensive regulatory frame of the subject: D.P.R. 915/1982 (It: Decreto del Presidente della Repubblica = En: Decree of the President of the Republic). Not only the new law replaced a 1940s law, but it also implemented some EEC (European Economic Community) directives on waste, such as the 75/442/EEC as an attempt to cover the management of different types of waste.

The 1982 law also promoted waste recycling and energy-recovery systems.

D.P.R. 915/1982 was further integrated and amended at different stages:

D.Lgs. n. 22/1997 (It: Decreto legislativo = En: Legislative Decree) also known as “Ronchi decree”, is a rundown of all previous regulations issued until that date, namely: 91/156/EEC on waste; 91/689/EEC on dangerous waste; 94/62/EC on packaging. Ronchi decree was the main regulatory reference on waste management in Italy until 2006.

The decree introduces two new concepts in Italy:

- waste management instead of disposal – to prevent waste production, promote recycling, reuse of energy, and to discourage landfill;
- the encouragement of voluntary agreements among waste management operators to achieve the aforementioned purposes.

A few other laws [Ammendola, G.] were issued in the following years in order to comply with the European regulations. It is worth to mention, the so-called “decree 30%” (Ministerial Decree 203/2003) which was conceived as an attempt to create better market conditions for recycled products.

It sets a minimum target for national and public agencies to meet at least 30% of their annual demand with recycled materials.

Nowadays the D.Lgs. n.152/2006, also known as “Environmental Code”, is the main legislative reference regarding environmental issues.

Its text has been repeatedly amended by means of several implemental decrees, which caused the Code to be not completely applicable due to the coexistence of old and new rules.

With regard to the use of construction and demolition waste (C&D) in the building sector in replacement of raw materials, the first draft for technical standard came up in 1996. In the same years the UNI (Italian National Agency of Unification) “Building Commission” formed Working group 7 also called “Construction and demolition waste” to draw up “Guidelines for decreasing of construction and demolition waste in construction”.

In 2000 the same Commission updated the standard UNI 10006 – “Road construction and maintenance - Technical provisions for the use of soil” thus providing standard instructions about the use of recycled aggregates for road construction.

However, a new norm EN 12620 “Aggregates for concrete” has already replaced it. It is an improvement of the former standards and provides a useful tool to determine characteristics and requirements of the aggregates for concrete.

This one has been further revised and its latest version, UNI 8520, defines the minimum requirements of the aggregate for concrete.

Table 1 shows the limit quantities set in the norm.

Table 1. UNI 8520 limit quantities

Use rate	Source	Strength category
Total or partial use	Demolition of buildings (debris)	≤C12/15
Total or partial use	Demolition of concrete elements	≤C20/25
≤ 10%	Demolition of concrete elements	≥C20/25
≤ 5%	Demolition of buildings (debris)	≥C20/25

In September 2005, D.M. 14.09.2005 (It: Decreto miniteriale = En: Ministerial Decree) named “Technical Norms for construction” was issued. It replaced previous norms and incorporated some European standards such as UNI EN 12620. This law contains important data about how to use recycled aggregates in concrete.

The law says: “...the use of recycled coarse aggregate is allowed according to table 2, provided that the manufactured concrete has undergone laboratory tests...”.

Table 2. Technical norms of constructions – limits for recycled aggregates

Source of recycled material	Cubic compression strength [N/mm^2]	Percentage of use
Demolition of buildings (debris)	< 15	100%
Demolition of concrete or reinforced concrete elements	≤ 35	≤ 30%
	≤ 25	≤ 60%

Reuse within certified prefabrication plants	≤ 55	≤ 5%

2 RECYCLING OF C&D WASTE - STAGES OF PROCESS AND PLANT'S COMPONENTS

There are 5 stages in the recycling process of C&D waste and they are carried out in the following order:

- Coarse separation
- Crushing
- Separation of ferrous elements
- Screening
- Removal of impurity by air separation (if necessary)

During the coarse separation (performed by means of grab or shears) the debris is chopped smaller so as to go smoothly into the crusher inlet. The crushing can be also performed in the following ways:

- Squeezing;
- Impacting;
- Grinding.

To obtain a decreasingly sized product three different crushing stages are performed:

- Primary crushing;
- Secondary crushing;
- Milling.

Granulometry classes are determined during the screening operation. If necessary, impurities like wood, plastic and paper can be removed. Air separation technique is more convenient than the washing separation which is instead more expensive due to the disposal of the washing mud. The process ends with the storage of the products.

The main components of a recycling plant are:

- Crusher;
- Magnetic separator;
- Screen;
- Air classifier (if necessary)

2.1 DESCRIPTION OF A FIXED PLANT

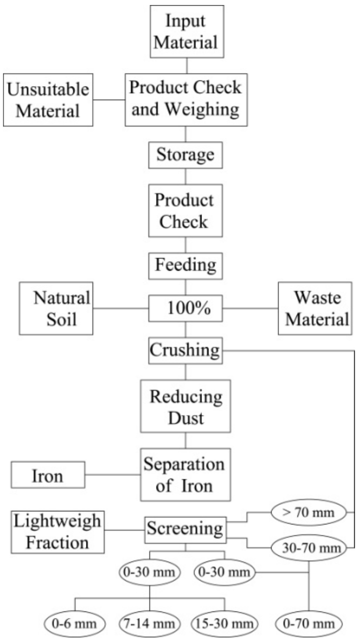

Figure 1. Flowchart of the fixed plant

The flowchart in figure 1 highlights the different stages of the material during the recycling process [Bressi, G.]. The cycle is arranged so as to avoid unsuitable material to be recycled.

Quality and quantity controls are completely automated.

The inlet material is automatically scanned out and discarded if found unsuitable to the set standards.

Three people only can fully control the plant through a video control system.

The inlet material is stored in heaps of the same kind, rolled down into the feeder through a mechanical digger in order to control the size of the inlet material. The whole process is under constant video-camera monitoring so that the rubble is checked out before entering the treatment cycle. The operator can therefore stop the feeding at any time for further checking and decide to discard unsuitable materials. The fine fraction will not be milled, therefore a first screening is carried out through a vibrating screen performs and the coarse material sent to the crusher.

An atomized water system eliminates and collects the dust after the crushing. A magnetic device then separates iron elements and stores them in a metallic box. Ceramic materials are then classed in different granulometry classes (0÷30 mm, 0÷70 mm, >70 mm this one can be crushed once again) thanks to a vibrating screen.

The vibrating screen also separates plastic from wood and paper elements and puts them into a special box.

The 30÷70mm fraction can be either stored or re-sent to the crushing. At the end of the process the different fractions are stored in heaps by a spinning device which minimizes the dust generated during the fall. Another conveyor belt can feed a further screening station which produces 0÷6mm, 6÷15mm and 15÷30mm fractions.

These granulometry classes are then further purified from impurities that are stored in special boxes.

2.2 DESCRIPTION OF MOBILE PLANTS

The mobile plants are mobile or semi-mobile machines sized for the road transport.

These machines are less expensive and easy to handle than the fixed ones, even though less efficient [Quattrone, M. & Basilico, V. 2005].

It is possible to use them inside the demolition site thus avoiding excessive handling of the debris and considerably reducing the cost of transport.

A mobile plant for C&DW recycling is made of:

- a crusher with a magnetic separator in the outlet
- a vibrating screen for the granulometry classification.

These machines are positioned next to each other to make up a recycling station (see figure 2). The crusher and the screen are usually separated.

Nowadays, it is possible to find a single machine with crusher, magnetic separator and screen (see figure 3).

Figure 2. Mobile plant composed by a crusher and a vibrating screen

Figure 3. Mobile plant composed by a single machine with crusher, magnetic separator and vibrating screen

2.3 ECONOMIC FEASIBILITY

The economic feasibility of a recycling station (fixed or mobile) depends on different factors.

This study does not consider the following factors:

- choice of the plant site;
- accessibility and availability of suitable areas;
- analysis of the building activity;
- competitors.

However, the study draws out some lines to invest in a recycling plant.

For either fixed and mobile plants, the following hypothesis can be followed:

- The price of the recycling aggregate is 80% the price of the related natural one;
- The fee to dump the rubble inside the recycling station is 85% the municipal dump fee;
- The plants produce 50% fine aggregate and 50% coarse aggregate, hence the average price of recycled aggregate is:

$$P_{av,rec} = 0.8\times P_{av,nat} = 0.8\times (0.5\times P_{fine,aggr} + 0.5\times P_{coarse,aggr}) = 9.00 \text{ €/t (euros per ton)}$$

- Based on the surveys carried out in different plants, the average quantity of iron scrap is 0.1% the quantity of produced aggregates. It shall be sold at 115 €/t.

For both plants, the net present value (NPV), the profitably index (PI) and the payback period (PP) will be calculated.

2.3.1 ECONOMIC FEASIBILITY – FIXED PLANT

Outlays and proceeds [Brugger, G.]are calculated considering the number of inhabitants N to get to the breakeven point (the minimum number of people needed to have equal proceeds and outlays).

The yearly production of C&DW is about 0.7 t/inhab. (tonnes per person). The output materials, after the recycling treatment, are as follows [Bressi, G. & Puia, P.]:

- $0.693\times N$ t/year (99%) aggregates to sell in the market;
- 6.93×10^{-4} t/year (0.1%) iron elements to sell at the steelyard;
- 7.00×10^{-4} t/year (0.1%) impurities to be disposed of in landfill site;
- 5.60×10^{-3} t/year (0.8%) aggregates unsuitable for commercial use

The breakeven point is equal to 49121 inhabitants (see figure 4). Figure 5 shows the non-discounted cash flow; table 3 shows calculated indicators under the following hypotheses:

- Hp 1: the number of inhabitants is twice N (2 x N);
- Hp 2: the number of inhabitants is three times N (3 x N).

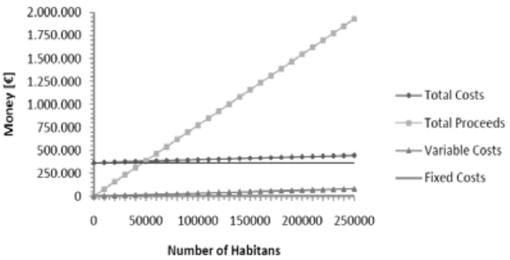

Figure 4. Costs and proceeds to determine the breakeven point

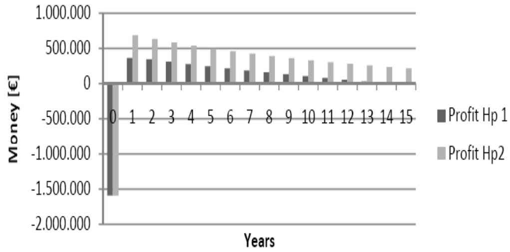

Figure 5. Not discounted cash flows

Table 3. Indicators for fixed plant

	Hypothesis 1	Hypothesis 2
Net Present Value	310.334,14	4.587.917,00
Profitably Index	0,984	1,7
Payback Period	86 months	30 months

Discount rate equal 6% for NPV, PI outlay and PP; discount rate for PI proceeds equal 8%

2.3.2 ECONOMIC FEASIBILITY – MOBILE PLANTS

Investigated mobile plants are shown in the table below.

Table 4. Characteristics of machineries

Plant	Machineries	Average Price [€]
Mobile plant A	Jaw crusher with magnetic separator - weight 30 t Vibrating screen – weight 22 t	420000
Mobile plant B	Double toothed shafts crusher with magnetic separator and vibrating screen – weight 36 t	350000

The following working hypotheses are valid:

- The capacity of the plant is 70% the maximum capacity;
- The value loss is 8% per year calculated with decreasing quotas method;
- The plant works 500 hours per year;
- The capacity of the plant decreases 4% yearly;
- Every machine is operated by one worker (labour cost is 50 € per hour per person).

Figure 6 shows the non-discounted cash flow; indicators are shown in table 5.

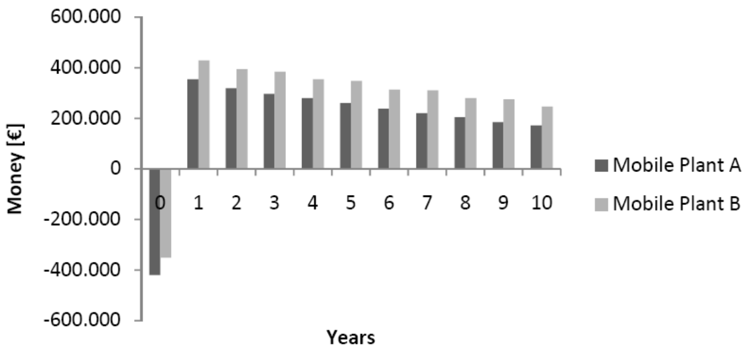

figure 6. Graph of non-discounted cash flows for two types of mobile plants

Table 5. Indicators for mobile plants

	Mobile plant A	Mobile plant B
Net Present Value	1.509.455,55	2.168.732,35
Profitably Index	1,994	3,008
Payback Period	16 months	11 months

Discount rate equal 6% for NPV, PI outlay and PP; discount rate for PI proceeds equal 7,2%

3. PRESENTATION OF STUDIES ON DEMOLITION MODES

Much interest has been lately shown towards the inert fraction (which is about 80% the total C&D waste) to be recycled in the building and civil works. All existing plants (used for collection, recycling and disposal) of metal scraps and lightweight discarded fraction can be used to treat the inert fraction.

To show pros and contras of C&D waste reclamation and reuse, the case study of an abandoned industrial area's renewal, North of Milan, is herein investigated. Prior the construction of new buildings, the old industrial structure must be dismantled. Different hypotheses about the reclamation and recycling of the debris have been formulated along with economic assessments and cost analysis.

There are several warehouses in the area: the old ones, dating back to early XIX century, are disused; the others, built in the 1960s and the 1970s, are still in good conditions.

The area is about 22800 m^2 and the total built volume is 173300 m^3. There are fifteen industrial buildings with a steel structure, lightweight roof (saw-tooth roof and saw-tooth with skylights) and external steel studwalls clad in bricks. Some sheet metal roofing material is used in the upper part of some under-roof external walls.

An inspection has to be performed and records of all the collected data have to be kept in a registry: materials, quantities, classification of elements and different recycling or reclamation methods.

This case study first analyzes how the buildings are knocked down and secondly how the materials are separated.

Economic assessments have been carried out. Costs and proceeds have been compared under the following hypotheses:

A. Building demolition and waste disposal;
B. Building demolition and C&D waste reclamation/recycling.

Table 6. Cost of demolition and disposal of all the waste produced in the hypothesis of their disposal in authorized landfill sites

Cost of demolition		1˙096˙468,00 €
Cost of asbestos-cement slabs disposal		186˙201,60 €
Cost of non-reusable material disposal		5˙167,08 €
Cement, brick debris cod.C.E.R. 17.01.07	57416,56 €	
Concrete - C.E.R. 17.01.07	10622,45 €	
Wood - C.E.R. 17.02.01	8080,45 €	
Plastic - C.E.R. 17.02.03	6572,78 €	
Iron and steel - C.E.R. 17.04.05	-123488,65 €	
Sandwich panels - C.E.R. 17.09.04	23884,00 €	
Difference between relative costs and remaining proceeds due to the disposal of the material products		-16˙912,21 €
	Total	1˙270˙924,47 €

Table 7. Cost of demolition and disposal of all the waste produced in the hypothesis of their disposal to dedicated storage and reclamation sites

Cost of demolition		1˙096˙468,00 €
Cost of asbestos-cement slabs disposal		186˙201,60 €
Cost of removal of some elements		51˙109,52 €
Cost of non-reusable material disposal		5˙167,08 €
Cement, brick debris cod.C.E.R. 17.01.07	-14835,00 €	
Concrete - C.E.R. 17.01.07	-9044,41 €	
Wood - C.E.R. 17.02.01	4150,80 €	
Plastic - C.E.R. 17.02.03	6148,96 €	
Iron and steel (first rate) - C.E.R. 17.04.05	-223142,18 €	
Iron and steel (second rate) – C.E.R. 17.04.05	-73431,16 €	
Sandwich panels - C.E.R. 17.09.04	12811,00 €	
Difference between relative costs and remaining revenues due to the recovery of the material products		-297˙342,37 €
	Total	1˙041˙603,83 €

Thanks to waste reclamation and recycling, 18% of the demolition costs can be cut off.

Disposal and reclamation costs for non-metallic fractions are outlined in table 6. The following operational hypotheses have been considered:

A. All waste are disposed of in authorized landfill sites;

B. All waste are recycled in specific plants;

C. All waste are recycled in specific plants but while inert fractions are crushed in demolition sites.

The metallic fraction is not included because it is always a proceeds.

Table 8. Comparison among the three working hypotheses

	Hp. A	Hp. B	Hp. C
Cost of non-reclaimable material dispos-al	5˙167,08	5˙167,08	5˙167,08
Cost disposal/reclaimed scraps	57˙416,56	57˙416,56	-14˙835,46
Cost disposal/reclaimed concrete	10˙622,45	10˙622,45	-9˙044,41
Cost disposal/reclaimed wood	8˙080,45	4˙150,80	4˙150,80
Cost disposal/reclaimed plastics	6˙572,78	6˙148,96	6˙148,96
Cost disposal/reclaimed sandwich panels	23˙884,19	12˙811,08	12˙811,08
total	111˙743,52	96˙316,94	4˙398,05
		-13,81%	-96,06%

Table 8 shows the cost differences in the different hypotheses. Hypothesis C allows 96% cost reduction out of the overall demolition and disposal costs than the first hypothesis.

4. CONCLUSION

This study confirms that building demolition and waste reclamation in specific plants provide high quality reclaimed materials that can be efficiently re-used.

Economic assessments show that a careful management of C&D waste can determine economic and environmental advantages.

This is true especially when debris is crushed inside demolition sites and reused in place. In a financial perspective, studies on mobile plants confirm they are sustainable in most respects.

Furthermore, mobile plants can be calibrated to be fuelled with bio-fuel.

Fixed plants, instead, are profitable when recycling and quarry's activity are complementary.

The use of machineries and special techniques for demolition and waste reclamation can reduce the environmental degradation and the depletion of raw materials.

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