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# Urban Mining: Quality and quantity of recyclable and recoverable material mechanically and physically extractable from residual waste

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ABSTRACT

The mechanically sorted dry fraction (MSDF) and Fines (<20 mm) arising from the mechanical biological treatment of residual municipal solid waste (RMSW) contains respectively about 11% w/w each of recyclable and recoverable materials. Processing a large sample of MSDF in an existing full-scale mechanical sorting facility equipped with near infrared and 2-3 dimensional selectors led to the extraction of about 6% w/w of recyclables with respect to the RMSW weight. Maximum selection efficiency was achieved for metals, about 98% w/w, whereas it was lower for Waste Electrical and Electronic Equipment (WEEE), about 2% w/w. After a simulated lab scale soil washing treatment it was possible to extract about 2% w/w of inert exploitable substances recoverable as construction materials, with respect to the amount of RMSW. The passing curve showed that inert materials were mainly sand with a particle size ranging from 0.063 to 2 mm. Leaching tests showed quite low heavy metal concentrations with the exception of the particles retained by the 0.5 mm sieve. A minimum pollutant concentration was in the leachate from the 10 and 20 mm particle size fractions.

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## 1. Introduction

The concept of Urban Mining (UM) concerns all the activities and processes of reclaiming compounds, energy and elements from products, buildings and waste generated from urban catabolism (Baccini and Brunner, 2012). In particular, material reuse, recycling and recovery from waste is one of the main issues to be addressed according to the latest EU Waste Framework Directive (WFR 2008/98/EC). The WFD imposes European countries to achieve reuse and recycling figures of not less than 50% w/w, at least for plastic, paper and cardboard, glass and metals, by 2020 and not less than 70% of recycling and/or recovery of construction and demolition waste (C&D) by 2050. This requires the transition from a linear approach, in which materials are definitively disposed of after use, to a circular approach, in which raw materials are extracted from the waste stream to be reused, recycled and recovered (Cossu et al., 2012; Cossu, 2013). Source segregation (SS) is one of the most relevant activities in waste management to be pursued for achieving these goals. Notwithstanding the current important efforts to increase SS, the residual municipal solid waste (RMSW) fraction still remains quite high (ISPRA, 2012) from 25% up to 70% w/w, depending on the different EU areas. According to the WFD and EU Landfill Directive 99/31/EC, which imposes limitations on the amount and quality of waste disposed of in landfills, incineration seems the most suitable solution for managing RMSW.

However, RMSW contains a large amount of potentially recyclable and recoverable materials that can be managed according to the UM concept. On the basis of their quality, these materials can be recycled and/or recovered not only for energy production but also for use in different sectors such as construction. Robinson et al. (2004) reported that reclaimed Portland cement concrete is a viable aggregate resource in urban settings with costs comparable to those of natural aggregate. Chang et al. (2010) showed that waste stone sludge and waste silts are a feasible substitute for raw sand and stone in the production of artificial aggregate. Kou et al. (2009) investigated the effect of using recycled waste plastics to replace river sand as fines aggregate for the production of light weight aggregate concrete. Results showed that the optimal replacement percentage is 15% by volume, leading to an increase in the durability and chloride ion penetration resistance, even if workability and compressive strength were reduced. Similar results were obtained by Hannawi et al. (2010) for mortars containing PET and PC waste.

*Abbreviations:* C&D, construction and demolition; COD, chemical oxygen demand; EDTA, ethylenediaminetetraacetic acid; MBT, mechanical biological treatment; MC, moisture content; MSDF, mechanically sorted dry fraction; MSOF, mechanically sorted organic fraction; NIR, near infrared; PC, polycarbonates; PE, polyethylene; PET, polyethylene terephthalate; PP, polypropylene; PS, polystyrene; RMSW, residual municipal solid waste; SRF, solid recovered fuel; SW, soil washing; TS, Total Solids; UM, Urban Mining; VS, volatile solids; WEEE, Waste Electrical and Electronic Equipment; WFD, Waste Framework Directive; 2-3D, 2-3 dimensional selector.

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Currently another widespread solution for managing RMSW in areas that lack incinerator and co-combustion facilities is mechanical biological treatment (MBT), mainly oriented to reducing waste mass, by metal extraction, and biological reactivity before final disposal (Di Maria, 2012). In these MBT facilities, RMSW is initially mechanically sorted/screened and split into three main streams. One stream is the mechanically sorted dry fraction (MSDF), rich in high-energy content materials such as plastic, paper and cardboard, wood and textiles. Another primary stream consists in the mechanically sorted organic fraction (MSOF) and a further stream is made up of Fines with a mean size <20 mm, usually rich in inert components such as lythoids and glass.

MSDF and Fines contain rather large amounts of materials that can be potentially recycled and/or recovered according to the UM concept. This goal can be pursued exploiting further mechanical and physical processes able to separate given waste components from the commingled streams. In particular, near infrared (NIR) selectors is a technology quite exploited both in industry and in waste management (Bonifazi and Serranti, 2006; Farcomeri et al., 2008; Leitner et al., 2003; Serranti et al., 2011; Tachwali et al., 2007) for selecting materials with specific features, like plastic, paper and glass. Combining NIR with 2 and 3-dimension selectors (2-3D) can lead to a relevant increase in plastic and aluminum extraction if the concentration of non-compatible materials is rather limited. Due to the previous screening operation performed in MBT, the MSDF seems to have rather suitable features for being further selected in facilities using such devices. However, there is a lack of information and of investigations on this aspect.

The inert concentration in Fines represents another important material source exploitable in the construction industry. A possible process that could be used for extracting the inert materials from the Fines could be soil washing (SW) (Mann, 1999; Griffiths, 1955). SW consists in several mechanical, physical and chemical treatments involving a large amount of water to remove contaminants from the soil grains. With an adequate combination of these treatments during SW, pollutants are moved into the liquid phase. The process water is then chemically and physically treated for reuse inside the SW facility, whereas all the pollutants are concentrated in the resulting sludge. SW is widely exploited for removing contaminants from contaminated soils, like heavy metals (Semer and Reddy, 1996; Sierra et al., 2010; Voglar and Lestan, 2013) polyolefin and hydrocarbons (Haapea and Tuhkanen, 2006; Zhu et al., 2012). SW concentrates all the pollutants in the process sludge, returning the soil particles grouped in different size classes as fines/silts (<0.063 mm) sand (0.063-2 mm) oversize (>8 mm) (Mann, 1999).

Similar technologies seem suitable for extraction of inert materials from the Fines arising from the MBT of RMSW. Regarding this further possibility there is also a lack of information and investigations.

In this work, starting from an existing MBT (Di Maria, 2012), the amount and quality of recyclable and recoverable materials extractable from the MSDF and the Fines was evaluated. MSDF was processed in a full-scale mechanical sorting facility also equipped with NIR and a 2-3D classifier. The mass balance and quality of outlet waste streams were investigated. Furthermore, the amount and size of inert extractable material from Fines samples by SW were preliminarily quantified and analyzed by lab-scale procedure.

## 2. Materials and methods

### 2.1. Waste sampling, processing and characterization

The waste samples were withdrawn from the mechanical sorting section of an existing MBT facility (Di Maria, 2012) that processes about 70,000 tonnes of RMSW per year (Fig. 1). A large sample of about 50 tonnes of MSDF was transported by trucks to the NIR and 2-3D selector facility (Fig. 2). Before being transported, the composition of the MSDF was manually investigated. Starting with five large samples of 1 tonne of MSDF, by the quartering procedure, 5 samples of about 100 kg each were obtained and manually sorted. Different components were visually identified and their fractions by weight on wet basis (%w/w) with respect to the whole sample mass were determined.

The Fines were analyzed by withdrawing 10 samples of about 5 kg each in different periods of the year from the same facility. Moisture content (MC) and consequently Total Solids (TS), both expressed as% by weight with respect to the total mass of the analyzed sample on wet basis (%w/w), were evaluated by measuring the mass loss of 1 kg after drying for 24 h at 105 °C. The remaining amount of sample was processed by lab-scale procedure according to the SW process as shown in Fig. 3. The aim of the SW process is to remove mainly the organic and other not compatible fractions, such as paper, textiles and wood, returning only the fraction potentially exploitable in the construction sector. The Fines were initially processed in an attrition cell with water and chemicals to remove organics, heavy metals and other components like paper, plastics, textiles and similar substances from the inert substrates. After the attrition cell, the medium was moved to a settling section with a screw to extract the settled materials. This settler can be equipped with air injection to aid the flotation of light and non-inert components. Also in this section further chemicals can be added to increase contaminant removal. During extraction with the screw, the material is continuously washed with a counter current stream of water. After the screw, the material is sieved in a multiple sieve device able to select different sized particles from <2 mm to >20 mm. Also during sieving the material is continuously washed with an energetic stream of water with additives. The cloudy suspension from the settler along with the <2 mm stream arising from the sieve is processed in a spiral classifier able to separate the sand from the silt. To simulate these processes at the lab scale the Fines were first processed in 130%v/v $H_2O_2$ to eliminate the organic compounds, then diluted with water and finally dried for 48 h at 105 °C. The composition of particles ⩾5 mm was manually investigated. Successively the material was put into a rectangular section tank, diluted with a 1:10 w/v solution of 1 M $H_2SO_4$. The mixture was then mixed for 30 min with two vertical stirrers spinning in opposite directions at 200 rpm. No additives were used during the lab process with the exception of $H_2SO_4$. The floating substances were carefully manually removed, whereas the sediment along with the solution was passed through a sieving column using different sized sieves starting from 30 to 0.063 mm. A large amount of washing water was used. During this operation, other non-inert visible components were manually removed and mass loss by ignition of different particle size classes was determined to eliminate the presence of further non-inert compounds. Finally, for each class of sieved material, a preliminary leaching test was performed according to the procedure imposed by UNI 10802 (2004). The concentration (mg/L) of the following main parameters was determined: $NO_3$, Cu, Zn, Ni, Cr, Pb, COD, and pH according to the HACH Lange procedure.

### 2.2. NIR and 2-3D selector facility

Fig. 2 shows the diagram of the full-scale NIR and 2-3D selector facility. The first operation performed on the MSDF is ferrous-metal separation using magnets. Then the MSDF enters two successive trommels with sieve sizes, respectively, of 30 and 90 mm. The oversize material exiting the 90 mm drum enters the 2-3D classifier. After further ferrous metal removal, the 2D stream enters the manual screening cabin, whereas the 3D stream enters the

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