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# RE4 Project

## REuse and REcycling of CDW materials and structures in energy efficient pREfabricated elements for building REfurbishment and construction

| D4.1<br>Composition of materials from demolition and available volumes of sorted fractions | |
|---|---|
| Author(s)[1]: | CDE, STAM, QUB |
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| Work package: | WP4 - Technical characterisation of CDW-derived materials for the production of building |
| Distribution[2] | PU |
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| Abstract: | D4.1 summarizes the results obtained within T4.1. It includes: a literature review on CDW composition, the theoretical composition of CDW, and the physical assessment on CDW samples to determine actual mass composition and general variability of unsorted CDW. |
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[1] Just mention the partner(s) responsible for the Deliverable
[2] PU: Public, RE: restricted to a group specified by the consortium, CO: Confidential, only for members of the consortium; Commission services always included.
[3] Draft, Revised, Final

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## Acronyms

| | |
|---|---|
| **BRE** | Building Research Establishment (UK) |
| **CW** | Construction Waste |
| **CDW** | Construction and Demolition Waste |
| **DW** | Demolition Waste |
| **SARMa** | Sustainable Aggregates Resource Management (South East Europe Cooperation Programme) |

# 1. Introduction

## 1.1. Summary

The Deliverable 4.1 (Composition of materials from demolition and available volumes of sorted fractions) summarise the results obtained by RE[4] team involved in task 4.1 [Collection of representative samples of CDW sorted material (lightweight, unsorted mineral, sorted mineral, ceramics)].
The activities were carried out according to the following methodology:

- an extensive literature analysis for collection of already available data was carried out by STAM;
- a study on the theoretical composition of unsorted CDW, based on the initial design of real buildings, was carried out by STAM with contribution from ROS and ACCIONA, in order to have a further baseline for evaluating the composition of CDW materials;
- laboratory analysis of Construction and Demolition Waste (CDW) composition was carried out both at QUB and CDE laboratories on samples coming from both Northern and Southern Europe, in order to determine actual mass composition of unsorted CDW and to estimate a general variability from sample to sample.

The literature analysis confirmed that the average composition of unsorted CDW is extremely variable among the different European countries. This suggests that a very flexible CDW sorting system will have to be developed within Work Package 2 (*Strategies for innovative sorting of CDW and reuse of structures from dismantled buildings*), because CDW fractions cannot be considered constant. Moreover, the technical and environmental considerations arising from the analyzed papers point out that sorting of CDW is a real added value for recycled aggregates and other secondary raw materials production, and that there is still potential for improving sorting results from a technological point of view (Task 2.4 *Innovative strategies and processes for sorting CDW based on advanced robotic system*).

Composition analysis showed that samples which originated from the same geographical region (e.g. Northern Europe) and were analysed in different laboratories (CDE and QUB) contained similar percentages of total mixed mineral aggregate/concrete, ceramics (bricks and tiles), bitumen/asphalt, steel, glass and lightweight (mixed wood/plastics) fractions. In other words, the variability with respect to samples from the same geographical source was low. In addition, composition analysis showed that samples which originated from different geographical regions (Southern and Northern Europe) and were analysed in different laboratories (CDE and QUB) contained similar amounts of coarse size mixed concrete/mineral aggregate readily available for use in the production of new concrete. Lightweight and sand (sum of fine and medium/coarse sand) fractions were also found to be similar in the range of less than 1% and 15%, respectively. On the other hand, significant differences were found when it comes to silt/clay, ceramics and bitumen fractions.

The study on the theoretical composition confirmed the great variability of CDW quantities and typologies based on several factors, including the construction process and typology, structure and '*age*' of the building. However, there are several good approximations from literature that can be used for obtaining a good estimate of CDW characterization, with various levels of accuracy depending on the amount of information available.

## 1.2. Task scope and objectives

The Work Package 4 (WP4) of the RE[4] project aims at the procurement, analysis, characterisation and quality evaluation of unsorted CDW materials. As a first step of this process, the composition of the CDW is an important information to gather for the development of a robust strategy for recycling. The nature of different materials and their respective amount in stockpiles have impacts on several aspects, namely:

- the availability of "high value" mineral aggregate (i.e. mineral aggregate with technical properties similar to virgin material) that can be recovered through sorting,
- the availability of other materials (e.g. ceramics, fines, glass, lightweight) available for alternative recycling routes (e.g. production of filler or supplementary cementitious materials, production of lightweight aggregate, production of fibreboards, production of plasters) and therefore the assessment of the economic viability of such alternative recycling routes,
- the performance boundaries for designing a selective sorting system which focuses on specific materials.

Composition of CDW may vary significantly according to the building typology (e.g. residential vs. commercial) and to local construction techniques (e.g. use of fired clay bricks, building blocks, plywood and other materials), which depend on the geographical source of materials.
While the first kind of variability can be avoided when sourcing CDW from a recycling facility (where materials from different demolition projects are collected, stockpiled and subsequently processed), the second kind of variability has to be assessed through focused analysis on representative samples from different geographical regions, ideally from Northern Europe and from Southern Europe.

The objectives of the activities described in this deliverable can be summarised as follows:

- to assess the actual composition of unsorted CDW samples sourced both in Northern and Southern Europe,
- to analyse the available technical literature for obtaining ranges of unsorted CDW composition for guidance purposes,
- to estimate potential available volumes of each fraction from technical analysis of case studies,
- to give indication about expected quantities to be processed during screening, sorting and recycling.

### 1.3. Relevant work package input

The production of Deliverable 4.1 did not require any input from previous deliverables. The obtained results are of interest for the development of activities in Work Package 2 (Strategies for innovative sorting of CDW and reuse of structures from dismantled buildings) and relevant deliverables, as well as in Work Package 5 (Development of precast components and elements from CDW) and relevant deliverables.

## 2. Literature review on CDW composition

The main goal of this Section is to present an analysis of the state of the art referring to the average composition of the Construction and Demolition Waste (CDW), with main reference to the European scenario, which is the geographical focus of the $RE^4$ project. In order to achieve this aim and to strengthen the main findings of Task 2.1 in the field of the composition of the building materials across Europe, a review of the scientific and technological literature has been carried out by STAM.

This literature review has been conducted through the aid of different publications on the subject of building materials, their life cycle and recycling opportunities. Different sources have been investigated and used during this task, taking into account the wide differences between the building practices and techniques in the different European countries. Moreover, the building typology is also a variable to deal with in this analysis, being another source of differences in the used materials and CDW composition.

### 2.1. Available literature data and assessment methods

This literature investigation aims at analysing the current situation referring to the CDW production and the related management/recycling technologies in the European scenario. In order to have a clear and complete sight of the state of the art, a series of information and data typologies to be found have been defined before starting their collection, on both the average composition and characterization of the CDW in Europe and the currently adopted methods to handle, differentiate and recycle them.

The first information STAM looked for during this activity refers to the amount of CDW currently produced by the European countries, with differentiation between the different sources from which these amounts came (namely, construction and demolition activities). Secondly, the composition of the CDW materials in the different European geographical areas, was studied, starting from the assumption that the different climates, availability of raw materials and architectural and cultural habits would strongly affect this aspect. Moreover, the different building typologies were analysed, in order to understand any substantial differences with respect to them.

Within the context of this CDW state of the art, the European Commission is working to mitigate the problems related to their production: also the goals of the EC with reference to CDW management and recycling are outlined in this literature review.

Together with the amounts and composition of CDW, STAM analysed the possibility to reuse or recycle the different components in it, and the potentially reusable volumes within all the produced waste. Moreover, the state of the art techniques and methods to recycle CDW are investigated, in order to compare them and their performances to the goals of the $RE^4$ project, with main reference to the separation and sorting activities to be performed within WP2. With this aim, literature about the existing CDW-derived materials was revised, with particular focus on their usability in the Building and Civil Engineering sectors, their related performances and market opportunities.

Finally, some considerations on the embodied energy of the traditional construction materials and recycled ones were collected, together with data about the environmental impact of aggregate life cycle, in particular for what the recycle methodologies are concerned.

The literature analysis was performed by STAM, who collected the required information from a set of papers and technical reports selected with the support of QUB, being in charge of leading WP4 and whose expertise in materials characterization and in scientific analysis methods have been exploited to assist this task.

Both scientific papers and reports published by various entities were analysed for this purpose, in the context of the research on demolition materials management and applications. More specifically, three different journal papers (*Resources Conservation & Recycling*, *Building and Environment* and *International Journal of Mining and Mineral Engineering*) were taken into account for what the State of the Art sorting methods and CDW materials life cycle are concerned. Moreover, other articles published by the Polytechnic

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University of Turin, Italy, were studied; finally, some handbooks and technical manuals published from different public entities at Italian and European level (European Commission, BRE, South-East Europe Cooperation Programme) were used as reference for this task.

## 2.2. Data gathering and comparison

The first aspect of the present study deals with the amounts and average composition of the CDW in the different European countries, which can be considered a key feature for its recycling and reuse methodologies, as far as the possible future applications of the CDW-derived materials and their technical/market value. In this regard, a research conducted within the SARMa project (Sustainable Aggregates Resource Management, co-financed by the European Union through the South East Europe Transnational Cooperation Programme) highlights how the CDW in 2008 represented over 30% of the total waste production in Europe [1]. This amount is averagely divided into two different macro-sources, namely the construction waste and the demolition waste, estimated to 850 million tons per year. In their country by country study, Bio Intelligence Service [2] highlighted that the most impacting European countries are Germany (72.3 tons in 2005), France (62.6 tons) and UK (55.2 tons). Moreover, Table 1 summarizes an aspect of their research work, underlining the huge variability of CDW composition in the different EU member States.

These large amounts of construction waste, mainly come from the maintenance and construction activities of buildings and civil infrastructures, while demolition waste comes from the partial or total destruction of the same works. The main materials in the mixed waste are concrete, cement, conglomerates bounded by bitumen, bricks, tiles, excavation soil, wood, paper, cellulose, polystyrene, metals, plastic, chalk, ceramic, glass and asbestos. Looking at an example from outside Europe, Poon et al. [3] quantified the average percentages of these components in Hong Kong at 53% concrete and reinforced concrete, 2% asphalt, 7% bricks, 12% soil, 7% wood, 0.6% plastic pipes, 3% metals, 0.2% glass and 15% others.

| Country | Netherlands | Flanders | Denmark | Estonia | Finland | Czech Republic | Ireland | Spain | Germany |
|---|---|---|---|---|---|---|---|---|---|
| Concrete | 40% | 41% | 32% | 17% | 33% | 33% | 80% | 12% | 70% |
| Masonry | 25% | 43% | 8% | | | 35% | | 54% | |
| Other Mineral Waste | 2% | - | 0% | 0% | - | - | 0% | 9% | - |
| **Total Mineral Waste** | **67%** | **84%** | **40%** | **17%** | **33%** | **68%** | **80%** | **75%** | **70%** |
| Asphalt | 26% | 12% | 24% | 9% | - | - | 4% | 5% | 27% |
| Wood | 2% | 2% | - | - | 41% | - | - | 4% | - |
| Metal | 1% | 0.2% | - | 40% | 14% | - | 4% | 3% | - |
| Gypsum | - | 0.3% | - | - | - | - | - | 0.2% | 0.4% |
| Plastics | - | 0.1% | - | - | - | - | - | 2% | - |
| Miscellaneous | 7% | 2% | 36% | 34% | 12% | 32% | 12% | 12% | 3% |

**Table 1:** CDW composition for some EU countries [6]

One of the main goals of the European Union in terms of environment protection is solving the problems resulting from the huge amount of produced waste. This goal is expressed in the Framework Waste Directive as reported in [1], which is summarised below, having the intention to set the baseline for the growth of the waste and CDW treatment field:

- sets a goal of recycling rate for CDW to 70% in terms of weight, to be reached by 2020 by every Member State,
- requires from the Member States to develop waste prevention programmes, taking into account the whole life cycle of products and materials,

- establishes a five-phase hierarchy as a priority for waste management:
    a) prevention,
    b) preparation for re-use,
    c) recycling,
    d) other recovery, e.g. energy recovery,
    e) disposal.

Referring to the current European situation, some virtuous countries are already following the requirements of this directive. Data from 2008 underlines that the Netherlands are the best country with 100% recovery of CDW, and also the UK which is over the required threshold (79%). Good results are achieved also by Czech Republic (44%) and Germany (37%), while the worst cases are represented by Austria (16%), Spain (14%), Italy (9%) and France (7%) [1].
In regards of these new requirements of the European Union, CDW is considered to be the most important source of innovative aggregates in the next future, thus changing the consideration of CDW from an unwanted load to a resource towards the aimed European "recycling society" [1].
Not only EU is struggling with the CDW problem: the Hong Kong government for example, has specified that CDW containing more than 20% of inert material by volume cannot be landfilled, but has to be sorted and recovered [3].
The importance of CDW recycling is related not only with the marketability of the derived materials and their economic impact for the end users, but also with the environmental impact of the different processes. Garbarino [4] pointed out that in the case of CDW recycling, the environmental benefits thanks to avoided landfilling of such waste and partial substitution of natural resources in construction industry are higher than induced impacts due to the recycling procedures themselves. Blengini [5] analysed the CDW recycling issue from the environment point of view, by exploiting the Life Cycle Assessment (LCA) methodology to evaluate the impacts of the whole life cycle of natural and recycled aggregates in the construction industry. In particular, it is pointed out that in the whole life cycle of a building, its use phase causes the largest amount of spent energy (close to 90%), and also for the other indicators (Global Warming Potential, Ozone Depletion Potential, Acidification Potential, Eutrophication Potential and Photochemical Ozone Creation Potential) the environmental impact is similar. By contrast, the pre-use phase (taking into account both the building operations and the raw materials production) causes 6-11.5% of the total impact. In order to assess the advantage coming from using recycled aggregates, the difference between avoided impacts due to the substitution of natural aggregates and the added impacts caused by transportation and recycling processes was calculated. Considering the pre-use phase of buildings, it was finally calculated that the recovered energy is around 19% for recycled aggregates, with a reduction of greenhouse emissions by 10%.
A further aspect of the present literature analysis deals with the state of the art of the CDW separation methods. At the time being, different technologies are adopted for CDW treatment, differentiated into stationary and mobile plants. Unlike the techniques that are being developed within the RE$^4$ project, the aim of the State of the Art technologies is separating the incoming CDW into three sections: stones (including concrete, bricks and other mineral-based products), lightweight fraction (e.g. wood and plastic) and metals. A first crushing step is usually performed by a jaw crusher or pulse crusher to make the CDW parts suitable for their final use; afterwards, a screening process separates the CDW into different size fractions. The real material separation stage can be performed by adopting different techniques, the most common being the separation of metal exploiting their magnetic properties and the gravimetric separation. However, the final quality of the recycled materials is not only related to the adopted separation techniques, but also to the demolition activities. In fact, a more effective CDW separation into homogeneous fractions already during the demolition phase, will give a more efficient recycling process. To achieve this, the demolition activity should be planned and operated as a selective demolition, which is not widely adopted yet due to its high costs [5]. Within this context, CDW obtained by traditional demolition

procedures can be separated and recycled by stationary recycling plants, able to eliminate non-inert materials, biodegradable materials, iron and light fractions. Garbarino and Mancini [6] analyzed in detail the possibility to obtain marketable products in the field of civil engineering by the use of gravimetric methods. Firstly, they underlined how the wet separation processes such as sink float method achieve a gravimetric separation without obtaining high-value recovered materials. As shown in Fig. 1, the introduction of the jig allows separating lightweight from heavy materials, based on the known average specific gravity distribution in the CDW. However, the results of their study highlight that also size and shape of the grains affect the separation, which is not a purely gravimetric sorting. In fact, grains having platy shapes tend to be separated as "light", even if their density is high. Moreover, Garbarino [4] compared currently used dry and wet separation processes. Dry processes aimed at separating lightweight from heavy materials, such as the crossflow air shifting, countercurrent air shifting and zigzag air separator, were concluded not to be very effective. Only the zigzag air separator achieved satisfying results in applications on concrete-brick debris. On the other hand, wet processes are more expensive but allow a better separation, which is controlled by a suspension media, loaded with particular particles according to the required cut specific gravity. Also, in this study, the separation technology indicated as the most promising among the currently existing ones is the jigging, which leads to high quality recycled aggregates.

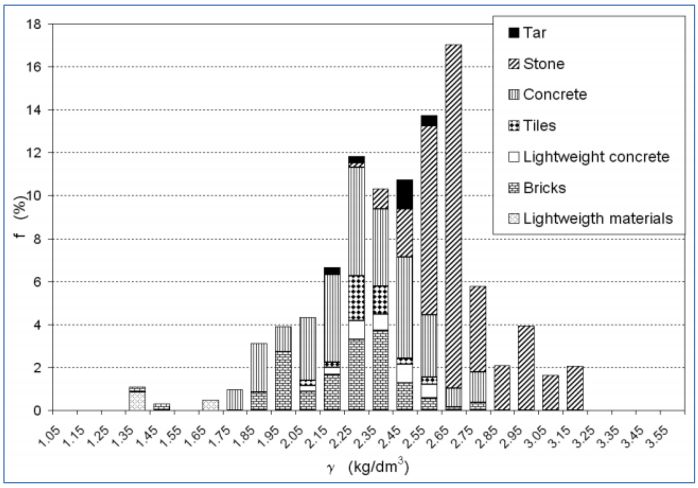


**Fig 1:** CDW specific gravity distribution [6]

Still referring to the CDW separation issue, Poon et al. [3] underline the importance of the adopted demolition method for the final separation of CDW materials, with main reference to the use of explosives, wrecking balls, hydraulic crushers and pulverizers and top-down method. In particular, the adoption of selective demolition allows retrieving recyclable and reusable items easily and systematically, with a very low level of contaminants. On the other hand, this is mainly manually done, and hence more costly comparing to the other methods. Within their study, they evaluated three different on-site CDW sorting systems. The first one ('Alternative 1') uses two refuse chutes for inert and non-inert materials, to be separately collected and managed. This allows achieving the highest percentage of reusable material (75%), but is more expensive and complex if compared to 'Alternative 2' and 'Alternative 3', using only one chute. In particular, 'Alternative 3' foresees a manual sorting procedure at the ground level. This requires training of workers, which is often the reason why contractors are pushed to select off-site separation procedures.
Another important aspect of the CDW sorting is the final application of the obtained materials, which is obviously dependent on their chemical and mechanical features. In this regard, the CDW-derived materials obtained by the current technologies can be recycled and used in two main applications, namely unbound applications such as road construction and railway ballasts (in particular, recycled aggregates can be used

for the construction of foundation layers of roads), and bound applications, such as concrete and bitumen production for civil engineering works [1]. The European Union has officially recognized the possibility to CE mark recycled aggregates, making them to all intents and purposes construction materials. Moreover, from a quantitative point of view, Garbarino [4] observed that when recycled aggregates are used in place of natural ones at a level of less than 50%, the reduction in compressive strength of the obtained concrete is less than 25-35%. However, she also underlined how there are controversial opinions within the scientific community: some authors consider the recycled aggregates only usable to compose the coarse fraction of the concrete, while the fine fraction has to be made by natural sand; other authors pointed out that only wet processes permit to exploit the performances of recycled aggregates.

Referring to the potential economic impact of CDW recycling activities, SARMa project underlined how the recycled aggregates will be able to increase the total demand of aggregates between 10% and 35% [1]. Their lower price if compared to the natural aggregates, together with the generally high demand of aggregates with low performances (for the above mentioned applications), and the reduction of transport costs in case the recycling plant is installed close to the demolition site, makes these aggregates extremely interesting for the construction industry.

## 2.3. Discussion

Referring to the Project purposes, according to the presented literature analysis it can be concluded that the average composition of CDW is extremely variable among the different European countries, thus suggesting that a very flexible CDW sorting system will have to be developed within Work Package 2, not being able to make reliable initial assumptions on the different percentages of the various components.

Moreover, the technical and environmental considerations arising from the analyzed papers point out that sorting of CDW is a real added value for recycled aggregates and other secondary raw materials production, and that there is still potential for improving sorting results from a technological point of view (Task 2.4 *Innovative strategies and processes for sorting CDW based on advanced robotic system*).

# 3. Theoretical composition of CDW

The goal of this chapter is to provide an overview of the theoretical composition of CDW from real case scenarios and compare it both with the state of the art review from Chapter 2 and with the physical assessment of CDW samples, presented in Chapter 4. The theoretical composition will be assessed based on standard ways of estimating CDW from an individual construction project and with real data from real construction projects provided by ROS and ACCIONA.

The chapter is structured into three main sections. In the first section, key terms and assumptions as well as the overall analysis rationale are defined. The variables affecting waste generation are then discussed, differentiating between those affected by planning and design prior to starting work, and those affected by building operations carried out on site. Moreover, the overall methodology for estimation of CDW composition and amounts will be described.

The second section, based on real bills of materials from construction projects, provided by ACCIONA and ROS will carry out an estimation of CDW quantities and composition according to the methodology described in the first section. Finally, in the third section the main outcomes of this study are reported.

## 3.1 Rationale

Estimating the types and quantities of waste in buildings can be an activity of interest for several reasons [7]:

- efficient planning of waste management on site;
- increased awareness and promotion of the reduction;
- recycling and recovery of waste on site and an estimate of the economic and environmental cost of waste management.

In this deliverable, the standard methodologies employed with these goals are used to estimate quantities and types of CDW from real C&D projects.

### 3.1.1. Introduction to CDW estimation

Several factors, such as construction techniques, design of the components, the adopted waste reduction criteria, documentation and technical quality of the project strongly affect the amount of waste generated at source.

CDW is usually mixed waste with a degree of heterogeneity that depends on the type of work (whether it is demolition or construction). This first parameter has a strong influence on the waste quantities since, on a per building basis, demolition waste quantities may be 20 to 30 times as high as construction debris.

Moreover, the types of produced waste also strongly depend on the process producing it:

**Demolition waste (DW)** is a product of dismantling at the demolition stage, or of the restoring and repairing of buildings and facilities. It is usually of a stony nature and more homogeneous than CW (Construction Waste) due to the absence of soil and packaging waste and has a greater volume and weight. Though the composition of DW depends on the construction techniques and materials used in the building to be demolished, it usually falls into four main categories [7]:

1. non-stony waste (building elements consisting of steel, iron, aluminium, copper, glass, wood, plastic, etc.).
2. stony waste (concrete, mortar, ceramics, aggregates and mixtures thereof).
3. hazardous waste (materials containing asbestos, lead, zinc, paints, varnishes, batteries, fluorescent tubes, lubricants, oils, grease, air conditioning facilities, etc.).
4. others (i.e. organic material).

One important factor is that DW usually contains a higher amount of hazardous waste than CW. This is mainly due to the absence of past restrictive regulations on the use of certain hazardous materials, such as asbestos and lead. Since most buildings to be demolished are more than 50 years old, these substances could be found more frequently while dismantling buildings. As a result of this, by the way of example, in Spain a Workflow Management System (WMS) of demolition and rehabilitation projects must include an inventory of hazardous waste to ensure separation and specific treatment.

**Construction waste (CW)** is generated as a result of work executed on buildings from the foundations up, and by civil engineering works such as roads, railways, canals, dams, sports and leisure facilities, ports and airports, etc. Once again, several factors related to the construction process influence the composition and quantities of CW. It falls into five main categories:

1. soil (sand, clay, stones, mud, etc.) generated from the excavations prior to construction. This waste can be mixed with organic and biologic elements,
2. packaging waste from building materials (wooden pallets, plastic, cardboard, etc.), which have a lower presence in civil engineering works,
3. remains of building materials (of a stony nature: concrete, ceramics, aggregates and mixtures thereof; non-stony: steel, iron, aluminium, copper, glass, wood, plastic, asphalt, etc.), which are more homogeneous in civil engineering works,
4. hazardous waste (contaminated soil and dredging spoil, materials and substances that may include some dangerous features: flammable concrete additives, adhesives, sealants and mastic (flammable, toxic or irritant), tar emulsions (toxic, carcinogenic), asbestos-based materials in the form of breathable fibre (toxic, carcinogenic), wood treated with fungicides, pesticides, etc. (toxic, ecotoxic, flammable), coatings of halogenated flame retardants (ecotoxic, toxic, carcinogenic), equipment with PCBs (ecotoxic, carcinogenic), mercury lighting (toxic, ecotoxic), systems with CFCs, gypsum-based elements (possible source of sulphide in landfills, toxic, flammable), containers for hazardous substances (solvents, paints, adhesives, etc.), and the packaging of contaminated waste likelihood),
5. others (i.e. organic material).

The types and amounts of waste generated on site are directly related to the classification characteristics and construction techniques employed in each building; CW will therefore vary between projects.

### 3.1.2. CDW estimation methodologies

Construction and demolition, differently from most of other industrial processes, tend to produce mostly inert wastes, thus not posing an environmental threat as great as that of hazardous waste or typical Municipal Solid Waste (MSW). This means that CDW in most European regions is not controlled in the same way as other sources of waste, with a consequent lack of data and statistics. This has been a limit in the last years, as several methodologies and technologies for CDW smart reuse and recycling are being developed, requiring some theoretical starting points. This is where the estimation of CDW, based on several construction parameters comes in play.
This section aims to provide an overview on the main tools, methodologies and tables for estimating waste quantities and types that may be obtained prior to starting work.

CDW estimation methodologies can be generally divided into two:

- a quantification procedure to obtain approximate estimates by the use of waste quantisation tables;
- a quantification procedure to obtain specific estimates for each project.

Both of these have pros and cons and it is up to the project manager to choose which one is to be used depending on the needed level of detail and on the available information.

**Estimates based on quantisation tables** are mainly provided by construction companies, organisations and associations in the construction sector. They are based on an algorithmic methodology:

- **Step 1**: Quantisation tables classified by project type are obtained (demolition, construction, rehabilitation); uses (residential, non-residential: industrial, commercial, etc.), and similar technologies relevant to the project (structure, masonry, etc.).
- **Step 2**: The features of the project are identified: type of project (demolition, construction, rehabilitation); use (residential, non-residential: industrial, commercial, etc.), and the main technologies (generally in relation to structure: metal, concrete or masonry).
- **Step 3**: The surface area of the project is calculated (in $m^2$).
- **Step 4**: The total waste amount (volume and/or weight) is obtained from the floor area of the project.
- **Step 5**: The waste composition is obtained (amounts by type of waste).

Waste quantification tables are available from the literature [7] and shown in Section 5.2 that presents the use of these tables to estimate the amount of CDW from real C&D projects.

**Estimates based on detailed tools**

Specific quantification methods, generally based on the modelling of measurements and budget documents of a construction project, may be applied when this data is available.

Within the scope of this task several real construction projects will be analyzed and the amount and typology of waste will be estimated.

## 3.2. Data source description

In this section, the tables for estimation of CDW will be described. Moreover, data from several real construction projects will be presented. Finally, CDW quantities and composition will be estimated for these projects according to the methodology described in section 5.1.2 and a Case study of real material recoveries from DW to be used again in construction is presented.

### 3.2.1. Estimation tables

Table 2 describes the relationship between construction surfaces and volume averages.

| Type of Construction | Volume average C&D waste generation rates ($m^3/m^2$) | | | |
|---|---|---|---|---|
| | Heavyweight constr.: masonry, concrete etc. | | Lightweight construction: precast elements, drywalls, wood frame, etc. | |
| | Residential | Non-Residential | Residential | Non-Residential |
| **New Building Construction** | 0.12-0.14 | 0.10-0.12 | 0.02-0.03 | 0.02-0.03 |
| **Rehabilitation** | 0.30-0.40 | 0.25-0.35 | 0.10-0.15 | 0.09-0.10 |
| **Demolition** | 0.80-1.00 | 1.00-1.20 | 0.50-0.70 | 0.70-0.80 |

**Table 2:** Relationships between construction surfaces and volume averages

Table 3, Table 4, and Table 5 describe the rounded average percentage of waste composition by volume in constructions, demolitions and rehabilitations (%).

| Type of waste | Sub-Type | Heavyweight construction: masonry, concrete, etc. [%] | Lightweight construction: precast elements, drywalls, light frame, etc. [%] |
|---|---|---|---|
| **Packaging Waste** | Paper cardboard pack | 2-4 | 1-4 |
| | Plastic packaging | 5-7 | 2-3 |
| | Wooden packaging | 50-55 | 25-45 |
| | Metallic packaging | 2-3 | 2-7 |
| | Mixed packaging | <1 | <1 |
| **C&D waste** | Concrete | 15-20 | 10-30 |
| | Ceramics-bricks | 10-13 | 0 |
| | Mixed concrete ceramics | 2-3 | 0 |
| | Drywalls | 3-4 | 10-15 |
| | Mixed C&D waste | 3-4 | 10-15 |
| **Soil and stones** | Soil and stones | Varies | Varies |

**Table 3:** Rounded average percentage of waste composition by volume in Construction

| Type of Waste | Residential | | Non-residential | |
|---|---|---|---|---|
| | Masonry | Concrete | Metal | Concrete |
| **Concrete** | 5-10 | 40-50 | 15-20 | 35-40 |
| **Ceramics-blocks mixtures** | 65-70 | 20-30 | 15-20 | 5-10 |
| **Concrete-ceramics** | 5-10 | 5-10 | 35-40 | 40-45 |
| **Wood** | 1-5 | 1-5 | 0.3 | 0.2 |
| **Glass** | 0.1 | 0.1 | 0.2 | 0.1 |
| **Plastics** | 0.1 | 0.1 | 0.8 | 0.3 |
| **Asphalt** | 0.5 | 0.5 | 0.1 | 4 |
| **Metals** | 1-2 | 2-3 | 10-15 | 1-5 |
| **Potentially Hazardous** | 2-10 | 2-10 | 0.6 | 0.2 |
| **Mixed C&D waste** | | | 5-10 | 5-10 |

**Table 4:** Rounded average percentage of waste composition by volume in Demolition

| Type of waste | Sub-Type | Heavyweight construction: masonry, concrete, etc. [%] | Lightweight construction: precast elements, drywalls, light frame, etc. [%] |
|---|---|---|---|
| **Packaging Waste** | Paper cardboard pack | 1-6 | 2-4 |
| | Plastic packaging | 3-8 | 2-5 |
| | Wooden packaging | 25-45 | 20-40 |
| | Metallic packaging | 5-15 | 5-20 |
| | Mixed packaging | <1 | <1 |
| **C&D waste** | Concrete | 5-10 | 5-10 |
| | Ceramics-bricks | 5-15 | 0 |
| | Mixed concrete ceramics | 10-25 | 0 |
| | Drywalls | 0 | 20-35 |
| | Mixed C&D waste | 5-15 | 5-25 |
| **Soil and stones** | Soil and stones | Varies | Varies |

**Table 5:** Rounded average percentage of waste composition by volume in Rehabilitation

These tables will be used to carry out a waste estimation analysis on real construction projects with data provided by ACCIONA and ROSWAG, briefly described in the following.

### 3.2.2. C&D Projects

**FLC VICALVARO TRAINING CENTER**

The plot for the construction of the Training Center of the Labor Foundation of Construction is located at Rivas street, nº25, in Vicálvaro district (Madrid). The Training Center is an exempt building, with 5 floors above ground level plus a basement, which is located on the perimeter of the plot where it is built, with its facades parallel to the vials that limit it. The plot has an area of 10,266.48 m$^2$. The total constructed area is of 16,131.90 m$^2$.

**SAN IGNACIO DE LOYOLA COLLEGE (3rd PHASE)**

The objective of the "San Ignacio de Loyola College 3$^{rd}$ Phase" Project is a global intervention in the plot that gives integral response to a complex functional program. The plot is irregular, with topography with marked unevenness. This extension is projected attached to the existing building. It is distributed in successive plants that are staggered on the ground communicated vertically by a total of seven ladder cores and two elevators. Two of these stairs and one of the elevators already exist in the previous phase. It has a total constructed area of 9.955,70 m$^2$ which will be rehabilitated.

**MULTI-PURPOSE CENTER "BARCELÓ"**

The work consists of three independent volumes, the market (7,150 m$^2$), the sports centre (2,850 m$^2$) and the library (1,950 m$^2$), an empty space, four floors below ground level and a large longitudinal green space. It has a total of 11.826,33 m$^2$ constructed surface above ground level, 26,868.89 m$^2$ below ground level, that is to say, 38,695.22 m$^2$ total constructed area, in 4,352.87 m$^2$ of total surface. It is a construction project.

**ROSWAG Residential – TIMBER**

ROS provided the bill of materials used for a residential building, mainly composed of timber. Within their construction process, they provide extremely accurate bills of materials that make it possible to start from much sounder assumptions in estimating the amount of wastes produced during construction or for rehabilitation and demolition. The provided data is reported in Table 6 and will be used to assess the waste generated in a demolition scenario.

| Material | Quantity | unit |
|---|---|---|
| **Concrete** | 106.96 | $m^3$ |
| **Perimeter Insulation** | 7.00 | $m^3$ |
| **Insulation Wood Shavings** | 364.49 | $m^3$ |
| **Slate** | 19.88 | $m^3$ |
| **Insulation Wood Fiber** | 11.78 | $m^3$ |
| **Timber** | 52.26 | $m^3$ |
| **OSB board** | 16.20 | $m^3$ |
| **Gypsum fiberboard** | 52.19 | $m^3$ |
| **Lime sand Brick** | 5.76 | $m^3$ |
| **Footfall sound insulation** | 3.67 | $m^3$ |

**Table 6:** Bill of Quantities for ROSWAG residential building

### 3.2.3. CDW Estimation

To proceed with the CDW quantities and types the information regarding estimation tables and the data from the real projects will be merged. Table 7 presents the outcome of the estimation of the first three projects based on tables. Moreover, the relationship between waste classes and the RE[4] material classes is shown.

| Type of process | Project Title | Building Type | Built Surface [m2] | Total Waste Volume [m3] | Paper cardboard pack | Plastic Packaging | Wooden Packaging |
|---|---|---|---|---|---|---|---|
| Construction | FLC VICALVARO TRAINING CENTER | Non Residential | 16131,9 | 1935,9; 2258,4 | 38,7; 90,3 | 96,7; 158,0 | 967,9; 1242,1 |
| Construction | MULTIPLE-PURPOSE CENTER "BARCELO" | Non Residential | 38965,22 | 4643,4; 5417,3 | 92,8; 216,6 | 232,1; 379,2 | 2321,7; 2979,5 |
| Rehabilitation | SAN IGNACIO DE LOYOLA COLLEGE | Non Residential | 9955,7 | 995,5; 1194,6 | 995,5; 5973,4 | 2896,7; 7964,5 | 24889,2; 448800,6 |
| RE4 material class | | | | | Discarded | PLASTIC | WOOD |

| Type of process | Project Title | Building Type | Metallic Packaging | Mixed Packaging | Concrete | Ceramics-bricks | Mixed concrete ceramics | Drywalls | Mixed C&D waste |
|---|---|---|---|---|---|---|---|---|---|
| Construction | FLC VICALVARO TRAINING CENTER | Non Residential | 38,7; 67,7 | 0; 22,5 | 290,3; 451,6 | 193,5; 293,6 | 38,7; 67,7 | 58,0; 90,3 | 58,0; 90,3 |
| Construction | MULTIPLE-PURPOSE CENTER "BARCELO" | Non Residential | 92,8; 162,5 | 0; 54,1 | 696,5; 1083,4 | 464,3; 704,2 | 92,8; 162,5 | 139,3; 216,6 | 139,3; 216,6 |
| Rehabilitation | SAN IGNACIO DE LOYOLA COLLEGE | Non Residential | 4977,8; 9955,7 | 0; 995,5 | 4977,8; 9955,7 | 4977,8; 14933,5 | 9955,7; 24889,2 | 0; 0 | 4977,8; 13937,9 |
| RE4 material class | | | Discarded | Discarded | MINERAL AGGREGATES | BRICKS/TILES | MINERAL AGGREGATES | BRICKS/TILES | EQUALLY DISTRIBUTED |

**Table 7:** Waste estimation based on estimation tables (waste volume by type [$m^3$])

Table 8 shows the waste generation estimate for the demolition of the ROSWAG residential home, based on real bills of quantities. Once again, the relationship between waste classes and the RE[4] material classes is shown.

| Type of process | Project Title | Building Type | Concrete | Perimeter Insulation | Insulation Wood Shavings | Slate | Insulation Wood Fiber |
|---|---|---|---|---|---|---|---|
| Demolition | ROSWAG Residential - TIMBER | Residential | 106,96 | 3,5; 6,3 | 182,2; 328,0 | 9,9; 17,8 | 5,8; 10,6 |
| RE4 material class | | | MINERAL AGGREGATES | discarded | WOOD | MINERAL AGGREGATES | WOOD |

| Type of process | Project Title | Building Type | Timber | OSB Board | Gypsum fiberboard | Lime sand Brick | Footfall sound insulation |
|---|---|---|---|---|---|---|---|
| Demolition | ROSWAG Residential - TIMBER | Residential | 26,1; 47,0 | 8,1; 14,5 | 26,0; 46,9 | 2,8; 5,1 | 1,8; 3,3 |
| RE4 material class | | | WOOD | WOOD | MINERAL AGGREGATES | BRICKS/TILES | PLASTIC |

**Table 8:** Data from real bill of quantities for demolition of residential building (waste volume by type, assuming a material/waste ratio between 50-90%, [$m^3$])

These estimates were combined with the average material densities defined during task 2.1 of the RE[4] project to estimate the weight of wastes for each typology. Table 9 shows the sum of waste volumes from the 4 example projects (average volume) and based on that and on the average material class density, calculates the average weight by material.

| Material Class | Average Volume [m3] | Average Density [kg/m3] | Average weight [kg] | Average weight [ton] |
|---|---|---|---|---|
| **PLASTIC** | 7,853.14 | 800 | 6,282,512 | 6,282 |
| **WOOD** | 2,253.14 | 700 | 1,577,198 | 1,577 |
| **MINERAL AGGREGATES** | 28,400.24 | 2,700 | 76,680,648 | 76,680 |
| **BRICKS/TILES** | 12,981.49 | 1,700 | 22,068,533 | 22,068 |
| **GLASS** | 1,941.99 | 2,400 | 4,660,776 | 4,660 |

**Table 9:** Weight of materials based on estimations

To complete this analysis, the **TERUEL PENITENTIARY CENTER** project will be considered, where real data on the demolition itself of a building and the real materials were studied. This particular project was for the extension of a Penitentiary Center by ACC, including the demolition processes of an old office building and the construction of a Penitentiary Centre in Teruel.

The construction process included the demolition of the old prison building and the construction of the new Penitentiary Center. The exiting building was built in 1951 and is located in Teruel. The work was executed in 3 main phases ensuring that the prison was in operation with the current capacity during the course of the construction project. The design was absolutely conditioned by the building process (construction, demolition, construction). The construction sequence was: new construction, prisoners transfer, demolition, construction. The total plot area was 61,111.09 m$^2$. The construction site comprised 22,591 m$^2$ that include: the building area (5,273 m$^2$), the courtyards (6,098 m$^2$) and the rest of the area were related with walls, outside edifications and land.

Due to the fact that it was necessary to maintain the prison in operation, the work was developed in different stages. A summary of the works done in the different phases are presented below:

- **Phase 1:**
  - Demolition of the north exterior wall and partial demolition of the north inside wall;
  - Construction of first residential module;
  - Construction of the exterior wall;
  - Construction of interior wall construction.
- **Phase 2:**
  - Demolition of some modules of the old building;
  - Demolition of building sleeping quarters;
  - Construction of the sport-cultural-health building.
- **Phase 3:**
  - Complete demolition of the old building and installation;
  - Complete construction of the new building: modules, external and internal wall.

**SUMMARY OF THE ACTIVITIES**:

Firstly, the building was intensively demolished in order to obtain mixed C&DW material (aggregates, ceramic, gypsum, plastic, wood…). Approximately 25 tons of the resulting C&DW was sorted off-site.

Aggregates from the demolition of a wall foundation were recovered and used for the manufacturing of a concrete slab. Optimal dosages were tested and two slab foundations (with 20% and 50% replacement of coarse aggregates, respectively) were manufactured and installed in the Penitentiary Centre. In addition, coarse mix aggregates were used for non-structural concrete application (lean concrete) and the quality of this recycled concrete was compared with non-structural concrete. Recovered non-mineral fractions like plastic, wood & mixed wooden materials and gypsum plaster board or wool insulation waste can be used for the manufacture of Wood-polymer composites (flooring elements to be used in the new building as an external pavement).

A multilayer panel composed of an external thermal insulation layer made of cement mortar with EPS and an internal structural layer made of concrete with 100% recycled coarse aggregates, was manufactured and implemented on the construction site. The elements were installed in a structure which provides service to the final building.

**DEMOLITION PROCESS**:
After the demolition process the total surface demolished was about 6,000 m$^2$. The materials recovered from demolition are described in Table 10.

| Total amount involved in the project | | |
|---|---|---|
| **Stony Fraction** | 7,650 | ton |
| **Plastic** | 19.2 | ton |
| **Wood** | 199,9 | ton |
| **Wool** | 11.5 | ton |
| **Gypsum** | 115.33 | ton |
| **Metals** | 38.46 | ton |

**Table 10:** Recovery of material from TEUREL project

The grouping of material is slightly different from the RE$^4$ material classes but given the construction surface ratio between the results presented in Table 7 and this particular project, the waste amounts are quite similar.

### 3.3. Results and discussion

The main outcome of this Section is the great variability of CDW quantities and typologies based on several factors, including the construction process, building typologies, building structure and its '*age*'. However, there are several good approximations from literature that can be used for obtaining a good estimate of CDW characterization, with various levels of accuracy depending on the amount of information available. In this section, three datasets of CDW were presented:

- CDW quantities and typologies based on estimation tables;
- CDW estimation based on buildings bills of materials;
- real CDW characterization from a real site.

This is valuable information when assessing the significance of a CDW sample or batch.

# 4. Physical assessment on CDW samples

## 4.1. CDW Processing plant description

Samples of CDW analysed in Task 4.1 were sourced in two CDW processing sites, one in Northern Europe (Oxford, UK) and one in Southern Europe (Gardanne, near Aix en Provence, Région Provence Alpes Côte d'Azur, southern France). A brief description of the processing plant in United Kingdom is given hereafter.

The company running the site is The Sheehan Group, which is also a Groundwork & Civil Engineering Contractor as well as being involved with plant hire and waste removal and reclamation. The facility is located at the Dix Pit complex in Stanton Harcourt that covers approximately 150 hectares. The site has previously been used as a sand and gravel deposit. The primary source of feed material is within Oxfordshire with a smaller amount coming from surrounding counties such as Buckinghamshire. External hauliers are bringing material from the fringes of Greater London.

The washing plant contains a range of equipment from the CDE product portfolio including a feed system, AGGMAX portable logwasher (https://www.cdeglobal.com/products/aggmax-modular-logwasher), PROGRADE aggregate screens (https://www.cdeglobal.com/products/product-categories/screening) and EVOWASH sand washing plant (https://www.cdeglobal.com/products/evowash). The system employs full closed circuit water recycling through the AQUACYCLE thickener (https://www.cdeglobal.com/products/aquacycle-thickener), as well as a GHT Filter Press (https://www.cdeglobal.com/products/filter-press). As material is delivered to the plant an overband magnet on the feed conveyor removes any metals before it is sent to the AGGMAX.

The pre-screening stage allows for any < 5mm particles to be liberated and delivered to the sand washing phase. The > 5mm aggregate material enters the integrated ROTOMAX logwasher and is subjected to a high level of attrition from the twin shaft machine. This further liberates more <5mm material while also floating off any lightweight contamination at the rear of the unit. This is subsequently dewatered on the trash screen and while the trash material (plastics, polystyrene, rubber, wood) is discharged into a bay and the <5 mm material and waste water are also sent to the EVOWASH sand washing plant to maximise recovery of the sand fraction.

As the scrubbed aggregates are discharged from the ROTOMAX they are delivered to a dewatering screen where they are given a final rinse before being sent to the aggregate sizing phase. A PROGRADE P275 dry sizing screen produces four recycled aggregate products (5-10mm, 10-20mm, 20-40mm and >40mm). The <5mm material is washed to produce two recycled sand products via the EVOWASH 102 dual sand plant.

The water treatment phase first involves the AQUACYCLE thickener, which receives waste water from the EVOWASH containing the <63 micron particles. The AQUACYCLE design allows for high rate settlement of these fine particles to the bottom of the thickener tank while the recycled water overflows to a concrete water recirculation tank before being recycled to the washing plant. A lightweight removal screen ensures that any material such as polystyrene that has not been captured does not re-enter the water circuit.

The settled sludge from the AQUACYCLE thickener is then delivered to a concrete buffer tank before being sent to the GHT Filter Press to maximise water recycling. In this instance the filter press is made up of 140 plates which press the sludge at extremely high pressure to remove the maximum volume of water. The waste material is then compressed to a filter cake containing 90% dry solids content which is dropped from the filter press into a bay below.

The end uses for the material to date have included pipe bedding, drainage material and paving. The recycled sands are being applied in concrete manufacture and concrete block making. Approximately 50% of the material is used by the Sheehan Group on its own construction and civil engineering projects with the remaining 50% sold to the local private construction market. Material are transported within a 25 mile (40 km) radius when used for in-group projects, but hauliers collecting material ex-pit are moving it further

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 723583

than this. The demand comes primarily from the private sector, particularly from those contractors operating within the 'Considerate Constructors' scheme.

## 4.2. CDW source identification and description of samples

### 4.2.1 Southern Europe sample

Unsorted CDW from Southern Europe source came from a recycling centre in Gardanne, near Aix en Provence in Région Provence Alpes Côte d'Azur in the south of France. The material was from mixed sources, e.g. from both commercial and residential buildings (Fig. 2 a). Four bags of this mixed CDW material (Fig. 2 b-c) weighing approximately 87 kg in total (Reference Code: Southern Europe Samples), were delivered to QUB Cement and Concrete Laboratories on 1 December 2016 (beginning of M4).

(a)

**Fig. 2:** (a) Mixed unsorted CDW from Southern Europe delivered to CDE

(b) (c)

**Fig. 2:** (b-c) Mixed unsorted CDW from Southern Europe delivered to QUB

### 4.2.2 Northern Europe sample

Unsorted CDW from Northern Europe source came from a recycling centre in Oxford, UK. The material was from mixed sources, i.e. both commercial and residential buildings (Fig. 3 a). Four bags of mixed CDW material (Fig. 3 b-c) weighing approximately 72 kg in total (Reference Code: Northern Europe Samples), were delivered to QUB Cement and Concrete Laboratories on 2 February 2017 (beginning of M6).

(a)


**Fig. 3:** (a) Mixed unsorted CDW from Northern Europe delivered to CDE

(b) (c)

**Fig. 3:** (b-c) Mixed unsorted CDW from Northern Europe delivered to QUB

### 4.3. Assessment methods

#### 4.3.1. Southern Europe sample

CDE & QUB carried out various assessments. On visual inspection at CDE a wide range of materials were observed:

- various organics – (Wood, soil, roots etc.),
- metals,
- ceramics (bricks and tiles),

- sand & aggregates,
- concrete Blocks,
- glass,
- various Plastics.

Hereafter only, analyses carried out at QUB are described, whereas results from the CDE assessment are shown in the annexes of this deliverable.

Initially, all mixed unsorted CDW materials were wet hand-sieved at QUB using a single 1.7 mm sieve.

The fine mixed CDW material (< 1.7 mm) was further wet hand-sieved using a 0.6 mm single sieve, thus creating a wet fraction 0.6-1.7 mm.

When it comes to the coarse mixed CDW material (> 1.7 mm), all coarse size concrete/mineral aggregates were hand-picked (result shown in Fig. 4) and then sieved using four different sieve sizes: 20 mm, 16 mm, 8 mm and 4 mm. Consequently, the following fractions of coarse size mixed concrete/mineral aggregate were obtained:

- mixed concrete/mineral aggregate (16-20 mm) (Fig. 5),
- mixed concrete/mineral aggregate (8-16 mm) (Fig. 6),
- mixed concrete/mineral aggregate (4-8 mm) (Fig. 7).

**Fig. 4:** Hand-picked mixed concrete/mineral aggregate (> 1.7 mm)

**Fig. 5:** Mixed concrete/mineral aggregate (16-20 mm) fraction

**Fig. 6:** Mixed concrete/mineral aggregate (8-16 mm) fraction

**Fig. 7:** Mixed concrete/mineral aggregate (4-8 mm) fraction

Next, the mixed concrete/mineral aggregate fraction passing the 4 mm sieve was added to the wet fraction (0.6-1.7 mm) described above. Hence, a new fraction of 0.6-4 mm in size was created, consisting of medium/coarse sand as shown in Fig. 8.

**Fig. 8:** Medium/coarse sand (0.6-4 mm) fraction

The remaining wet fine CDW material (< 0.6 mm) shown in Fig. 9 was further divided into two fractions:

- fine sand (0.075-0.6 mm),
- silt/clay (< 0.075 mm).

**Fig. 9:** Fine CDW material (< 0.6 mm)

The fine sand fraction (0.075-0.6 mm) (Fig. 10) and the silt/clay fraction (< 0.075 mm) (Fig. 11) were estimated by sieving a sample of 0.302 kg of fine CDW material (< 0.6 mm) using a 0.075 mm sieve and then projecting the results to the whole amount of fine CDW material (12.727 kg).

**Fig. 10:** Fine *s*and (0.075-0.6 mm) sample

**Fig. 11:** Silt/clay (< 0.075 mm) sample

Finally, all coarse CDW materials (> 1.7 mm), after removal of all mixed concrete/mineral aggregate particles (< 20 mm) described above, were separated by hand into 6 different fractions:

- mixed concrete/mineral aggregate particles (> 20 mm) (Fig. 12),
- mixed mortar/plaster (> 1.7 mm) (Fig. 13),
- ceramics (bricks and tiles > 1.7 mm) (Fig. 14),
- glass (> 1.7 mm) (Fig. 15),
- steel (nails, re-bars, hooks, tags etc. > 1.7 mm) (Fig. 16),
- lightweight (mixed wood/plastics > 1.7 mm) (Fig. 17).

**Fig. 12:** Mixed concrete/mineral aggregate (> 20 mm) fraction

**Fig. 13:** Mixed mortar/plaster (> 1.7 mm) fraction

**Fig. 14:** Ceramics (bricks and tiles > 1.7 mm) fraction

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**Fig. 15:** Glass (> 1.7 mm) fraction


**Fig 16:** Steel (nails, re-bars, hooks, tags etc. > 1.7 mm) fraction

**Fig. 17:** Lightweight (mixed wood/plastics > 1.7 mm) fraction

Finally, all fractions were oven-dried and weighted in order to determine their precise quantities.

### 4.3.2. Northern Europe sample

CDE & QUB carried out various assessments.
On visual inspection at CDE a wide range of materials were observed:

- various organics,
- metals,
- ceramic (bricks and tiles),
- sand,
- concrete blocks,
- glass,
- various plastics,
- asphalt.

Hereafter, only the analysis carried at QUB is described, whereas results from CDE assessment exercise are shown in the annexes of this deliverable.

Initially, all mixed unsorted CDW materials at QUB were wet hand-sieved using a single 1.7 mm sieve.

The fine mixed unsorted CDW material (< 1.7 mm) was further wet hand-sieved using a 0.6 mm single sieve thus creating a wet fraction 0.6-1.7 mm.

When it comes to the coarse mixed CDW material (> 1.7 mm), all coarse size concrete/mineral aggregate were hand-picked as shown in Fig. 18 and then sieved using four different sieve sizes: 20 mm, 16 mm, 8 mm and 4 mm. Consequently, the following fractions of coarse size mixed concrete/mineral aggregate were obtained:

- mixed concrete/mineral aggregate (16-20 mm) (Fig. 19),
- mixed concrete/mineral aggregate (8-16 mm) (Fig. 20),
- mixed concrete/mineral aggregate (4-8 mm) (Fig. 21).

**Fig. 18:** Hand-picked mixed concrete/mineral aggregate (> 1.7 mm)

**Fig. 19:** Mixed concrete/mineral aggregate (16-20 mm) fraction

**Fig. 20:** Mixed concrete/mineral aggregate (8-16 mm) fraction

**Fig. 21:** Mixed concrete/mineral aggregate (4-8 mm) fraction

The mixed concrete/mineral aggregate fraction passing the 4 mm sieve was added to the wet fraction (0.6-1.7 mm) described above. Hence, a new fraction of 0.6-4 mm in size was created, consisting of medium/coarse sand as shown in Fig. 22.

**Fig. 22:** Medium/coarse sand (0.6-4 mm) fraction

The remaining wet fine CDW material (< 0.6 mm) shown in Fig. 23 was further divided into two fractions:

- fine sand (0.075-0.6 mm),
- silt/clay (< 0.075 mm).

**Fig. 23:** Fine CDW material (< 0.6 mm)

The fine sand fraction (0.075-0.6 mm) (Fig. 24) and the silt/clay fraction (< 0.075 mm) (Fig. 25) were estimated by sieving a sample of 1.283 kg of fine CDW material (< 0.6 mm) using a 0.075 mm sieve and then projecting the results to the whole amount of fine CDW material (6.542 kg).

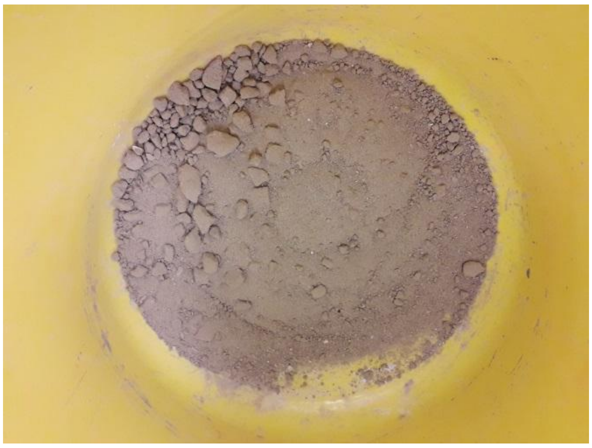

**Fig. 24:** Fine *s*and (0.075-0.6 mm) sample

**Fig. 25:** Silt/clay (< 0.075 mm) sample

Finally, all coarse CDW material (> 1.7 mm) left after removal of all mixed concrete/mineral aggregate particles (< 20 mm) described above was separated by hand into 7 different fractions:

- mixed concrete/mineral aggregate particles (> 20 mm) (Fig. 26),
- mixed mortar/plaster particles (> 1.7 mm) (Fig. 27),
- ceramics (bricks and tiles > 1.7 mm) (Fig. 28),
- bitumen (> 1.7 mm) (Fig. 29),
- glass (> 1.7 mm) (Fig. 30),
- steel (nails, wire, pipe fragments etc. > 1.7 mm) (Fig. 31),
- lightweight (mixed wood/plastics > 1.7 mm) (Fig. 32).

**Fig. 26:** Mixed concrete/mineral aggregate (> 20 mm) fraction

**Fig. 27:** Mixed mortar/plaster (> 1.7 mm) fraction

**Fig. 28:** Ceramics (bricks and tiles > 1.7 mm) fraction

**Fig. 29:** Bitumen (> 1.7 mm) fraction

**Fig. 30:** Glass (> 1.7 mm) fraction

**Fig. 31:** Steel (nails, wire, pipe fragments > 1.7 mm) fraction

**Fig. 32:** Lightweight (mixed wood/plastics > 1.7 mm) fraction

Finally, all fractions were oven-dried and weighted in order to determine their precise quantities.

## 4.4. Results and discussion

### 4.4.1 Southern Europe sample

The mass of each fraction in kilograms and as a percentage of the total weight of mixed CDW material delivered to QUB is shown in Table 11 and Fig. 33.

| Fraction | Mass (kg) | % of total mixed CDW material |
|---|---|---|
| Silt/clay (< 0.075 mm)* | 7.712 | 8.9 |
| Fine sand (0.075-0.6 mm)* | 5.015 | 5.8 |
| Medium/coarse sand (0.6-4 mm) | 8.280 | 9.6 |
| Mixed concrete/mineral aggregate (4-8 mm) | 4.140 | 4.8 |
| Mixed concrete/mineral aggregate (8-16 mm) | 4.949 | 5.7 |
| Mixed concrete/mineral aggregate (16-20 mm) | 1.619 | 1.9 |
| Mixed concrete/mineral aggregate (> 20 mm) | 32.704 | 37.8 |
| Mixed mortar/plaster (> 1.7 mm) | 9.211 | 10.6 |
| Ceramics (bricks and tiles > 1.7 mm) | 11.955 | 13.8 |
| Glass (> 1.7 mm) | 0.113 | 0.1 |
| Steel (nails, re-bars, hooks, tags etc. > 1.7 mm) | 0.110 | 0.1 |
| Lightweight (mixed plastics/wood > 1.7 mm) | 0.643 | 0.9 |
| **Total** | **86.453** | **100** |

* Estimate based on projected results of an analysed sample weighing 0.302 kg.

**Table 11:** Composition of mixed CDW material from Southern Europe delivered to QUB.

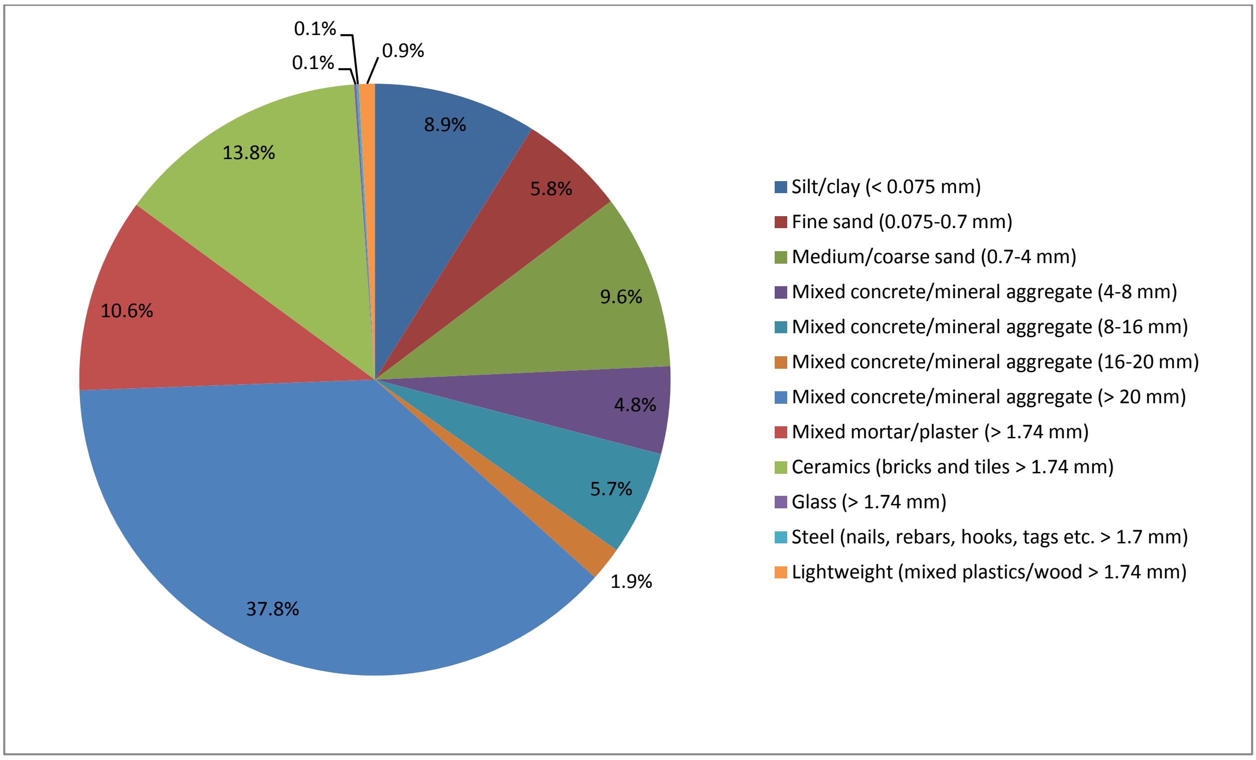


**Fig. 33:** Percentage composition of mixed CDW material from Southern Europe delivered to QUB

Table 11 and Fig. 33 show that the mixed CDW material from Southern Europe contained approximately 12.4% of coarse size mixed concrete/mineral aggregate readily available for use in the production of new concrete. More specifically,

- approximately 4.8% mixed concrete/mineral aggregate (4-8 mm),
- approximately 5.7% mixed concrete/mineral aggregate (8-16 mm),
- approximately 1.9% mixed concrete/mineral aggregate (16-20 mm).

In addition, by far the largest fraction (approximately 37.8%) of the delivered mixed CDW material was mixed concrete/mineral aggregate particles (> 20 mm) as shown in Fig. 33. Assuming that the w/c ratio used for manufacturing the concrete from which these particles originate was 0.5 (max. cement content used 300 kg/m$^3$) and taking into account the old UK system of concrete proportions 1-2-4 (1 part of cement, two parts of fine aggregate and 4 parts of coarse aggregate), significant amounts of coarse mineral aggregate (4-20 mm) can be recycled by crushing and sieving the above fraction.

### 4.4.2 Northern Europe sample

The mass of each fraction in kilograms and as a percentage of the total weight of mixed CDW material delivered to QUB is shown in Table 12 and Fig. 34, whereas results from CDE assessment exercise are shown in Fig.35.

| Fraction | Mass (kg) | % of total mixed CDW material |
|---|---|---|
| Silt/clay (< 0.075 mm)* | 1.812 | 2.5 |
| Fine sand (0.075-0.6 mm)* | 4.730 | 6.6 |
| Medium/coarse sand (0.6-4 mm) | 5.703 | 7.9 |
| Mixed concrete/mineral aggregate (4-8 mm) | 3.214 | 4.5 |
| Mixed concrete/mineral aggregate (8-16 mm) | 4.105 | 5.7 |
| Mixed concrete/mineral aggregate (16-20 mm) | 0.899 | 1.2 |
| Mixed concrete/mineral aggregate (> 20 mm) | 25.153 | 34.9 |
| Mixed mortar/plaster (> 1.7 mm) | 4.263 | 5.9 |
| Ceramics (bricks and tiles > 1.7 mm) | 19.097 | 26.5 |
| Bitumen (> 1.7 mm) | 2.466 | 3.4 |
| Glass (> 1.7 mm) | 0.136 | 0.2 |
| Steel (nails, wire, pipe fragments etc. > 1.7 mm) | 0.197 | 0.3 |
| Lightweight (mixed plastics/wood > 1.7 mm) | 0.221 | 0.3 |
| **Total** | **71.996** | **100** |

* Estimate based on projected results of an analysed sample weighing 1.283 kg.

**Table 12:** Composition of mixed CDW material from Northern Europe delivered to QUB.

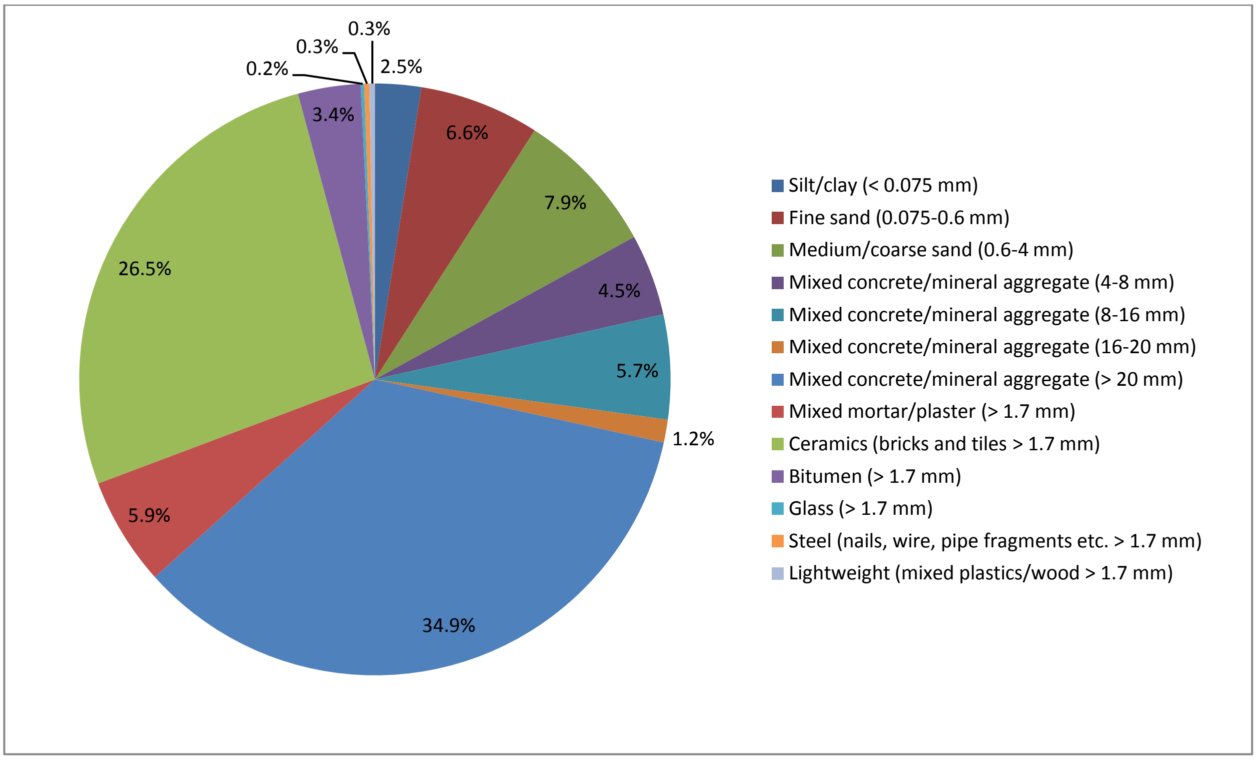


**Fig. 34:** Percentage composition of mixed CDW material from Northern Europe delivered to QUB

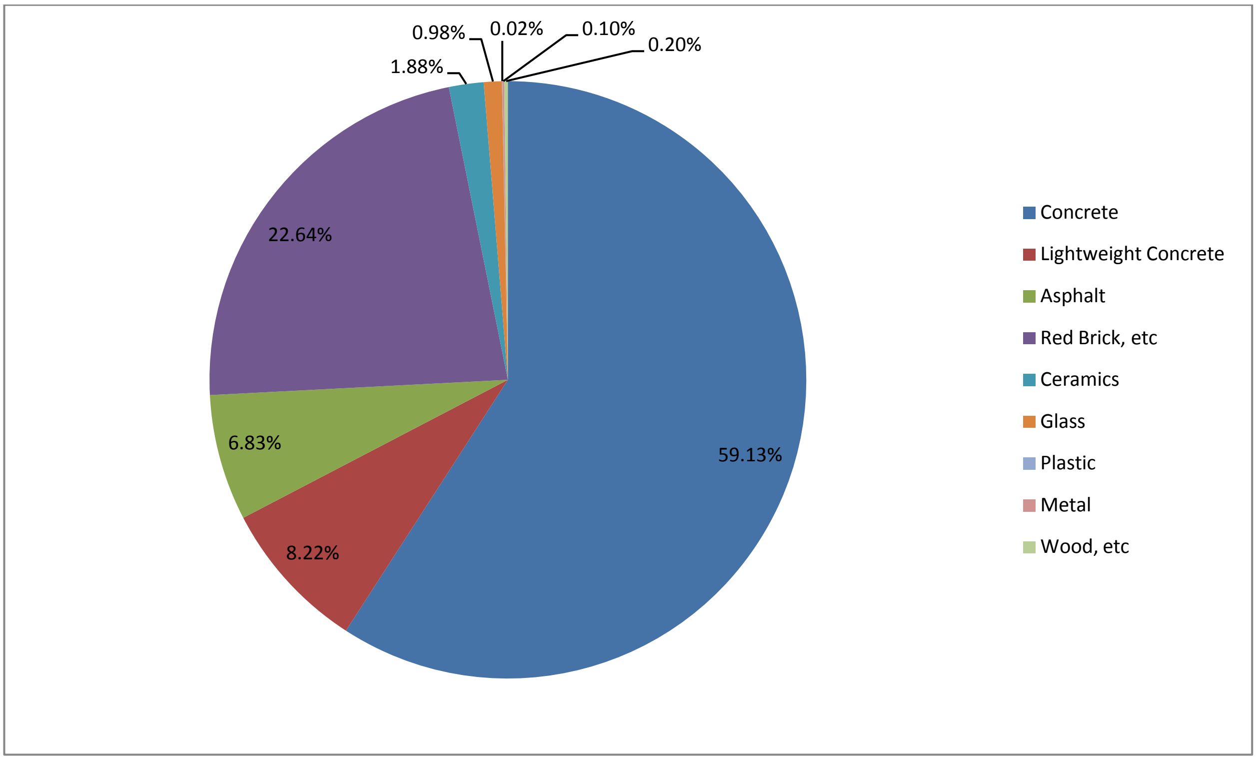


**Fig. 35:** Percentage composition of mixed CDW material from Northern Europe delivered to CDE

As shown in Table 12 and Fig. 34 the Northern Europe mixed CDW sample contained an additional fraction (Bitumen > 1.7 mm) when compared to Southern Europe sample. The Bitumen (> 1.7 mm) content was found to be approximately 3.4% of the total mixed CDW sample.

Results also show that the mixed CDW material from Northern Europe contained approximately 11.4% of coarse size mixed concrete/mineral aggregate readily available for use in the production of new concrete. More specifically,

- approximately 4.5% mixed concrete/mineral aggregate (4-8 mm).
- approximately 5.7% mixed concrete/mineral aggregate (8-16 mm).
- approximately 1.2% mixed concrete/mineral aggregate (16-20 mm).

In addition, by far the largest fraction (approximately 34.9%) of the delivered mixed CDW material was mixed concrete/mineral aggregate particles (> 20 mm) as shown in Fig. 34. Assuming that the w/c ratio used for manufacturing the concrete from which these particles originate was 0.5 (max. cement content used 300 kg/m$^3$) and taking into account the old UK system of concrete proportions 1-2-4 (1 part of cement, two parts of fine aggregate and 4 parts of coarse aggregate), significant amounts of coarse mineral aggregate (4-20 mm) can be recycled by crushing and sieving the above fraction.

The above results are very similar to the ones obtained from the Southern Europe sample. Consequently, the presence of bitumen in relatively small quantities (approximately 3.4% of the total mixed CDW material) does not significantly lower the amount of coarse size mixed concrete/mineral aggregate readily available for use in the production of new concrete.

Similarly, considerably higher levels of ceramics recorded in the Northern Europe sample (26.5%) as opposed to the Southern Europe sample (13.8%), do not significantly alter the amount of coarse size mixed concrete/mineral aggregate readily available for use in the production of new concrete.

It should be noted that small amounts of ferrous material were recovered from both samples (0.1% of Southern Europe and 0.3% of Northern Europe mixed CDW samples). Taking into account the ability of the proposed RE4 improved sorting system to process large quantities of mixed CDW material, the installation of magnets during manufacture of its conveyor belt is highly recommended, as the amount of ferrous material recovered can be significant.

Finally, it should be noted that different samples originating from the same geographic region (Northern Europe) and analysed in different laboratories (QUB and CDE) contained similar percentages of total mixed mineral aggregate/concrete, ceramics (bricks and tiles), bitumen/asphalt, steel, glass and lightweight (mixed wood/plastics) fractions.

## 5. Conclusions

D4.1 summarizes the results obtained within T4.1 of RE4 project. The work carried out has been detailed in the three main sections of this deliverable: 1. literature analysis for collection of already available data on CDW composition; 2. laboratory analysis of specific CDW samples allocated to RE4 project and coming from both Northern-EU and Southern-EU, to determine actual mass composition and general variability of unsorted CDW; 3. a study on the theoretical composition of unsorted CDW, based on real case studies, to have a further baseline for evaluating the composition of CDW materials.

All these sections clearly illustrate that high volumes of reusable materials are present in CDW.

The **Literature Analysis** (Section 2) confirmed that the average composition of unsorted CDW is extremely variable among the different European countries. This suggests that a very flexible CDW sorting system has to be developed within Work Package 2 (*Strategies for innovative sorting of CDW and reuse of structures from dismantled buildings*), because CDW materials cannot be considered constant. Literature assessments also indicate the volumes of each fraction can vary greatly depending on the construction process, building typology, building structure and age. It is important to consider these variances in WP2 and ensure the innovative sorting system developed can deal with such variances in feed material without jeopardising the quality of output recycled fractions. Literature review also highlighted Germany, France and UK as top producers of CDW, this is in line with the sources selected for CDW materials procurement within $RE^4$ project.

The study on the **Theoretical Composition** (Section 3) confirmed the great variability of CDW quantities and typologies based on several factors, including the construction process and typology, structure and '*age*' of the building. However, there are several good approximations from literature that can be used for obtaining a good estimate of CDW characterization, with various levels of accuracy depending on the amount of information available.

The **Composition Analysis** (Section 4) carried out in two different labs (QUB and CDE) on unsorted CDW materials allocated to $RE^4$ project, both from Southern EU (France) and Northern EU sources (United Kingdom), provided accurate quantities of each material fraction. By way of example, approximate quantities of each fraction (average values on S-EU and N-EU batches) found during physical assessments by QUB lab are summarised below:

- sand (0-4mm) 15% wt;
- mixed concrete/mineral aggregates (4-20mm) 12% wt;
- mixed concrete/mineral aggregates (>20mm) 35% wt;
- ceramics (bricks and tiles) 20% wt;
- glass 0.15% wt;
- steel/metals 0.2% wt;
- lightweights 0.6% wt;
- silt/clay 5.5% wt.

Although the lightweights/organics only constituted a small fraction of the CDW by weight, due to their low density they make up a larger fraction by volume. The organics volume is an important consideration for WP2 (*Strategies for innovative sorting of CDW and reuse of structures from dismantled buildings*), since it can greatly affect the throughput of the innovative sorting system developed in that work package. The fine organics in the sand fraction may also require further processing in order to create a material as close to natural sand as possible. This will be investigated further in WP2.

Composition analysis showed that samples which originated from the same geographical region (e.g. Northern Europe) and analysed in different laboratories (CDE and QUB) contained similar percentages of total mixed mineral aggregate/concrete, ceramics (bricks and tiles), bitumen/asphalt, steel, glass and lightweight (mixed wood/plastics) fractions. In other words, the variability with respect to samples from the same geographical source was low. In addition, composition analysis showed that samples which originated from different geographical regions (Southern and Northern Europe) and were analysed in different laboratories (CDE and QUB) contained similar amounts of coarse size mixed concrete/mineral aggregate readily available for use in the production of new concrete. Lightweight and sand (sum of fine and medium/coarse sand) fractions were also found to be similar in the range of less than 1% and 15%, respectively. On the other hand, significant differences were found when it comes to silt/clay, ceramics and bitumen fractions.

The analysis about the typical composition and volumes of CDW reported in D4.1 represents an essential and well-structured starting point to support the full development of innovative sorting systems for CDW expected in WP2, such systems will produce recycled products suitable for use in high value applications as intended by RE$^4$.

## References


[1] The Production of Recycled Aggregates from Inert Waste, The SARMa manuals, 2011

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## Annex 1. Physical assessment of CDW samples by CDE (Southern Europe samples)

Construction & Recycling | Mining | Specialist Sands | Environmental

# Material Analysis

# January 2017

## Contents







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## Introduction

Raw sample of approx. 600Kg was provided to CDE lab.

The Intention is to run chemical and physical examination on the material.

- Establish content (materials present)
- Physical properties
- Percentage waste/useable material

## Innovative steps

The RE4 project will develop an innovative project to remove all contaminants and further process recycled aggregate to produce materials which can be used in a wide range of higher value applications.






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## Plan of Action

1. Sample of 600kg will be dispensed onto a flat area to be picked
2. 3 random samples of approx. 20kg will be taken
3. +125mm will be removed and analysed from each sample. Waste materials and organics will be also removed at this stage
4. -125mm will be sieved using a vibration laboratory sieve
5. Pictures and analysis of each sieve
6. Wash and dry -8mm material to simulate CDE plant washing system
7. Compare washed sample with unwashed to show improvement
8. Conclusion regarding washed and sieved material
9. Table showing materials present along with other waste/contaminants present
10. Pie chart to show distribution of valuable material compared to raw feed
11. Results and discussion





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## Material used

*Material was received in a large 1/2 ton bag*

At first glance there is a huge range of material present,

- Various Organics – (Wood,soil,roots etc)
- Metals
- Ceramic
- Sand
- Building Blocks
- Tiles
- Glass
- Various Plastics

*Pictures show the variation of fine material along with large particles*

## Testing process

The first sample was taken from random sample points in the four piles of material. Approximately 20kg sample was taken and processed.

1. **Stage 1 Organic and oversize removal**

The sample is spread across flat surface and inspected; large organics, plastics and other waste materials are removed at this stage, along with +125mm aggregate material.

## 2. Stage 2 Aggregate separation

This stage consists of sieving material from 0-125mm using the BSEN sieve grading. During this stage, organics and other plastics/waste that were not removed at the initial stage 1 will also be removed.

Material ranging from 8-125mm is then separated and weighed at this stage.

Large quantity of organics/waste was removed at this stage and will be added to the organics removed at stage 1 to give an overall value for this sample



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### 3. Stage 3 Sand analysis

At this stage of the process, 0-8mm material will be weighed and dried. This is to prepare the sample for sieve analysis and to allow the moisture content of the material to be recorded.

Once dried, the material is sieved using vibration to separate each particle size according to the BSEN sieve grading.

### 4. Stage 4 Results

At this stage the cleanliness of the raw material can be determined; this will give us an insight into the percentage of waste within the material.

Silt content and fines percentage can be taken from the sample; also the overall sample will be accounted for and results to follow.

Picture shows the smaller particles after a long process of soil removal from the 0-4mm sample



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5. **Stage 5 Conclusion**

**At this stage, we will look at the results of each and compare between samples.**

To conclude from what we found in the 1st sample, material present consisted of metal, organics, plastics, soil, sand and gravel. Approx 1 % of the full sample contained waste material such as glass, metals, plastics and organics.

**Sample 1**

| *Sieve Size (mm)* | *Grams Retained* | *% Retained* | *% Passing* |
|---|---|---|---|
| 180.0 | 0.00 | 0.0 | 100.0 |
| 125.0 | 758.20 | 4.2 | 95.8 |
| 90.0 | 0.00 | 0.0 | 95.8 |
| 63.0 | 2741.44 | 15.2 | 80.6 |
| 45.0 | 609.53 | 3.4 | 77.2 |
| 31.5 | 1615.79 | 9.0 | 68.2 |
| 22.4 | 867.04 | 4.8 | 63.4 |
| 16.0 | 692.06 | 3.8 | 59.6 |
| 11.2 | 829.59 | 4.6 | 55.0 |
| 8.0 | 685.14 | 3.8 | 51.2 |
| 4.0 | 1535.03 | 8.5 | 42.7 |
| 2.0 | 1237.80 | 6.9 | 35.8 |
| 1.0 | 1574.12 | 8.7 | 27.1 |
| 0.500 | 1376.50 | 7.6 | 19.5 |
| 0.250 | 1286.33 | 7.1 | 12.3 |
| 0.125 | 884.40 | 4.9 | 7.4 |
| 0.063 | 1091.45 | 6.1 | 1.4 |
| Pan | 245.81 | 1.4 | |
| ***Total*** | 18030.22 | 100.0 | |
| ***Comments*** *To BSEN Standards* | Mixed Organic Mat'r. - 161.17 gms. | | |

| | |
|---|---|
| Glass | 13.97 |
| Metal | 6.95 |
| Plastic | 9.55 |
| Other | 130.70 |



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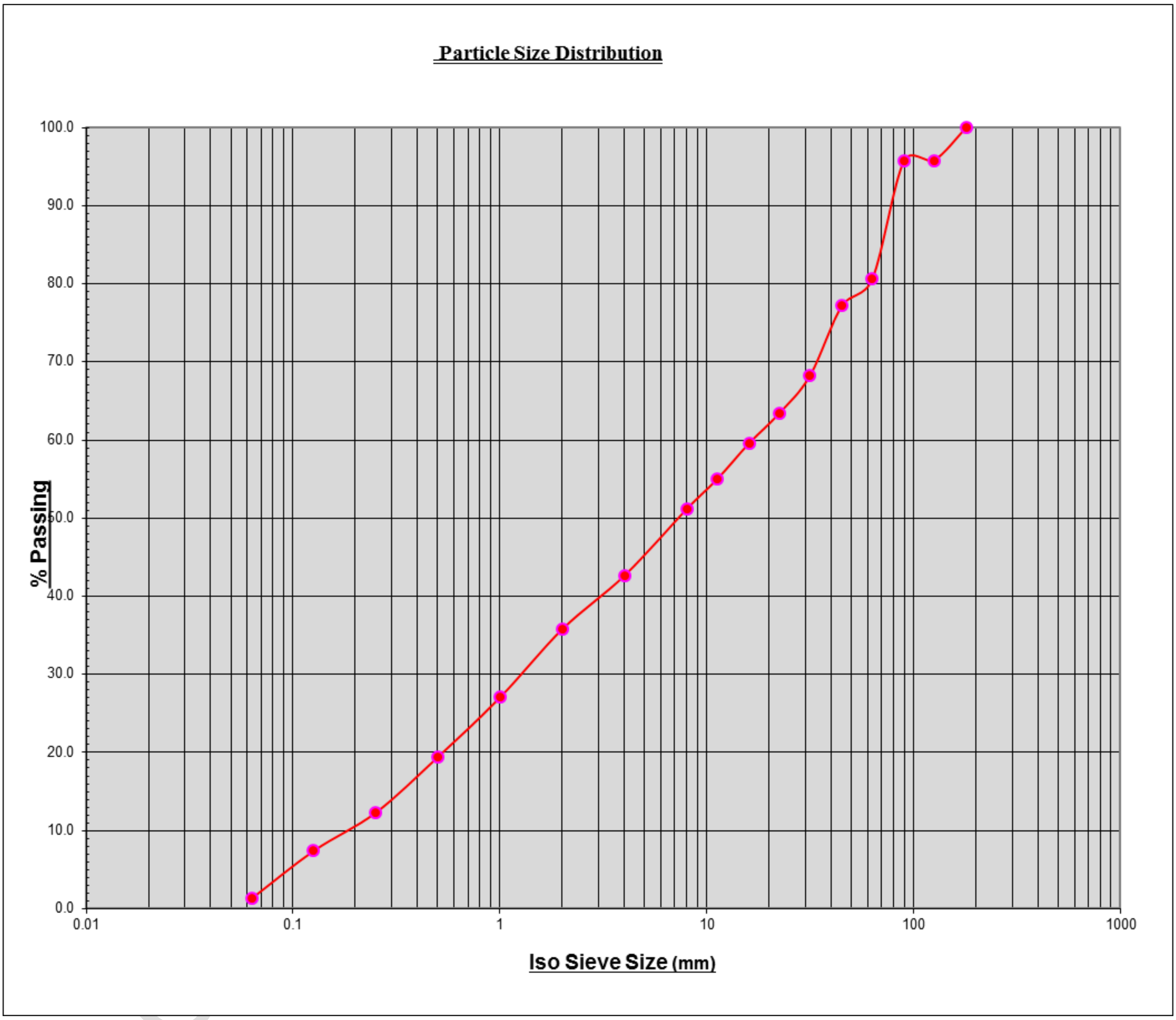
A positive correlation within the grading shows a good variation of useable material present. A silt content of 6% and a small oversize (+125mm) content of 4.2%



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The pie chart below shows the variation of material present in the 1st sample.

Consisting of mainly,

Sand 42%

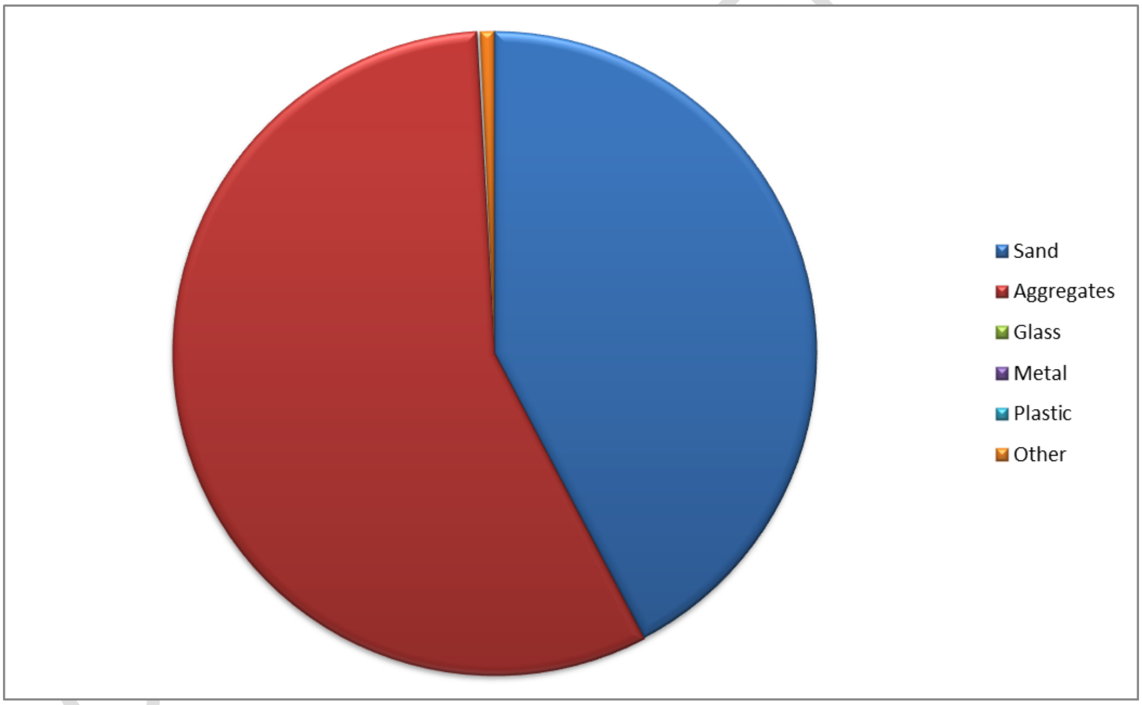
Aggregates 57%.

Organics 0.7%

Glass 0.08%

Plastic 0.05%

Metal 0.04%



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**Sample 2**

To conclude from what we found in the 2nd sample, material present consisted of metal, organics, plastics, soil, sand and gravel. Approx. 1.6% of the full sample contained waste material such as metals, plastics and organics.

| ***Sieve Size (mm)*** | ***Grams Retained*** | ***% Retained*** | ***% Passing*** |
|---|---|---|---|
| 180.0 | 0.00 | 0.0 | 100.0 |
| 125.0 | 1437.65 | 6.9 | 93.1 |
| 90.0 | 1160.34 | 5.6 | 87.5 |
| 63.0 | 3258.57 | 15.7 | 71.8 |
| 45.0 | 1486.30 | 7.2 | 64.6 |
| 31.5 | 1373.60 | 6.6 | 58.0 |
| 22.4 | 704.61 | 3.4 | 54.6 |
| 16.0 | 790.06 | 3.8 | 50.8 |
| 11.2 | 587.83 | 2.8 | 48.0 |
| 8.0 | 1045.46 | 5.0 | 42.9 |
| 4.0 | 1464.69 | 7.1 | 35.9 |
| 2.0 | 1041.34 | 5.0 | 30.8 |
| 1.0 | 1377.95 | 6.6 | 24.2 |
| 0.500 | 1293.44 | 6.2 | 18.0 |
| 0.250 | 1346.23 | 6.5 | 11.5 |
| 0.125 | 982.20 | 4.7 | 6.7 |
| 0.063 | 1295.28 | 6.2 | 0.5 |
| Pan | 102.00 | 0.5 | |
| ***Total*** | 20747.56 | 100.0 | |
| ***Comments*** *To BSEN Standards* | Mixed Organic Mat'r. - 337.16 gms. | | |

| | |
|---|---|
| Glass | |
| Metal | 148.97 |
| Plastic | 36.98 |
| Other | 151.2 |





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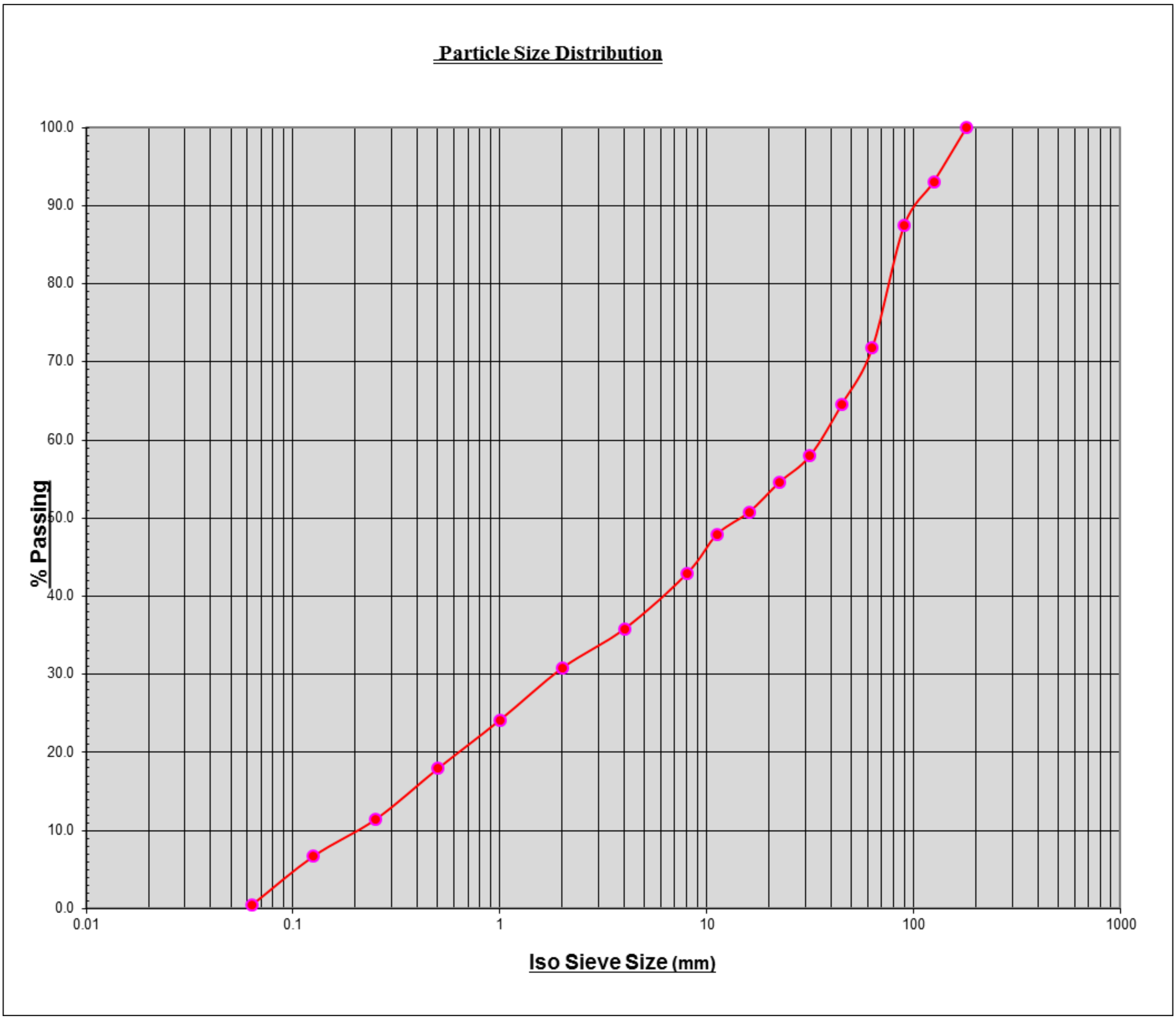
Similar to the first sample, there is an expected positive correlation in the grading present within the material. A silt content of 6.2% and a slightly larger than sample 1 oversize content of 6.9%



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The pie chart below shows the variation of material present in the 2nd sample.

Consisting of mainly,

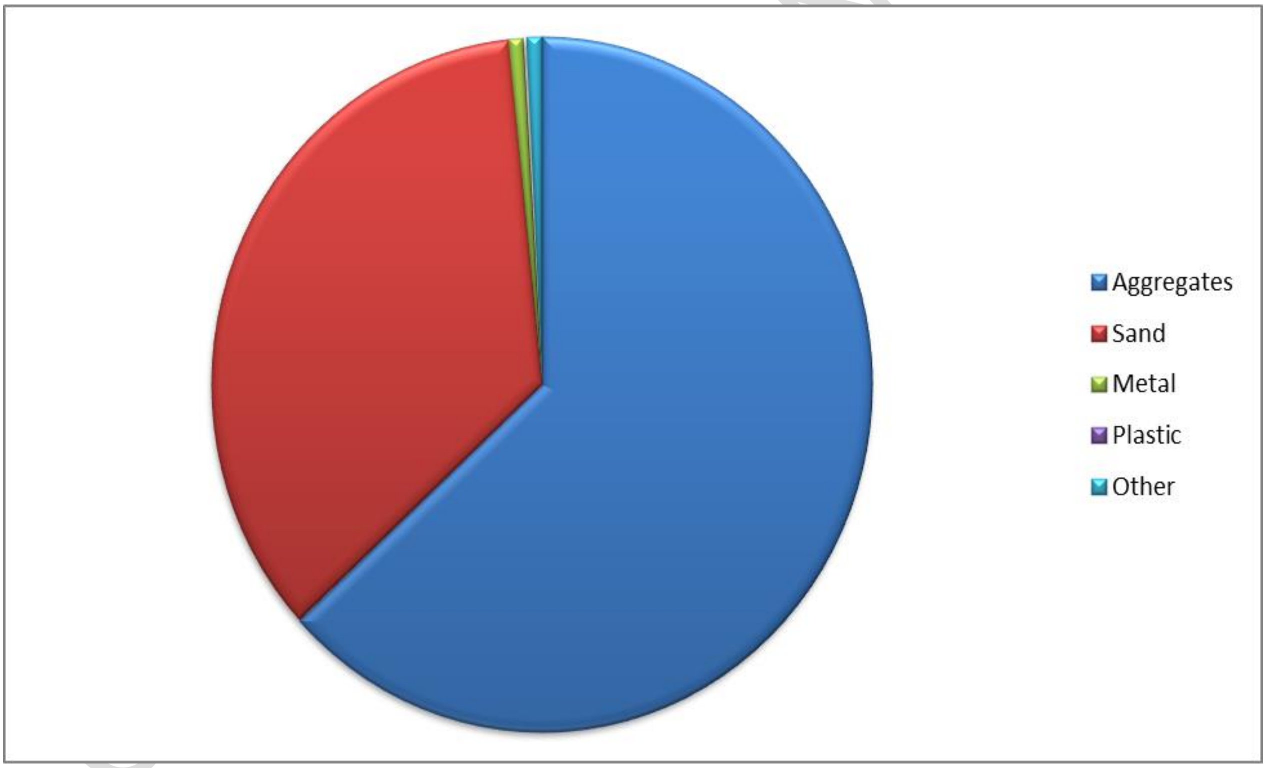
Aggregates 63%.

Sand 35%

Organics 0.7%

Metal 0.7%

Plastic 0.18 %



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**Sample 3**

To conclude from what we found in the 3rd sample, material present consisted of metal, organics, plastics, soil, sand and gravel. Approx 3 % of the full sample contained waste material such as glass, metals, plastics and organics. This was the highest percentage across all three samples

| Sieve Size (mm) | Grams Retained | % Retained | % Passing |
|---|---|---|---|
| 180.0 | 0.00 | 0.0 | 100.0 |
| 125.0 | 777.53 | 3.8 | 96.2 |
| 90.0 | 1657.06 | 8.0 | 88.2 |
| 63.0 | 1727.30 | 8.4 | 79.8 |
| 45.0 | 2029.81 | 9.8 | 70.0 |
| 31.5 | 1679.56 | 8.1 | 61.8 |
| 22.4 | 1042.18 | 5.1 | 56.8 |
| 16.0 | 651.65 | 3.2 | 53.6 |
| 11.2 | 951.25 | 4.6 | 49.0 |
| 8.0 | 849.83 | 4.1 | 44.9 |
| 4.0 | 1532.96 | 7.4 | 37.5 |
| 2.0 | 1218.70 | 5.9 | 31.5 |
| 1.0 | 1438.03 | 7.0 | 24.6 |
| 0.500 | 1265.90 | 6.1 | 18.4 |
| 0.250 | 1253.65 | 6.1 | 12.4 |
| 0.125 | 901.22 | 4.4 | 8.0 |
| 0.063 | 1135.16 | 5.5 | 2.5 |
| Pan | 512.25 | 2.5 | |
| ***Total*** | 20624.04 | 100.0 | |
| ***Comments*** *To BSEN Standards* | Mixed Waste - 677 gms | | |



| | |
|---|---|
| Glass | 254.82 |
| Metal | 290.16 |
| Plastic | 12.85 |
| Other | 118.73 |



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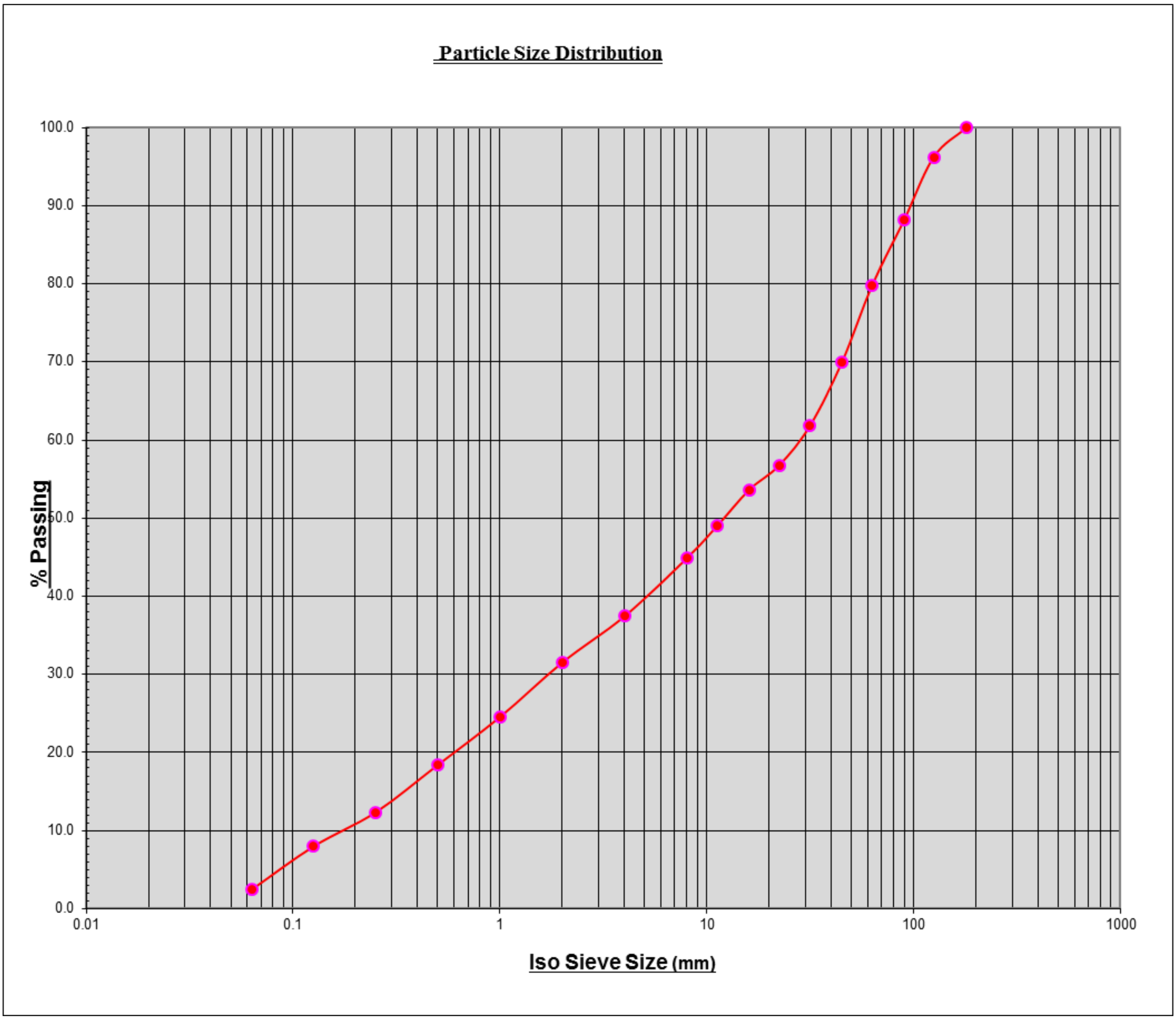
Similar to the first and second sample, there is an expected positive correlation in the grading present within the material. A silt content of 5.5% which is relatively average when compared to the other two samples taken.



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The pie chart below shows the variation of material present in the 3rd sample.

Consisting of mainly,

Aggregates 60.5%.

Sand 36%

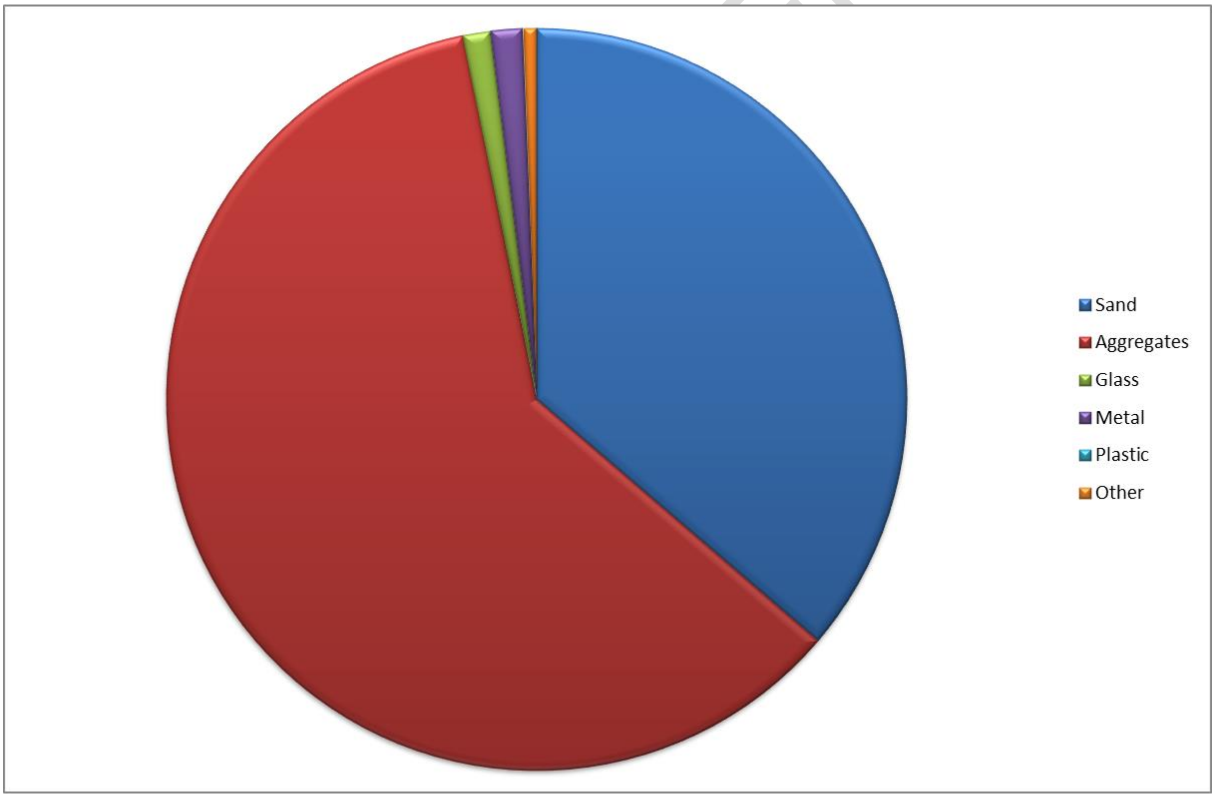
Organics 0.56%

Metal 1.36%

Plastic 0.06 %

Glass 1.2%





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In this final stage, we will compare the overall results to achieve an Overall Comparison

| *Sieve Size (mm)* | *Grams Retained* | *% Retained* | *% Passing* |
|---|---|---|---|
| *180.0* | 0.00 | 0.0 | 100.0 |
| *125.0* | 2973.38 | 5.0 | 95.0 |
| *90.0* | 2817.40 | 4.7 | 90.3 |
| *63.0* | 7727.31 | 13.0 | 77.2 |
| *45.0* | 4125.64 | 6.9 | 70.3 |
| *31.5* | 4668.95 | 7.9 | 62.4 |
| *22.4* | 2613.83 | 4.4 | 58.0 |
| *16.0* | 2133.77 | 3.6 | 54.4 |
| *11.2* | 2373.67 | 4.0 | 50.5 |
| *8.00* | 2579.93 | 4.3 | 46.1 |
| *4.00* | 4532.68 | 7.6 | 38.5 |
| *2.00* | 3497.84 | 5.9 | 32.6 |
| *1.00* | 4390.10 | 7.4 | 25.2 |
| *0.500* | 3935.84 | 6.6 | 18.6 |
| *0.250* | 3886.21 | 6.5 | 12.0 |
| *0.125* | 2767.82 | 4.7 | 7.4 |
| *0.063* | 3521.89 | 5.9 | 1.4 |
| *Pan* | 860.06 | 1.4 | |
| ***Total*** | 59406.32 | 100.0 | |
| ***Comments***<br>*To BSEN Standards* | *Mixed Waste Mat'r. - 1184.9 gms* | | |



| | |
|---|---|
| Glass | 278.79 |
| Plastic | 59.38 |
| Metal | 446.08 |
| Other | 400.63 |



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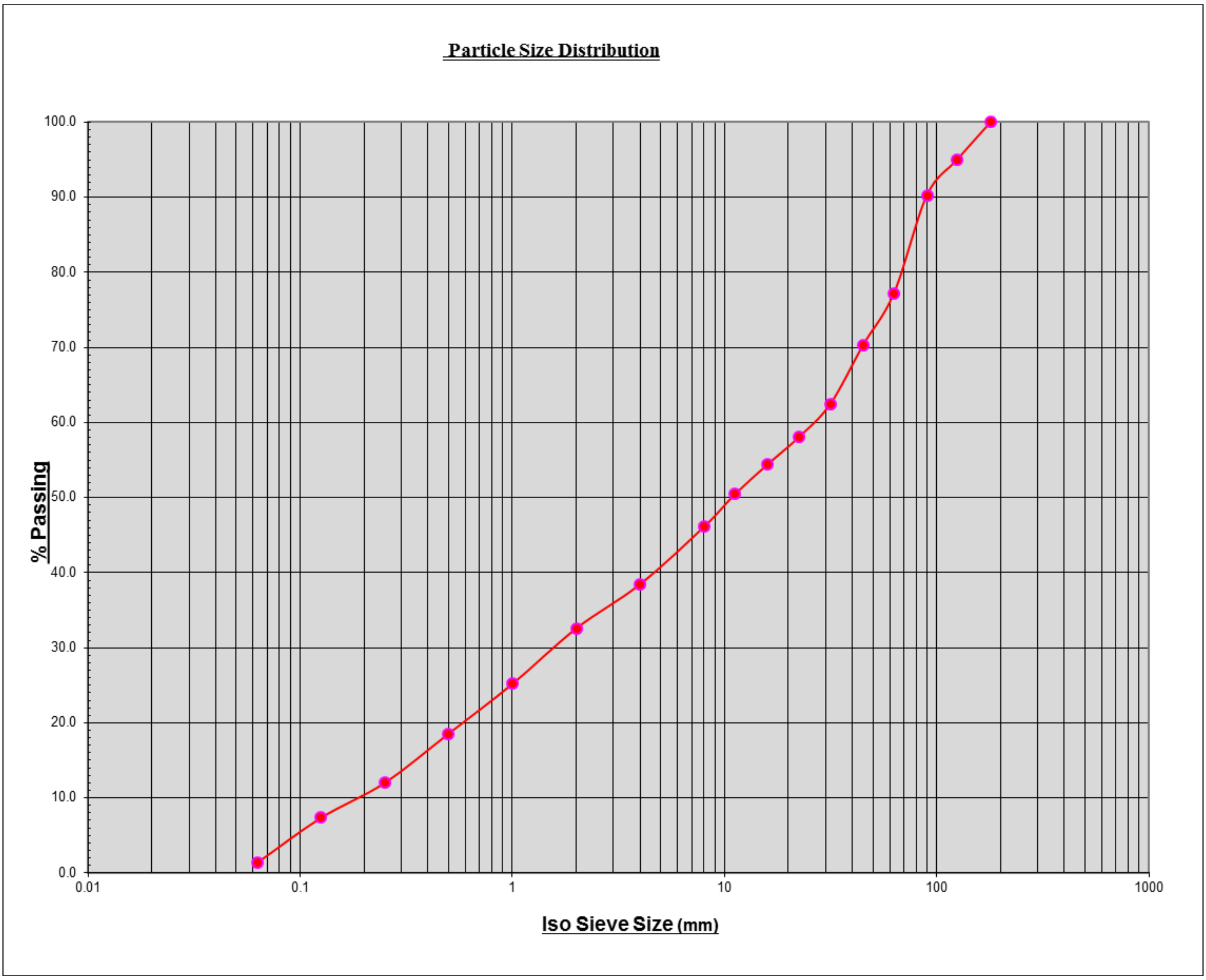
The overall PSD shows a general trend that was recognised in all samples. A positive correlation shows a good spread of aggregate and useful sand within the material. There are no real anomalies within these samples showing a good consistent feed of raw material, important for sand washing practices. Silt levels within all 3 samples also remained consistent which can insure an efficient sand washing process, the average coming in at 5.9%



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The pie chart below shows the variation of material present in the 2nd sample.

Consisting of mainly,

Aggregates 60.3%.

Sand 37.7%

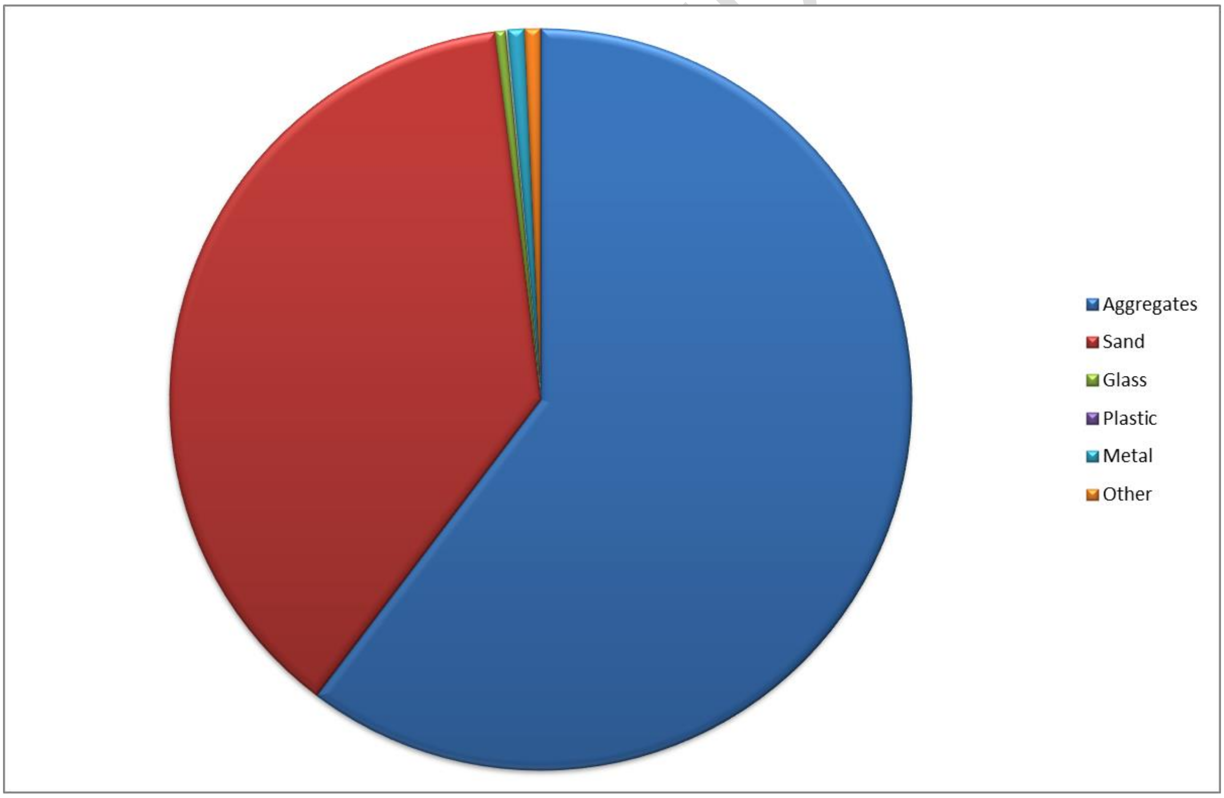
Organics 0.66%

Metal 0.74%

Plastic 0.1%

Glass 0.46%





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## Coarse particle separation

In this section of the testing, particles from sizes, 4-11mm underwent further examination. The material was separated according to physical properties to give a further insight into the content within the sample 3.







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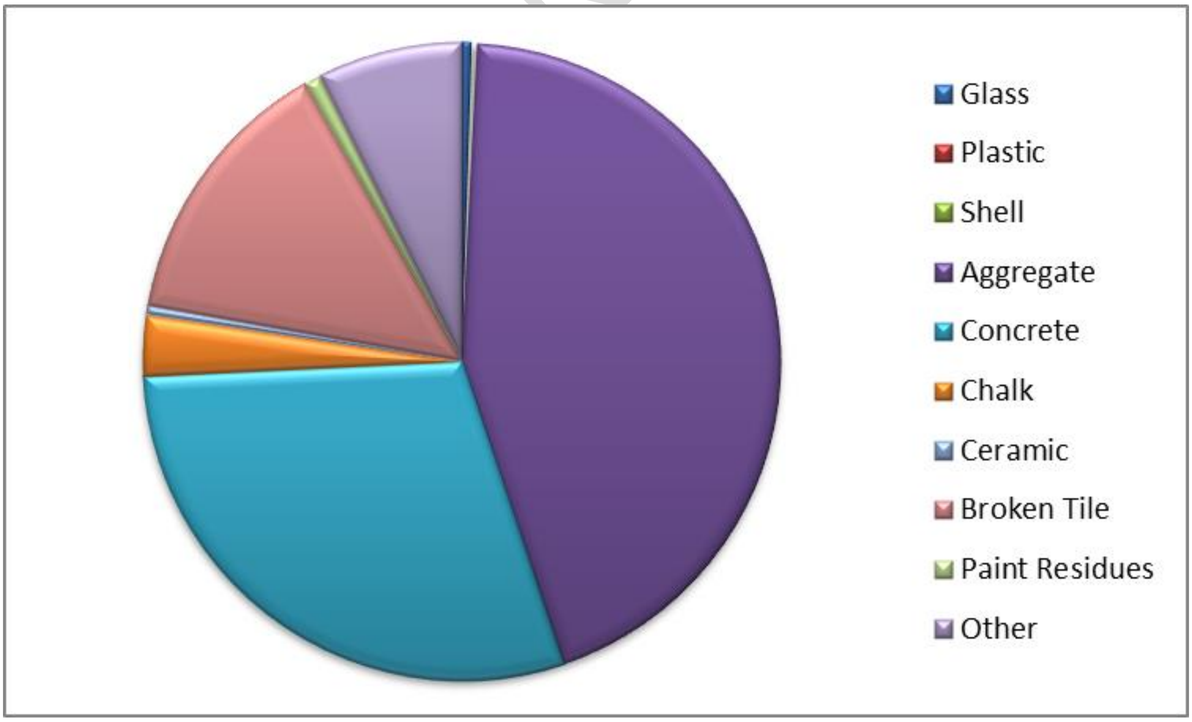
The results of this material separation from sample 3 are as follows

From the results, it is clear that there is a large array of material present within the sample, consisting of mainly aggregate and concrete material, along with a small percentage of plastic and paint contaminants.

| Materials - 4 mm - 11.2 mm | | Percentage |
|---|---|---|
| | (g) | % |
| Glass | 10.18 | 0.4 |
| Plastic | 1.74 | 0.1 |
| Shell | 6.19 | 0.3 |
| Aggregate | 1012.44 | 44.0 |
| Concrete | 676.65 | 29.4 |
| Chalk | 70.86 | 3.1 |
| Ceramic | 10.53 | 0.5 |
| Broken Tile | 322.37 | 14.0 |
| Paint Residues | 19.11 | 0.8 |
| Other | 169.21 | 7.4 |
| Total | 2299.28 | |





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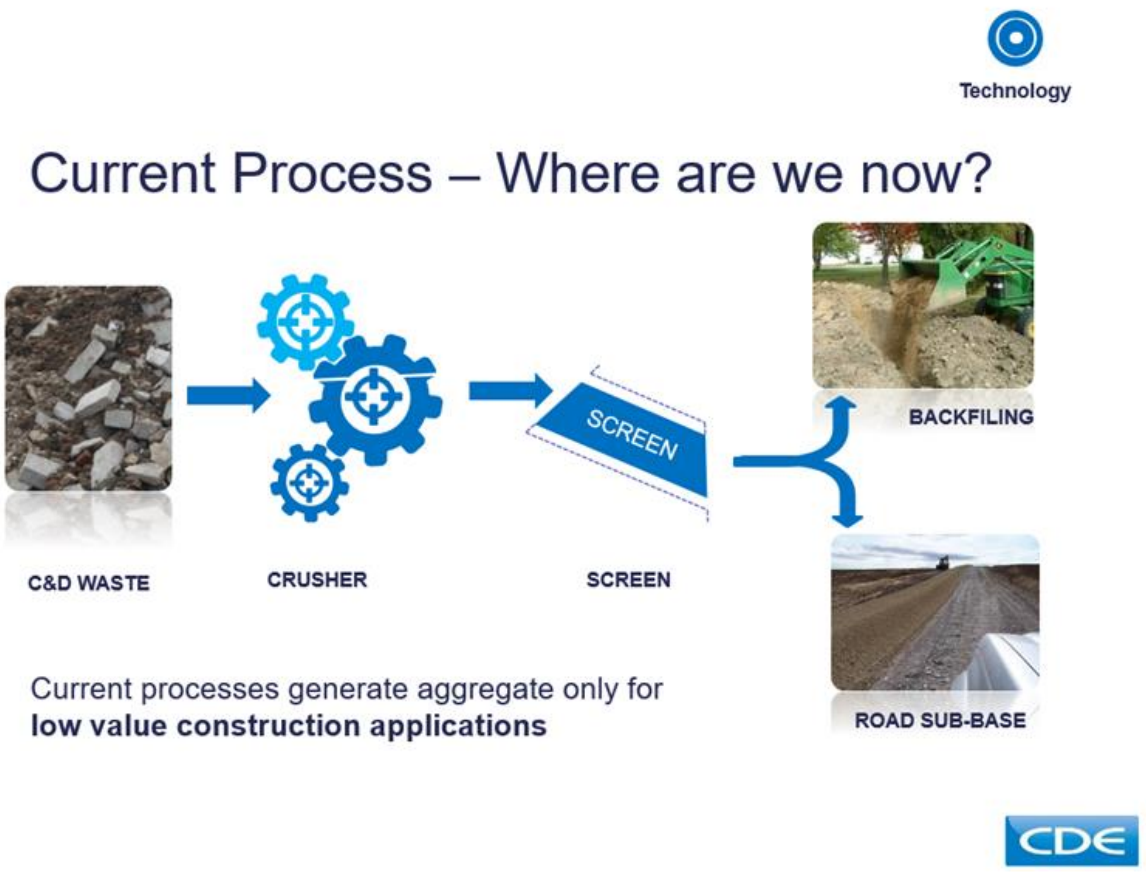
## Conclusion

To conclude, from the material analysis we have established the content within the material along with the percentage waste and useable material

The material had an average silt content of approx.6%, a consistent grading of 63-57% aggregates and 35-42% sand. This consistency is the key in establishing a relative product sizes and achievable output values from a CDE washing plant point of view.

Waste materials contained within the material such as organics and plastics can all be removed using water-washing systems that CDE currently impose and metal removal via magnetic process can eliminate metallic waste within the products.

These materials can be implemented into current processes (crushing and screening) to generate aggregates only for low value construction applications.



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## Appendix

*Examples of various sieve samples*

Mixed waste Sample 2


Mixed waste Sample 1






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+125mm Sample 2


+16mm Sample 2






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+4mm Sample 2


+31.5mm Sample 2






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## Annex 2. Physical assessment of CDW samples by CDE (Northern Europe samples)

Construction & Recycling | Mining | Specialist Sands | Environmental

# Material Analysis

February 2017

# Contents







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## Introduction

Raw sample of material was provided to CDE lab. Approx.200kg

The Intention is to run chemical and physical examination on the material.

- Establish content (materials present)
- Physical properties
- Percentage waste/useable material

## Innovative steps

The RE4 project will develop an innovative project to remove all contaminants and further process recycled aggregate to produce materials that could be used in a wide range of higher value applications.




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## Plan of Action

1. Sample of 200kg will be dispensed onto a flat area to be picked
2. A large representative sample will be taken and processed approx. 70kg
3. Large oversize will be analysed and removed from each sample. Waste materials and organics will be also removed at this stage
4. All undersize material will be sieved using a vibration laboratory sieve
5. Pictures and analysis of each sieve
6. Wash and dry -8mm material to simulate CDE plant washing system
7. Compare washed sample with unwashed to show improvement
8. Conclusion regarding washed and sieved material
9. Table showing materials present along with other waste/contaminants present
10. Pie chart to show distribution of valuable material compared to raw feed
11. Results and discussion





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## Material used

*Material received in a large 1/2 ton bag*


At first glance, there is a huge range of material present,


- Various Organics
- Metals
- Ceramic
- Sand
- Concrete Blocks
- Red Brick
- Tiles
- Glass
- Various Plastics
- Asphalt





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## Testing process

A representative sample was removed at random from the raw material. Approximately 60kg sample was taken and processed.

### Stage 1 Aggregate separation +100mm

This first stage consists of a physical separation of the larger aggregate materials. From the raw sample, various different materials were found present. Pictures below show some of the material that remained on the +100mm, particles of Asphalt also remained on the sieve after testing.

+100mm Red Brick

+100mm Light Concrete

+100mm Concrete

+100mm Asphalt





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### Stage 2 Aggregate separation 32-100mm

In this section, material gathered on the 32mm sieve will undergo physical separation and placed in separate piles according to their appearance. In this section, we see the addition of Ceramic material along with some glass particles.

32-100mm Red Brick


32-100mm Light Concrete


32-100mm Concrete

32-100mm Ceramic






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## Stage 3 Aggregate Separation 16-32mm

In this section, material gathered on the 16mm sieve will undergo physical separation and placed in separate piles according to their appearance. The quantity of different material particles has considerably increased as expected as the smaller sieves are analysed. Materials such as Glass, organics (wood) and smaller metallic pieces are found present within this grade.

16-32mm Red Brick

16-32mm Light Concrete

16-32mm Concrete

16-32mm Ceramic





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## Stage 4 Aggregate Separation 8-16mm

In this section, material gathered on the 8mm sieve will undergo physical separation and placed in separate piles according to their appearance. Similar to the previous sieves we have a large variation and quantity of material, mainly made up of the three most consistent materials through the aggregate analysis; red brick, Concrete and light concrete.

8-16mm Red Brick


8-16mm Concrete


8-16mm Ceramic






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### Stage 5 Wash Simulation 2-8mm

In this section, material gathered on the 2mm sieve will undergo a wash and analysis. This part of the section will focus on removal of waste materials through a simulation wash to represent a CDE washing system. There will be a before and after PSD to determine the amount of waste % versus useable material % within the sample 2-8mm. It will also produce a further separation into what particle sizes are present within the 2-8mm.

2-8mm Unwashed Material


- From the table below it is evident that a percentage of the material contains 3.8% silt (-0.063mm). Approximately 35% is passing 4mm therefore this would indicate we have a large 65% of the 2-8mm remaining in the 4-8mm bracket.

| Sieve Size (mm) | Grams Retained | % Retained | % Passing |
|---|---|---|---|
| 11.2 | 0.00 | 0.0 | 100.0 |
| 8.0 | 0.00 | 0.0 | 100.0 |
| 4.00 | 2594.51 | 64.4 | 35.6 |
| 2.00 | 1150.73 | 28.6 | 7.0 |
| 1.00 | 128.11 | 3.2 | 3.8 |
| 0.500 | 0.00 | 0.0 | 3.8 |
| 0.250 | 0.00 | 0.0 | 3.8 |
| 0.125 | 0.00 | 0.0 | 3.8 |
| 0.063 | 0.00 | 0.0 | 3.8 |
| Pan | 154.37 | 3.8 | |
| **Total** | 4027.73 | 100.0 | |





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2-8mm Washed Material


- From the table below we can see the percentage change within the sample. After completing a simulation wash on the 2-8mm sample there has been a 10% increase in the amount of material passing 4mm. A reduction of waste (silt content) in the material is very apparent as the -0.063mm content has been reduced by approx. 60%

| Sieve Size (mm) | Grams Retained | % Retained | % Passing |
|---|---|---|---|
| 11.2 | 0.00 | 0.0 | 100.0 |
| 8.0 | 0.00 | 0.0 | 100.0 |
| 4.00 | 278.59 | 52.1 | 47.9 |
| 2.00 | 228.44 | 42.8 | 5.1 |
| 1.00 | 17.18 | 3.2 | 1.9 |
| 0.500 | 2.78 | 0.5 | 1.4 |
| 0.250 | 0.00 | 0.0 | 1.4 |
| 0.125 | 0.00 | 0.0 | 1.4 |
| 0.063 | 0.00 | 0.0 | 1.4 |
| Pan | 7.32 | 1.4 | |
| Total | 534.31 | 100.0 | |





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## Stage 6 Wash Simulation 0-2mm

In this section, material that passed the 2mm sieve will undergo a simulation wash and analysis

<u>0-2mm Unwashed Material</u>


- The table below shows the unwashed sample 0-2mm. We can see that 50% of the material will pass 0.5mm and within this fraction there is 6.5% silt content that will need to be washed out.

| *Sieve Size (mm)* | *Grams Retained* | *% Retained* | *% Passing* |
|---|---|---|---|
| *11.2* | 0.00 | 0.0 | 100.0 |
| *8.0* | 0.00 | 0.0 | 100.0 |
| *4.00* | 0.00 | 0.0 | 100.0 |
| *2.00* | 0.00 | 0.0 | 100.0 |
| *1.00* | 1052.53 | 22.3 | 77.7 |
| *0.500* | 1302.61 | 27.6 | 50.1 |
| *0.250* | 1199.59 | 25.4 | 24.7 |
| *0.125* | 471.37 | 10.0 | 14.7 |
| *0.063* | 387.54 | 8.2 | 6.5 |
| *Pan* | 308.90 | 6.5 | |
| ***Total*** | 4722.55 | 100.0 | |





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0-2mm Washed Material


- From the table below we can see the percentage change within the sample. After completing a simulation wash on the 0-2mm sample, A reduction of waste (silt content) in the material is very apparent as the -0.063mm content has been reduced to 0.5% from the previous 6.5%.

| *Sieve Size (mm)* | *Grams Retained* | *% Retained* | *% Passing* |
|---|---|---|---|
| *11.2* | 0.00 | 0.0 | 100.0 |
| *8.0* | 0.00 | 0.0 | 100.0 |
| *4.00* | 0.00 | 0.0 | 100.0 |
| *2.00* | 0.00 | 0.0 | 100.0 |
| *1.00* | 93.69 | 24.2 | 75.8 |
| *0.500* | 103.61 | 26.8 | 49.0 |
| *0.250* | 106.41 | 27.5 | 21.4 |
| *0.125* | 44.41 | 11.5 | 10.0 |
| *0.063* | 36.55 | 9.5 | 0.5 |
| *Pan* | 1.93 | 0.5 | |
| ***Total*** | 386.60 | 100.0 | |





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## Conclusion Overall Sample

At this stage, we will look at the results of each and compare between samples.

From completing a range of washing simulation and analysis testing, we can initially see what is valuable and what is waste material within the provided sample. From the breakdown of material, it is clear to see that there is a consistent amount of each distinguished material within each sieve, materials such as ceramics, red bricks and concrete, due to this consistency between sieve sizes the material becomes easier to more efficiently sort and clean.

The table below shows the PSD grading of the overall sample that was analysed.

With majority of the material being between 32-100mm at 48% and the least being 8-16mm material at 3.2%

| ***Sieve Size (mm)*** | ***Grams Retained*** | ***% Retained*** | ***% Passing*** |
|---|---|---|---|
| *180.0* | 0.00 | 0.0 | 100.0 |
| *125.0* | 0.00 | 0.0 | 100.0 |
| *90.0* | 19552.71 | 27.3 | 72.7 |
| *31.5* | 34704.89 | 48.5 | 24.2 |
| *16.0* | 6282.93 | 8.8 | 15.4 |
| *8.00* | 2269.89 | 3.2 | 12.2 |
| *2.00* | 4027.73 | 5.6 | 6.6 |
| *Pan* | 4723.34 | 6.6 | |
| ***Total*** | 71561.49 | 100.0 | |





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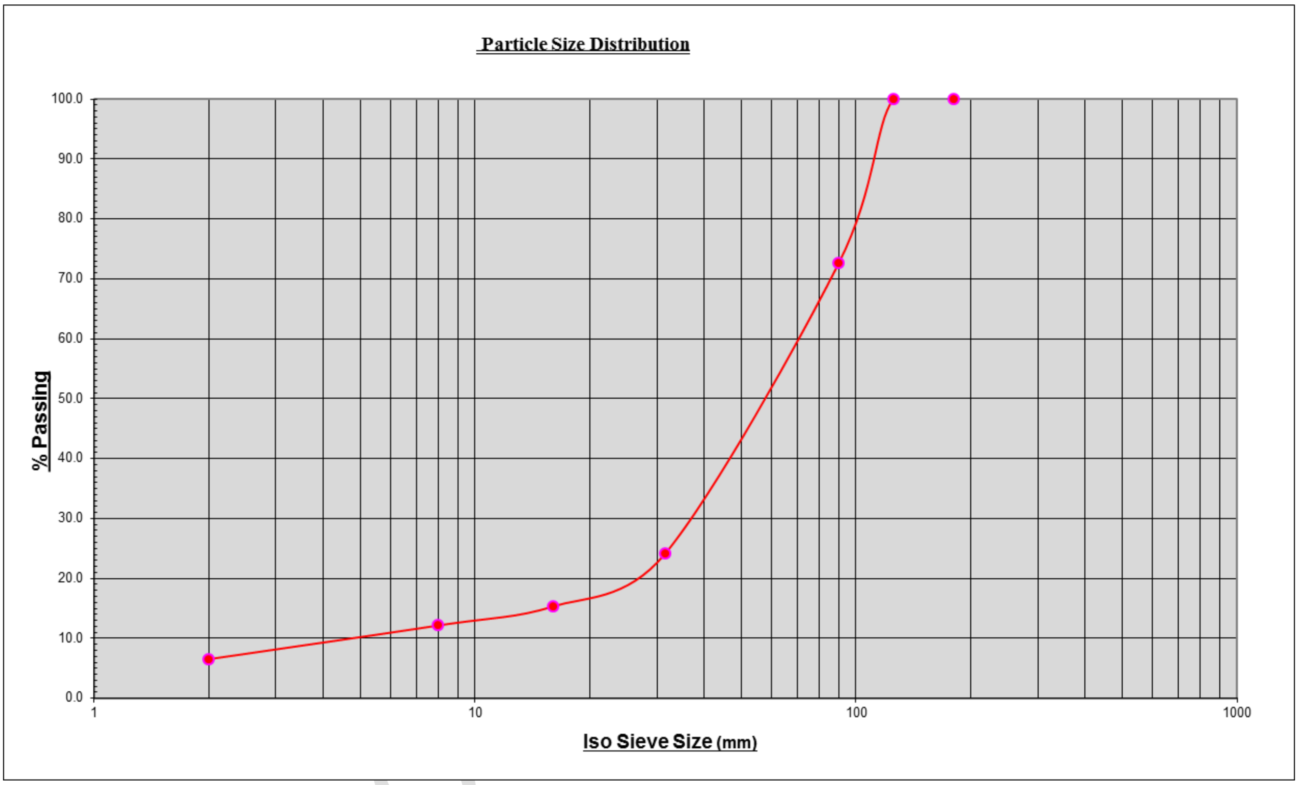
The graph below shows a representation of the PSD table from the previous page. This graph shows a positive correlation within the sieve analysis, it is also clear that the vast majority of the sample is contained within the 32-100mm limits.





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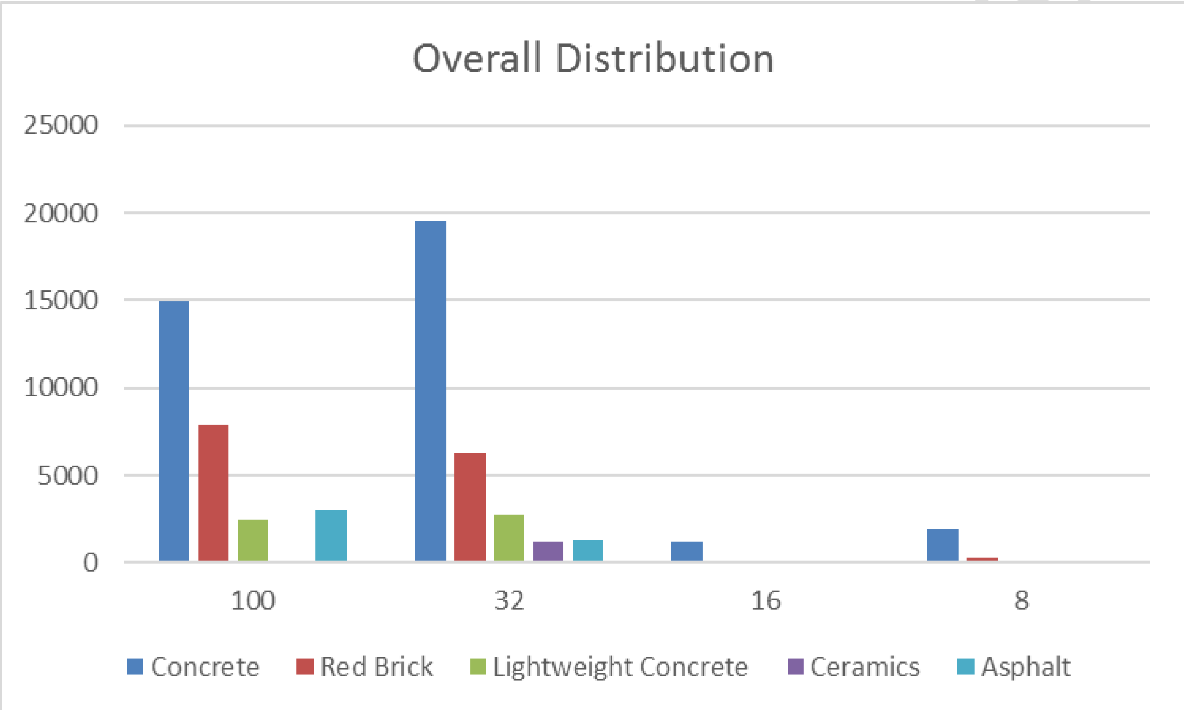
## Material Distribution

The chart below shows the variation of material that was contained within each aggregate sieve size.

Concrete being the most common material present within all sieves. Asphalt was present in only the larger aggregate sieves such as +100mm and 32-100mm. Red brick was consistently present in all samples, and ceramics was present between the 8-32mm limits.





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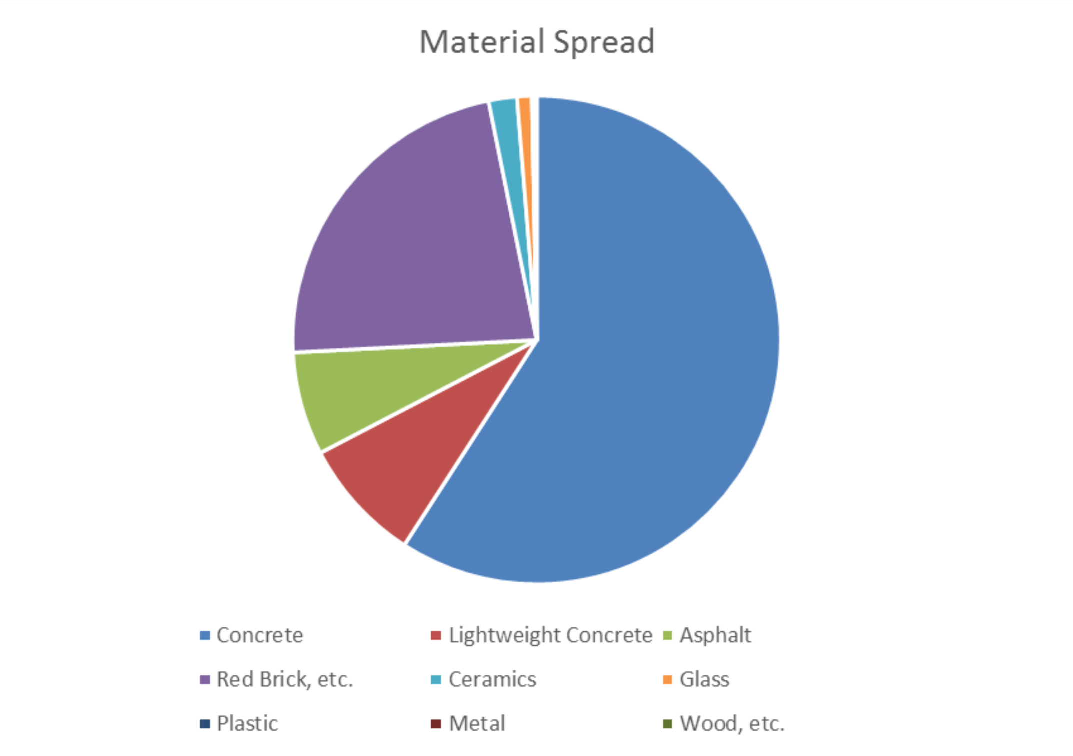
## Material Spread

The Pie Chart below shows what all exactly was contained within the tested sample.




Materials contained

| | Mass (g) | Percentage % |
|---|---|---|
| Concrete | 37627.63 | 59.13 |
| Lightweight Concrete | 5233.68 | 8.22 |
| Asphalt | 4346.10 | 6.83 |
| Red Brick, etc. | 14408.77 | 22.64 |
| Ceramics | 1194.94 | 1.88 |
| Glass | 624.23 | 0.98 |
| Plastic | 12.23 | 0.02 |
| Metal | 63.03 | 0.10 |
| Wood, etc. | 124.96 | 0.20 |
| Total weight | 63635.57 | 100 |



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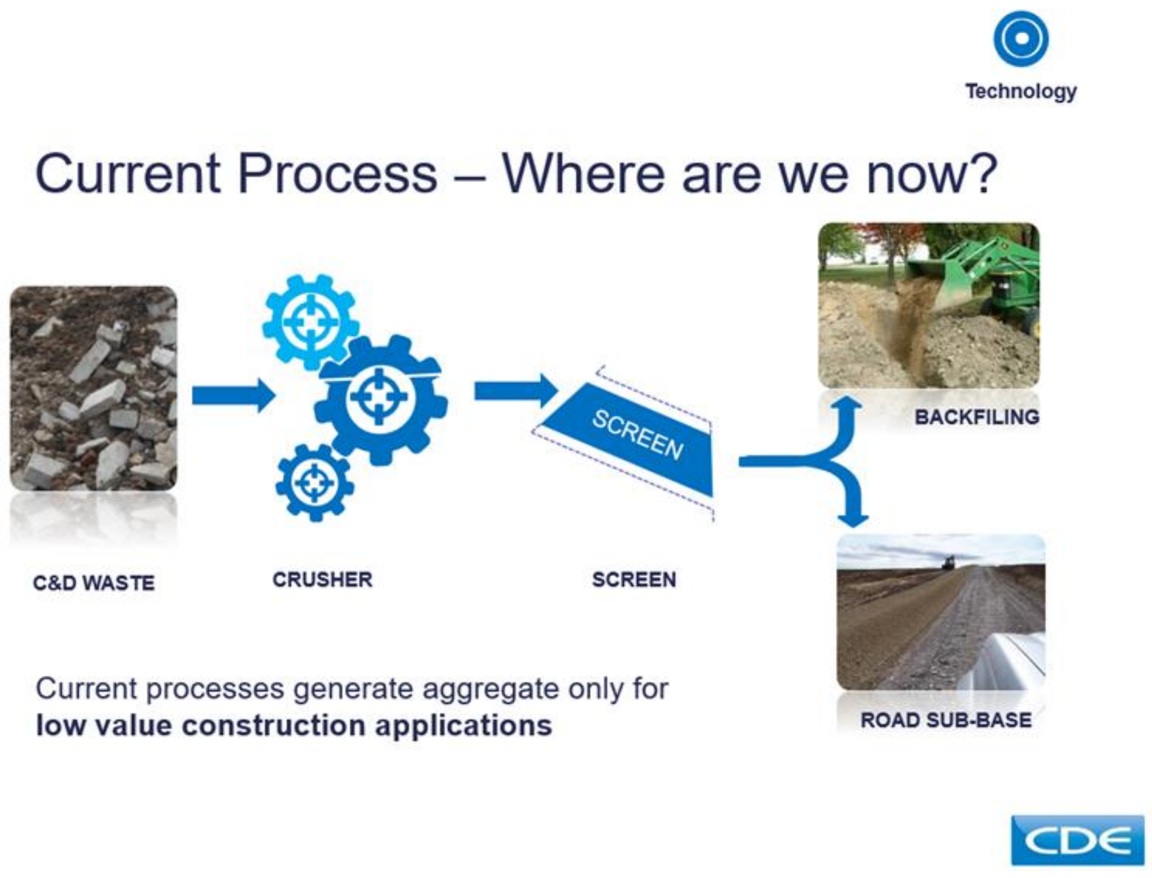
## Discussion

To conclude, from the material analysis we have established the content within the material along with the percentage waste and useable material.

The material had an average silt content of approx.6%, a grading of 90% aggregates and 10% sand.

Waste materials contained within the material such as organics and plastics can all be removed using water-washing systems that CDE currently impose and metal removal via magnetic process can eliminate metallic waste within the products.

These materials can be implemented into current processes (crushing and screening) to generate aggregates only for low value construction applications.



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## Appendix

Metal present in sample






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Plastics present in sample






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Organic material present within the sample






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Glass present in the sample






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