

Pre-demolition audit as a tool for appropriate CDW management – a case study of a public building

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Abstract. The identification of hazardous construction and demolition waste (CDW) is crucial for the appropriate and safe waste management. The pre-demolition audit is not compulsory in all EU member states, so if the control is not strict the hazardous CDW might pollute the inert fraction and create risks for human health and environment. In Bulgaria, only some industrial sites are considered as a potential source of hazardous CDW. Classification of hazards can be difficult also because the European Waste Catalogue is not specific on the hazardous CDW (with some exceptions). For example, heavy metals are among the most dangerous substances but very often remain undiscovered or underestimated. A case study of an abandoned 100-year-old public building has been performed to illustrate the importance of the pre-demolition audit. A handheld XRF analyser is used to identify contaminated materials. Samples were taken from those materials for doing leaching tests. It was proven that there was a high content of heavy metals in different paints, on internal and external walls, and fenestration. In addition to the discussion of results, some measures to separate the hazardous coatings from the recyclable masonry and wooden waste are discussed to provide higher recovery rates for the CDW.

1 Introduction

The identification of hazardous construction and demolition waste (CDW) is very important for the appropriate waste management but also from occupational health and safety standpoint. The hazardous CDW can contain polluting substances coming from the composition of materials, e.g. tar, asbestos, mercury, PCBs, etc., but in other cases the contamination might occur during the operation stage of the buildings.

The European List of waste (LoW) [1] contains several codes for the designation of hazardous CDW, but they are not specific enough and can barely serve for the identification of hazardous CDW during the demolition process. Moreover, the characterisation of CDW as per the Waste Framework Directive [2] is applicable for the purposes of landfilling only.

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Hazardous components are normally identified during the pre-demolition audit (PDA), but the obligation to perform a PDA vary widely in Europe – from “required” (e.g. Denmark, France) through “voluntary or required only in some regions” (e.g. Spain, Italy) to “not occurring” (e.g. Portugal, Croatia) [3]. The level of detail of PDA can be quite different and sometimes it is merely a desk study or a formal procedure of visual inspection. The best practices for PDA are summarized in [4], but the document has no legally binding status. In Bulgaria, the PDA obligations are contradictory: the Bulgarian Territorial act [5], governing all construction/deconstruction activities and the Waste management act [6] do not recognize the PDA as a part of the demolition process, nor as a waste management process. The provisions in the Ordinance on CDW include doing a PDA for qualifying and to quantifying the different CDW streams [7], but with no requirement for characterization, except for CDW from listed industrial sites with potential contamination. In case of public and private buildings, only asbestos containing materials are currently identified and properly managed. The problems related to the presence of heavy metals are widely ignored although they are among the most dangerous substances for the human health [8]. Furthermore, the management of hazardous CDW requires additional expenses, and, in the absence of clear procedures and rules, the identification of hazardous CDW and its eventual decontamination remain an unwanted option for the demolition contractors.

The present study aims at illustrating the role of the PDA in identification of heavy metals contamination within CDW from buildings which are not assumed as polluted by the legislation. The challenges in the quantification are described, some measures to separate the hazardous coatings from the recyclable masonry and wooden waste are outlined and could support a higher recovery rate for the CDW.

2 Heavy metals in CDW

Heavy metals are defined as metals that have a density higher than 5 g/cm³. These include zinc, copper, lead, cadmium, chromium, nickel, iron, cobalt, magnesium, etc. A primary source of heavy metals in CDW are the lead-containing paints in which lead is used as a pigment (in the form of lead carbonate - "white lead", lead sulfochromate - "yellow lead", lead chromate molybdate sulfate - "red lead" and others.). In addition, lead can be used as an additive that accelerates the drying, increases the durability, gives a fresh appearance, and protects the paints from moisture. Lead-containing paints were used quite extensively in the past as wall coatings, on metal structures and equipment, as well as on wooden surfaces. After demolition, lead-contaminated waste (plasters) is very often mixed with inert waste.

Since December 2006, when Regulation EC No. 1907/2006 [9] was published, buildings built before 2007 in the European Union are at risk of contamination with lead-containing paints. Ever since, the placing on the market and the use of lead-containing paints was prohibited. Exceptions (but subject to a notification regime to the European Commission) are made only for works of art and buildings of historical value. However, the procedures for proving the absence of lead in paints are not standardized (in some countries it is required to be explicitly declared, in others - to be tested), so there is still some risk for use of lead-containing paints.

Lead dust or fumes can be generated during the operation period of the building when lead-containing paints are removed by scraping and dry sanding or heating – processes that occur during repair and maintenance in buildings. Lead-containing dust or flakes (from metal surfaces) can also be formed by impacts and friction with painted surfaces, which is a common practice during major repairs, reconstruction and demolition/dismantling of buildings and structures. This is the main mechanism for pollution of CDW with lead. Another path for lead exposure occurs after lead was accumulated on the surfaces and objects from where it can enter the human body or can be released in the environment (soil and

water). Other heavy metals, though less impactful, can also be found in CDW [10-12]: arsenic in products for wood impregnation; cadmium as a stabilizer for polyvinylchloride, in pigments, as surface treatment of metal sheets, as alloying element, for glazing of ceramic materials and batteries; chromium is used as alloying element for steel and other metals, fire resistant materials, additive for paints, cements, wood impregnators, etc.; copper is used in covering boards and façade elements, pipes, alloys, cables, paints.

Nowadays, there are many restrictions on the use of hazardous substances in construction materials, so the chance of having hazardous waste during the construction and use phase is low. Yet, for many buildings that were constructed 30-40 years ago these restrictions were not in force and there was no or limited awareness about hazardous components [13] (e.g., bans on use of lead and asbestos started in 1970s and 1980s across different countries). Therefore, demolition of these buildings poses a real risk of release of hazardous substances during renovation or demolition processes and, in order to avoid this risk, a thorough pre-demolition audit together with appropriate demolition and waste treatment procedures need to be specified.

3 Pre-demolition audit of a public building – a case study

3.1 Description of the building

A four-story public building, known as Cooperative Palace Tsarevets (1930s÷1944) and as “State Council Sanatorium” (1944÷1989), located in the town of Bankya, Bulgaria, was investigated. The building was commissioned around 1930 and renovated several times after that. In the 1970s, an extension was built, as well as a boiler room. At present, the building is abandoned and, because of thefts, lack of maintenance, roof leakages, self-accommodation and unregulated use, it is in a poor condition, without glazing and is in process of self-destruction – Figure 1. There is no available documentation from the construction and use stages, so it was not possible to do the first step of the PDA in full (a desk study) [4]. The approximate age of the building is calculated – ca. 100 years. No design and as built drawings, neither record on the maintenance, repair or rehabilitation works have been found. Thus, no list of hazardous substances is available. In order to get some preliminary information about the potential risks, a field survey was conducted.



Fig. 1. General view of the building and its present condition.

3.2 Field survey

The field survey included the following components: site visit, architectural and structural survey, general audit and inventory, detailed audit and inventory, sample taking and analysis.

The field survey was performed in accordance with the recommendations of [4], i.e. careful identification of locations, different structures and technical systems, and their materials. Special attention was paid on materials that seem very similar, for instance in the cases of complex systems where a material can be covered by another material. A set of diagrams, notes and pictures was prepared.

The built area of the site is ca. 1901 m² and the total floor area is ca. 6667 m². The floor plan of the ground floor and second floor are presented on Figure 2 and Figure 3. Some investigations on the operating mode of the building, location of the various rooms, equipment used, warehouses, etc. were performed. It was found that the main materials which were used in the construction of the building were concrete, low-carbon steel, ceramic bricks, ceramic tiles, lime-sand and cement-lime-sand plasters and renders, cement-based screeds and wood. Additionally, during construction and repair works, various types of paints, linoleums, cables, putty mixtures, floor/wall coverings, window frames, etc. were used. The quantities of the different CDW as per the LoW were determined.

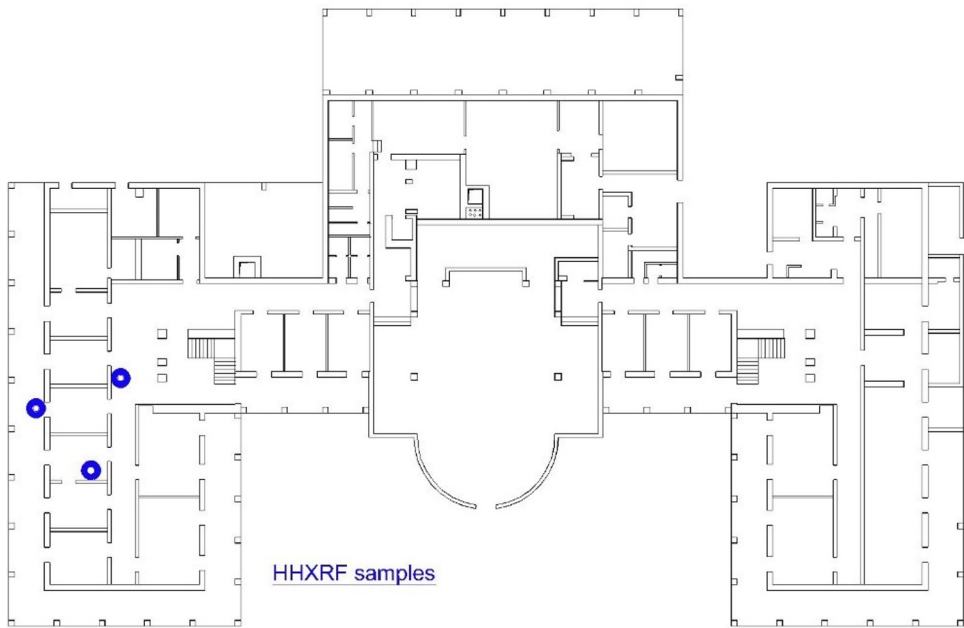


Fig. 2. Ground floor plan of the building.

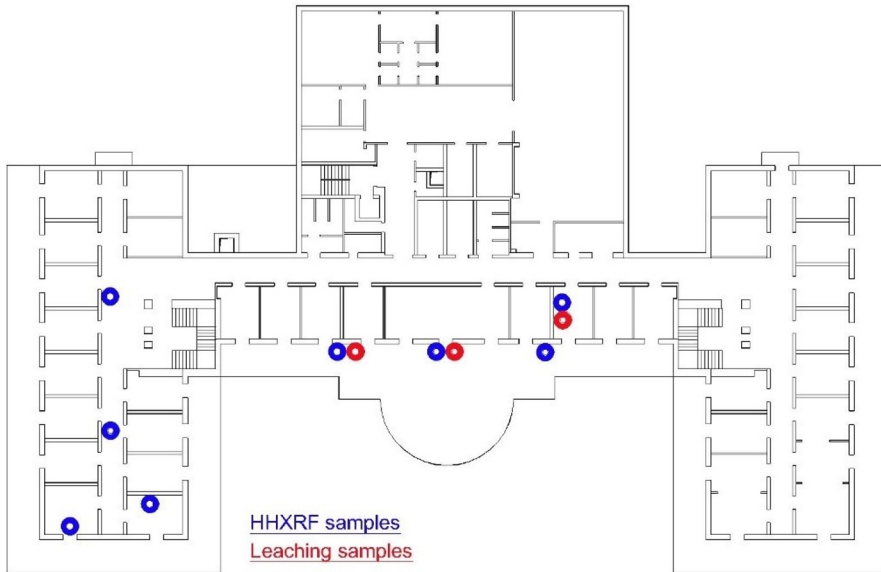


Fig. 3. A plan of level 2 of the building.

To identify the parts of the building that are potentially contaminated by heavy metals, a handheld X-ray fluorescent spectrometer (HHXRF) was used. XRF spectrometry is an analytical method based on the principle that when individual atoms are excited by an external energy source emitting X-ray photons of a specific energy and wavelength, the atoms in turn emit X-Ray fluorescence radiation [14]. This fluorescence is unique for the different chemical elements, so measuring the radiation allows for the identification of the chemical composition of the sample. An advantage of the non-destructive method is that no preliminary preparation of the sample is required, and the duration of the testing is short. On the other hand, the results strongly depend on the state of the sample (solid, powder), which determines the depth of penetration of the X-ray beams. The Bruker's S1 TITAN 600 is equipped with 50 kV high voltage source, Rh X-ray tube and Silicon Drift Detector (SDD). X-ray tube spot size is 8 mm. The S1 TITAN integrated calibrations allow measuring heavy metals in light, medium and heavy polymers, soils and geo-materials. It is known that there can be an uncertainty of the results due to the built-in calibration which might not always correspond to the environment in which the field measurement is done [15]. Some studies [15] have found out that the results from HHXRF can vary up to twice for the same material depending on the tool settings and the conditions of the environment.

During waste identification, many of the surfaces were found to have paint coatings potentially containing heavy metals. These paints were flaking and dusting, creating a health risk for demolition workers and for leaching into the soil and water around the building. Dismantling elements with strong bond between the paint and the substrate would result in heavy metals entering the substrate, thus contaminating the concrete, brick and wood underneath the paint. This risk would likely remain undetected because the CDW is not usually characterized. According to the requirements of the Ordinance for CDW management [7], 85% of concrete, 70% of brick and 80% of wood CDW must be submitted for material recovery. In doing so, conditions will be made available for the spread of heavy metal pollution outside the considered site.

The measurements with HHXRF were carried out by classifying the rooms and their elements by type and color of the painted surface. Three main groups were defined: window frames (2 options), interior plaster in a room/corridor (5 options), facade plaster (2 options). Each plaster group was examined in 3 places and the arithmetic mean values of the measured

parameters were determined for presence of Pb, Cr, Ni, As, Hg and Cd. Where the paints were present in several layers, each layer was examined successively. The field survey records contain data on the measurement locations, layer of the paint that was measured, and the condition of the paint (continuous layer, peeling or flaking).

3.3 Sampling

After the results from the field survey were processed, a sampling procedure for potentially hazardous paints of each group was done. Samples were collected with scraping and cutting instruments (trowel) to separate layers and material pieces. Samples were properly sorted, placed in plastic bags, and labelled (classified). The characterisation was done by leaching tests [16] of the samples in an accredited laboratory (CNIL at the University of Mining and Geology, Sofia). The test is performed acc. to BDS EN 15216:2021 in an eluate after leaching, using liquid to solid ratio of 2 l/kg. The estimated content of heavy metals in the eluate was compared with the limit values for non-hazardous granular materials.

3.4 Results

Altogether 120 test points have been evaluated by the HHXRF. These paints have high levels of lead and represent 36% of the examined surfaces, which amounts to about 505 tons of hazardous construction waste (including woodwork and plaster on walls). High levels of Cr, Ni, As were registered in 27% of the tested paints. Some of the paints that were found to have high levels of pollutants by the HHXRF are indicated in Table 1. The locations where measurements were done are graphically presented on Figure 2 and Figure 3.

According to REACH [17] the following restrictions on registered substances are introduced:

- Pb – 0.05% by weight (500 ppm) in materials supplied to the general public;
- Cr – cement and cement-containing mixtures shall not be used, if they contain, when hydrated, more than 2 mg/kg (0.0002 %) soluble chromium VI related to the total dry weight of the cement;
- Ni – for products intended to come into direct and continuous contact with the skin, the rate of nickel release shall not be greater than 0.5 µg/cm²/week;
- As – shall not be used in the preservation of wood;
- Hg - shall not be used as substances or in mixtures;
- Cd - shall not be used in paints with concentrations greater than 0.01% by weight (100 ppm). For paints with zinc content exceeding 10% by weight, the concentration of cadmium shall not be greater than 0.1% by weight (1000 ppm).

Compared with the above-mentioned limits, it is obvious that part of the values of dangerous substances in the investigated paints exceed the limits for safe materials.

In order to classify the potential CDW from the studied building, and, respectively, to conclude whether the CDW are inert, non-hazardous or hazardous, leaching tests must be performed. This is outlined in the national legislation at the location of the investigated building [16] and in European regulation Orden AAA / 661/2013 (Spain, 2013) [18, 19].

Table 1. Results for lead content in the studied building elements (HHXRF data).

| Studied paints | | Unit | Pb | Cr | Ni | As | Hg | Cd |
|--------------------|--|------|-------|------|-----|-----|----|----|
| Ground floor | outside window frames outside | ppm | 14529 | 1238 | 193 | 0 | 0 | 0 |
| | interior plaster, room (white) | ppm | 5495 | 696 | 258 | 0 | 0 | 0 |
| | interior plaster, corridor (orange) | ppm | 0 | 602 | 107 | 102 | 0 | 0 |
| Level 2 - rooms | wall plaster (green, lean) | ppm | 1339 | 760 | 53 | 279 | 0 | 0 |
| | wall plaster (green) | ppm | 2337 | 981 | 116 | 275 | 0 | 0 |
| | internal window frames (white, yellow) | ppm | 0 | 582 | 140 | 133 | 0 | 0 |
| Level 2 - corridor | wall plaster (yellow) | ppm | 4865 | 472 | 0 | 0 | 0 | 0 |
| | wall plaster | ppm | 319 | 0 | 0 | 49 | 0 | 0 |
| Level 2 - terraces | facade plaster (white, blue) | ppm | 801 | 0 | 56 | 0 | 0 | 0 |
| | outside plaster (blue_ | ppm | 2372 | 0 | 68 | 0 | 0 | 0 |
| | outside window/door frame | ppm | 20906 | 949 | 249 | 0 | 0 | 72 |

Heavy metals in different concentrations were found in all of the examined samples from the building. Arsenic [17] was identified in the largest amount in masonry and facade plasters. Cadmium in more significant amounts was found in interior plaster and window paint, but was below the REACH threshold [17]. The lead contamination in the paint of window frames, interior and facade plasters is the most concerning because the REACH threshold is exceeded by nearly 40 and 30 times, respectively. The high levels of lead can most likely be explained by the coloring pigments used in the paints. Regarding chromium, the total amount, including III- and VI-valent chromium, has been identified, while under REACH the restrictions apply only to VI-valent Cr (carcinogenic). The content of total Cr is limited by regulations related to soil contamination [20] and waste disposal [16]. According to Ordinance No. 6 on Landfills [16], in order to classify a given waste as inert, the content of total Cr must not exceed 0.2-0.5 mg/kg depending on the test method, and to be considered non-hazardous, Cr must to be lower than 4-10 mg/kg. Therefore, despite the differences in the test methods, it can be reasonably concluded that the total Cr content is also quite high.

Considering the degree of destruction and pulverization of the plasters and paints, it is possible that a large part of the heavy metals contained in them entered the soil around the building, and from there leached into the groundwater. The results of this research show the problems related to heavy metals that need to be addressed when carrying out construction and repair activities, and demolishing of old buildings. In Bulgaria, unfortunately, these problems are still neglected.

Due to the uncontrolled parameters of the environment in which the research takes place, HHXRF gives approximate, indicative values about the chemical composition of the materials under investigation. A leaching test was done for precise determination of the substances. The selected sampling locations correspond to areas where relatively high levels of harmful substances in paints are recorded, as shown on Figure 3. It should be taken into account that leaching samples contain material not only from the surface layer of paint, but also a part of the underneath plaster. This sampling approach was selected because when

demolishing brick walls, the lime plaster would peel off together with the thin layer of paint on it. Therefore, two waste streams will be distinguished. Results of the selected leaching samples are shown in Table 2. Finding out the precise amount of leached harmful substances allows us to understand the water solubility of the investigated paints and whether they would infiltrate and pollute the environment if deposited on a site for inert or non-hazardous construction waste. Table 2 also shows the limit values for inert and non-hazardous materials according to [16], confirming the potentially harmful impact of paints in the building on people and environment

Table 2. Results from the leaching tests of building samples.

| No. | Indicator | Unit | Indicator value | | | Limit value for inert waste acc. to [16] | Limit value for non-hazardous waste acc. to [16] |
|-----|------------------------------|-------|------------------------|---------------------------|---------------------------|--|--|
| | | | Wall paint and plaster | Facade paint with plaster | Painted wooden door frame | | |
| 1 | Arsenic – As | mg/kg | <0.5 | <0.5 | <0.5 | 0.2 | 0.4 |
| 2 | Barium – Ba | mg/kg | <1 | <1 | <1 | 7 | 30 |
| 3 | Cadmium – Cd | mg/kg | <0.04 | <0.04 | <0.04 | 0.03 | 0.6 |
| 4 | Chromium – Cr | mg/kg | 6.8 | <0.2 | <0.2 | 0.2 | 4 |
| 5 | Copper – Cu | mg/kg | <0.5 | <0.5 | <0.5 | 0.9 | 25 |
| 6 | Mercury – Hg | mg/kg | <0.01 | <0.01 | <0.01 | 0.003 | 0.05 |
| 7 | Molybdenum - Mo | mg/kg | <0.5 | <0.5 | <0.5 | 0.3 | 5 |
| 8 | Sodium - Na | mg/kg | 45.7 | 497 | 91.4 | - | - |
| 9 | Nickel - Ni | mg/kg | <0.2 | <0.2 | <0.2 | 0.2 | 5 |
| 10 | Lead – Pb | mg/kg | <0.5 | <0.5 | 0.9 | 0.2 | 5 |
| 11 | Antimony - Sb | mg/kg | <0.05 | <0.05 | <0.05 | 0.02 | 0.2 |
| 12 | Selenium - Se | mg/kg | <0.1 | <0.1 | <0.1 | 0.06 | 0.3 |
| 13 | Zinc– Zn | mg/kg | <0.5 | 2.3 | 1991 | 2 | 25 |
| 14 | Chlorides | mg/kg | <100 | 104 | 753 | 550 | 10000 |
| 15 | Sulphates | mg/kg | 1324 | 4630 | 4210 | 560 | 10000 |
| 16 | Total dissolved solids (TDS) | mg/L | 3489 | 4826 | 11390 | 2500 | 40000 |

The leaching test results do not confirm the high degree of hazard of the studied samples obtained with HHXRF. However, the investigated CDW are not inert due to the excess amounts of leachables, Sulfates, TDS, and, for one sample, total Cr content. One of the samples is hazardous due to the leaching amounts of total Cr. There are three main reasons for the different results between the HHXRF and the laboratory testing. The first reason is related to the calibration of HHXRF which might not always match the characteristics of the sample medium, so the results would be mostly indicative and not so accurate. Secondly, the HHXRF gives results only for the surface layer, while in the leaching study, the plaster layer

below is also considered because of their monolithic connection. And, of course, the goals of the two methods are different – the XRF indicates a general chemical composition, while the leaching behaviour describes the solubility of the substances in water and the possibility to infiltrate other inert materials, soils or groundwater when deposited.

4 Need of decontamination

The public building under study will be completely demolished some day. The painted surfaces with a high content of heavy metals represent around 36% of the total the walls surface. High hazardous content was also found in the paints applied to various wooden elements (floors and fenestration). In case the high presence of heavy metals is considered as contamination (which it is), it would lead to 505 tons of hazardous CDW for the whole building. The waste flows that would be generated during the demolition of the investigated building are classified with codes 17 01 06* and 17 02 04* [1]. At the moment, there is no a company in Bulgaria with a permit for landfill of 17 02 04* waste, and there is only one company having a permit for landfill of 17 01 06* waste (located about 300 km from the building under study). These circumstances determine the economic and regulatory need of decontamination of surfaces that contain harmful substances. This would reduce the total amount of hazardous waste to about 73 tons, classifying it with code 17 09 03* and separating it from the other inert CDW. To ensure the protection of environment, occupational health and safety and the health of people living in the vicinity of the site, a site-specific and effective decontamination plan shall be prepared.

Based on the analysis of the existing conditions in the building and the available modern technologies for the separation of contaminants from the mineral fraction (concrete and brick waste), the following possible scenarios were researched:

- 1) Scenario 1 – the concentration of contaminants is within the permissible limits and it is not necessary to apply a special method for their removal;
- 2) Scenario 2 – the concentration of contaminants exceeds the permissible limits and it is necessary to apply methods for their removal;

Scenario 2 was considered for this study because pollutants in some samples were found to exceed the threshold values. Various methods for safety decontamination were analyzed – HEPA sanding [21, 22], HEPA vacuum blasting [21 - 23], HEPA vacuum needle gun [21, 23], heat treatment [21 - 23], chemical stripping [21 - 25] and wet-hand scraping/sanding [21 - 23, 25]. The most suitable technology for removing lead-containing paints is HEPA vacuum blasting using a sponge-jet system. Despite the relatively high cost of the equipment, and the need for skilled workers, this method for decontamination has high efficiency compared to the other proposed technologies. The paint is removed by blasting little recyclable sponge media with embedded abrasive bits. When blasted onto mechanical surfaces, small particles effectively remove layers of lead-based paint with minimal lead dust creation and debris. In addition to the small dusting (up to 95% less pollution), this method is also highly environmentally friendly, as the abrasive material can be reused (it is collected back into the machine) [26]. Though it is the preferred method, the sponge-jet system is of limited availability in Bulgaria which makes it difficult for use. Another suitable method would be the wet-hand scraping, it has lower productivity and is more labor intensive, but the lack of need for experienced workers and the low investment required make this method favorable over the other options. The wet-hand scraping allows for a large part of the hazardous particles to be successfully removed from the CDW. The reduced content of lead in the mineral fraction (concrete and brick waste) in turn reduces the degree of hazard in CDW and can increase the potential for their recycling.

There are other methods for removing lead-containing paints such as torch or flame burning, open abrasive blasting, uncontained water blasting, machine, on-site use of

methylene chloride and dry scraping. However, these methods were found to be hazardous and with unsatisfactory results.

5 Conclusion

It has been proven that the problem of heavy metals containing paints might be quite extensive in old buildings in Bulgaria. Overlooking the risks poses a threat to both the demolition/rehabilitation workers' health and the environment (air, soil, ground water).

The PDA shall be performed in a responsible, thorough and detailed way. There should be obligatory procedures to follow to prevent misinterpretation and unsatisfactory performance by the demolition contractor.

At the same time, the results of fast and easy, but not standardized in situ methods such as XRF, are disputable, so those methods can serve mainly for a rough identification of potentially hazardous CDW. A sampling shall be always performed, although it is time consuming. There are also some technical parameters to be clarified, e.g. how thin the paint sample should be to avoid the dilution of hazardous compounds; how the testing should be performed because some of hazardous components are not soluble and the leaching results might not be relevant; what limit threshold for the hazardous components should be applied to reduce the risks for humans. The Waste framework directive limits for hazardous waste were established for landfilling purposes. The REACH limits were established for manufacturers of new products and it is debatable whether they are applicable to old materials. There are no limits of dangerous substances when the CDW is submitted for recycling, nor are there any limits for the exposure of workers to the hazardous substances during the demolition process.

When such limits are not adopted at European or national level, the decontamination seems to be the only reliable solution. It is performed prior to the demolition and contributes to: a) the occupational health and safety when the demolition is done; b) minimization of the hazardous CDW (which has also economic benefits) and c) eliminates the risk of pollution of the substrate materials which usually represent non-hazardous materials suitable for recycling such as concrete, masonry, metals and wood.

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