Innovative 3D training platform for recycling of waste coming from Electric and Electronic Devices

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Abstract

Due to EU Commission publication of the 20 critical raw-material (CRMs) list in 2014, the need of applying a circular economy approach to the management of the waste coming from electric and electronic equipment (WEEE) has emerged. The struggle of achieving zero waste and resource recovery aims in the WEEE management procedures amplified the need for special treatment, not only because of their high content of valuable materials including CRMs but also for the hazardous nature of their content. Therefore, WEEE equipment dismantling requires specialized procedures and educated personnel, ensuring safe and efficient processing of waste. In this framework project RECDEV – Innovative 3D Training Platform for recycling of WEEE (www.recdev.eu) – found significant potential in developing an innovative 3D training platform (ICT-based, self- and distance learning), familiarizing learners/users with the disassembly of electrical and electronic devices and the identification of types and qualities of materials embodied.
The platform is developed based on a methodology that uses a 3D software application and integrates 50 selected electric and electronic devices, as training scenarios. Each scenario has been depicted in such a way that extensive information about the materials contained is displayed. Based on the "learning by doing" methodology, trainees will be able to interact with 3D WEEE by "digitally" disassembling devices and have access to information for each part such as included materials: toxicity, recycling, potential reuse and up-scaling.
A 12-month period will be devoted to pilot development and testing in different Recycling Centres in the 5 participating countries. The participation of real users/technicians as well as management personnel to the pilot implementation phase, will ensure real, practical results and conclusions, that are going to be used in order to cover actual users' needs in practice.
In order to respond to the above challenges, RECDEV project develops a set of high quality 3D training scenarios that simulate WEEE disassembly and offer information on the parts and materials included (types and qualities). The pedagogical context targets low skilled users to upgrade skills, make them more efficient in activities such as disassembling and packaging, require less supervision and minimize risks in the disassembly of electronic devices, as well as higher level personnel to develop skills quickly and easily, identifying types and qualities of materials contained in EEE.
Keywords: WEEE, recycling, training, interactive, 3D.

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1. INTRODUCTION

The production of Electric and Electronic equipment (EEE) is one of the fastest developing sectors of the universal industrial production. This development makes these products as one of the most important waste categories that need to be treated suitably due to high content of valuable materials and risks related to toxic parts. In the last decade, considerable efforts with regard to the management of this problem were noted, owing to shortening product life. One crucial element of the recycling process is the early identification and removal of the toxic parts of the WEEEs. At that time the screening and disassembly of different parts of each device follows, and different materials are forwarded to the pertinent factories.
Knowledge is a key point of this procedure. The great variety of manufacturers, and the evolution of the relevant industries, obstructs sometimes the identification and the proper handling of all parts of the devices (safe extraction without damages to valuable or harm from hazardous materials).

EU legislation (Directive 2002/95/EC) [1] restricts the use of dangerous substances in EEE and additionally promotes the collection and recycling of such equipment (Directive 2002/96/EC). The principal objective is to increase the recycling and/or re-use of such products. However, only one third of Electrical and Electronic Waste (EEW) in the EU is reported as separately collected and appropriately treated. A part of the other two thirds is disposed to landfills as well as to sub-standard treatment sites either inside or outside the EU. The collection target, per person, of 4 kg/a (per year) does not properly reflect the amount of WEEE arising in individual Member States. Illegal trade of electric and electronic waste to non –EU countries continues to take place in EU borders.

2. PROJECTS' OBJECTIVES

The consortium brings together the resources of 7 participating organizations from 5 countries of which, 2 universities with research work in the recycling sector (Mendel Un. of Brno in the Czech Republic and Un. Of Maribor in Slovenia), 3 partners with expertize in Waste Recycling, Environmental Protection and Waste Management[ARVIS Environmental Enterprises of Greece SA (ARVIS), Hellenic Solid Waste Management Association (HSWMA) and the Romanian National Centre of Sustainable Production & Consumption(CSPC)], an Austrian consulting company specializing in implementation of sustainable development and preventive environmental protection (BAN Sozialökonomische BetriebsgmbH) as well as a strong technological partner; an expert in 3D content management systems (Omegatech, located in Greece).
The project consortium has already been working for more than 2 years, in order to identify the gaps in the training offered in the sector. After visiting recycling factories,the following important shortcomings that the RECDEV project is going to adress were identified:

- Disability of the higher personnel to identify the type and quality of recycling materials in devices(especially the new ones,medical equipment ,etc.).The current practice is a time consuming one since it requires contacting the manufacturer for technical information.
- There is a training need for employees(low level workforce) to be trained in the various disassembling and packaging aspects required for the different recycling materials.
- Knowledge and recall is a key point to the recycling of the WEEE.The employees need to be trained in identifying the internal parts of the devices.For example for PCs,the factories usually hire people previously experienced in computers.Because of the technological evolution,continuous training for them and their supervisors is absolutely necessary.Thus,the need for early identification and removal of the hazardous parts(toxic parts) from the aforementioned devices must be taken into consideration.
- Part of the employees, as mentioned above, are economic immigrants, so the language part of training offered needs to be addressed.

WEEE devices can be classified into the following eight broad categories according to the existing regulatory framework [7]:

- domestic equipment- e.g. vacuum cleaners, fridges, washing machines and ovens,
- Information and Communication Technology (ICT) equipment- e.g. laptops, printers, monitors, telephones and CPUs,
- consumer goods- e.g. televisions, radios, cameras and musical instruments,
- lighting equipment- e.g. straight and compact fluorescent lamps,
- electrical and electronic tools- e.g. sewing machines, drills and saws,
- electric games and sports equipment- e.g. electric trains and running machines,
- medical devices- e.g. (non-contaminated) analyzers, dialysis machines and cardiology equipment,
- different types of sensors and dispensers- e.g. smoke detectors, thermostats and money or hot drinks dispensers.

The most common problems for dismantling these devices are:

- wide variety of different types of devices and assemblies,
- complex physical structure of the devices,
- many different materials in each device for economy and performance reasons,
- lack of data from the producers.

3. PROJECT OUTPUTS

RECDEV project aims to supply simply and easily what hazardous waste is, how it looks and the proper way of storing, transporting and disposing of it. Furthermore, as far as the target group is concerned, i.e. people with low academic level, will have the opportunity to follow a complete training program regarding WEEE understanding, dismantling and disposal techniques, giving them a rather easy to comprehend skill and ability to work in the WEEE sector. The project will provide access to all Social Partners and can be easily integrated to any possible academic or Vocational Training Programme and can be adjusted to the needs of each target group. The 3D scenarios designed for low skilled disassemblers (blue collars), will have an optional 'video mode' where the whole procedure will be presented without the need for interaction from the trainee. This applies to the situation where the trainees do not have the technical skills for the completion of the interactive training. The pilot implementation phase will encompass the training of using tools as well as the access to the effectiveness of this training.

Long term target groups:

- Vocational training providers and entities at National and European level associated with recycling.
- Both public and private recycling companies that aspire to train their employees or newcomers to specific requirements or to upgrade skills.
- Training institutions and all types of education agencies that want to integrate virtual environments in their training procedure.

In order to respond to the above challenges, RECDEV project develops a set of high-quality 3D training scenarios that simulate the disassembly of electrical and electronic devices and offer information of the parts and materials embodied (types and qualities).The pedagogical training content targets both low level workforce, aiming at strengthening employability, making them more efficient in activities such as dismantling and packaging with less supervision, safety at work, as well as white collars (higher personnel) to develop skills on quickly and easily identifying types and qualities of materials included in EEE.

The specific objectives of the RECDEV project are:

1. Integration of existing practices and experience of the partners into the design of high-quality 3D training scenarios.
2. Development, pilot implementation and evaluation of an interactive, multimedia and multilingual training approach that will familiarize low level trainees with the WEEE disassembly and packaging before going to the physical device.
3. Development, pilot implementation and evaluation of an interactive training approach that will help higher personnel of the recycling sector to ameliorate skills concerning the types and qualities of the material in WEEE.
4. Modernization of WEEE educational content with state of the art ICT tools and ontology on WEEE.
5. Offer of visual multilingual comprehensible, training tools for economic immigrants that constitute a great deal of the workers in WEEE recycling.
6. Enhancement of networking between WEEE employers and experts in the field from different countries in Europe.
7. Offer of an incentive to EU Recycling industries with regard to a periodical training of their managerial and technical workforce in aspects of modern disassembly methodologies and to the Health & Safety issues arising.
8. Dissemination and further exploitation assurance of is outcomes.

4. RESEARCH METHOLOGY

RECDEV project's main objective is the development of ICT-based-self-and distance learning training courses acquainting learners/users with the dismantling of EEE and the identification of types and qualities of materials contained. In particular, it targets both low skilled personnel (disassembly) in order to upgrade skills and ensure a safe work environment, as well as higher employers(materials identification) covering a crucial training gap in the WEEE industry. The training material will be prepared in the form of 3D scenarios, enhanced with multimedia material. In these scenarios, virtual representations of 50 real devices will be enacted and as a result the beneficiaries will be able to disassemble the WEEEs to their components simulating real life.

The project connects the popular Virtual Environments technologies to current training needs. Traditional training usually requires expensive resources whereas we do not achieve a high recall rate of the learners. On the contrary, the proposed 3D training platform will offer learners the possibility to apply the received knowledge in training scenarios, as many times as they need, addressing cultural diversities, thus providing a European dimension in systems and practices. The pedagogical methodology behind the project idea is based on an adaptation of the ´learning by doing´ method to the singularities of the recycling field, utilizing the interactivity and the simulation offered by virtual environments. The combination of these methods supports improvements in quality and innovation in training.

Metals, glass and plastics are the three main materials found in EE scrap. More specifically, ferrous metals represent more than 50%, non-ferrous metals for ca. 8% and plastics for 20-25 % of waste. Other essential materials are oil and cooling agents[2]. Taking into consideration the fact that most types of EE products contain varying quantities and types of plastics, the range of plastics used in EEE should be minimized so as to facilitate more effective recycling.

The project research focused in the types of plastics and metals included in the devices that would be further developed to the 3D scenarios.

The plastics that are commonly encountered in EEE are listed below:

- acrylonitrile butadiene styrene (ABS)
- polycarbonate(PC)
- PC/ABS blends
- high impact polystyrene(HIPS)
- polyphenylene oxide blends (PPO)
- polyethylene and polypropylene (PE & PP)

It is quite common to find many more types of materials used in special applications. The type of polymer, the cost compared to virgin material and the work needed to produce recovered material with the required purity and quality, are the main factors influencing the ability to find uses for recycled plastics. For example, the separation of materials and the removal of potential contaminants such as labels, screws and fixings can significantly increase the cost of recycled materials. It is also noteworthy to take into account the implications of recycling plastics that contain brominated flame retardants, on account of the increasing proscription and unpopularity of these substances. [3]

Due to the publishing of the Restriction of Certain Hazardous Substances (RoHS) (EU, 2002), the presence of these hazardous materials has been restricted. Nevertheless, WEEE that is now being processed still contains these additives. For example, the color impedes the correct identification of the material if the piece has no international identification; the flame retardants reduce the material melting point, which complicates mechanical and other recycling treatment. Additionally, flame retardants raise environmental concerns that limit plastics recovery, since they are almost entirely prohibited from burning in incineration plants, and their use in cement kilns is limited.

The need to evaluate the recyclability of WEEE plastics, in such a way that could promote better WEEE dismantling methodologies and improve plastics recovery by the recycling sector, justifies the need for greater knowledge of them.[4]

As for the metals included in WEEE, the benefits of using scrap iron and steel are savings in energy and virgin material use, reduction in water, mining and consumer wastes, air and water pollution.

Almost all the metals that are found in nature find application in electrical technology. During their processing, use, disposal, etc. compounds collectively termed heavy metals may be produced, which are necessary for the life processes as trace elements at low concentrations. By contrast, at higher concentrations, their toxicity is manifested. For human beings, heavy metals can disrupt the nervous system, damage the kidneys, or can be a source of mutations, tumors, etc. They can also be collected in the soil causing sterility, or may accumulate in

plants and as a consequence affect the food chain. Finally, most heavy metals gradually accumulate in sediments or living organisms [6].

Recycled materials energy savings over virgin materials are shown to the following Table [5]:

Material	Energy savings fraction [%]
Aluminum	95
Copper	85
Iron and steel	74
Lead	65
Zinc	60
Paper	64
Plastic	>80

4.1 DEVELOPMENT OF THE TRAINING COURSES

Two distinctive training courses have developed addressing two different levels of skills of the EE waste management personnel. The two courses contain:

1. A course for low skilled employees working on the dismantling of EEE. Identification of internal parts and safe disassembly and packaging of the materials for recycling, comprise the skills that will be upgraded.
2. A course for higher level workforce, decision makers in the WEEE industries. The topics that the course will cover are: the identification of the parts and materials included in the devices (type at first and quality in a second stage).

4.2 DEVELOPMENT OF TRAINING SCENARIOS/DEVICES

The training material will be prepared in the form of scenarios using all the information gathered as mentioned above. Those scenarios have been enhanced by using a multimedia format and allowing an interactive way of educational courses (ICT- based self-and distance learning training courses).The beneficiaries/learners participate in simulation of real- life situations (based on the training scenarios) and take the EEE apart. Screen shots from the RECDEV application are shown below:

Image 1: ***Main menu***

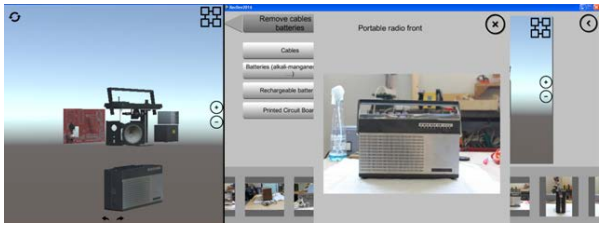

Image 2: Scenario: ***Radio***

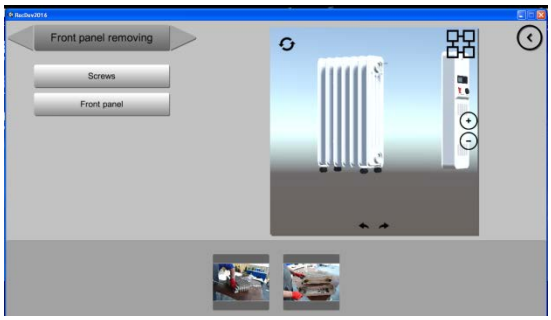

Image 3: Scenario: ***Oil heater***

Considering the present state, that training is commonly offered by traditional means and on the job practices, the project's objective is the development of innovative training scenarios validated with the aid of 'control groups' following the traditional training methods.

Virtual technologies combined with the innovative training pedagogies they offer (learning by doing) are going to enhance and transform the existing training material to interactive content, offering attractive and instructive disassembly and material identification courses to people not familiarized with the reading of big manuals and technical details.

The ICT innovation in the project is based on research work of Omega Technology (Partner 2) on dynamic virtual reality applications. More specifically, 3D representations of the WEEEs and their parts become manageable through a WEB 3D CMS (combination of a popular game engine- Unity3D, C# and JavaScript code as well as external calls to web services). All the information associated with the 3D Objects is dynamically set and updated by content authors. Multilingualism is another key feature of the platform due to the fact that there is a tool to easily translate online all the content of the application in the preferred languages.

5. DISSEMINATION ACTIVITIES

Appropriate visual and editorial support elements for all documents issued and regular information on the project's on-going progress will increase the visibility of the project to all interested parties. Emphasis was placed on the suitable selection of the information provided, on an articulate and illustrative presentation and on the protection of particular technical knowledge of the project partners for the purpose of keeping the exploitation of results safe.

Dissemination and exploitation strategies were planned to impart results, innovations and technical achievements of RECDEV to a great extent, dealing with at least three dissemination levels: the WEEE dismantling and recycling field, by using a comprehensive set of materials, dedicated workshops and in-person meetings; the wider public, through the RECDEV project website and information spread in social media and at last, dissemination to the scientific community at conferences (CEMEPE, ERSCP), and publications of several scientific papers in the conferences proceedings.

Three interactive workshops already took place in Bucharest, Romania (May 2014), in Graz, Austria (June 2015) and in Brno, Czech Republic (October 2015) inviting local WEEE companies and stakeholders to be initiated into the developing software and to give feedback about the utility of the training tool for the recycling sector. Consequently, important feedback (comments concerning the software) to be taken into consideration in the further design and development of the final version of the 3D software/platform was obtained. The 4th and final workshop will take place in Athens, Greece (September 2016) for the purpose of presenting to the Greek stakeholders and companies the final improved version after the pilot phase.

Dissemination seminars, in –person meetings and conferences were great opportunities for RECDEV partners to meet other experts and organizations concerned about the area of WEEE dismantling and recycling, to identify possible synergies and common opportunities such as the ECOTIC LIFE + Caravan Project and Project INFOCYCLE -LIFE +.

RECDEV partners aspire to jointly mainstream and exploit the project results by the development of a joint legal entity that will undertake the commercialization of the project's outputs. Regarding its business scheme, the formation of a European Economic Interest Grouping (EEIG) is already under negotiation within the partnership. EEIG entails no particular rules in its Regulation which either stipulates the requirement of a minimum capital or determines the maximum capital. This financial flexibility plays a significant role in enterprises, universities as well as NGOs, as it facilitates the formation of a cooperation framework, especially when the envisaged activities of the grouping do not require substantial capital at all.

Apart from these, other exploitation strategies are planned, such as the use of the platform of EEE producers for eco- design purposes, awareness raising and training, considering the perspective of the extended producer responsibility, and by the WEEE Associations for training their business partners, contributing to quality and safe disassembly of WEEE in regions. Finally, as far as the project's results are concerned, they will certainly be available in all the partners' languages.

6. TRAINING INTEGRATION AND PILOT IMPLEMENTATION

When the development of the 3D scenarios is fully completed there will be a 12-months pilot implementation phase, where the tools will be assessed by real users (both lower and higher level personnel). The feedback taken will contribute to fine tuning the application to be an efficient European tool for WEEE recycling.

The targeted users to participate at the pilot implementation will be those from the recycling companies, already expressed their interest in the project and more of them from other industries that are in close cooperation with the partners in each country. More specifically, at least 40 employees per country will be involved in RECDEV's pilot implementation (12, 5% higher personnel, 87, 5% low level workforce), while simultaneously 10 users in each country will receive traditional training to perform as control groups for the project achievements.

First the users will be trained how to use the training virtual environments and they will be monitored in real use of the tools with a view to evaluating the market potential of the 3D training material in each country. Adaptation of the training scenarios will be taking place throughout the procedure to improve the efficiency of the tools.

ISO/IEC 25010:2011 in conjunction with Systems and software engineering will be used in order to measure the user's satisfaction, the system's effectiveness/efficiency, freedom from risk and Context coverage. Additionally, along with ISO 9241-110 on usability that provides a framework, the analysis, design and evaluation of interactive systems (Suitability, Self- descriptiveness, Controllability, Familiarity, Robustness, Individualization and Learnability) will comprise the main assessment tool for the RECDEV platform.

The planned activities until the end of the project include:

- start the pilot implementation to all countries by setting up the training platform to recycling centers
- training of the trainers on the function of the platform
- perform training/pilot sessions in recycling centers
- monitor the training/pilot sessions and support the users to any possible problems
- evaluate the training/pilot sessions at their completion
- produce a mid-term evaluation report
- produce the final evaluation report
- make corrections/updates if necessary to the training platform and the supporting technical/scientific material based on the users info and pilots evaluation

7. BUSSINESS PLAN

The exploitation of the expected results is one of the major tasks with regard to the project. This task will be initiated the moment that a clear description of the RECDEV expected outcomes will be documented, and

integrates all actions associated with setting up the environment for exploiting the project's outputs and products, and developing the required business plan.

Activities such as internal workshops in the participating organizations for the purpose of acquiring commitment for the required commercialization and re- engineering investment, presentations to potential investors for the next round funding, liaisons establishment with regional vendors, distributors or business partners, cooperation with standardization bodies as well as those involved in products patenting (upon request), contribute to the success of commercializing.

The following basic categories of information will be included in the business plan:

- market definition (size, state of development, type of users and competitors),
- product definition and the reasons why a recycling company would want to use outcomes of the project,
- marketing strategy and estimated fees of the platform,
- servicing costs and forecasts of profitability,
- management and management control systems necessary to roll-out the service, as part of a consolidated consortium,
- financing requirements to launch the venture,
- further steps that will offer added value to the platform such as the utilization of the recycled parts and how these can lead to innovative products that can create opportunities for further exploitation,
- guidelines on how the product (methodology and tools) can be replicated for other industries.

8. CONCLUSIONS

RECDEV project comes to offer a brand new solution to the gaps in the training offered in this sector by the development of specialized training methodology and content for the dismantling of EEE and the identification of the type and quality of materials in this. Moreover, the project will ultimately develop a new skill in the business sector of WEEE industry at European level and also set the framework on offered vocational education for the WEEE staff. Namely, the user friendly 3D software through exploitation of a modern multimedia technology can become a comprehensible and targeted educational method for WEEE personnel and can finally establish an innovative 3D training tool as a Best Practice training approach in the EU WEEE industry.

RECDEV project will last three years, ending September 2016. A 12-month period is devoted to pilot development and testing, where the participation of real users to the pilot implementation phase is ensured as well as the projects' outputs; available in several languages (English, French, Greek, Slovenian, Czech, Austrian and Romanian), are going to cover real users' needs.

The methodology and tools will be developed aspiring to be easily extended to other industries beyond the WEEE recycling field. Finally, any Professional Sector can adapt this proposal to its needs or even further develop it with new modern tools and data thanks to its implementation in the sense of the open code.

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