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A web-based Decision Support System for the optimal management of construction and demolition waste

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ABSTRACT

Wastes from construction activities constitute nowadays the largest by quantity fraction of solid wastes in urban areas. In addition, it is widely accepted that the particular waste stream contains hazardous materials, such as insulating materials, plastic frames of doors, windows, etc. Their uncontrolled disposal result to long-term pollution costs, resource overuse and wasted energy. Within the framework of the DEWAM project, a web-based Decision Support System (DSS) application – namely DeconRCM – has been developed, aiming towards the identification of the optimal construction and demolition waste (CDW) management strategy that minimises end-of-life costs and maximises the recovery of salvaged building materials. This paper addresses both technical and functional structure of the developed web-based application. The web-based DSS provides an accurate estimation of the generated CDW quantities of twenty-one different waste streams (e.g. concrete, bricks, glass, etc.) for four different types of buildings (residential, office, commercial and industrial). With the use of mathematical programming, the DeconRCM provides also the user with the optimal end-of-life management alternative, taking into consideration both economic and environmental criteria. The DSS's capabilities are illustrated through a real world case study of a typical five floor apartment building in Thessaloniki, Greece.

1. Introduction

Construction and demolition waste (CDW) are generated on active building sites (Stein, 1996). CDW include a wide range of materials depending on the source of the waste, namely excavation materials (e.g. earth, sand, gravel, rocks and clay), road building and maintenance materials (e.g. asphalt, sand, gravel and metals), demolition materials (e.g. debris including earth, gravel, sand, blocks of concrete, bricks, gypsum, porcelain and lime-cast), as well as other worksite waste materials (e.g. wood, plastic, paper, glass, metal and pigments) (Fatta et al., 2003). CDW are problematic not mainly for their hazardous nature, but mostly for the significant volume generated. In the European Union, more than 450 million tonnes of construction and demolition waste is generated annually. Excluding earth and excavated road material, the amount of CDW generated is estimated to be roughly 180 million tonnes per year (EC, 2000). This stream presents the third largest in quantities, only following waste from the mining and farming industry (Dorsthorst and Kowalczyk, 2002).

Up to recently, common practice was to discard CDW materials and debris in landfills, most often the same ones built for the disposal of MSW (Garrido et al., 2005). The substantial volume of CDW presents significant pressure to landfill capacities and have led to considerable environmental concerns (Esin and Cosgun, 2007). Disposal of CDW cannot in any case be considered as a sound management practice for end-of-life building materials. Even worse, there are many cases reported where CDW ended up in uncontrolled open dumps, not taking into account the severe burden imposed upon the environment (Fatta et al., 2003). Apart from the aesthetic degradation, environmental impacts of such practices include, soil and water contamination, air pollution as a result of resulting fires, reduced land and property values, destruction of open spaces and landscape blight (El-Haggar Salah, 2007). In addition, heaps of CDW may include asbestos waste, which poses a significant health risk, especially in building sites which are later converted into residential areas or playgrounds (Hendricks et al., 2000).

Following the waste management prioritisation of alternatives, CDW disposal stands on the basis of pyramid and indicates the least favourable building materials' end-of-life option following "Avoidance", "Reduce", "Reuse" and "Recycle". Among measures to minimise CDW quantities are considered also the control of aspects such as design quality, applied technology and habitual construction methods (Ekanayake and Ofori, 2004; McDonald and Smithers, 1998). The stream is characterised by its very high

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recovery potential, since total waste recycled can reach 80% (Bossink and Brouwers, 1996). However, in current practice, the vast majority of CDW (almost two thirds) is being landfilled. However, there are countries with significant achievements in the field, such as Denmark, the Netherlands and Belgium that have surpassed 80% recycling rates (Erlandsson and Levin, 2005). Best recycling practices have been achieved in cases where both raw materials and necessary disposal sites are scarce (Lauritzen, 1998). In addition, recycling plays a crucial role in order to preserve areas for future urban development, and to improve at the same time local environmental quality (Kartam et al., 2004). Prior to recycling, CDW can be also reused. For instance, inert, uncontaminated end-of-life building materials can be used as filling material for land reclamation purposes (Poon et al., 2001).

In order to assist construction companies, public bodies, engineers and individuals towards environmental-friendly sound management of CDW, a web-based Decision Support System (DSS) has been developed, namely DeconRCM. A beta version of DeconRCM can be visited at: http://pandora.meng.auth.gr/deconrcm. Currently, the application is built for the case of the Region of Central Macedonia, Greece, but can be easily expanded to other areas with the necessary adjustments. In this paper, functional specifications of DeconRCM are provided, together with a brief description of its technical aspects. The DSS tool's capabilities are illustrated through a real-world case study of a five-floor residential building in Thessaloniki, Greece.

2. Overview of the DeconRCM

The main objective of DeconRCM is twofold. It provides an accurate estimation of the generated quantities of 21 different waste streams produced by two main processes (renovation and demolition). Four building types are considered, namely residential, office, commercial and industrial. Generated CDW are based on the typical construction practice in Greece (Anastaselos, 2009). An algorithmical model, is constructed and embodied in the DSS tool for the estimation of the generated quantities of CDW (Anastaselos, 2009). The model that was developed and incorporated into the DeconRCM tool for the analytical calculation and the quantification of materials embodied in existing buildings was validated for its performance. Two residential buildings that were demolished were examined, one in the city of Kalamaria and another in the city of Kozani.

The accuracy of the derived results was considered as acceptable, with the overall deviation between the actual and the calculated CDW quantities (for mixed CDW) to lie in the order of 8–9%. More specifically, the difference between the calculated quantities with the use of the developed model in comparison to the actual quantities weighted on site varies from 6% to 10% for the various waste streams in the case of the building in Kalamaria and from 5% to 9% for the various waste streams in the case of the building in Kozani. The only exception in both cases was the estimation of cables' mass. Cables heavily vary on building structure and use and thus it is considered as the hardest stream to be quantified with the use of a generic model. However, the estimations were not totally disoriented since the deviation in this particular waste stream rose to 26% and 18% for the cases of Kalamaria and Kozani, respectively. The comparison between CDW quantities calculated with the tool developed for the DeconRCM application and actual waste quantities weighted on site for the two aforementioned case studies are detailed in Moussiopoulos et al. (2009).

Furthermore, the model for the estimation of the generated CDW quantities was also validated in the case of the waste from construction activities in the Aristotle University campus, Thessaloniki, Greece (Banias et al., 2011a). Maintenance of the university's buildings (mainly construction and electromechanical works) is conducted annually with a significant CDW volume generated, which leads to considerable management cost. The deviation between the model's calculated quantities and the actual weighted CDW quantities in this case was in the order of 10% (Fragkoudakis, 2011). The deviation is also considered as acceptable, taking also into consideration that this particular case study refers to large-scale activities of heavily differentiated buildings.

On top of the above, DeconRCM specifies the optimal management strategies for all generated CDW streams, taking simultaneously into account economic and environmental criteria. This is achieved with the use of mathematical programming. All end-of-life treatment facilities (including landfills) within the limits of the Region of Central Macedonia are incorporated in appropriate databases – analytically presented in the material to follow – and illustrated in Google maps. Optimal routes from the worksite to treatment facilities are also communicated to the end user, together with an estimation of the overall management cost. DeconRCM's structure and data flow are depicted in Fig. 1.

DeconRCM is built with the use of a web mapping via Google Maps API, a free web mapping service application and technology that powers many map-based services (Google, 2011a). A database with all the necessary information (e.g. coordinates, contact details, available technologies, accepted streams, pricing policies, etc.) regarding disposal sites within the area under consideration is embodied in the application. The database, which is MySQL 5x (MySql, 2011), can be accessed and edited only by the application's administrator. Feedback forms, based on PHP 5.2 scripting language (CodePlex, 2010), are designed in order to assemble all necessary input data regarding the source worksite of the building under demolition or renovation (e.g. coordinates, type of building, number of floors, surface, year of construction, type of heating system, etc.) (Banias, 2009). The full description of the web-based DSS's technical and functional specifications is provided in Section 3.

Estimation of the generated CDW quantities is realised with the use of an algorithmical model in Excel file format, based on building practices in Greece (Anastaselos, 2009). The output is stored in databases, also developed with MySQL. Optimisation is achieved with the use of a mixed-integer linear programming (MIPL) model (Aidonis, 2009). Fixed and variable cost elements included in the optimisation approach concern the building's deconstructing or demolishing process, CDW separation, renting/loading/using a container, etc. Revenues from secondary materials' sales are also considered (Aidonis et al., 2008).

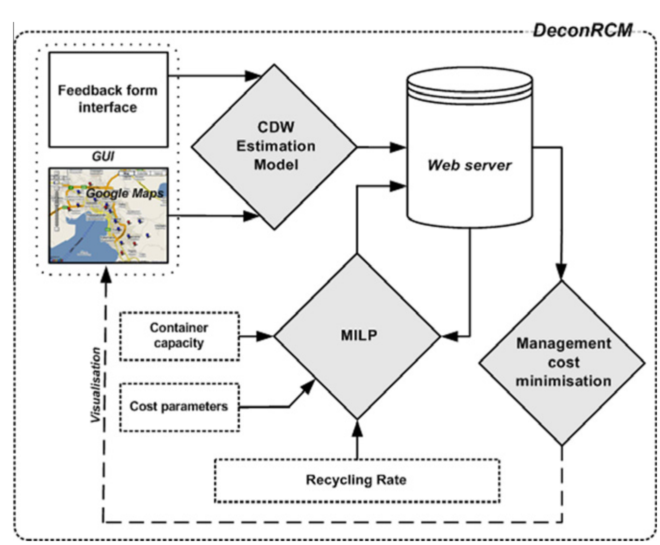

Fig. 1. Structural components of DeconRCM.