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Predicting fuel energy consumption during earthworks

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ABSTRACT

This research contributes to the assessment of on-site fuel consumption and the resulting carbon dioxide emissions due to earthworks-related processes in residential building projects, prior to the start of the construction phase. Several studies have been carried out on this subject, and have demonstrated the considerable environmental impact of earthworks activities in terms of fuel consumption. However, no methods have been proposed to estimate on-site fuel consumption during the planning stage. This paper presents a quantitative method to predict fuel consumption before the construction phase. The calculations were based on information contained in construction project documents and the definition of equipment load factors. Load factors were characterized for the typical equipment that is used in earthworks in residential building projects (excavators, loaders and compactors), taking into considering the type of soil, the type of surface and the duration of use. We also analyzed transport fuel consumption, because of its high impact in terms of pollution. The proposed method was then applied to a case study that illustrated its practical use and benefits. The predictive method can be used as an assessment tool for residential construction projects, to measure the environmental impact in terms of on-site fuel consumption. Consequently, it provides a significant basis for future methods to compare construction projects.

1. Introduction

The construction industry's efforts to use resources more sustainably have mainly been directed towards building energy optimization (European Union, 2010) and the sustainability of construction materials (European Union, 2011). Only marginal interest has been shown in on-site resource management (i.e. energy, water and materials), because construction management has been mainly driven by decisions related to the maximum efficiency of operations, optimizing economic resources, timing, and the use of new technologies (Schaffhauser-Linzatti, 2012; Turkan et al., 2012; Zhang et al., 2013).

Previous research has mainly focused on the quantification and management of operating energy in buildings, while there has been less emphasis on embodied energy related to the construction process, namely on-site construction (Davies et al., 2013). A few studies have addressed the sustainability of the construction process. They demonstrated the existence and importance of the on-site environmental impact of construction projects, and developed criteria, methods and models for identifying and assessing this impact (Fuertes et al., 2013; Gangolells et al., 2009, 2011; Magnusson et al., 2015; Šelih, 2007; Shen et al., 2011; Zhao et al., 2006). However, none of these studies focused on the prediction of earthworks fuel consumption before the execution phase of the construction process.

Other studies (Chau and Muttil, 2007; Muttil and Chau, 2006, 2007; Wu and Chau, 2006) tackled sustainability by proposing statistical and mathematical methods for analyzing data related to pollution issues, but they did not propose an innovative, simple method for predicting earthworks fuel consumption during the planning phase of new residential construction projects.

Energy consumption due to on-site construction activity is also commonly ignored in life cycle assessment (LCA) studies, owing to a lack of available data and the inconsistent use of LCA boundaries (Davies et al., 2013). In other cases, it is simply approximated because the analysis is very complicated or the impacts are thought to be small (Guggemos and Horvath, 2006). The environmental impact of infrastructure and construction may be much lower than

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the impact of a building's operation. However, when we examine these environmental impacts in a different time frame, or as a function of all buildings, they may be considerable (Sharrard et al., 2008). In general, the construction phase has been found to contribute to 0.4–12.0% of the environmental impact. This figure is low due to the overwhelming impact of the use phase, which is much longer (Davies et al., 2013; Guggemos and Horvath, 2005; Junnila et al., 2006). According to Sharrard et al. (2007), on-site energy usage in the United States construction sector represents 2.6–3.0% of the entire US energy consumption, including passenger vehicles and shipping, while Ahn et al. (2010) report that consumption related to construction equipment use accounts for 0.8% of Canada's total energy consumption. However, these data underestimate the real consumption, since they do not include the use of on-road trucks.

Sharrard et al. (2007) indicate that gasoline and diesel fuel are responsible for the majority of energy consumption in the construction industry at 62–75% of all use, while electricity varies between 10 and 25% of the total energy consumption.

Substantial differences in the estimation of on-site fuel consumption in construction projects have been reported by Kotte (1996) and Peters and Manley (2012). Although construction equipment manufacturers provide power consumption information in their technical specifications, the challenge is that construction projects may involve complex and unique products and include a wide variety of construction techniques and systems (Gangolells et al., 2011). Thus, construction projects involve a great variety of tasks of variable duration, and the use of a range of equipment at different intensities. Other relevant factors are the distributed nature of construction and the subcontracting of activities (Sharrard et al., 2007). A lack of data on subcontractor fuel consumption (Peters and Manley, 2012) and a lack of data verification (Davies et al., 2013) are also highlighted as difficulties in the quantification of on-site energy consumption. Similarly, Kenley and Harfield (2011) stated that methods for measuring carbon dioxide and other greenhouse gas emissions in construction processes have yet to be developed, and Barandica et al. (2013) confirmed that statistics are needed on the fuel consumption of specific machinery.

Several authors have agreed that emissions generated by construction equipment are the main source of on-site environmental impact. Consequently, it is important to mitigate this impact (Ahn et al., 2009; Barandica et al., 2013; Carmichael et al., 2012; Frey et al., 2010; Kaboli and Carmichael, 2012). Ahn et al. (2009) proposed a method that integrates the emission model of construction vehicles with the simulation model of construction operations. However, the approach did not use information from project documents. Other authors such as Frey et al. (2010) and Zarotti et al. (2009) focused on on-site fuel consumption. Frey et al. (2010) published a set of field data on non-road equipment, including engine attributes, representative duty cycles, and average fuel use and emission rates, while Zarotti et al. (2009) analyzed fuel consumption during the operating cycle of an excavator, while it was in use with a professional operator. However, only the operating cycle was taken into account in this study; on-site excavator movements and pauses with the engine running, which can take up to half a workday, were not considered. Other studies, such as those by Al-Hasan (2007), Shikata (2009) and Kecojevic and Komljenovic (2011), also focused on earthworks machinery and its operation in relation to fuel consumption and emissions. Kecojevic and Komljenovic (2011) analyzed the impact of engine load conditions on fuel consumption and the subsequent carbon dioxide emissions, with a specific focus on bulldozers. Along the same line, Shikata (2009) indicated that bulldozer fuel consumption is highly dependent on factors such as site geography, weather and the maintenance program. Some recommendations about operation methods were also provided. Al-Hasan (2007) studied the impact of outside temperature on fuel consumption. Thus, although previous research has focused on the development of methods for estimating the fuel consumption of construction equipment, a predictive model based on information contained in construction project documents is still lacking.

Therefore, the aim of this research was to develop an innovative predictive model to estimate in advance (during the planning stage) the on-site fuel consumption and corresponding carbon dioxide emissions arising from earthworks in residential construction projects, using information from project documents. A number of four construction activities were reviewed, along with their corresponding fuel consumption agents. As a result of this review, we decided to focus on earthworks and related fuel consumption agents, because of their high environmental impact. We then developed the proposed method through a careful and in-depth analysis of machines' parameters. Over a hundred pieces of equipment made by the best-known manufacturers were considered and classified into main types. Classification parameters, in particular engine load factors, were identified.

Following this introduction, the second section describes the method adopted in this research. Then, to illustrate a practical application of the model, a case study is reported in the third section. The third section discusses also the results obtained using the model, and compares them with data collected on-site. The fourth section reports the conclusions of this research and the fifth presents future research issues.

2. Method

The method used in this research included the following steps:

1. Identification of earthworks activities and corresponding fuel consumption agents
2. On-site fuel consumption analysis for earthworks activities
   2.1 Characterization of the fuel equipment
   2.2 Characterization of the load factor
3. Analysis of fuel consumption in transport
4. Estimation of on-site fuel consumption related to earthworks in building projects

2.1. Identification of earthworks activities and corresponding fuel consumption agents

In order to identify the fuel consumption related to each earthworks sub-activity, we used a process-oriented approach, similar to that applied by Gangolells et al. (2009). First, earthworks sub-activities were identified based on the Ente Nazionale Italiano di Unificazione UNI 8290-1 (Italian Company for Standardization, 1983), the Classification of Building Elements and Related Sitework of the American Society for Testing and Materials International (American ASTM, 2009), and the Spanish database from the Catalan Institute of Construction Technology (ITeC, 2013). The activities that were considered included: (1) stripping overburden, (2) excavations, (3) embankments and (4) compaction (Fig. 1).

Secondly, fuel consumption agents were identified, taking into account the Italian Joint Territorial Committee's list of equipment (Comitato Paritetico Territoriale, 2009). More than 100 pieces of equipment were considered and classified under the categories of (1) logistics services, (2) placed equipment, (3) aerial handling machines and (4) mechanized handling machines (Fig. 1).

As a result of this process, a list of earthworks sub-activities and corresponding fuel consumption agents were obtained. The agents included (1) dozers, (2) excavators, (3) loaders and (4) compaction