A computational paradigm for the optimisation of steel building structures based on cost and carbon indexes in early design stages

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Abstract. The study explores a practical engineering paradigm that aims to augment the cost and carbon analysis of steel building structures. Cost and carbon functions were developed specifically for this purpose including raw material, fabrication, design, fire protection, and erection components. A customised computational model for the analysis of structural alternatives is investigated. The proposed model is tested in an actual building case where several benchmark designs are computed. The outputs from the model are compared with a small number of actual design alternatives which were developed by engineering practitioners. The proposed method can significantly increase the understanding of the design space's boundaries whilst the computed solutions have exhibited enhanced cost and carbon performance compared to actual designs.

1. Introduction

Although steel framed building structures are designed according to standards, which define minimum safety limits, their material efficiency is rarely being systematically addressed in practice. This inherently creates large inefficiencies in the way building structures are designed and constructed. Moynihan and Allwood investigated 79 steel-framed buildings, and concluded that unused mass of steel framed buildings could reach nearly 46% of the building's total mass due to over-specification of the steel sections (Moynihan & Allwood, 2014). Furthermore, Dunant et al. in their study confirmed that 35-45% of the steel by mass of the steel frame is not required in terms of structural efficiency (Dunant, et al., 2017).

Traditionally, the relationships between the cost of materials and the cost of fabrication in construction is considered to have a significant impact on the final design selection. In the literature, cost optimisation can be found in several instances: welded steel structures (Jarmai & Farkas, 1999), steel frames with semi-rigid connections (Hayalioglu & Degertekin, 2005), design, fabrication, and manufacturing (Sawada, et al., 2006; Heinisuo, et al., 2010; Haapio, 2012) and entire steel structures (BCSA & TATA, 2013). Cost as a single metric is easy to comprehend and quantify, however, its relationship with other environmental impact metrics is more complicated to determine. For example, even though material reductions are important in CO_2 optimisation this does not mean that material reduction will also yield cost optimum solutions.

Although optimisation methods are available to engineering practitioners for more than three decades, their implementation is limited by the different requirements addressed in every project (Prager, 1970). Even though mathematical techniques are well established in structural optimisation, which vary from construction scheduling (Zhou, et al., 2013), construction site layout (Zhou, et al., 2009), construction management (Suliman, et al., 2011), size, shape and topology optimisation (Frans & Arfiadi, 2014), and member optimisation in high rise buildings (Kingman, et al., 2015; Stromberg, et al., 2012; Stromberg, et al., 2012), more practical optimisation models are still needed. Despite the different optimisation studies of steel buildings found in the literature, the relationship between cost and carbon performance in early