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The role of geometric characterization in supporting structural steel reuse decisions

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ABSTRACT

Reuse of structural steel can be more attractive than recycling in many cases, if associated costs and risks are lowered, and if externalities are considered. Geometric characterization is demonstrated in this article to have a key role to play in the decision process for each case of potential steel reuse, because it is necessary for identifying unknown in situ member sizes and assembly geometries, and for quantifying uncertainty when assessing the reliability of a structure. Without automation of this analysis, it is speculated that such a detailed decision making process would not be feasible. The key role of geometric characterization is demonstrated in this article through a series of remote, 3D imaging experiments and reliability analyses. The reliability analysis demonstrated that automated geometric identification using an algorithm developed for the current study results in a 56% reduction in capacity when compared to similar new steel members. Alternatively, more manual methods of remote geometry detection resulted in only a 2% reduction in capacity. It is concluded that semi-automated geometric characterization has the potential to support increased steel reuse through reduced identification costs and improved reliability. A new set of methods and an understanding of their utility in making reuse more attractive through reduced costs and improved reliability is thus contributed.

1. Introduction

Most structural steel from facilities that have reached the end of their service life is demolished and transported to recycling facilities where it is melted down and incorporated into the new steel production and fabrication supply chain. In spite of well-established recycling practices, iron ore and steel production is growing exponentially (Yellishetty et al., 2010). It is predicted that the steel industry will remain heavily dependent on new steel resources until at least the year 2050 (Oda et al., 2013). In the past there has been a focus on the recycling process (Ayres, 1997) but reusing steel avoids this process and eliminates the energy and water requirements of recycling steel. Weisenberger (2011) presents an outline of considerations to be made by designers for sustainable construction. One important consideration is material choice, and the reuse potential of structural steel is noted as one of the material's key advantages. Salvaged steel components come from the demolition or deconstruction processes. The differences between these processes are explored by (Thomsen et al., 2011). The process of incorporating these salvaged components into new designs, commonly referred to as "reuse", is not an unknown process to the steel construction industry. The importance of reuse as a means to achieve sustainable steel construction has been explored by Burgan and Sansom (2006), who also present a number of design considerations for reducing the cost and difficulty of steel reuse. These design considerations include using bolted connections and maximizing member length. The state of structural steel reuse in Canada was reported after extensive surveying of various groups in the steel industry (Gorgolewski, 2006). Based on this survey, it was estimated that the rate of steel reuse could be further increased by up to 150%. This increase could occur if economic conditions were less prohibitive or externalities, in the form of environmental impact, were considered. While conducting this survey, a process model was developed (Gorgolewski, 2006), linking the various steel industry stakeholders and showing their contribution to the reuse process. A summary of this model is provided in Fig. 1.

The feasibility and benefits of structural steel reuse were explored in a case study where it was found that reused steel could comprise up to 30% of the steel used in a rehabilitated train station in Italy (Pongiglione and Calderini, 2014). In the same study, it is suggested that new steel members may need to be over-sized to ensure the safety of the overall structure.

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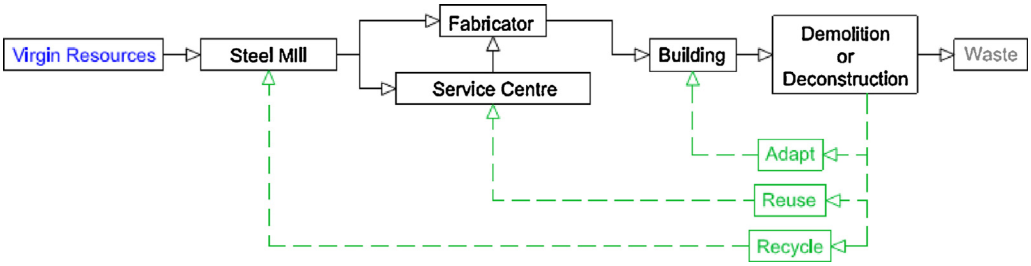

Fig. 1. Process model for structural steel construction.

Adapted from Gorgolewski (2006).

One method for reducing the uncertainty associated with the use of reused steel components in new building construction could come as a result of a paradigm shift in structural steel manufacturing. Ness et al. (2015) propose digital tracking and modeling of structural steel to help facilitate reuse. The proposed sensors and digital tags could hold information about a component's material properties, dimensions, and stress conditions during its service life. This information could be used to increase confidence in the capacity of the member and facilitate more efficient purchase and sale of reused components. Unfortunately this paradigm shift does not aid in reusing structural steel that currently exists within buildings, because the proposed trackers and digital models have not yet been integrated into these buildings.

Although the existing research regarding the current state of steel reuse is broad-ranging, two important gaps have been identified in the current knowledge base and are the subject of the current paper. Firstly, several supply chain models have been presented in the field of steel reuse but these models do not incorporate engineering decision making processes. In this context, decision making processes refer to decisions around the feasibility of effectively salvaging structural steel for reuse. For example, *is there structural steel worth salvaging? Should the demolition contractors be required to maintain the integrity of as much steel as possible?*, etc. The decision making processes form an important model component, because they would aid decision makers by showing them when to investigate structural steel reuse and how to make reuse decisions. Secondly, the current state of the art has adequately identified the barriers to and potential benefits of steel reuse, but it has not suggested how to overcome these barriers, which are the high identification, analysis and transaction costs, and increased uncertainty and liability associated with reused steel (Gorgolewski, 2008).

2. Background research

In the following section, a detailed review of research on the automated identification of structural member sizes and geometry is first presented, followed by a review of the limit states design approach and structural reliability analysis. In order for engineers to confidently design with reused steel, the automated identification results need to be used in a structural reliability analysis before being incorporated into the limit states design approach.

One possible approach for reducing the analysis cost of existing structures for reuse is automating parts of the analysis. This might begin with acquiring the accurate 3D geometry of the structure. This may include the identification of connection geometry and deviations from the design dimensions, as well as basic information such as the nominal member sizes, in cases where original structural drawings are not available. Methods for capturing 3D point cloud data for this purpose can be separated into two categories: (1) image based systems, and (2) time-of-flight based systems. An example of point cloud data for a low-rise structural steel building can be seen in Fig. 2. Image based systems typically have a higher speed data collection rate but lower accuracy (Dai et al., 2013). This makes image based systems ideally suited for real-time analysis (Han and Lee, 2013) and sufficiently accurate for activities such as infrastructure reconstruction (Brilakis et al., 2011). Image based systems also offer the flexibility of capturing data from unmanned aerial vehicles (UAVs) (Remondino et al., 2011). While time-of-flight based systems, such as laser scanners, lack the data collection speed of image based technologies, they are able to acquire very dense and highly accurate point clouds allowing them to be used (for example) for assessing initial imperfections of pipelines when constructing accurate models (Kainat et al., 2012) or tracking the progress of a construction project (Turkan et al., 2011).

In the field of civil engineering, automated object recognition has mainly focused on maintaining and updating building information models (BIMs). A method has been presented for calculating and monitoring the progress of a construction site by comparing 3D point clouds to 3D BIMs (Bosché and Haas, 2008; Bosché, 2009; Turkan et al., 2011). Point cloud data has also been used for dimensional compliance checks of concrete (Tang et al., 2011) and marble façades (Al-Neshawy et al., 2010). However, both of these studies were developed with the assumption that the subject of the 3D scan is expected to be perfectly flat, as is the case for a wall or floor element (Bosché and Guenet, 2014).

All of the aforementioned automated object recognition methods require a priori knowledge in order to identify components. This limitation has been identified and is currently an area of high interest within the research community. The issue of automatically associating semantic content with simple, flat surfaces has been addressed recently (Xiong et al., 2013). Other automated methods for converting a 3D point cloud into a BIM also exist (Tang et al., 2010).

Developments in this field have led to various commercial products that are capable of locating structural steel sections (ClearEdge 3D, 2014) or identifying internal frame connections (Cabaleiro et al., 2014) within a 3D point cloud. Unfortunately, these methods and others are only able to provide, at best, limited reporting of the reliability of automated detection results (Anil et al., 2013). A structural design oriented analysis of the confidence level in the results is essential before the results can be used as input for new designs.

In most of the world, steel structures are designed using a limit states design approach (e.g. CSA, 2009), which involves the application of load and resistance factors to the calculated load effects and nominal resistance of a structure to ensure that a particular level of safety is achieved. These factors consider the various sources of uncertainty and inherent variability associated with the parameters and models used to predict the structure's performance during its service life. A reliability analysis can be performed to incorporate the random nature of structural characteristics, whereby a target failure probability is assumed, and a set of load and resistance factors associated with this failure probability are calculated. The resistance factors for structural steel appropriate for the design of