PhD Abstract – 'Material efficiency in construction'

Producing steel causes 6% of global anthropogenic carbon dioxide emissions. Experts recommend that these emissions are reduced by half by the year 2050 in order to avert the worst consequences of climate change. Demand for steel is predicted to double in the next 36 years, meaning that a 75% reduction is emissions per unit of steel produced is necessary to reach the recommended limit. Process efficiency improvements cannot deliver this magnitude of reduction; however if steel is used more efficiently so that less new material is required to deliver the same service --- a concept termed `material efficiency' --- then this could allow demand to be satisfied whilst emissions targets are achieved.

Construction is the single largest use of steel globally, therefore using steel more efficiently in construction will reduce emissions. Three material efficiency strategies are identified as having most potential for this industry: using less material, using products for longer, and reusing components. In order to prioritise areas for research, steel flows into construction are mapped, finding that industrial buildings and utility infrastructure are the largest uses of steel, while superstructure is confirmed as the main use of steel in a typical building.

To estimate the potential to use less steel in buildings, 23 steel-frame designs are studied, sourced from three leading design consultancies. The utilisation of each element is found and the building datasets are analysed to infer the amount of steel over-provided. The results suggest that such buildings contain almost twice as much steel as necessary for structural performance, and indicate that this amount of over-provision occurs to minimise labour costs, which are a larger proportion of total costs than materials.

To investigate how buildings and infrastructure could be used for longer, reasons for their failure are reviewed. Based on interviews with industry professionals a set of strategies is proposed, tailored to each failure cause and distinguishing between cases where failure can and cannot be reasonably foreseen.

Steel sections could be reclaimed from old buildings and reused in new buildings but this does not occur because they are damaged during demolition. Designing for deconstruction would facilitate reuse but is not practised due to its cost. Data from interviews and a commercial working group are analysed to identify three aspects of designing for deconstruction that provide financial and operational benefits to clients, thus encouraging their use.

One remaining technical barrier to deconstruction is composite steel-concrete systems, where welded connectors make it impractical to separate the steel beam from the concrete slab without damage. A novel bolted composite connector is proposed and tested in three beam experiments. The bolted connector allows successful separation of the components, facilitating reuse. Its structural performance is similar to that of welded connectors and can be predicted using current design standards.

Each of the investigations reveals significant opportunities to reduce steel use in construction by using material more efficiently. Achieving these savings would reduce demand for new steel production and thereby decrease carbon dioxide emissions.

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