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Sustainability of Cold-formed Steel Portal Frames in Developing Countries in the Context of Life Cycle Assessment and Life Cycle Costs

Ross P.D. Johnston[a,b], Teresa McGrath[b], Sree Nanukuttan[b], James B.P. Lim[c], Marios Soutsos[b], Mei Chee Chiang[d], Rehan Masood[c,*], Mohammad Afjalur Rahman[c]

[a] *Hanna + Hutchinson Consulting Engineers Ltd, Lisburn, Northern Ireland, United Kingdom*
[b] *School of Natural and Built Environment, Queen's University of Belfast, David Keir Building, Stranmillis Road, Belfast BT9 5AG, United Kingdom*
[c] *Department of Civil and Environmental Engineering, Faculty of Engineering, The University of Auckland, Auckland 1142, New Zealand*
[d] *EcoSteel Sdn. Bhd., Kuching, Sarawak, Malaysia*

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ABSTRACT

There is often a demand in developing countries for single-storey buildings, for industrial and agricultural use. Whilst conventional hot-rolled steel sections are still commonly used for the primary column and rafter members, for frames of modest span (up to 30 m), a viable alternative can be the use cold-formed steel sections. Advantages include pre-galvanised sections that do not require painting to prevent rusting; reduced transportation and acquisition costs as the cold-formed steel used for the secondary members can come from the same supplier; bolted joints that are easy to assemble on site. This paper compares both types of portal steel buildings in terms of a life-cycle assessment (LCA) and a life-cycle cost (LCC). Three sizes of buildings are considered: 18 m, 24 m and 30 m. It is shown that in terms of the primary framing, use of cold-formed steel for the 18 m and 24 m span buildings can result in up to 30% less embodied carbon than hot-rolled steel. However, when secondary members and cladding are taken into account in the LCA, the differences in embodied carbon of cold-formed and hot-rolled steel are found to be negligible. LCC is concerned not only with the cost of the steel, but also with the labour costs and the cost of having a crane on site. It is shown that the 18 m and 30 m span cold-formed steel frames are cheaper than the hot-rolled steel frames by 33% and 15%, respectively, primarily owing to the fact that the erection of cold-formed steel portal frames have less demand for having a crane onsite. The use of LCA and LCC has therefore helped quantify associated embodied carbon and costs, with differences between section types for the primary framing shown to be relatively negligible when considered in context of the entire building, and the real differences between the two types of steel due to the ease of erection on site.

1. Introduction

In developing countries, there is often a demand for single-storey buildings for industrial and agricultural use. Whilst the choice of material used for such buildings is normally specified on the basis of initial capital costs, designers throughout the world are increasingly encouraged to consider life cycle assessment (LCA) and life cycle costs (LCC).

In Australia, the Building Code of Australia (BCA) by the Office of the Queensland Parliamentary Counsel [1] has been one of the main drivers for the use of cold-formed steel, with their principals being implemented by BlueScope Steel. In BlueScope's technical booklets [2], the reduce-reuse-recycle system is explained, with particular focus placed on the importance of dematerialisation.

Dematerialisation is a term defined as the development of high-strength steel products, with the same function achieved as would be through the use of fewer raw materials. Such innovations maintain structural integrity and functionality, with lower material use. With its inherent high strength-to-weight ratio, the use of cold-formed steel in portal frame building design is an example of such an innovation.

The UK government has set an ambitious and, legally binding target to reduce national greenhouse gas emissions [3]. Drivers include The Target Zero [4] programme of work, which provides guidance on the design and construction of sustainable, low and zero carbon buildings in the UK.

Portal frames are conventionally constructed using hot-rolled steel sections (see Fig. 1). In such buildings, hot-rolled steel is used for the primary load-bearing members (i.e. columns and rafters), with cold-

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* Corresponding author.
undefinedrmas769@aucklanduni.ac.nz",0,0,2
>rmas769@aucklanduni.ac.nz (R. Masood).

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Fig. 1. Hot-rolled steel portal frame.

Fig. 2. Cold-formed steel portal frame (photograph courtesy of CSB).

formed steel used for the secondary elements (i.e. purlins, side rails and sheeting). However, for portal frames with modest spans of up to 30 m [2], the use of cold-formed steel sections for the primary columns and rafters is a viable alternative (see Fig. 2) [5]. Advantages include higher strength-to-weight ratio of the steel, ease of transportation, ease of erection by manual semi-skilled labour [6,7], and savings in transportation due to cold-formed steel sections being able to be stacked. Furthermore, hot-rolled steel sections require fabrication costs, with haunches and purlin cleats that require welding; unlike cold-formed steel, which has a galvanised layer, hot-rolled steel sections require painting to prevent rusting.

This paper is concerned with a comparison between the life cycle assessment (LCA) and life cycle cost (LCC) of hot-rolled steel and cold-formed steel portal frame buildings. In the literature, no other work has considered such a comparison for a whole building, with previous work being limited to a single secondary member [8]. Malaysia is used for the purposes of this study, as it has a maturing steel industry with no heavy snow load, Malaysia is chosen for the purposes of this study. For the comparison, the weight of steel includes both primary and secondary members. Local industry has provided estimates for labour and erection costs, as well as providing design in accordance to the Australian/New Zealand Standards.

LCA and LCC are two management methodologies that can be used to evaluate the environmental impacts and life cycle costs of a product or building. Different stages of the life cycle of the product or building may be examined. Employing both methodologies in construction practices can allow for the development of more sustainable buildings. Instead of focusing solely on the initial capital cost, clients and designers can assess the environmental and economic impact of decisions in terms of the overall life of the building [9]. Both methodologies have inherent limitations as they often require assumptions related to how a building will be maintained and operated. Circumstances of accidental damage due to fire or natural hazards, which are difficult to predict and therefore can't be assumed, are not included within the scope.

2. Literature review

2.1. Life cycle assessment

Building materials used in the construction industry have an important environmental impact due to the energy used and carbon dioxide emitted in the production process [10]. These impacts are often ignored by designers, although a better choice of materials and construction methods along with optimisation of the structure can significantly reduce the amount of energy embodied and CO_{2eq} in a building. Building materials which incorporate industrial and consumer wastes, e.g. fly-ash concrete, can reduce both the depletion of natural resources and the pollution generated by the extraction of the raw materials.

Life cycle assessment (LCA) is a methodology that quantifies the environmental impacts of a product, considering the entire life cycle, starting from the extraction of the raw materials, manufacturing, use phase and eventually the final disposal.

In the early 1990s, a series of meetings arranged by the Society for Environmental Toxicology and Chemistry (SETAC) saw LCA methodology presented. With broad international harmonisation, these meetings brought about the international standardisation of LCA practices through the ISO 14040 [11]. The resulting LCA methodology prevents ‘burden-shifting’ from one stage to another, or from one location to another.

LCA consists of four interlinked phases; these phases are listed and explained in Fig. 3. The first phase is goal and space definition which establishes the intended application and audience (goal) and the functional unit and system boundary of the study (scope). The functional unit is the quantified definition of a products function and may often incorporate dimensions, weight or strength characteristics, for example the functional unit of steel may be expressed as kg of steel or the m^2 of a steel construction. The system boundary defines what steps of the steel products life cycle are included in the study. For example “cradle to gate”, examines the extraction and manufacturing stages of a product's life, whilst “cradle to grave” would include these steps with the addition of transport, operation/maintenance over life and predictions for eventual disposal (Table 1).

Recycling rates of steel vary depending on product type and geographical location with Yellishetty et al. [12] reporting ranges between 50 and 85%. In UK, the high recycling rate for steel at the end-of-life

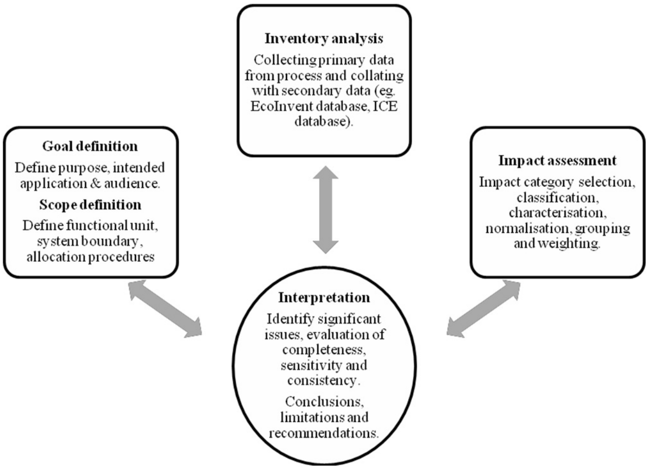

Fig. 3. Life cycle assessment stages ([11] altered).