RE-USE POTENTIAL OF STEEL IN BUILDING CONSTRUCTION

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ABSTRACT

This paper builds on the end-of-life results of the ECSC research project, entitled “LCA for steel construction” (see references), which was carried out by the steel industry in the Netherlands, the United Kingdom, and Sweden. This study confirmed the relatively minor environmental impact of downstream semi-manufactured products in phases of the building life cycle. It also shows that, at the end of life, 83% of steel construction products are recycled, 14% are re-used, and only 3% are landfilled. Therefore, steel can be recognized as material having almost a closed-loop material cycling. The re-use potential of steel products in buildings is clearly demonstrated through principles of modular construction, deconstruction, and reconstruction of steel frame buildings, as well as through widely applicable, moveable inner-wall systems in office buildings.

The Dutch Government is propagating re-use and deconstruction by sponsoring innovation in these areas through IFD projects (Industrial, Flexible & Demountable projects). Therefore, this paper builds upon the ECSC end-of-life results, and will present a few IFD innovations, illustrating the high re-use potential of steel structures achieved by optimisation of design parameters for disassembly.

KEY WORDS: Closed Loop; Life Cycle; Re-use Potential; Recycling Potential; Transformation

INTRODUCTION

Steel, as a construction material, provides many beneficial and essential services to society. To understand how, where, and why environmental impacts linked to steel in construction occur, and to quantify these impacts, the European Coal and Steel Commission (ECSC) funded a project, “LCA for Steel Construction,” of which the final report was published in July 2002. Steel producers and steel construction institutes in the Netherlands, Sweden, and the United Kingdom carried out the project. The project builds upon a previous LCI study, undertaken by the International Iron and Steel Institute (IISI), addressing steel production processes of semi-finished products.

On the basis of the end-of-life results (recycling, re-use, and landfill) of the different steel products from the ECSC project, examples will be given to explore the re-use potential to increase the re-use percentage of products, thereby decreasing environmental impacts.

RESULTS OF THE END-OF-LIFE ANALYSES

ECSC examined the environmental burdens (pollutive emissions and use of resources) of all the processes associated with the life cycle of selected steel construction products in the Netherlands, Sweden, and the United Kingdom. These processes have been systematized into five phases.
- Phase 1 Production of “intermediate” (semi-finished) steel products, e.g., coil, plate, sections, etc.

- Phase 2 Production of finished steel construction products. Transport from the steel mill or stockholder to the manufacturing facility is included within this phase.

- Phase 3 Construction phase (to include on and off-site erection, fixing, and assembly of selected products for specific applications. Transport to the construction site is included in this phase).

- Phase 4 In-use phase (to include product life span, functional maintenance, repair and replacement of products within a structure or building under different environmental exposure and aesthetic conditions).

- Phase 5 End-of-life phase (to include demolition and deconstruction activities, reuse and recycling rates, scrap processing activities, and final disposal). Transport from the deconstruction site to the scrap handling and/or waste treatment site are included in this phase.

The environmental impact per life cycle phase has been presented through four categories: primary energy consumption, carbon dioxide emission, non-combustible waste generation, and VOC emissions. (Figure 1).

![Figure 1: Major contributions within the life cycle of Heavy structural steel, excluding allocation](image)

For all products studied, the environmental impact of the steel production phase is dominant. Considering energy consumption, steel production typically accounts for 75% of the whole life cycle impact (ranging from 55 to 89%). The major negative environmental impact of steel production is created by CO2 emissions, and primarily reflects the means by which energy is generated in Western Europe (predominantly from fossil fuels).
The environmental impact is further summarized per the end-of-life scenario. From Table 1, on average, it can be stated that at the end of life, 83% of steel products are recycled, 14% of steel products are re-used, and 3% are landfilled. According to these figures, steel can already be recognized as material having almost a closed-loop material cycling. The closed loop of steel is explained by the fact that steel always has a positive value, and that the material properties of steel are preserved so that almost no down-cycling will take place. Increasing the percentage of re-use can decrease the environmental impact of steel. This saves production of semi-finished products, which typically accounts for 75% of the whole life impact of steel products [1].

<table>
<thead>
<tr>
<th>Product</th>
<th>Recycling (%)</th>
<th>Re-use (%)</th>
<th>Landfill (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Girder</td>
<td>88</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>Lintel</td>
<td>88</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Road barrier</td>
<td>65</td>
<td>34</td>
<td>1</td>
</tr>
<tr>
<td>Post coated inner wall components</td>
<td>59</td>
<td>7</td>
<td>34</td>
</tr>
<tr>
<td>Doorframes</td>
<td>90</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>Insulated inner wall box</td>
<td>87</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Metalstud wall</td>
<td>92</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>Services</td>
<td>87</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Light gauge steel (housing)</td>
<td>87</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Purlins and rails</td>
<td>87</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>Composite floor decking</td>
<td>81</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Composite sandwich cladding panels</td>
<td>53</td>
<td>37</td>
<td>10</td>
</tr>
<tr>
<td>Roof plate (coated)</td>
<td>81</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Profiled cladding and roofing panels</td>
<td>81</td>
<td>15</td>
<td>4</td>
</tr>
<tr>
<td>Heavy structural sections</td>
<td>87</td>
<td>11</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1 Average end-of-life scenario data

In order to increase the reuse potential of steel products, the deconstruction potential of product and building structures should be increased.

**DESIGN FOR DECONSTRUCTION**

The term *deconstruction* has been used to describe the generic process of “breaking up” buildings and structures at the end of their useful life. Deconstruction is further sub-divided into the two processes of demolition and dismantling.

*Demolition* is defined as the process whereby a building is broken up with little or no attempt to recover any of its constituent parts for re-use (the products of demolition may, however, be recycled). Demolition represents one directional material flow, from extraction to demolition. Agenda 21 from the 1992 UNESCO conference in Rio stated that cyclic processes must replace linear ones to create sustainable development.

If we recognize the potential for a closed cycle of life, it is possible to divert the flow of materials from disposal and save the energy in them by introducing the disassembly phase (Figure 2).
Dismantling is defined as the process by which a building is selectively taken apart with the intention of reusing some (or all) of its constituent parts. Recycling is defined as the end-of-life recovery and reprocessing (by re-melting) of steel construction products to form new steel products. Re-use is defined as the end-of-life recovery and re-use of steel construction products (as a product filling the same function) with or without some reprocessing.

By designing product and building structures for disassembly, not only can environmental efficiency of steel products be improved, but steel can also contribute to reduce the total environmental impact of buildings. Besides re-use potential of steel products, re-use potential of other materials and systems can be improved by the use of steel. In that respect, steel can be seen as an important element of sustainable construction. Key aspects of design for deconstruction are independence and exchangeability of building parts within one building configuration. Independence of one component within a particular configuration can be provided by systematic clustering and ordering of building parts, so that one open hierarchical structure is created. Such open hierarchy can be defined by specification of an intermediary (frame) on different levels of a specific configuration (Figure 3).

Figure 2: Circular life cycle model of materials and products achieved by design for deconstruction

Figure 3: From closed hierarchy, left, to open hierarchical structure, right [3]
Elements that are ordered in the form of an open hierarchy are only connected to the frame (intermediary), and have no relationship with each other. In such a way, dependence of parts is minimized by a reduction of relationships between the parts.

Besides independence, exchangeability of building parts is another criteria of design for deconstruction. Exchangeability of one component can be provided by design of an open product edge that will allow for parallel assembly sequences, as well as for the use of external accessory connections that provide independence between two connected elements.

Keeping in mind the level of independence and exchangeability of building parts, all building structures could be specified in a range from fixed to deconstructable. The main characteristic of fixed structures is maximum integration and dependence between building components caused by: (i) closed hierarchy of assembly which is not related to the component service life or expected time until obsolescence, (ii) application of sequential assembly sequences, (iii) design of integral joint types (components are shaped in such a way that bringing them together forms a joint), and (iv) use of chemical connections. On the other hand, the main characteristics of deconstructable structures are: (i) use of accessory joint types (they require an additional third part to form the joint between two components), (ii) application of parallel instead of sequential assembly/disassembly, (iii) use of mechanical connections in place of chemical connections, and (iv) open hierarchy.

Thus, two factors will determine the reuse potential of steel products within building structures. First, the relational pattern between components that will result in certain type of hierarchy. Accordingly, hierarchy could be defined from stuck assembly, layered assembly, to star assembly. Second, the type of connections will result in different jointing methods. Accordingly, connections could be defined from chemical to click connections. (Figure 4)

![Figure 4: Reuse potential as a function of type of assembly and type of connections.](image)
Increase of Re-use Potential of Steel by Design for Disassembly

Re-use of components is at the top of the environmentally-beneficial hierarchy of end-of-life scenarios. At the moment, 83% of steel products are recycled, 14% of steel products are re-used, and 3% of steel products are landfilled. One of the main reasons for the low re-use percentage is the design of structural configuration and its connections. Figure 5 shows re-use potential of a few products, determined by type of assembly and type of connections.

![Diagram showing re-use potential in relation to type of connections](image)

**Figure 5:** Re-use potential in relation to type of connections

**Stuck assembly**, for example, stands for not-accessible connections. In such a situation, one component can be replaced only by demolition or complex operation, which causes damage of the component.

![Stuck assembly diagram](image)

**Figure 6 Left, conventional steel doorframe; Right, alternative for disassembly and re-use of steel frame**

A standard steel doorframe in the Netherlands is one example where such a connection type is applied (Figure 6, left). An alternative to the conventional doorframe is presented in Figure
6, right, where assembly sequences and connections between the door-frame and the wall can be seen as a star assembly, since all components are connected via one intermediary. As such, components are independent from each other.

**Direct connections with additional devices** is another type of connection which causes low disassembly potential of steel products, since steel components are being damaged by nails or screws. As such, the quality of the steel element is weakened and, therefore, is not suitable for re-use. Such detailing is typical for metal stud walls and steel frames. This detailing can be improved by the design of special geometry of connection, which does not need additional connection devices (metal click wall), or by design of an intermediary between two products (Figure 7).

A metal stud wall has a re-use percentage of 7%. This percentage can be increased by the design of a connection that will provide a direct relationship between the stud and the wall panel, by the edge geometry or which will use an intermediary between the stud and the wall panel. This is the case with the metal click wall (Figure 7, below).

*Figure 7 Above, metal stud wall; below, metal click*
These types of system walls are already widely used in office buildings, giving great adaptability to the floor plan in the changing requirements of the owner.

**Increase of re-use potential of other materials by use of steel products**

Besides improvement of re-use potential of steel products (through design for disassembly), steel can play an important role in improving re-use potential of other materials, such as concrete, brick, wood, etc. The ideal type of connection for deconstruction is an indirect connection, which has an intermediary between two components. Steel is a material that can be easily used as an intermediary between different materials (See Figure 8). Steel can improve the re-use potential of other materials as well.

![Figure 8: Steel as an intermediary between concrete floor components, brick components, and wooden structural elements.](image)

The third role that steel can have in sustainable construction is in solving the problem of integration of different functions, such as installations, partitioning walls, and finishing. The current integration of these functions frequently causes demolition, especially in housing. Recently, a system has been developed in the Netherlands where the above-mentioned integration is solved by the introduction of the steel duct, taking care of separation of different types of components (Figure 9).

Diagrams in Figure 9, left, represent the relationships between installation, wall, and finishing components in a traditional situation. Conventionally, electricity components are inserted into the wall service manually during the construction stage. After installing the components, wall service is flattened and plastered, making the network of cables invisible. The diagram in Figure 9, left, presents the relational dependence between components created by such an assembly strategy. Replacement of one component will influence all other components that are part of the partitioning wall. Figure 9, right, illustrates an alternative to the conventional approach. Independence between installation components and other parts of the partitioning wall structure is provided by element A, which stands for steel duct. This method provides a visible zone for installation components through the base of the wall and the doorframe, which is always accessible, and whose components are demountable (Figure 9, right).
**CONCLUSIONS**

The preliminary conclusions from an assessment of the relative impacts resulting from each life cycle phases include the following:

1. The ECSC study has confirmed the high recycling rates of steel construction products within Western Europe. On average, 83% of all steel construction products are recycled at the end of life, 14% are re-used, with only 3% landfilled. Although these results are encouraging, greater environmental benefits could be gained by increasing the proportion of products that are re-used.

2. Re-use percentage of steel products can be increased by a more conscious detailing process which will take into consideration assembly/disassembly planning, geometry of product edges, hierarchy of products according to life cycle coordination, and connection methods.
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