Embodied Energy and Carbon Reduction Savings and Benefits of Reusing Structural Steel in Office Buildings

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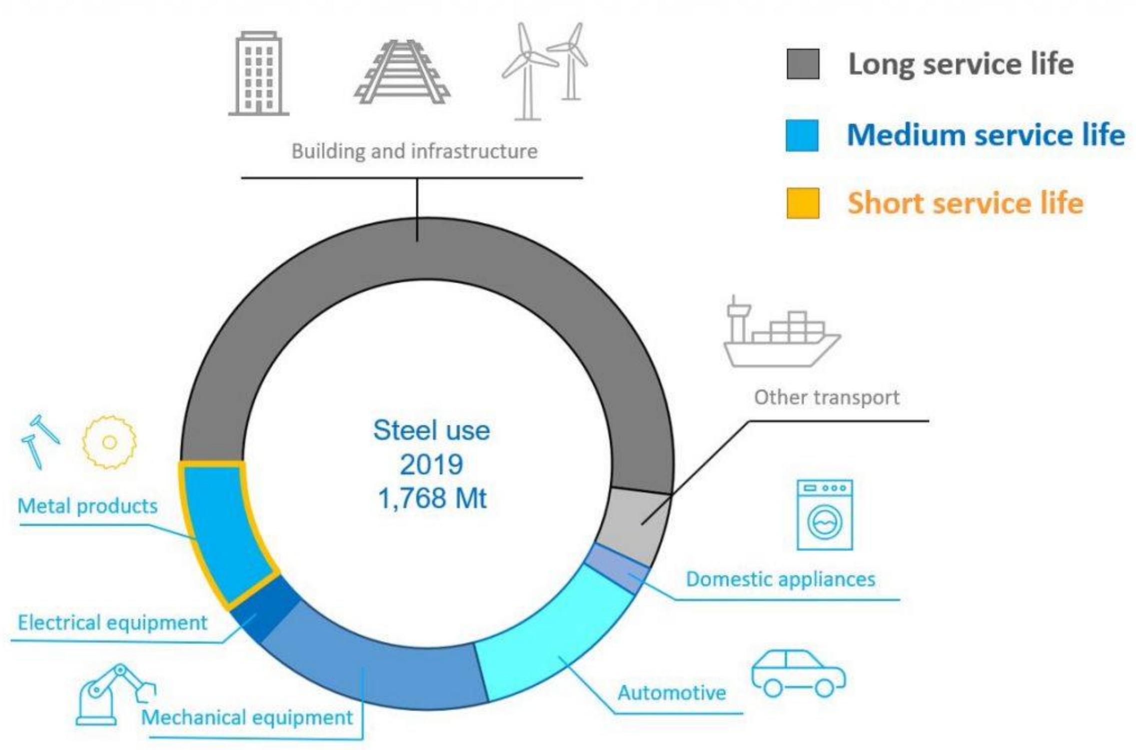
Abstract

This study provides estimates of embodied energy and carbon reductions when structural sections of buildings are reused in a typical office building. The structural material quantities are estimated for a typical steel frame structure in a low-rise office building. The embodied carbon of this conventional design is then compared with values collected from a series of similar existing steel buildings (LCI database) as benchmark. Various scenarios regarding the impact of selective deconstruction, transportation, and cross-section oversizing are modelled and analyzed. The study then calculates carbon savings over the life cycle of the building using LCA. Results show that materials reuse/recycle remains beneficial for long transport and high oversizing components. The findings call for more refined metrics for quantifying selective deconstruction and carbon reduction.

Intro + Research Need



Steel use in 2019 (Source: World Steel Association)

Steel is one of the most utilized metals in the world, making up everything from the tallest skyscrapers, cars, to the everyday kitchen utensils. Steel has driven technological growth and advancement through the Industrial Age and continues to fuel innovation today, with over 1.95 billion tons produced in 2021.

Around 50 % of material use in the U.S. is related to the built environment, which generally constitutes the most resource intensive sector in many developed countries. In addition, more than 30 % of the waste generation originates from the construction sector.

Because of their high material mass and energy intensive production, Structural systems are currently responsible for the biggest portion of embodied energy, carbon emissions, and waste production in buildings. Therefore, it's evident that the design and construction of buildings could be improved by making a more efficient use of construction materials.

Impact of Steel Recycling + Reuse

Environmental Impact

Steel has an extremely high turnover rate of recycled products in both the steel itself and byproducts used in its production process (e.g. slag). Nearly 70% of steel is recycled in the U.S. each year. Steel recycling efforts save 75% of the overall embodied energy used in production from raw materials. This has huge benefits in saving natural resources and prevent excess greenhouse gas emissions.

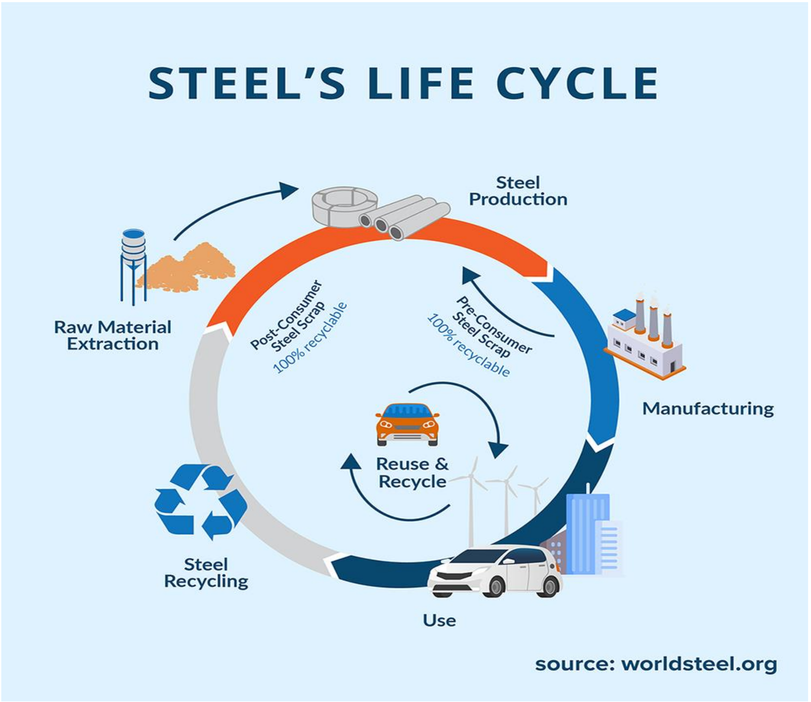
Economic Impact

Manufacturers drastically reduce the price of production costs. The recycling process in the steel industry also drives job creation producing over 531,000 jobs in scrap recycling. This resulting in over $110 billion in economic activity (according to the American Iron and Steel Institute).

How to measure the benefits of recycling?

Life Cycle Assessment (LCA) is a quantitative analytical tool that tracks energy and materials input and environmental impacts output of products and buildings (regulated by ISO 14040)

In LCA, the benefit of recycling is considered as an 'environmental credit' or benefit. Recycling avoids the higher burdens of primary material production, but this environmental saving lies in between two adjoining product systems, i.e. the upstream system (demolition of the building) which produced the scrap materials; and the downstream system (steel reproduction) which will consume the recycled material. How this 'benefit' is allocated between the two input/output systems is an important and critical issue in LCA.



Steel Reuse

Steel can be completely reused instead of going through the costly procedure of extracting it from raw ore. Reuse has little to no reprocessing. Reuse offers even greater environmental advantage than recycling since there are very few environmental impacts associated with reprocessing. For example, reusing a steel beam in its existing form is better than remelting it and rolling a new steel beam, i.e. the energy used to remelt and reroll the beam is saved.

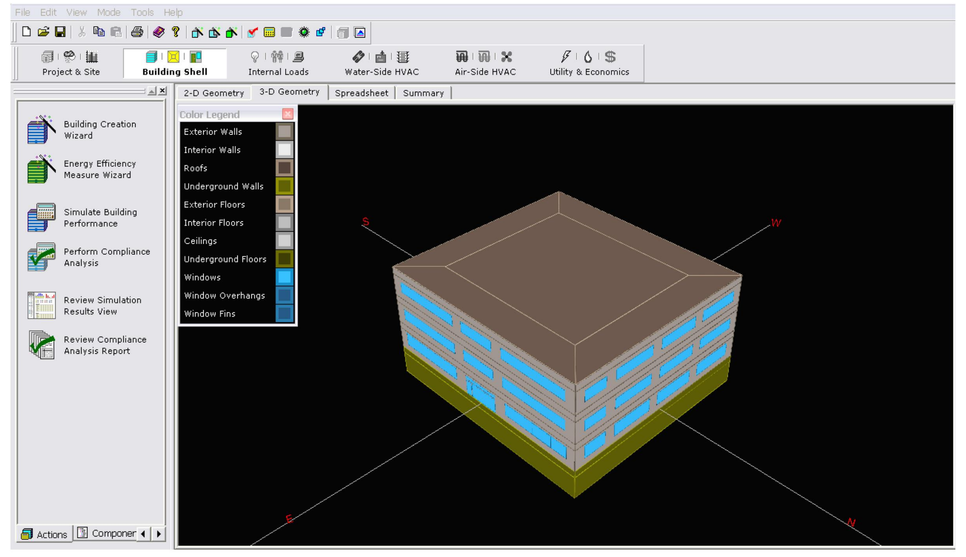
Designers are encouraged to think about not only how their buildings can be easily constructed but also how they can be efficiently deconstructed with a view to preserving the integrity of the reclaimed products for subsequent reuse. This is called Design for Deconstruction or Disassembly DfD

Case Study Building

The case building has 29,000 sq ft (2690 m2) of gross floor area, and a volume of 423,000 cu ft (11978 m3). The building consists of 3 floors (9700 sq ft each, 14.6 ft average height) plus a partial basement. The structural frame is broad flange (W sections) columns and W sections beams. Floors are metal decking with 2" concrete topping.

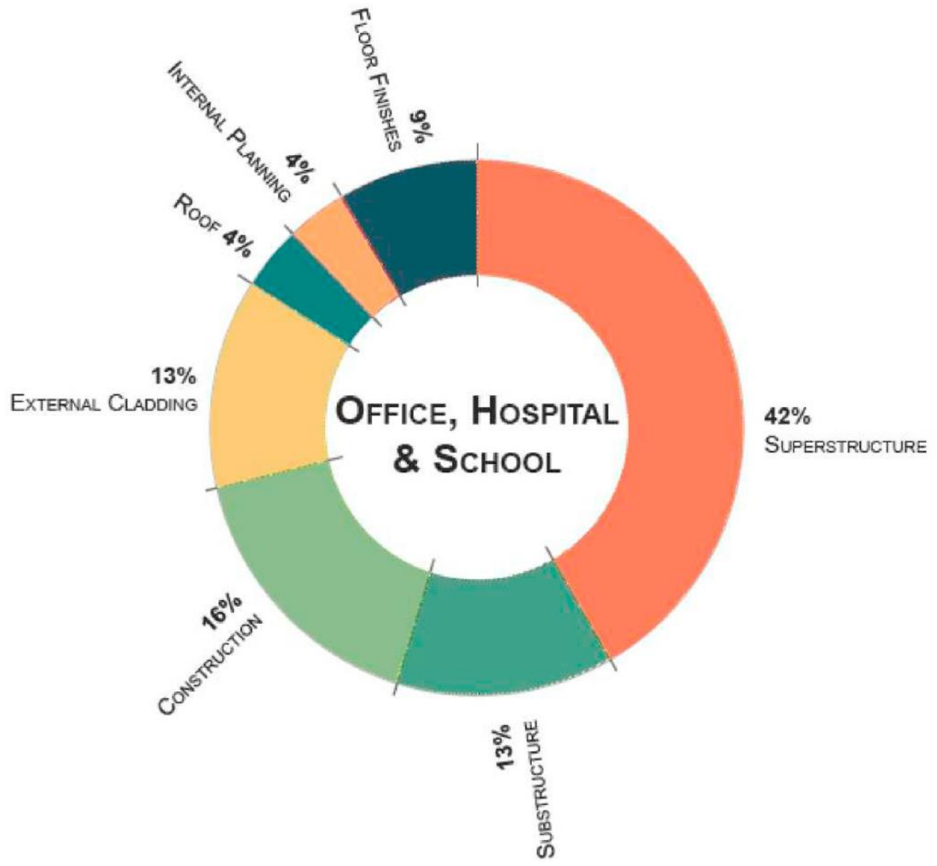
LCA modeling is conducted using ATHENA 4.3 Impact Estimator. The program filters the LCI results through a set of characterization measures based on the *mid-point impact assessment* methodology developed by the U.S. Environmental Protection Agency (U.S. EPA); the *Tool for the Reduction and Assessment of Chemical and other environmental Impacts* (TRACI) version 2.2.

modeling is only applied to the steel structural skeleton. The foundation, core, and slabs are kept at a constant amount of materials. The embodied impact of the building is computed and compared to data collected industry wide, deQo (2018).



Results and Conclusion

- Structural systems contribute the largest share of embodied energy (42%)
- Structural steel also account for 50% of the embodied carbon of the case study building



Average breakdown of embodied energy for building elements. Source: Author, Qarout (2017), and Kaethner and Burridge (2012).

Results and Conclusion

- Greenhouse gas GHG emissions reduction through reuse relative to the conventional construction can be up to 30 % when considering the impacts for selective deconstruction, and a transportation distance of 250 miles or less.
- Results show embodied carbon savings of 30 % can be achieved by designing with reused structural elements (steel beams and columns) in mind.
- The embodied carbon savings would be even higher if a prefabricated concrete slabs could be equally reused along with steel sections.
- Design for Disassembly and Reuse significantly reduce embodied energy and embodied carbon.
- It is suggested to design a structural grid to be flexible enough to accommodate different functions throughout its life cycle(s) in order to reduce buildings obsolescence related to use changes and reuse thereafter.
- Design for Reuse implies the existence of a stock of construction elements ready for reuse.
- To that end, it is proposed to design buildings for reuse in two ways: "with a stock" or "from a stock".
- A "design from a stock" leads to 100% of building elements reused, using only elements from the stock.
- A "design with a stock" seeks to integrate as many reused building elements available in the stock as possible, completed with others and new elements.
- As with all LCA studies, results of this study cannot be generalized to all types of buildings or with high rise. Specific LCA studies should be performed for other structural materials (e.g. concrete, wood) and other building types.

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