

CLEAR - an LCA model for construction

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Abstract Tata Steel Research and Development have developed a comprehensive, fully transparent, cradle-to-grave Life Cycle Assessment model which allows any multi-material building to be assessed. The model 'Construction Life-Cycle Environmental Assessment Resource' (CLEAR) allows the user to define key parameters in terms of building materials, lifetime, maintenance requirements and end-of-life scenarios and calculate the associated environmental impacts. It has also been subject to full critical review as required by the ISO14040 standard. CLEAR has been used to generate embodied carbon figures for 5 major building types with the aim to understand the implications for steel construction in the design of low and 'zero' carbon buildings. Going forward CLEAR will be further developed to allow non LCA experts within Tata Steel Europe to utilise the model through a simplified front end when dealing with customers.

1 Introduction

The concept of sustainable development has firmly entered into the thinking of many policy-makers and is now high on the agenda of many governments. The principal idea, of a balanced approach to economic activity, social progress and environmental responsibility, is becoming more familiar. In the environmental arena, the UK Climate Change Act (2008) stipulates that anthropogenic greenhouse gas emissions should be reduced by at least 80% from 1990 levels by 2050. Each sector of industry, for example transport or construction, can expect to be measured against these emissions in the near future, and has to make its own contribution to this extremely challenging target. As buildings contribute perhaps as much as 50% of carbon dioxide emissions, through those embodied in materials and released in the use phase, there is a particular emphasis in the construction sector. The UK Government's drive for zero carbon buildings by 2019 has meant that there is a growing need in this sector to understand the environmental impacts

of a building's full life cycle, especially with regard to carbon footprint and the impact of the materials contained in them.

There exists, therefore, a clear requirement for the development of tools and methods to evaluate the environmental impacts of buildings over their complete lifetime, taking into account the manufacture of materials, construction, use and end-of-life phases. This process has in fact been under way for some time and tools have emerged for assessing the sustainability and environmental performance of buildings, from organisations including the United States Green Building Council (Leadership in Energy and Environmental Design (LEED) Green Building Rating System [1]) and in the UK, the Building Research Establishment (BRE) [2].

Using Tata Steel's own Life Cycle Assessment expertise, we have developed an LCA tool for construction, in order to be able to improve the understanding of how building design and materials selection affects environmental performance through all stages of a building's life. The tool, known as Construction Life-Cycle Environmental Assessment Resource (CLEAR), has been developed in full compliance with the ISO14040 set of standards governing good LCA practice and has passed critical review against those standards.

CLEAR provides powerful support to decision-makers in the construction sector in understanding how choices made about different design options can affect environmental impacts over the full life-cycle of buildings. Working with a consortium of major construction companies, we have used CLEAR to inform guidance on how to achieve the zero carbon building target for five major building types.

2 Goal and Scope

Tata Steel's strategy is to engage fully with environmental and sustainability considerations across all areas of its business, including in the construction sector. To this end, the overall aims of this tool were to:

- be able to respond to external debates and studies on the environmental merits of solutions for building projects;
- support pro-active communications on sustainability in the construction sector;

- gain a general understanding of how building design and materials selection affects environmental performance;
- provide support for customers enquiries on construction sustainability issues;
- provide a basis for generating Environmental Product Declarations (EPDs) and other product support literature.

The principal means by which these aims were to be achieved was through the development of a generic LCA tool that would allow a user to model a building from 'cradle to grave'.

Whilst some existing tools for the environmental assessment of buildings are based on relatively basic concepts, for example considering only factors such as waste and recycled content (e.g. WRAP Net Waste Tool [3]), a more comprehensive approach is to use a full Life Cycle Assessment (LCA) technique. Guidance for good practice in life cycle assessment is provided by a series of international standards [4][5], which include, for example, a hierarchy of preferred methods for dealing with allocation issues (the treatment of shared environmental burdens).

A particular feature of the CLEAR tool is the ability to readily compare the environmental impacts of different construction (including material) options for the same functional building. In this way, decision support can be provided to key professionals early in the design stages of a construction project. Options for extending the functional lifetime of a building can also be examined and environmentally sound end-of-life scenarios developed, using LCA methodology, to generate practical design guidance. The tool can also be used to retrospectively assess the environmental impacts of a particular building (providing accurate data pertaining to the building is available). The tool can be used for life cycle inventory analysis and can also assess a range of environmental impact methodologies, not just global warming potential.

In theory the model can be used to assess any type of building such as, schools, offices, warehouses, residential and retail buildings, as long as sufficient detail is available on their material makeup. Different construction techniques can also be assessed, such as off-site manufacture, where data is available on the 'off-site' processes that would normally be carried out 'on-site' during the construction phase.

3 Allocation Principles

Allocation principles are the guidelines by which complicating factors such as by-products, co-products and recycling are handled within an LCA study. There are various techniques that have previously been used for allocation, most of which are controversial since their use may be adopted in order to artificially enhance the environmental performance of the product system rather than to model reality.

The World Steel Association (worldsteel) provides authoritative, industry, LCI data for a range of steel products that can be used in construction products. Various common allocation principles were comprehensively reviewed as part of the worldsteel LCI data collection project. The project report concluded that for the steelmaking process, the so-called 'system expansion' method provided the most consistent solution to avoiding the problems associated with the alternative principles (physical partitioning, economic partitioning, and energy allocation). In order to remain consistent with worldsteel LCI data, the system expansion procedure was adopted in the CLEAR tool, however it is recognised that this approach may not always be desirable where users need to assess the environmental impacts of using a co-product, such as blast furnace slag, as a construction product within the same building system. In this case a credible allocation procedure that shares the manufacturing burdens (preferably based on physical relationships) may be required, and this could form part of a future enhancement of the CLEAR tool.

The system expansion technique follows the guidelines for allocation procedures laid out in ISO 14044 and is described as one of the preferred methods since it "avoids" allocation. The principle is based on the assumption that the production of co-products and by-products replaces their production elsewhere, thereby giving credits for that production by subtracting the associated flows from the LCI. A similar approach has also been used for materials that are recycled during the production phase and at the end-of-life of the product system. The following sections discuss the recycling principles used in more detail.

3.1 Recycling methodologies - open and closed loop

There are a range of methodologies that can be used to assess the benefit of reuse and recycling. The basic premise of many of the methods is to evaluate what is

being 'saved' or what impacts are 'avoided' as a result of recycling. For example, scrap steel can be recycled to avoid making steel from basic ores, thereby avoiding the impacts associated with the primary route to steel manufacture.

With the recycling of most materials there is a quantifiable difference between the quality of the secondary product compared with that of the virgin, primary product. The result of this is that the function of the secondary product may not be the same as the primary and, hence, it becomes incorrect to assume simple displacement of primary material. For example, when clear glass is recycled, it is not possible to obtain the required clarity for the secondary glass, and it must be made into coloured glass. Therefore, it is not correct to displace the requirement for virgin clear glass with recycled clear glass. Where one product system is recycled to form another product system with different inherent properties, this is known as open loop recycling. This can be dealt with in LCA modelling in several ways, depending on how the difference in quality between the two products is quantified. A common approach is to use economic partitioning, where virgin material displacement is assumed but a factor is used to reduce the credit given. This factor is the ratio of the monetary value of the secondary and primary products. However this approach suffers in a similar way to economic value allocation, in that there is no inherent link between monetary value and environmental impact.

Other materials are capable of being recycled without loss of quality, thus keeping the same functional use. This is known as closed loop recycling. Perhaps the best example of closed loop recycling is that of steel. When steel is remelted in either the EAF or BF/BOS process it is also refined in order to produce the desired grade, which may be of higher quality than the original scrap. Therefore, there is no inherent loss in quality associated with the process, and partitioning (economic or otherwise) is not necessary (although the burden of the recycling processes must of course be included).

The CLEAR model also has the option of modelling open loop material recycling in terms of avoided virgin material production, however, the recycled materials do not directly displace the full burdens of virgin material production and so an efficiency factor (0-100%) has to be employed in order to account for the loss in properties. The recycling efficiency factor offers flexibility in modelling end-of-life, and can be determined by differences in the physical properties or other allocation methods. The benefits of reuse can be evaluated in a similar way, e.g. by considering the number of subsequent uses.

4 Data Input

CLEAR was developed to offer the user a high degree of flexibility in defining the building under study and was designed to allow a comprehensive range of technologies and materials to be considered in the analysis of the manufacturing and construction, use and end-of-life phases of the subject building. It was modelled on a GaBi software platform and developed to allow the user to define key parameters in terms of building material (type and quantity), transport distances, lifetime (including use phase energy and maintenance requirements) and fate of materials at end of building life (including rates of recycling, re-use and disposal). In Table 1, a section of the data entry table is shown, for several options for a functionally equivalent office building. Material quantities and other key parameters for the building sub-units (e.g. foundations, structure, floor, facade) can be entered for each of the different building options under study (in the example shown, a Base case and Options 1 & 2).

To facilitate the use of the CLEAR tool in conjunction with customers and end clients, a user friendly front end to the model has been developed using the 'i-report' functionality of the GaBi software. This enables easier data entry and automatic visualisation of results.

Table 1: Selected parts of the CLEAR data input table for functionally equivalent construction options for a typical office building.

GaBi Object	Parameter	Base Case	Option 1	Option 2	Comments
Foundations	C32	5883000	5883000	4429000	kg concrete
Foundations	steel-pile	0	0	486500	kg
Services	clay-pipe	27000	27000	27000	kg
Structure	column	311000	16550	338000	kg
Floor	concrete	248000	248000	248000	kg
Floor	Distance	80	80	80	km
Floor	Rebar	2020	2020	2020	kg
Facade	Conc_block	44500	44500	44500	kg
Roof	Alum_Sheet	21000	21000	21100	kg
Roof	Mineral wool	4000	4000	3600	kg
Recycling Foundations	Rebar	92	92	92	%
Disposal Foundations	Rebar	8	8	8	%

5 Building assessment case studies

The CLEAR model has been used in a number of case studies to evaluate the environmental performance of buildings, and advise customers where the most significant environmental impacts occur. One of the most recent studies has been the Target Zero project (<http://www.targetzero.info/>), which is a £1 million collaborative research project to provide guidance on the design and construction of sustainable, low and zero carbon buildings in the UK. This is in direct response to the challenging targets being set by the UK government for new non-domestic buildings to be zero or low carbon by 2019. Whilst the focus of the project was to reduce the operational CO₂ emissions of the buildings with minimal cost, the influence of building design on embodied carbon was studied using the CLEAR model. The study found that approximately 80% of the CO₂ emissions from the assessed base case buildings came from the operational phase and only 20% from embodied emissions over the lifecycle. However, it was recognised that as operational emissions are reduced, embodied carbon emissions were becoming increasingly significant, and so design guidance on embodied emissions was also needed. Although it is advisable to study a range of environmental impacts, the goal and scope of this particular study was restricted to the greenhouse gas emissions from the building construction, use and end-of-life. This was because the study intended to address the government targets which largely relate to greenhouse gas emissions. The CLEAR model was used to assess the following building types using a cradle-to-grave approach: school, warehouse, supermarket, office, and mixed use.

The following results are taken from the school building where the existing base case was studied alongside alternative and optimised building designs. Figures 1 and 2 show the mass of materials, by building element (including excavated materials) and by material type respectively, that made up the school building of 9,637 m² gross internal area. Options 1 and 2 represent different design options resulting in different material usage to deliver the same building of equivalent function. These material quantities were then used to calculate the lifecycle CO₂ equivalent emissions. Use phase CO₂ emissions were calculated separately using established building simulation models to satisfy building regulations. Figure 1 shows that most of the materials are used to build the foundations and ground floor, which is reflected in the large quantity of aggregate and concrete used in all three designs (Figure 2).

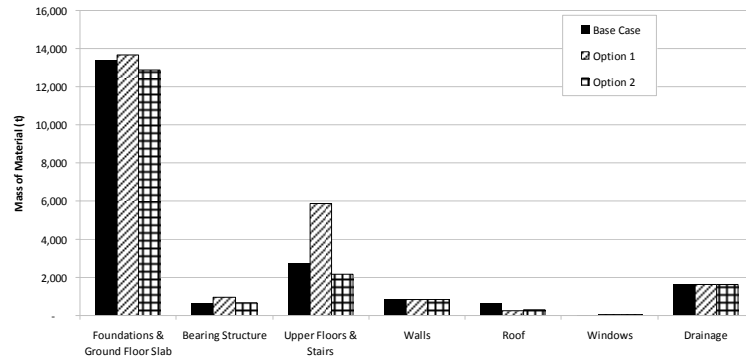


Figure 1: Mass of materials by building element for different design options

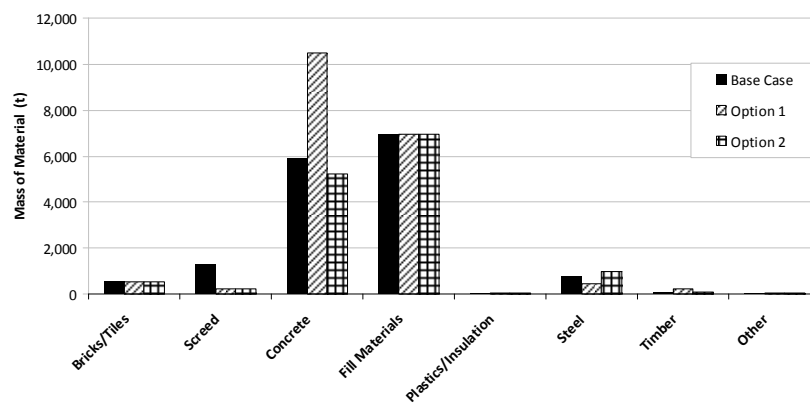


Figure 2: Mass of materials by material type for different design options

Figure 3 shows how the CLEAR tool can be used to analyse the embodied carbon contribution of different building elements. In this case design Option 1 uses significantly more concrete and screed in the bearing structure and floors, as well as requiring heavier foundations, resulting in overall higher CO₂ emissions.

The importance of including the whole lifecycle in any building design comparison is illustrated in Figure 4, which shows the striking contribution of the end-of-life phase of the building, where materials can be recycled resulting in significant environmental benefits. Although option 2 had slightly higher emissions on a cradle-to-site basis (construction), the increased recyclability of materials at end-of-life resulted in overall lower lifecycle emissions than the two

alternative designs. Many carbon footprint studies are limited to cradle-to-gate emissions, whereas the CLEAR tool allows a holistic lifecycle approach to be taken and assess the relative importance of end-of-life scenarios.

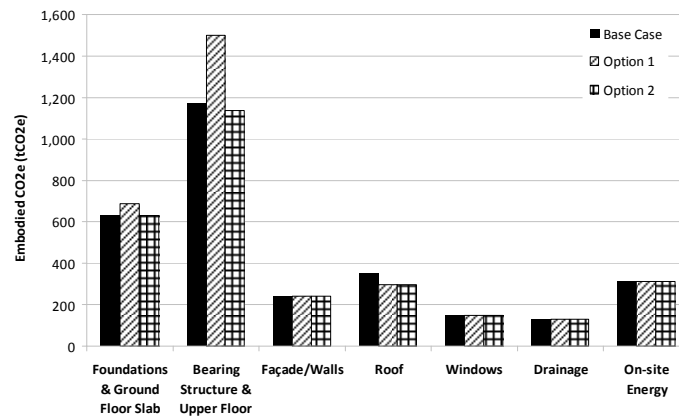


Figure 3: Embodied lifecycle carbon emissions by building element for different design options

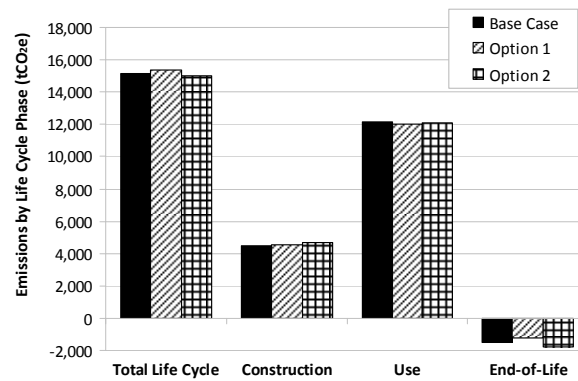


Figure 4: Lifecycle carbon emissions for different design options (use phase emissions over 25 years - calculation based on meeting 2006 UK building regulations with updated 2010 grid electricity and gas emission factors)

6 Conclusions

The CLEAR tool has been developed in accordance to ISO standards 14040 & 14044 and allows building designs to be assessed for a range of environmental impacts. An important feature of the tool is the consideration of the entire lifecycle of buildings, and in particular end-of-life aspects of materials, which are too often ignored in building assessments. The flexibility in the tool allows the integration of open loop and closed loop recycling, depending on the material and end-of-life scenario. Building case studies have revealed that foundations, floors and bearing structure are the most significant contributors to the embodied carbon emissions, which are also elements of the building that are inter-related in terms of design. Whilst use phase emissions still dominate many buildings, it is recognised that embodied impacts will become more significant as energy efficiency and low carbon energy generation becomes widely adopted in new building design. CLEAR can therefore be a powerful tool, when it is used to inform building design, to help achieve a more environmentally sustainable built environment.

7 References

- [1] US Green Building Council
<http://www.usgbc.org/DisplayPage.aspx?CategoryID=19>, (Accessed 08.04.2011).
- [2] Building Research Establishment <http://www.bre.co.uk/>, (Accessed 08.04.2011).
- [3] Waste & Resources Action Programme
<http://www.wrap.org.uk/construction/>, (Accessed 08.04.2011).
- [4] ISO 14040 (2006): Environmental Management - Life Cycle Assessment - Principles and Framework.
- [5] ISO 14044 (2006): Environmental Management - Life Cycle Assessment - Requirements and Guidelines.