Paper

Environmental impacts of structural materials –

Finding a rational approach to default values for software

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Keywords: Materials, Environment, Software, Databases Embodied energy, Carbon dioxide, Emissions, Concrete, Steel

Received: 11/10: **Modified**: 02/11-04/11; **Accepted**: 05/11

Synopsis

Structural engineers need to understand the environmental impact of their designs. This paper describes a project undertaken to review the confusing array of data and provide an approach which links data, tools and real-life material specification. The aim was to find a method of presenting environmental impacts alongside other design parameters, such as strength, so that these issues can be considered as a normal part of the design process. Environmental impact factors have been reviewed from international sources for a set of structural materials. A methodology for presenting the range of values for unreinforced concrete was developed using practice guidelines. Default data was developed to familiarise engineers with the relative impacts of materials and lead them to mitigation strategies through specification and further exploration of the issues. This data is for inclusion in structural software programs Oasys AdSec and GSA so that embodied impacts are reported alongside other structural design parameters. Because the software offers design options for different codes of practice in different countries, impact values for different countries were also needed.

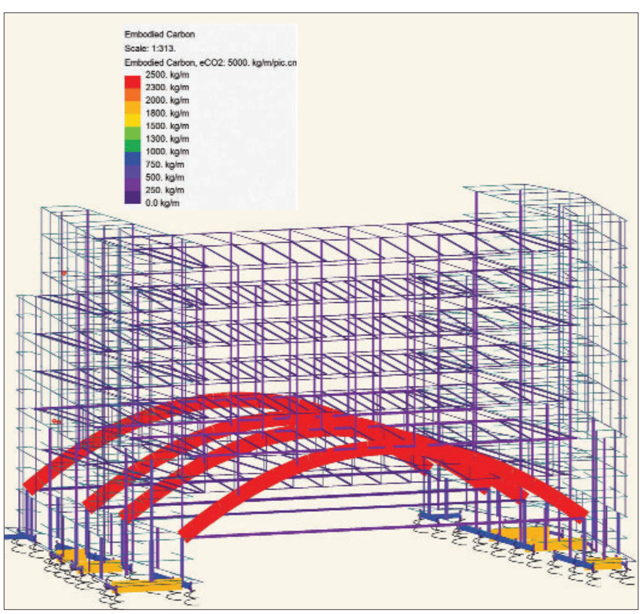
Introduction

It is becoming increasingly important that structural engineers are equipped to contribute to the investigation of environmental impact in their work. However, the picture is confusing. A review of data across the world showed gaps in information, data which was too general to be useful to the structural engineer or data inaccessible due to commercial interests (such as the BRE data in the UK). Taking concrete as an example, there are many sources of environmental impact data for concretes and calculators that can only be used after the contractor provides the mix design. But what is lacking is environmental impacts for the full range of concretes as defined by concrete codes, and a means for engineers to consider alternative specifications. The project described in this paper endeavoured to familiarise engineers with environmental data produced alongside traditional structural analysis output, based only on the information the structural engineer has during design. The solution chosen was to incorporate default data for sustainability measures into structural software.

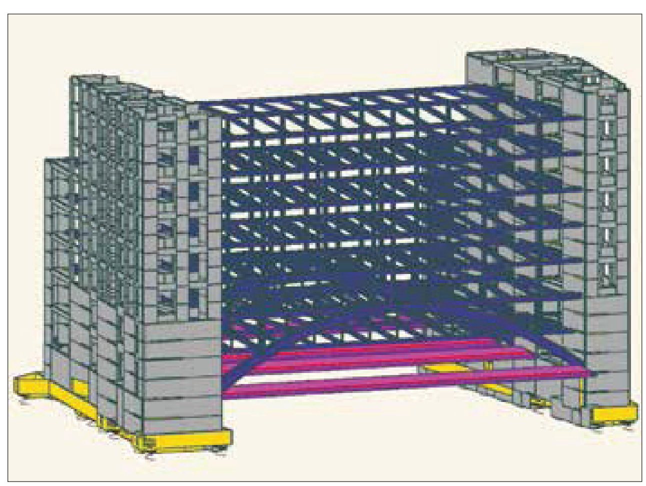
Through this project, the software package developed by Arup for structural frame analysis (Oasys GSA) now reports the environmental impact of a particular structural model using three commonly used measures.

– embodied energy (eE);
– embodied CO_2 (eCO_2);
– recycled content (%RC).

The sectional analysis programme Oasys AdSec will report more detail on the same measures in future releases. The software programs will simply combine environmental impact measures with the material quantities in the model. The work described in this paper aimed to provide default values of the environmental impact for the structural materials used in the software, namely concrete,



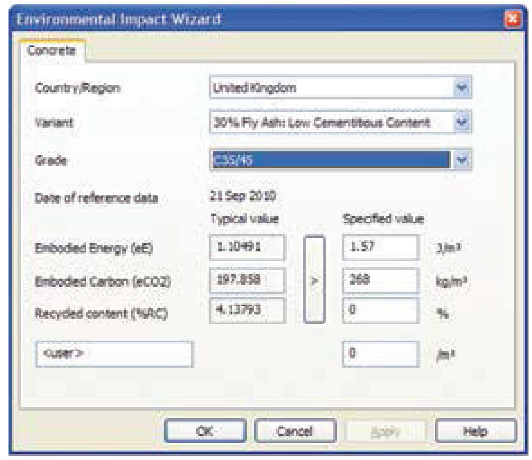
1 Graphical display of environmental impacts on structural model. Plot 1: Contour of embodied impact;



Plot 2: Contour of element size and material

Country	Database	Description
Australia	RMIT[4]	Sustainable built environment programme within the Centre for Design at the University of Melbourne, Australia.
Canada	Athena Sustainable Materials Institute[5,6]	Third party research organisation based in Canada, creators of Athena environmental impact estimation tools suite for buildings. Athena has been used for both Canadian and American materials. References 4 & 5 are relevant to Canadian material supply chains.
Germany	GaBi 4 Database[7]	PE International, private sustainability consultants, developers of GaBi LCA software.
New Zealand	Centre for Building Performance[8]	Research group at Victoria University of Wellington, New Zealand.
United Kingdom	University of Bath Inventory of Carbon and Energy (ICE)[1]	Largest compilation to date of data from world-wide literature search, evaluated and adjusted for the United Kingdom. Also used for 'Europe' values when a country is not specified.
United States	Athena Sustainable Materials Institute Data Reports[6,9]	See above. Athena has been used for both Canadian and American materials. References 5 & 9 are relevant to US material supply chains.

Table 1 International databases used to establish default parameters



2 Example of default data in software

structural steel sections, steel reinforcement, structural timber and aluminium.

A fourth 'user defined' parameter was included to allow the software user to analyse other environmental measures because we recognise that the three measures chosen do not represent a full scope of impacts. The fourth parameter will allow designers to use systems, such as BRE's 'ecopoints', which portray a combined approach to a number of different impacts, based on life-cycle assessment results. Unfortunately it was not possible to populate this field with default data due to difficulty in obtaining the necessary information from third parties. It is hoped that industry will recognise the benefits of a more proactive approach and share this information more widely.

Because the software is in use in many regions of the world, international data was needed to match the many design codes offered. The project needed to look beyond sources of data and established practice in the UK such as the Inventory of Carbon and Energy from Bath University and refer to primary Life Cycle Inventory data sources where possible,

This project produced one small part of the tools required to consider environmental impacts of structure. The impact represented by the structural model is only part of the consideration of sustainable design. The project has proved very valuable nevertheless. It has allowed a focus on defining metrics for the main structural materials and the provision of default data in simple everyday tools encourages engagement with the issues in the round. By producing embodied impact results by default alongside other design parameters for a whole structural model the project sought to extend the work of Kriejger and Ashby who have published graphical representations of impacts compared to structural properties, such as CO_2 emissions per unit strength or stiffness (Fig 1).

Engineers will also need to view the results in the context of the whole life impacts of the structures they design; this assessment will include non-structural embodied impacts, operational impacts and end of life impacts. The relative importance of these will be very different for different types of structures such as bridges and buildings and for different environmental impacts. As an example, for buildings the authors have found that structure can represent 40-50% of the total embodied CO_2 and that embodied impacts can represent 20-50% of the total life-cycle CO_2 emissions.

Data sources

The default environmental data included in the software are based on a literature search covering databases across the world.

Most of the databases used were publicly available. Data was only found for a few of the regions required, as shown in Table 1. German and European data was sourced through the commercial tool 'GaBi' and the developers PE International agreed to be development partners for the project. Unfortunately no reliable source of environmental impact information could be found for the relevant materials for India and China, both of which produce a high proportion of the world's total of cement and steel. Values are being developed with local academic contacts.

Out of all the materials considered it was found that the variability in the impact of concrete was substantially within the control of the structural designer or constructor. The range of data for concrete is greater than the variability between regions. This is because differences in concrete mix design and constituent material production result in a very large range in impact values. Thus, for concrete, best practice guidance and concrete codes were also used to source data for generating a default range of likely upper and lower bound impacts based on cementitious material 'variants' for the software:

– CEM I or Ordinary Portland Cement (OPC);
– 30% fly ash (FA);
– 50% ground granulated blast-furnace slag (GGBS).

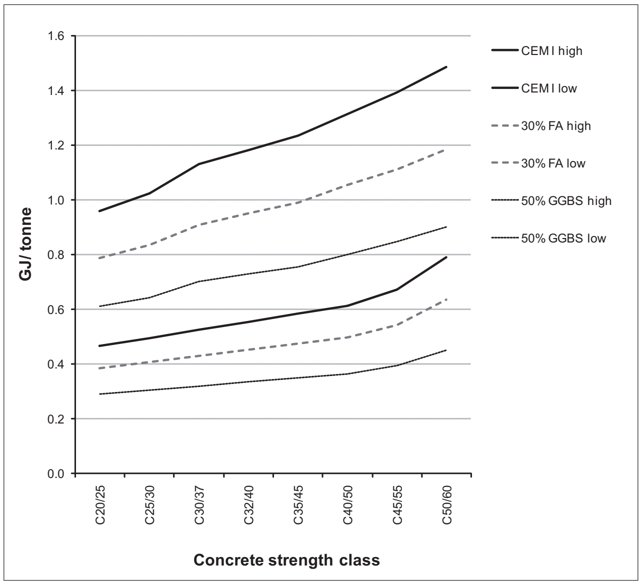
These variants are particular to concrete and are provided because they are within the engineer's control. The other materials – rebar, steel, timber and aluminium—do not offer variants in impacts that are as easily or appropriately specified by designers. For example, guidance from the steel industry[10] is that specification of production method or recycled content of metallic products will not result in reduction of impacts overall due to the high recovery rate of metals from waste streams and the global nature of that supply chain. For these other materials the project sought reasonable average or typical values.

Background to the default data

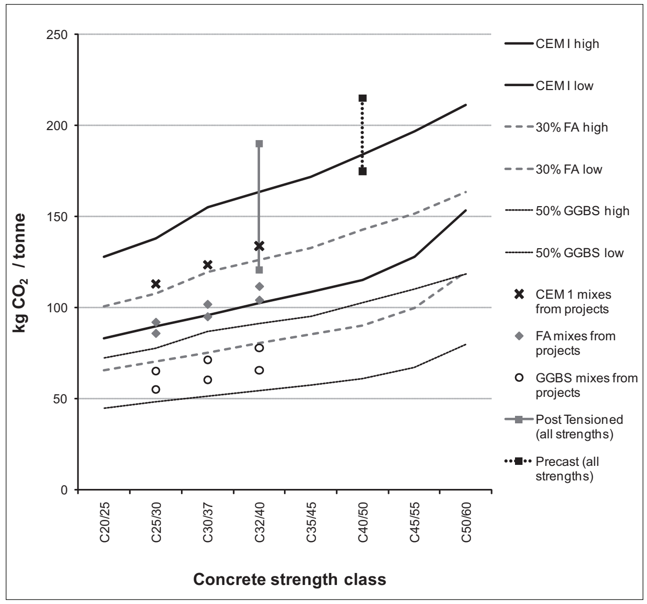
The following sections describe the generation of the default data. In all cases it is possible for the software user to edit or create new data (Fig 2). The purpose of the default is to provide a benchmark and also to ensure that reasonable output is produced even when the user does not interact with the environmental impact module. Although the values output by the software in Fig 2 show the default data to a high number of significant figures it is hoped that the engineer will understand the potential for variation from the following sections of this paper. As with any engineering software output the values are the result of the process of generating results from a combination of constituents and the number of significant figures should not be taken as an indication of accuracy.

	Cementitious content (kg/m³)	
Strength class	Minimum to BS 8500	High according to CIRIA C660
C20/25	240	275
C25/30	260	300
C30/37	280	340
C28/40	300	360
C35/45	320	380
C40/50	340	410
C45/55	380	440
C50/60	460	475

Table 2 Low and high cement content from British codes and guides



4 eE against concrete strength class, UK



3 eCO_2 against concrete strength class, UK

Default values for unreinforced concrete eE and eCO_2

For unreinforced concrete, the aspiration was for the software to offer default environmental impact values for the full range of strengths found in concrete design codes for each region. In addition engineers need to be aware of the potential range of impacts due to mix design variation within a given concrete strength class. In other words, the software was to report a high (and low) impact from the combination of cementitious material, aggregates, water, and admixtures that resulted in greatest (and least) cumulative impact. However, the values found during the literature search did not cover the range required.

Luckily, even though the potential variability in concrete mixes for a given strength is huge, an engineering decision could be made which led to a powerful and simple methodology. This involved separating the variability in the highest impact constituent from all the other much lower impact materials. The results of the simplified method, described in this section, produce upper and lower bound predictions which envelope the more detailed calculations from project experience and published values.

Initial study of the sensitivity of eCO_2 to concrete parameters showed, as might be expected, that cement has the largest influence on eCO_2 of concrete. Thus, the study split the ingredients in the concrete between Portland cement and 'all else'. The variation in the eCO_2 of 'all else', i.e. aggregate, transport, supplemental cementitious materials, admixtures, etc was very small compared to the Portland cement eCO_2. For the population of concretes investigated, which covered a wide range of strength and cement replacement levels, the eCO_2 attributed to 'all else' generated a standard deviation of only 5kgCO_2/m³ in the concrete data whereas for the same population the standard deviation due to the eCO_2 of Portland cement in the concrete was 70kgCO_2/m³. The eCO_2 of 'all else' was typically 10% of the total for the structural concrete grades. The findings were similar, but less marked, for eE calculations.

This finding was used to generate the upper and lower bound predictions by adding single high and low values of 'all else' to a range of impacts from Portland cement, instead of breaking the mix down further.

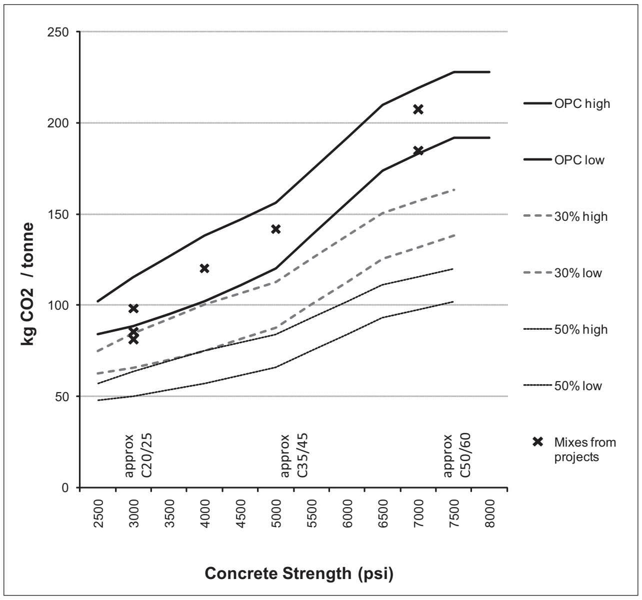
The range of cementitious content was determined using UK guidelines and standards (CIRIA C660[11] and BS 8500-1[12]) for each strength. A survey of concrete building codes in other regions did not yield comparable guidance so the UK variation in cementitious content was used during generation of upper and lower bound values in all cases. The ranges of cementitious content are shown in Table 2.

The total cementitious content was adjusted for the inclusion of fly ash. Based on practical experience the lower bound cementitious content for FA replacement was taken as 10% greater than in a concrete with no cement replacement. No increase in cementitious content was included with GGBS. For strengths higher than C50/60, or f'c = 6000psi, no Portland cement replacement was considered, although some supplemental cementitious material may be added in reality. With the simplified method, the Portland cement impact was calculated using the appropriate percentage from total cementitious content. This value was then added to the upper or lower bound value of 'all else'.

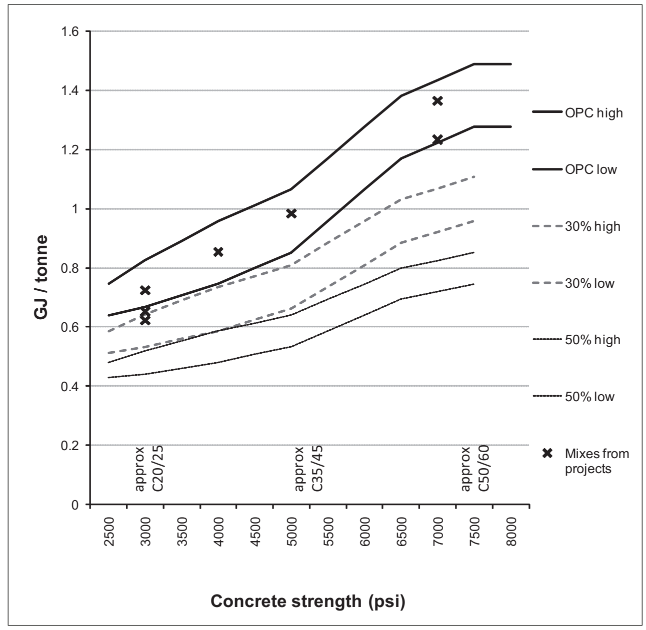
Factors for Portland cement and for 'all else' were based on investigation and reliability assessment of data available at the time in various countries. These are expected to change as production impacts reduce, and data quality improves; however for the purposes of providing an envelope of typical values for engineering calculations the results will hopefully remain relevant for some time. Regional variation was found not only due to different production processes but also to different methodologies for assessing the impacts of the constituent parts. Comparison between regions is not necessarily helpful.

The results of the simplified methodology were compared to detailed calculations of eE and eCO_2 values for concretes from projects. The results were also compared to the values for concrete found during the literature search. The validation data was within the range of the 'low' and 'high' points for each strength and variant.

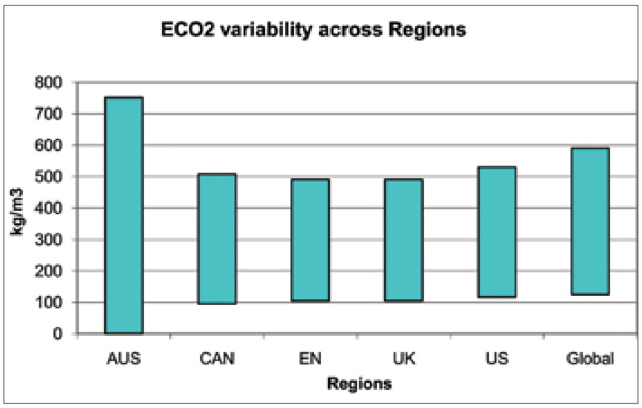
The exception to this was the post-tensioned concrete where research on projects shows the requirement for early strength



5 eCO_2 against concrete strength class, USA



6 eE against concrete strength class, USA



7 Variability in eCO_2 of concrete across regions

AdSec strength class	CEM I / OPC		30% PFA		50% GGBS	
	Low cem. content	High cem. content	Low cem. content	High cem. content	Low cem. content	High cem. content
C20/25	0%	0%	3%	4%	5%	6%
C25/30	0%	0%	3%	4%	6%	6%
C28/35	0%	0%	4%	4%	6%	7%
C32/40	0%	0%	4%	5%	6%	8%
C35/45	0%	0%	4%	5%	7%	8%
C40/50	0%	0%	4%	5%	7%	9%
C45/55	0%	0%	5%	6%	8%	9%
C50/60 to C90/105	0%	0%	N/A	N/A	N/A	N/A

Table Note:'Low' and 'High' refer to cementitious content as per Table 2 not low and high potential values of recycled content.

Table 3 Variation in recycled content by mass for low and high cementitious content

over-rides the 28-day requirements. Post-tensioned concrete impacts will be added to the software using a special concrete type based on data gleaned from projects and research conducted in collaboration with Stanhope and Laing O'Rourke.

Figs 3 and 4 show the bands of values for UK unreinforced concrete, with data from real concretes overlain. It can be seen that all the project mixes fall within the ranges generated by the simplified method.

It should be remembered that the impact of every concrete will vary. Also not all concretes within the default range will be appropriate or available in all project contexts. Limitations of the data are discussed below. Regardless of their limitations the graphs demonstrate the strong message that careful specification is at least as important in reducing embodied impacts as careful selection of concrete strength.

No guidelines for cement content were found in the US, however the Life-Cycle Inventory Athena included details of the concrete mixes used to generate the impact data published in the inventory. The cement content of mixes used in the Athena Life-Cycle Inventories were taken as an average and adjusted according to the variation described in the UK guidance. The resulting eE and eCO_2 were observed to be within the same range of values as for the UK as shown in Fig 5 and 6. The range is smaller overall and this was found to be due to the smaller range in 'all else' values which were generated.

Australia and New Zealand have less data and do not provide guidance on cement content. Furthermore, New Zealand data gave unusually high values for concrete and low values for steel. Thus the procedure for Australia copies the methodology and cement content employed for UK values, except that cement and concrete unit impacts come from Australian inventories. Further study of the New Zealand data will be required before its incorporation in Oasys software. Impact data for the default region/country selection of 'global,' is derived from regional data. It can be seen from Fig 7 that the range of impact for concrete due to specification is greater than the variability in data between regions.

Default values for recycled content of unreinforced concrete

Due to the high mass of aggregate in concrete, the recycled content by mass of concrete is relatively insensitive to the inclusion of fly ash or GGBS as cementitious material. Therefore the default concretes chosen to generate the eCO_2 and eE ranges will all have similar recycled content by mass. The variation in recycled content is shown in Table 3, where 'high' and 'low' labels refer to high and low cementitious content not high and low recycled content. Inclusion of secondary or recycled concrete aggregate would increase these values significantly, possibly to around 60%. However inclusion of secondary or recycled aggregate should only be considered if an appropriate local supply is available, or rail or ship transport can be arranged. Hence properties should be defined on a project by project basis and default data was not

	Worldwide all steel	Australia	Canada	Germany	New Zealand	United Kingdom	United States
eE GJ/t	22	22	19	15	9	9	17
eCO_2 kg/t	1740	1760	600	1520	350	460	420
% RC	39%	20%	100%	80%	90%	98%[(a)]	99%
Note a: This recycled content was taken from CELSA Environmental Statement 2010							

Table 4 Default impact values for steel reinforcement

	Worldwide all steel	Australia	Canada	Germany	New Zealand	United Kingdom (EU)[(a)]	United States
eE GJ/t	27	22	31	21	9	22	25
eCO_2 kg/t	1890	1760	2200	2060	352	1420	1060
% RC	39%	20%	9%	50%	90%	59%	68%
Note a: This recycled content is based on European production. The recycled content of steel section produced in the UK will be lower than this and impacts correspondingly higher.							

Table 5 Default impact values for structural steel sections

	Global	Australia	Canada	Germany	United Kingdom	United States
eE GJ/t	170	210	180	150	150	180
eCO_2 kg/t	11 700	18 100	10 800	10 900	8200	10 800
% RC	33%	33%	50%	33%	33%	50%

Table 6 Default impact values for aluminium

	Global	Australia	Canada	Germany	United Kingdom	United States
eE GJ/t	7.7	8.3	5.8	7.8	12.0	4.4
eCO_2 kg/t	690	810	520	1060	390 + 450[(a)]	520
% RC	0%	0%	0%	0%	0%	0%
Note a: The value of 390 excludes the CO_2 from bio-energy if the timber comes from a sustainably managed forest						

Table 7 Default impact values for timber

developed.

Most evaluation systems which consider recycled content, such as WRAP[13] and LEED[14], will require recycled content by value (%RCBV), not by mass (%RCBM). Due to the ongoing fluctuations in material costs and the need to provide globally applicable data, the project did not attempt to provide default data for RCBV. The software output would not be useful for formal LEED submissions which require an overall project value to be calculated. Instead the RCBM output allows the structural engineer to understand the recycled content of their part of the project.

Default impact values for steel and aluminium

Published environmental impacts of steel depend primarily on the amount of recycled material used in the process. Different steel products result from either the electrical arc furnace (EAF) or basic oxygen furnace (BOF) process. BOF is the process required to produce mainly primary material, while EAF can utilise a large amount of scrap.

Sometimes the region-specific data stated the amounts of scrap used in the types of plant providing steel for that region. Countries making products with greater production from EAF mills often report region-specific data while those with greater production from BOF like to report the global recycled content and corresponding impacts data which are lower than BOF impacts. This inconsistency in approach overstates the global recycled content of steel. Steel markets work across borders and have nearly optimised use of the world-wide supply of scrap. Additionally, recovery rates of steel for recycling are very high. Recycled content is not in the control of the engineer and specification which attempts to impose recycled content levels could arguably pose a threat to the efficiency of the current flows. Thus, it was deemed most appropriate to offer the worldwide recycling rate of all steel products and consequent embodied impacts as default data. This average value represents the steel market well by including both current end-of- life recycling practice and new steel production. Because it is an average value it will not represent the impact of a particular single steel element installed in a construction project but will represent the global impact of choosing steel as a construction material.

Compared to steel sections, rebar is usually made with higher recycled content. This is reflected in region-specific data. Like steel sections, however, rebar is understood to be embedded in the worldwide steel market, so it is difficult to justify reporting lower embodied impacts for rebar than for worldwide steel. Despite this, some rating systems, such as LEED, do accept recycled content based on the manufacture of individual products, so it is valuable for the engineer to know what recycled content can be used to meet the requirements of their project rating system. Therefore both regional and product-specific environmental impact and recycled content information have been amassed, where available, as well as the worldwide data, as shown in Tables 4 and 5. The method of accounting for the end of life recyclability of steel in embodied impact assessments is the subject of much discussion in the industry. The various options for approaching this topic are presented and discussed in the guidance and annex to the ICE Bath database and the recommended approach is likely to be defined by European standards through the work of CEN TC 350. The default values derived for the Oasys software are cradle to factory gate and so future recyclability is not considered, However, through adopting the global average recycled content value, recyclability in current market conditions is represented.

Data for New Zealand looked questionable and therefore was not included in Oasys software until further investigation can be undertaken.

Like steel, aluminium can be produced either from virgin raw materials, or reclaimed material. The eE and eCO_2 for production of aluminium from raw materials can be five times higher than production from reclaimed materials. The values reported generally represent average properties based on the current market split of process methods rather than one production method or another. This is reflected in the data available from the life-cycle inventories listed in Table 1. Values quoted for aluminium extrusions were deemed most typical for structural use and this choice of specification significantly reduced the variability of the data (Table 6).

Recycled content figures for aluminium were only available for the US and Canada; the UK data refers to global recycled content levels. Considering that aluminium scrap is traded globally, the global recycled content value was assigned to the other regions.

Default impact values for structural timber

Structural glu-lam was chosen as representative of timber. These default impacts follow the method discussed in ICE Bath database and do not include either sequestration of CO_2 during growth or release of greenhouse gases at end of life. Data was found for all the study regions which fitted this methodology. For timber, the engineer must establish the likely life-span of the element in use adjusting the default data to include 'sequestration' or carbon storage. CO_2 absorbed during the growth phase of the timber and stored during its use in a structure is likely to be emitted at end of life. As with steel impacts the ICE Bath guidance and annex is a useful overview of the different approaches to choosing impact values for timber. The latest values in the ICE database also provide enough information for engineers to allow for the inclusion or exclusion of the emissions associated with bio energy. This can adjust the impact by roughly a factor of 2 (Table 7).

Discussion

The default data presented in the sections above demonstrate a consistent approach to the regional and material-specific variations in this relatively new field. While the calculation of eE and eCO_2 will hopefully encourage discussion and awareness of the impacts of structural designs, it is important to also understand the uncertainty band surrounding the information. The values presented are just one possible approach to the issue. The data used in the software will be updated as new information becomes available and consistency in method develops across the industry and the world.

Also, as with all sustainability topics, there are trade-offs between different environmental impacts: we are only looking at three. There may also be trade-offs between embodied impacts and performance effects. Designing towards sustainability considers all effects over the materials' lifetime. The parameters reported should only be seen as a small part of the total impact of the design.

The materials investigated during this project present different challenges in the choice of environmental impact values. The values presented are chosen to help typical engineering design decisions but different methodologies from those adopted may be more appropriate depending on the particular design decision in question. Data can be found that follows a different methodology; for example data which includes the issues discussed below, including treatment of waste materials, recyclability at end of life and sequestration of CO_2 during growth. Further life cycle stages beyond the factory gate may be included in the material data, or calculated separately. For example 'gate to site' impacts are likely to be important in a region such as the Middle East where transportation impacts can be significant. With that said, the values summarised in this paper were chosen in order to achieve consistency between the regions and materials studied using values from reputable independent sources.

Sources of variability

The primary source of variability comes from differences in the materials through specification or supply. In addition, there are other, sources of variability, as described below.

Fuel type

The sources of primary energy have a significant effect on the resulting carbon emissions. The fuel type also largely determines efficiency, and thus the amount of fuel needed. Examples of the use of fuels which effect the environmental impact of materials include the use of hydro-power for metal production, waste fuels for the production of cement or biofuels for timber products,

LCIA methodology

Since there currently are no strict rules defining LCA methodology to obtain embodied impacts – even the most recognised international standard, ISO 14040[15], allows a great deal of interpretive flexibility – the basis for data differ across inventories. Different decisions are made regarding life-cycle boundaries, process types, product grouping, and theoretical against actual recycled content. The variability from this source will hopefully reduce with the development of European standards for whole building life cycle assessment.

Boundaries

All inventories we have referenced use a cradle-to-gate boundary, tracking material and energy flow from extraction to leaving the factory gate. In the case of concrete, this is generally the gate of the ready-mix plant. All also use primary as opposed to delivered energy, which includes losses in inefficiency and transmission. A few include capital equipment used to extract, manufacture and transport the material as well.

Process type

This can affect the values, particularly for cement, steel and aluminium. More energy is needed for wet-kiln compared to dry-kiln cement production. EAF uses much less energy than BOF in making steel. Most data reflect the proportion of each process occurring within the region for which the data have been reported. Thus the variations reflect the weighted average due to differences in processes employed between regions.

Furthermore, databases group products differently. This would explain the very high number for Australian steel eE, because the database did not distinguish between different structural steel products and only offers information for a nearly virgin product.

Multiple life cycles

How recycling is accounted for is a complex issue. For specific products, some inventories cite impacts based on what recycled content can be achieved, while others cite values based on what was actually achieved within plants in their region.

The default data chosen for the software was selected to achieve a consistent approach. An estimate of the potential variation in data can be found by referring to the range and scatter graphs published with the ICE Bath Database. For example for steel the ICE quotes a range of ±30% for the embodied energy values. The effect of variation in calculation method and in specification has been investigated in a separate research project by the authors with the UK Concrete Centre.This work looks at the effect of variation in material impact values on whole building embodied CO_2 calculations.

Guidance for user-generated material data

This section sets out lessons learned in the course of this research. This may help engineers who wish to source values themselves for different impacts, regions and materials or who wish to understand differences between published sources. Values will be found which differ from the default values presented here. In addition to the reasons for variability explained above, the user should be aware of other additional sources of variability between life-cycle assessment results.

Some life-cycle assessment models include impacts from life cycle stages after gate: transport to site, construction, maintenance and end-of-life.

These values will vary with every project and every region. It was decided during development of the default data that further life cycle stages are best considered separately and in addition to the values listed in this paper. In order to generate or check generic values, average gate to site impacts can be generated from the available literature, trade association data and government statistics. In the UK, government and material supplier data is updated regularly for average transport distance of many construction materials and average emissions for various modes of transport. WRAP data can be used for site wastage rates if no other data is available. Methods for calculating overall site impacts are available in publically available tools based on project programme and value.

As noted above, there are variations in how reuse of material is accounted for. An alternative approach to the recycled content method is to consider the recyclability instead, which discounts primary material by the number of times and proportion which it is likely to be reused[16]. Other methodologies could account for reuse in a separate end-of-life stage, so discounting would not appear in the cradle-to-gate figure selected as default data for the software. Thus until a consistent method is adopted, figures, even ones associated with the same recycled content, may differ.

Inventories may group a larger array of products, and include products with greater environmental impacts. For example, stainless steel requires nearly three times more energy than carbon steel, and corrosion protection with zinc and aluminium increases the impacts by about 50%. Including coatings and fireproofing will raise the values as well. It is certainly justifiable to use these numbers if they are more appropriate for a particular application. The importance is to explain fully what the impact values are based on and keep the basis consistent across comparisons.

Values published by regional trade organisations or individual companies as part of key performance indicators or sustainability reporting can be very useful sources of up-to-date primary data which is often audited by a third party.

Limitations

The following are conditions in which the default values are likely to be too low:
– higher cement quantity than that recommended by CIRIA C660
– long-distance transport of heavy and low impact materials by road (eg precast concrete elements and aggregate)
– less aggregate than in a conventional mix of same strength
– slag and fly ash requiring greater processing than accounted for in the Life Cycle Inventories.
– materials from countries without robust reporting regulations
– early strength requirements for concrete over-riding 28-day strength requirements (e.g. precast and post-tensioned elements)
– studies where local or product specific recycled content for metallic products would be more appropriate.
– high processing energy for timber
– any material from a new source

Recommendations for future work

This is an area where there are rapid developments and a number of areas for future work have been identified:
– data from China and India
– data for other regions, such as the Middle East
– review of new and updated inventories. Data has been updated in many of the sources during the course of this research.

The aim is to eventually use data sets from a single, widely-accepted methodology. Real concretes from actual projects will continue to be mapped onto the impact against strength curves and the upper and lower bounds of ‘all else’ impacts refined.

The impact of pre-cast concrete is higher per tonne than *in situ* concrete, but this is generally offset by material and efficiency savings. Publicly available values for different precast products are needed.

Conclusion

The project summarised in this paper provided a global overview of material data available to the structural engineer for the calculation of the environmental impact of their design. Although much variation was found for the particular environmental impacts considered this could generally be accounted for. A consistent set of data could be developed for use as default values in software which will allow meaningful comparison between structural designs.

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Acknowledgment

The authors thank Andrea Charlson, William Arnold, PE International and Oasys Ltd[17] for their input. More information about the data marked as ‘Germany’ can be found here:

http://www.pe-international.com/
http://documentation.gabi-software.com/
More information about the software can be found here:
http://www.oasys-software.com/