Proceedings Paper:
De Wolf, C, Iuorio, O orcid.org/0000-0003-0464-296X and Ochsendorf, J (2014) Structural Material Quantities And Embodied Carbon Coefficients: Challenges And Opportunities. In: Griffin, C and Mollner, J, (eds.) Proceedings of the 5th Annual School of Architecture Symposium. 5th Annual School of Architecture Symposium - Sustainable Structures: The Intersections of Structural Systems and Green Buildings, 16-18 Apr 2014, Portland State University, Portland, OR, USA. School of Architecture, Portland State University , pp. 309-328. ISBN 978-0-9718903-1-2

STRUCTURAL MATERIAL QUANTITIES AND EMBODIED CARBON COEFFICIENTS: CHALLENGES AND OPPORTUNITIES

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Abstract

Many innovations in recent decades have attempted to lower the operational energy use of buildings, which has increased the percentage of embodied energy in the life cycle of structures. Despite a growing interest in this field, practitioners still need an embodied carbon estimator, an agreement on the appropriate Embodied Carbon Coefficient (ECC expressed in kg-CO_2e / $kg_{material}$) standards and the collection of material quantities in building structures.

This paper defines the challenges in obtaining the material quantities and estimating the embodied carbon of structural materials. By critically reviewing existing efforts and interviewing several leading design firms, this paper aims to build literacy on challenges and opportunities in obtaining the embodied carbon of buildings. Two primary variables are analyzed: the material quantities ($kg_{material}$ / m^2) and the ECCs. The outcome will give confidence in the Global Warming Potential (GWP measured in kg-CO_2e / m^2) of buildings.

The main challenges consist of creating incentives for data collection, identifying default ECC values per location and marrying transparency and intellectual ownership protection. The main opportunities are generating large amounts of data from Building Information Models, proposing an agreement on ECC ranges and outlining a unified methodology for the definition of reference buildings.

Topics: low-carbon structural materials

INTRODUCTION

Life cycle energy in buildings includes operational energy for heating, cooling, hot water, ventilation, lighting and embodied energy for material supply, production, transport, construction and disassembly. The term ‘embodied carbon’ refers to the greenhouse gas emissions embodied in the building materials or Global Warming Potential (GWP), expressed in carbon dioxide equivalents (CO_2e). Many leading structural engineering and design firms are currently developing in-house embodied carbon estimators. What is the embodied carbon for different structures? Structural engineers and architects want to answer this question for multiple reasons.

This paper is limited to structural material quantities. Cladding and other non-structural materials are not considered for two reasons. Firstly, structure represents the largest weight in buildings and contributes to about half of the total carbon emissions due to materials (Webster et al., 2012). With a breakdown of embodied carbon for the different elements of offices, hospitals and schools, Kaethner and Burridge (2012) also demonstrate that the super- and substructure together accounts for about half (Figure 1). Secondly, this helps to focus attention on a well-defined quantity while still having a significant impact (Wise et al., 2013).

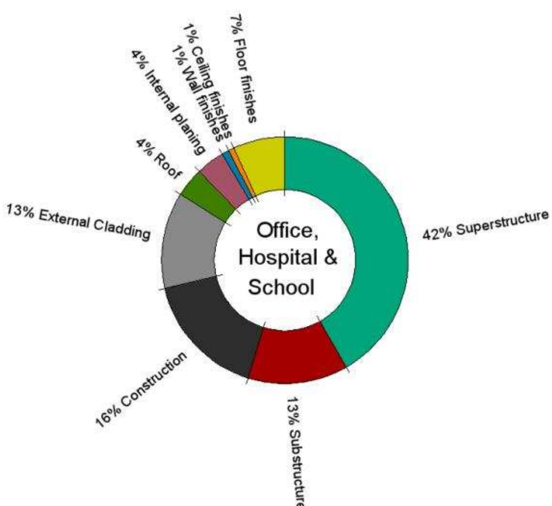


Figure 1: Average breakdown in building elements of embodied carbon in offices, hospitals and schools, based on figures in (Kaethner & Burridge, 2012)

Also, the question looks at embodied carbon for two reasons. Firstly, reducing the operational energy of buildings has been very effective in recent decades resulting in innovative design solutions for low energy buildings and the use of renewable energy sources. As innovations continue to decrease the operational energy, embodied energy will become a more significant percentage of the greenhouse gas emissions caused by buildings. Secondly, structural engineers and architects are eager to understand how anthropogenic carbon emissions are associated with the material choices they make in their projects, in order to significantly impact and lower their embodied carbon (Dixit et al., 2012).

Next, rating schemes in the United States and elsewhere have begun including embodied carbon and energy in their credit system. LEED version 4 defines a new section on environmental impact requiring an analysis with Life Cycle Assessment (LCA) based tools. However, to award the credit, an improvement over an undefined baseline building is necessary. The further research on an embodied carbon database will help to define a reference building for benchmarking (Yang et al., 2013; USGBC, 2013).

The multiple efforts for estimating the embodied carbon of projects within firms show there is a need for a conceptual embodied carbon estimator across practitioners. Various tools are available or in development, however there is no global database of structural material quantities in existing buildings including their environmental impact that could be used as a baseline for comparison. Embodied Carbon Coefficients (ECC) are expressed in kg of CO_2e (kg_{CO2e}) per kg of material (kg_m), where CO_2e stands for the equivalent in carbon dioxide of the greenhouse gases (GHG) produced for the manufacturing and transportation of these materials. There is no clear standard or agreement on appropriate ECC values for common structural materials at the moment.

The value for embodied energy is not the same as the value for embodied carbon. The same embodied energy can emit different contents of GHG depending on the used fuel and the carbon emitted or absorbed by the materials processed. It is useful to account in terms of embodied carbon, as CO_2 contributes considerably to climate change. Also, the measure can be combined with emissions in the operational phase to assess the whole life cycle impacts in buildings (Kaethner & Burridge, 2012). The other greenhouse gases such as CH_4, N_2O, SF_6, PFC and HFC can be converted to CO_2e using conversion factors in order to obtain a common unit for the environmental impact (IPCC, 2007).

This research develops a transparent and interactive database of building projects including the structural material quantities and their embodied carbon. The aim is to build literacy on "what is the embodied carbon" of a typical structure in a specific location for various materials. However, such an ambitious data collection project presents considerable challenges in order to be transparent, accurate and user-friendly. As illustrated in equation [1], the GWP (expressed in kg_{CO2e}/m^2) is obtained by multiplying the two key variables: the material quantities (MQ, expressed in $kg_{material}/m^2$ or kg_m/m^2) and the ECC values (expressed in kg_{CO2e}/kg_m).

$$\mathbf{MQ}\ (kg_m/m^2) \bullet \mathbf{ECC}\ (kg_{CO2e}/kg_m) = \mathbf{GWP}\ (kg_{CO2e}/m^2) \qquad [1]$$

Figure 2 illustrates how the GWP of different materials can be added for multiple building projects. This represents the embodied carbon the multiple materials within a building. A unified embodied carbon database would give confidence in the GWP numbers. Indeed, as no framework or reliable database exists yet to assess the embodied energy or carbon of the structure, many buildings use materials in a wasteful way with impunity. This paper synthesizes the challenges of developing such a database.

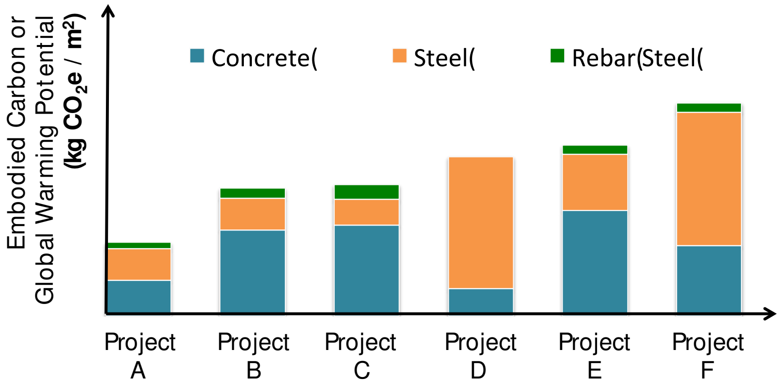


Figure 2: GWP divided in composing materials of different building projects

1. PROBLEM STATEMENT

While individual companies and researchers are developing their own in-house databases, it is important to understand the challenges. For an accurate, complete and reliable database, it is essential to know the obstacles before it is possible to overcome them. The paper therefore addresses the lack of methodology or regulation divided among three topics:

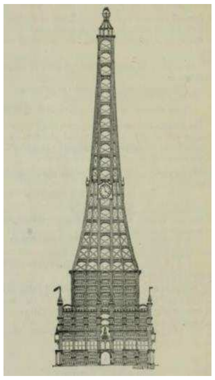
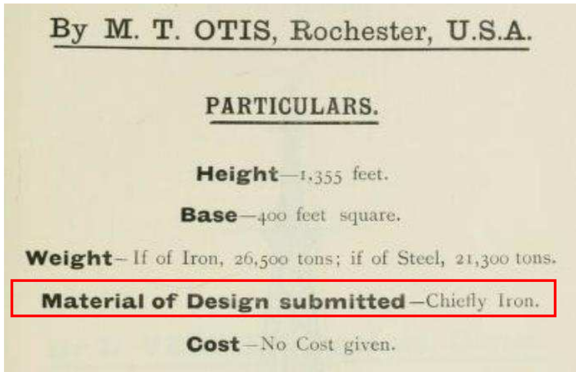
1. The first task is to collect material quantity data and assess their quality. This can allow for comparisons across building types and structural systems.
2. The second goal is to propose standards for Embodied Carbon Coefficients that are reasonably accurate but at the same time do not require a complicated calculation from a complete LCA for each material and each project.
3. The third topic handles the implementation of the database. It includes unifying the different methodologies, while being as transparent as possible and respecting intellectual property.

2. LITERATURE REVIEW

This section summarizes the state of the art on material quantities, embodied carbon literature, tools and databases, indicating gaps and challenges to be addressed.

2.1. Material quantities

In the 1890s, a tower design competition in London asked for material weight as one of the design criteria (see Figure 3) and in the 1920s, Buckminster Fuller asked the question "How much does your house weigh?" (Lynde, 1890; Braham & Hale, 2013). However, most constructions today are designed in a static way and material efficiency is not always a primary driver. Indeed, as no framework yet exists to assess the embodied energy or carbon of a structure, many buildings use materials in a waste-full way with impunity. Recently, more studies attempt to map material efficiency of tall buildings considering the number of floors and structural efficiency (Cho et al., 2004; Elnimeiri & Gupta, 2009; Ali & Moon, 2007).



By M. T. OTIS, Rochester, U.S.A.

PARTICULARS.

Height—1,355 feet.

Base—400 feet square.

Weight—If of Iron, 26,500 tons; if of Steel, 21,300 tons.

Material of Design submitted—Chiefly Iron.

Cost—No Cost given.

Figure 3: Particulars of the design competition for the London tower in 1890 (Lynde, 1890).

Some studies on tall buildings recently started to analyze the material efficiency considering the number of floors and structural systems. Cho et al. (2004) gives unit material quantities in volume (m^3 per m^2) for concrete and in mass (kg per m^2) for rebar and steel. In Figure 4, they compare the structural steel quantities for various story heights. As Elnimeiri and Gupta (2009) express it, "good structural engineering revolves around achieving efficiency and minimization of material". Ali & Moon (2007) and Rizk (2010) give weights of steel in psf versus the number of floors for steel framed tall buildings (Figure 5). The Council on Tall Buildings and Urban Habitat (CTBUH) points out it is often difficult to compare these material quantities, as some studies may include or exclude the foundations, mezzanine floors, etc (CTBUH Journal, 2010).

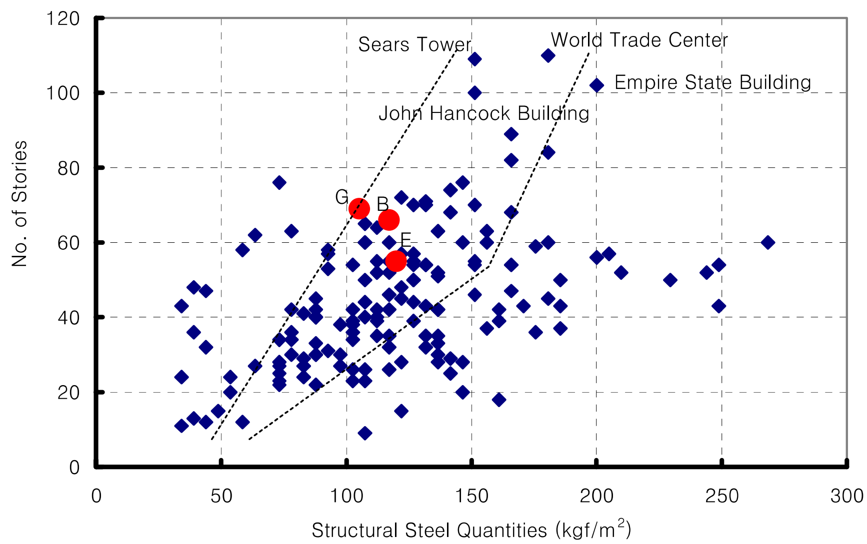


Figure 4: Structural steel quantities variation with the number of stories (Cho et al., 2004)

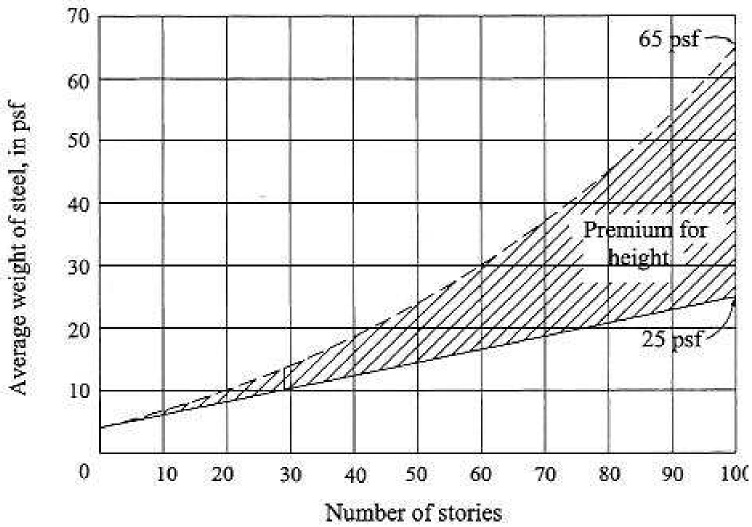


Figure 5: Average limits of the weights of steel for various number of stories (Ali & Moon, 2007).

Because studies tend to focus on certain types of structural system or building use (Amato & Eaton, 1998), literature is lacking about the ranges of material weights in typical buildings.

2.2. Embodied Carbon Coefficients

Another topic studied in literature is the embodied energy and embodied carbon for specific materials. Simonen (2011) and Moncaster & Symons (2013) express the general lack of data in the field of embodied carbon. Alcorn (1996) discusses the "Embodied Energy Coefficients" (EEC) of building materials, while Dias and Pooliyadda (2004) define "Embodied Carbon Coefficients" (ECC).

Various reports have analyzed the environmental impact of concrete (Vares & Häkkinen,1998; Lagerblad, 2005; Collins, 2010; Struble & Godfrey, 1999), as well as the impact of cement (Young, Turnbul & Russel, 2002). Other articles describe the embodied energy of metals (Chapman & Roberts, 1983) and in particular steel (Institute of Stainless Steel Forum [ISSF], 2004; International Iron and Steel Institute [IISI], 2003; European Steel Industry and Climate Change, 2000; Stubbles, 2007). Next to concrete and steel, the embodied energy of other construction materials such as timber has been discussed (Pullen, 2000). The industry also works on developing better LCA data for wood (CORRIM, 2014), steel (World Steel, 2014) and concrete (NRMCA, 2014). However, there is a consequent variability in the results for both EEC and ECC values.

The Inventory of Carbon and Energy (ICE) report from the University of Bath summarizes EEC and ECC values for most construction materials (Hammond & Jones, 2010). Figure 6 illustrates the variability of the available data of embodied energy of steel. The wide range of available EEC/ECC values jeopardizes the comparison of environmental impact of different buildings. The ICE report selects the best available embodied energy and carbon data. However, there is still a need for values per country or region. The same concrete mix used in a big city in China or a small town in the United States will not have the same coefficients if factors such as transport are included (Ochsendorf, et al., 2011). The vocabulary “Carbon Intensity Factors” is sometimes used interchangeably for the “Embodied Carbon Coefficients” (ECC).

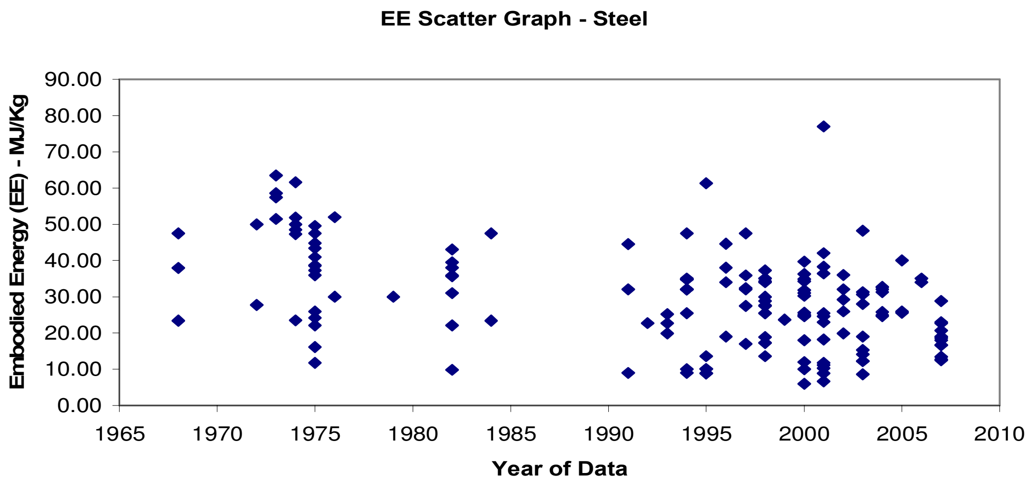


Figure 6: Variability of the publically available data of embodied energy of Steel (Hammond & Jones, 2010)

The Carbon Working Group (Webster et al., 2012) discusses the embodied carbon of common construction materials. They discuss the uncertainty of carbon footprints, data quality and variability. As different sources might not use the same assumptions, the Carbon Working Group identifies a need for a more reliable and comparable definition of ECC values.

Several LCI and LCA tools exist to calculate impacts of single projects or materials. The commercial LCA software Gabi (GaBi PE International, 2003) and SimaPro (SimaPro, 2013) can perform an LCA of a unit of construction materials to estimate the ECC values. These commercial tools are common practice for LCA calculations, but their data details are proprietary.

2.3. Examples of existing implementations

The following paragraphs illustrate several existing databases and tools for estimating embodied carbon. The Athena Institute is a non-profit organization based in Canada that has integrated LCI data into building industry specific tools: the Athena Eco Calculator (free) and the Athena Impact Estimator (Athena, 2009). Also, ECOINVENT provides thousands of LCI datasets in various from agriculture to electronics (EcoInvent, 2013)

Next, various companies have developed in-house tools focused on estimating the embodied carbon of their projects. Kieran Timberlake and PE International just released the TALLY tool (Tally^{TM} beta, 2013) extracting data from Revit models. The SOM Environmental Analysis tool is a user-friendly embodied carbon calculator for design projects (SOM, 2013).

In the United Kingdom, the non-profit Waste Reduction Action Program (WRAP) is developing a project-based database of embodied carbon (WRAP, 2009). WRAP asks users of the web-interface to clearly mark building life cycle stages and to reference the used LCA software, without asking specifically for material quantities (Charlson, 2012).

Many leading structural engineering firms have started an in-house database of structural material quantities or embodied carbon of their own projects. One thoroughly developed example is the Arup Project Embodied Carbon and Energy (PECD) mainly consisting of Arup buildings or projects from literature (Kaethner & Burridge, 2012; Yang, 2013). Although PECD contains approximately 600 projects, it does not allow the definition of a baseline yet due to the data scarcity and their wide ranges. Other companies such as Thornton Tomasetti have also developed a database of the material quantities, extracted via a Revit plug-in, and embodied carbon in their projects.

Table 1 gives a brief overview of companies and institutes working on similar problems.

Table 1: Leading efforts in material quantity collection, ECC values, database implementation

	Material Quantities	**ECC**	**Implementation**
Reports			
Inventory of Carbon & Energy (ICE)			
Structure and Carbon (Carbon working group)			
Cole & Kernan, 1996		□	
Eaton & Amato, 1998			
Council of Tall Buildings and Urban Habitat (CTBUH)			
Software			
Athena			
Gabi, Simapro			
SOM Environmental Analysis Tool			
Tally^{TM} beta tool			
Build Carbon Neutral, 2007			
Databases			
Arup PECD			
Thornton Tomasetti			
WRAP			

* EEC not ECC

3. METHODOLOGY

The methodology for defining challenges in estimating embodied carbon is threefold. First, the review of ECC and material quantity literature gives a summary of gaps and difficulties in defining these two key variables. Next, conversations with leading structural engineers and design firms identify incentives for companies on sharing material quantity project data and shaping the current common practice in embodied carbon estimation. Finally, the review of existing carbon estimating tools is a needed step towards a unifying implementation of an embodied carbon database.

3.1. Literature review

The study of publicly available carbon data of typical construction materials shows how the variability in assumptions and organizations can affect the numbers. Comparing the published numbers and synthesizing the existing literature would lead towards an agreement proposal for the two variables: the typical material quantities and embodied carbon coefficients.

3.2. Personal Interviews with practitioners

A series of interviews provided feedback from the professional field of design, engineering and construction of buildings (Table 2). These interactions with experienced practitioners give a critical review of what should be included in the database to have a complete and accurate baseline for embodied carbon and energy in structures while keeping it user-friendly and easily accessible to the stakeholders. Also, this contact with professionals led to a considerable amount of data on material quantities in building structures.

Table 2: Interviews with leading structural engineering and design firms

Company	Contact Person	Interview Reference
Arup	Frances Yang	Yang, 2013
Buro Happold	Edward Sauven	Sauven, 2012
Thornton Tomasetti	Wolfgang Werner	Wolfgang & Dugum, 2013
Schlaich Bergermann und partner	Jörg Schlaich	Schlaich, 2012
Skidmore, Owings & Merrill	David Shook, William Baker	Yang et al, 2013 Baker, 2013
Webcor	Phil Williams	Yang et al, 2013

3.3. Assessment of existing embodied carbon estimating tools

This paper uses and compares various existing embodied carbon estimating tools. Software or databases such as the Athena Impact Estimator for Buildings, the GaBi LCA software, the SOM Environmental Analysis Tool, the rtei^{TM} beta or Tally^{TM} tool (Kieran Timberlake and PE International) and others have been assessed (Table 3). Very little has been written previously on the comparison of available embodied carbon estimating tools.

Table 3: Existing reviewed embodied carbon estimating tools

Company	EC estimating tool	Reference
Athena Sustainable Materials Institute	Impact estimator	Athena, 2009
PE International	GaBi Software	GaBi, 2003

Kieran Timberlake & PE international	Tally^{TM} beta real time environmental impact tool	Tally^{TM} beta, 2013
Skidmore, Owings & Merrill	Environmental Analysis Tool SOM Carbon Footprint Calculator	SOM, 2013

4. RESULTS AND DISCUSSION

For each of the three problems identified, this paper defines opportunities as well as challenges. The opportunities illustrate the possibilities of the environmental impact database and can solve part of the tasks in each topic, but challenges remain to be undertaken. This overview needs to be defined before taking next steps towards the data collection and GWP calculations.

4.1. Getting Material Quantities

The first challenges consist in obtaining accurate material quantities and generating as much data as possible. For accurate data, the scope of what is included should be very well defined (for example, should the sub-structure be included?). Generating large amounts of data requires incentives for architecture, engineering and construction firms to share their project information. Indeed, hundreds of projects are needed to create a representative sample pool.

The opportunity in getting structural material quantities lies in the quick and automatic data generation based on Building Information Modeling (BIM) tools such as Revit. With this generation from models, a considerable amount of quantitative data is already available in design firms. Also, a user-friendly interactive web-interface should help populate the database. These widely spread ways of populating the data pool allows for comparative data amongst various typologies and locations.

4.2. Accurate Embodied Carbon Coefficients

The definition of the ECC is an important and complex issue. Typically these data are obtained from Life Cycle Inventory (LCI) databases. The Life Cycle Inventory is one of the four phases in evaluating the environmental impact from cradle to grave or ‘performing the LCA’ of a product or material. After defining the goals and scope (phase 1) for this process, the LCI defines the in- and outputs of materials and energy (phase 2), followed by a Life Cycle Impact Assessment (phase 3) and finally the interpretation of the previous steps with a sensitivity analysis (phase 4).

Many databases are available such as Bath University’s ICE report (Hammond & Jones, 2010), Athena (Athena, 2009) and ECOINVENT (EcoInvent, 2013). In particular, the ICE presents ‘cradle-to-gate’ data for carbon and energy impacts of primary building materials, mainly focused on the United Kingdom market. The Athena tools include average transportation distances (results customizable for different United States regions) as well as the impacts from construction, maintenance and demolition (Athena, 2009). The goal is to help designers evaluate the environmental impact of construction without developing detailed material quantity take-offs. No reference to data quality is included. The ECOINVENT datasets are based on industrial data and are compatible with major LCA and eco-design software tools (EcoInvent, 2013).

In order to understand the variability of the ECC among different databases, the values for cement and concrete obtained by ICE and Athena are reported in Table 4. In particular, it can be noted that for the concrete the ECC can vary in a significant way depending on strength (Table 4 and Figures 7 and 8), cement quantity, percentage of fly ash (Figure 8) and blast furnace content. Moreover, in case of reinforced concrete the environmental impact of rebar has to be considered: the ICE suggests adding 0.77 for each 100kg of rebar per m^3. Different concrete strengths and rebar contents can result in a variation of embodied carbon per m^3 of about 3 times (240 vs. 788, Figure 8). A critical study is needed to interpret the wide variation and reliability of the available concrete ECCs.

Table 4: ECC for cement and concrete estimated by ICE 2010 and Athena

	ICE (kg_{CO2e} / kg_m)	**Athena** (kg_{CO2e} / kg_m)
Cement	0.74	0.776
Concrete 16/20	0.100	0.091
Concrete 25/30	0.113	0.128

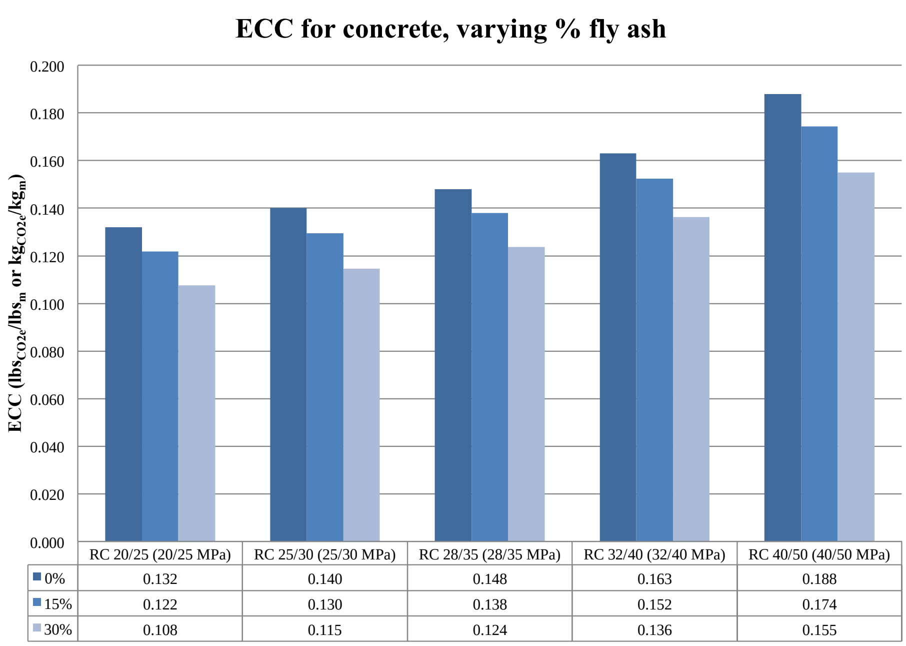
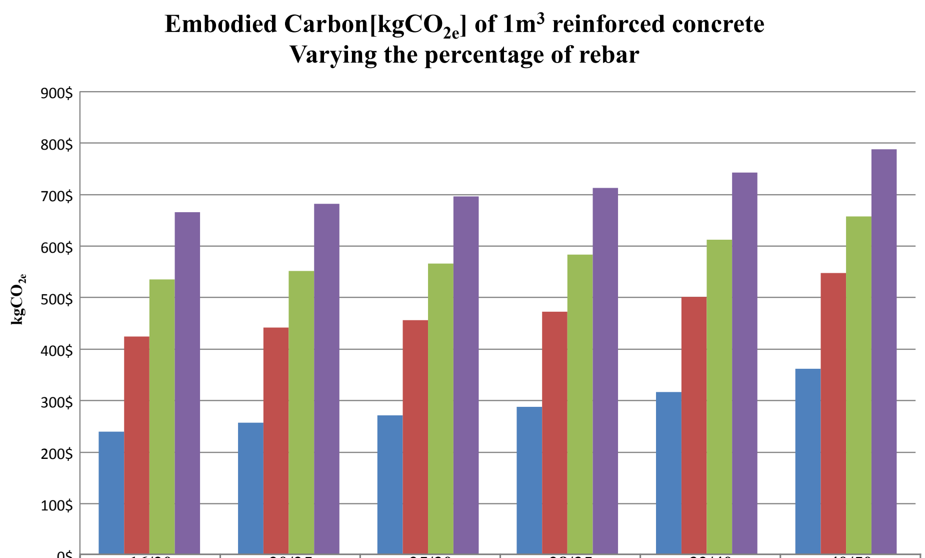


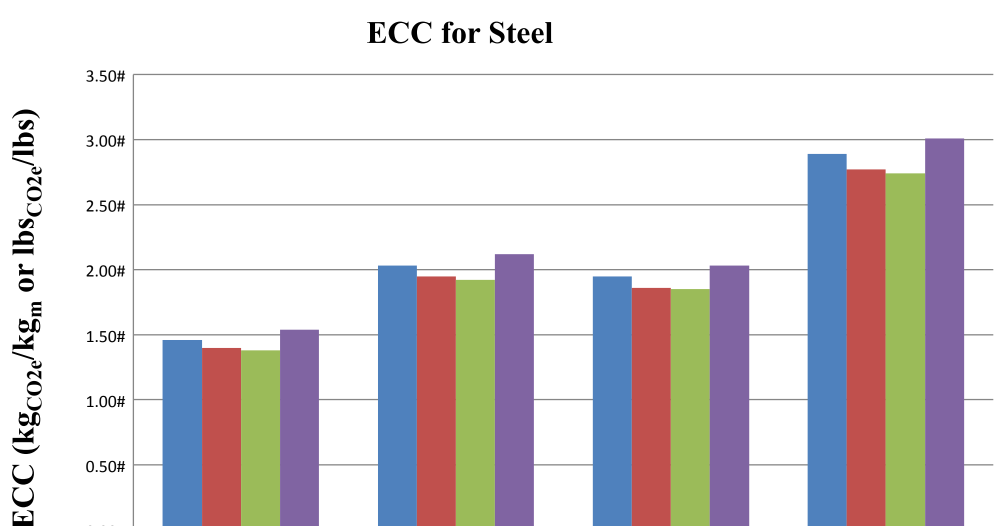
Figure 7: Variability of EC of concrete at varying of strength and percentage of fly ash, with datapoints extracted from (Hammond & Jones, 2010), multiply MPa values by 134 for psi



	16/20	20/25	25/30	28/35	32/40	40/50
0%	240	257	271	288	317	362
1%	425	442	456	473	502	547
2%	535	552	567	583	612	658
3%	665	682	697	713	742	788

Figure 8: Variability of EC for a 1 m^3 of concrete at varying of strength and percentage of rebar

Next to concrete, the ECC for steel products also presents an important variation (Figure 9).



	UK Typical - EU 59% Recy.	R.O.W. Typical - 35.5% Recy.	World Typical - World 39% Recy.	Primary (100% hypothetical virgin)
General	1.46	2.03	1.95	2.89
Bar&Rod	1.40	1.95	1.86	2.77
Coil (Sheet)	1.38	1.92	1.85	2.74
Coil (Sheet Galvanized)	1.54	2.12	2.03	3.01

Figure 9: Variability of embodied carbon for different steel products varying the recycling content, with datapoints extracted from (Hammond & Jones, 2010)

Table 5 provides ECC values after ICE and EcoInvent to propose average default values. The opportunity lies in the definitions of average numbers per location. If a future database could propose an agreement for ECC standards, it can allow practitioners to use both average and more sophisticated customized values.

Table 5: Recommended default values for the ECC of structural materials (Iuorio et al., 2013)

	Material	EC [lbs_{CO2e}/lbs or kg_{CO2e}/kg]
Concrete*	Standard	0.11[1]
	High Strength	0.13[1]
Steel	Sections (beams, columns)	1.14[2]
	Sheeting	2.56[2]
	Studs	1.24[2]
	Plates	2.46[2]
Rebar	65% recycled content	1.24[2]

*The Carbon coefficients for concrete can vary in a significant way depending on strength, cement quantity, percentage of fly ash and blast furnace content, in this table two values are provided that can be applied respectively for normal concrete (C20/25 - C28/35 and 30% fly ash) and high strength concrete (C32/40 - C40/50 and 30% fly ash). This does not include reinforcing steel in the concrete.
[1] Coefficients evaluated based on (Hammond & Jones, 2010);
[2] Coefficients evaluated based on ECOINVENT.

In order to obtain an agreement for comparable ECCs, an option would be to develop product or material specific Environmental Product Declarations (EPDs). Including this in the material specifications would improve the quality of ECC values and make the results comparable.

4.3. Implementation: Unification, transparency and intellectual property

The last challenge defines the implementation of a database with material quantities and embodied carbon. The first step is to analyze existing embodied carbon estimator tools (Table 6). Current developments are mainly design-oriented. Usually, tools do not give a specific indication of what the baseline is. A database-oriented tool is needed to shift away from the design process towards disclosure of projects after construction, in order to give an idea how the embodied carbon of a new design will compare to a typical building of the same typology and structural system.

Table 6: Review of used and tested tools

Tools	Advantages	Disadvantages
TALLY beta version	- Uses BIM output - Design oriented	- How to control what is included in the BIM model - Transparency
SOM Environmental Analysis Tool	- Basic data input - Assumptions already made, but option to enter sophisticated model data	- Normalized metrics would be preferred (kg/m^2 instead of absolute values in kg)
Athena Carbon	- Established estimator	- Non user-friendly

Estimator		- Transparency
ARUP PECD	- Uses BIM output - Hundreds of projects available	- How to control what is included in BIM - Transparency

Two important aspects contradict each other: the need for transparency and the protection of intellectual property. Indeed, if a comparative database divulges all projects, the risk exists that companies will try showing "lower" embodied carbon compared to competitors, which could result in skewed data-points. Also ownership of data should be taken into account. An option would be to allow anonymous data input, which then undermines the transparency. Also, the implementation has to make sure the input method is unified, so that apples are compared with apples.

Therefore, uniform methods are necessary. If the same two variables (MQ in kg_m/m^2 and ECC in kg_{CO2e}/kg_m) are used for all project entries, with a clear definition of what is included (sub/superstructure), it will be possible to compare similar building types (office, residential, healthcare, stadiums, etc.), structural systems or locations. A unified and transparent database, with clear standards on ECCs and populated with hundreds to thousands of projects, would give a greater confidence in the Global Warming Potential (kg_{CO2e}/m^2) of construction projects and result in a baseline for comparison in the field of material weight and embodied carbon.

Examples of potential outcomes of the database are given in Figure 10 and 11. These express the preliminary results of the GWP of real projects. The user can filter by different parameters, such as building type (Figure 10) or structural system (Figure 11). The preliminary results of available data show that average values range from 200 to 500 kg_{CO2e}/m^2 or 40 to 100 psf of CO_2e.

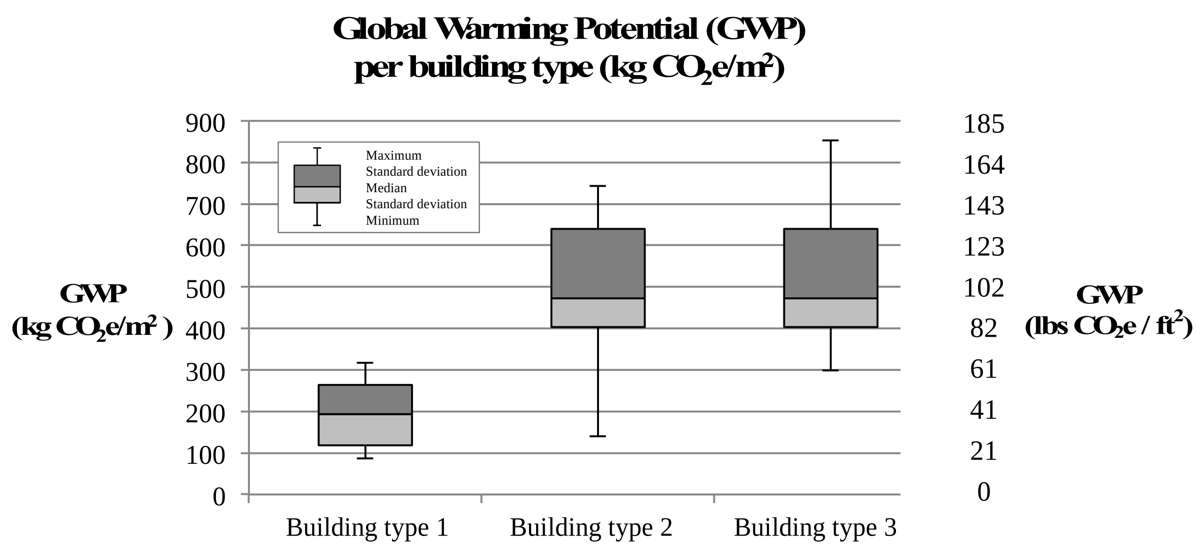


Figure 10: Example of GWP graphic showing range for different building types

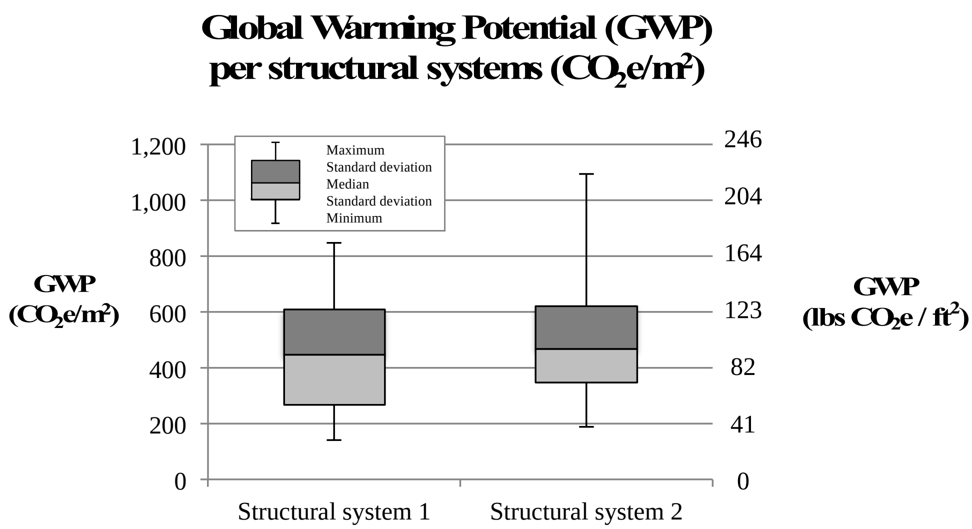


Figure 11: Example of GWP values showing range for different structural systems

CONCLUSIONS AND FUTURE WORK

The main challenges discussed in this paper are the following.

- The creation of incentives for companies to share data on their building projects.
- The identification of accurate default ECC values considering various location.
- The resolution of data transparency while protecting intellectual ownership.

Nevertheless, these challenges also lead to opportunities.

- The compatibility of data collection with Building Information Modeling tools allows for the generation of hundreds to thousands of data-points.
- The proposal for an agreement of ECC value ranges will facilitate the calculation of the embodied carbon of buildings.
- The unified methodology for calculating the GWP of buildings will define reference buildings for assessing the embodied carbon of building structures.

The key contribution of this paper is to pave the way to a more unified method for collecting structural material quantities, defining accurate ECC ranges and calculating the GWP of building structures. The challenges encountered in literature, in the review of existing tools and in practice have been synthesized and can point to several opportunities to enhance the understanding of embodied carbon in buildings. By separating the calculation of embodied carbon in building projects into three clear topics and defining challenges and opportunities for each of them, this paper creates the basis of a more unified and transparent methodology.

In the next steps towards creating the database, the research contributes by collecting hundreds of project data from various companies and relating these data to each other. This will create a baseline to benchmark embodied carbon in buildings. Ultimately, designers will incorporate Global Warming Potential as one of the factors to take into account in their design process.

ACKNOWLEDGMENTS

The authors would like to thank Frances Yang and Andrea Charlson from Arup for supervising the visiting academic research on embodied carbon in their offices. The authors would also like to acknowledge Wolfgang Werner from Thornton Tomasetti for collaborating and sharing data for our study. As beta tester of the Tally™ tool, the authors would like to thank Kieran Timberlake and PE International for allowing us to use their tool. Also, the authors are grateful for the feedback from the SEAONC Sustainable Design Committee and SEI Sustainability Committee. The authors gratefully acknowledge the financial support from the Belgian American Education Foundation, Gustave Boël – Sofina fellowship and the KuMIT project.

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