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Stand-alone calculation tools are not the answer to embodied carbon assessment

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Abstract

Recent studies have shown that the importance of embodied carbon is growing in relation to assessing the environmental impact of buildings. This paper investigates how designers are looking to tackle this, and the effectiveness of some of the methods chosen. Although a number of commercial and non-commercial organisations are developing in-house tools to calculate embodied carbon, these lack the flexibility to be adopted by a wide range of users as well as the efficiency required to be appealing to designers at the early stages of a design. An alternative to these stand-alone tools is offered through the functionality of Building Information Modelling (BIM) software, which is capable of incorporating embodied carbon assessments as part of the normal design process. The potential of plug-in tools to obtain embodied carbon data from suppliers is an area that remains to be explored further.

Selection and peer-review under responsibility of KES International

Keywords: Embodied carbon; buildings; greenhouse gases; carbon dioxide; envionmental impact assessment

Nomenclature

LCA	Life Cycle Assessment
BIM	Building Information Modelling
3D	3 Dimensional

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1. Introduction

‘The Stern Review’, commission by the UK Government in 2006, pointed to the overwhelming amount of scientific evidence that highlighted the serious risks of climate change and the need for urgent action towards reducing emissions of greenhouse gases on a global scale [1]. Although the estimates of emissions associated with the construction industry tend to vary it is generally accepted that one third to one half of UK’s carbon dioxide emissions are related to the construction and operation of buildings [2,], [3], [4]. The Innovation and Growth Team’s report, ‘Low Carbon Construction’ made a number of recommendations to implement a low carbon approach in construction in the UK. This report identifies the importance of whole life carbon assessment during the design process (see Figure 1 below).

Recommendation 2.1: That as soon as a sufficiently rigorous assessment system is in place, the Treasury should introduce into the Green Book a requirement to conduct a whole-life (embodied + operational) carbon appraisal and that this is factored into feasibility studies on the basis of a realistic price for carbon.

Recommendation 2.2: That the industry should agree with Government a standard method of measuring embodied carbon for use as a design tool and (as Recommendation 2.1 above) for the purposes of scheme appraisal.

Fig. 1. Innovation and Growth Team’s Recommendations [5, pp. 29–30]

Embodied carbon is defined as the sum of fuel-related and process-related carbon emissions associated with a building [6]–[8]. Calculations for embodied energy and carbon tend to include a number of stages for the life cycle of a building. The boundaries considered vary depending on the end results required and can be illustrated as in Figure 2 [2], [9], [10].

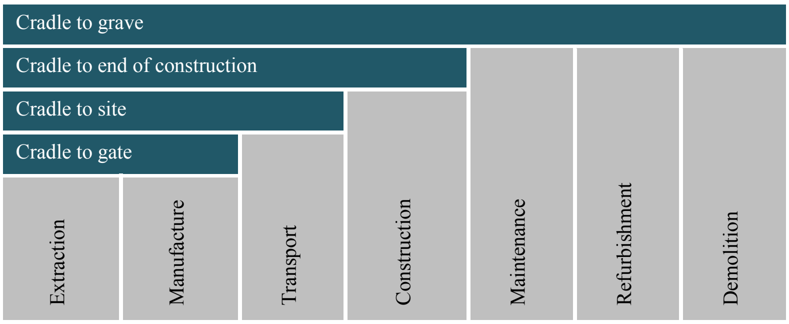

Fig. 2. Life Cycle Assessment Stages

The unique nature of buildings, multiple functionality, on-site assembly and long design life makes the life cycle assessment in the construction industry relatively limited [11]–[13]. Difficulty in obtaining a complete set of environmental data also makes the assessment process complex [11], [14]. There are a number of life cycle assessment tools currently in use. Athena Eco Calculator, Knowledgebase, Butterfly Tool, Carbon Calculator and BEES (Building for Environmental and Economic Sustainability) are some of the construction specific tools available to carry out life cycle assessments [8], [15].

The right time to carry out an environmental impact assessment on a design is a matter for debate. Although sustainability consultants claim that this should be done at the earliest possible stage, the decision is often affected by factors such as budget, programme and resource availability. Arguably, the most important design decisions are made at the early stages of the design process [11], [16], [17]. However, in common practice environmental performance analysis of designs is often left until the design is developed to a detailed stage. This lack of early integration of sustainability assessments into the design process leads to extensive modifications being required at later stages to meet the performance criteria [18].

Existing environmental methods such as BREEAM, which is widely used in the UK, requires specialist knowledge and is seldom incorporated at the early stages of the design development. Furthermore, embodied carbon is not always addressed under these assessments. Particularly with BREEAM, the main focus is given to the operational carbon component [19]. A number of organisations have identified the lack of tools available to carry out the embodied carbon assessment and are looking to explore the options to develop commercially viable methods. This paper investigates two of the existing commercially available tools for assessing embodied carbon and their effectiveness for utilisation from early stages of the design. It also explores the options for incorporating the assessments to Building Information Modelling (BIM) software to improve the efficiency levels.

2. Assessing Embodied Carbon

It is important to understand the requirements and preferences of designers for information as well as the type of tools available to carry out the embodied carbon assessments. Hence, this study included scoping stage discussions and a survey to collect opinions from practicing built environmental professionals followed by the analysis of two of the tools currently in use. Semi-structured expert interviews were used to better understand the tools and alternative options available. The two tools that were selected for this study represented two of the methods utilised in in-house embodied carbon assessment tools; spreadsheet and web-based calculation tools. Due to commercial sensitivity associated with the two existing tools analysed, they are referred to as LCA Tool 1 and LCA Tool 2 from here onwards.

For the scoping stage, an initial online discussion within the professional networking site LinkedIn was used to identify the areas to be further investigated in the research. This information was used to produce a short survey which was paper-based and hand delivered. The survey was distributed to a network of practicing built environment professionals known to the author. The professionals were selected due to their current involvement in the industry as well as for having over 3 years of experience. The survey was handed to 43 professionals representing architecture (27%), civil engineering (38%), project management (11%). quantity surveying (8%), services engineering (8%), sustainability (5%) and planning (3%). There were 38 replies and only one out of these was discounted due to it being incomplete. The survey replies were used to identify the ideas and trends to be explored further during the expert interviews.

The expert interviews were focused on exploring the LCA Tool 1, LCA Tool 2, BIM and use of modelling software as shown in Table 1 below. Interviewees were selected based on their knowledge on the specific tools and application of the concepts in real life projects.

Table 1. Details of expert interviews

Area explored	Interviewee Reference	Relevance
LCA Tool 1	Consultant A	Concept designer for LCA Tool 1
LCA Tool 2	Consultant B	Concept designer for LCA Tool 2
BIM	Consultant C	Responsible for promoting BIM in a multinational engineering consultancy
	Consultant D	BIM software developer
Modelling software use in design	Designer E	Services Engineer, user of Dialux lighting software
	Designer F	Services Engineer, user of fire engineering modelling software

2.1. Assessing Embodied Carbon using LCA Tools 1 and 2

One of the key ideas identified through the survey was the preference for quantitative information about the environmental assessment of a design from early stages of a project (Fig. 3). These findings were reinforced further by the comments of Designer F who highlighted the industry's tendency to "chase numbers". Both the LCA Tools 1 and 2 provide quantitative embodied carbon analysis of designs and therefore seen as suitable choices for this study.

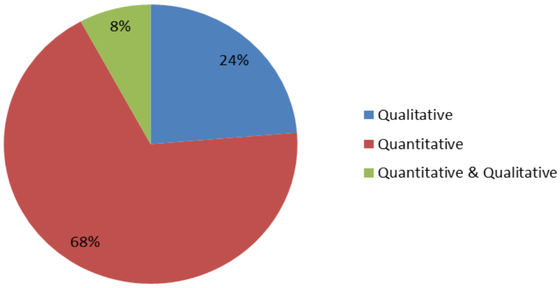

Fig. 3. Preference for the type of information on sustainability

LCA Tool 1 uses a number of spreadsheets interlinked to each other to carry out the embodied energy and carbon calculations alongside other energy, carbon and cost assessments. The options exist to input a limited amount of design parameters, materials and to specify items such as window types and other fittings. Once these items have been specified, there are options to look at the whole life costs, energy and carbon implications. It was evident that the design options that could be incorporated are limited to relatively basic geometrical shapes.

According to its concept developer, as the tool was designed to assess mainly housing schemes this has not been an issue since these designs tend to have essentially basic layouts. This is one of the common problems with the tools developed by individual organisations. The tools may work well within the environment they practice, but severely lack the flexibility to be adopted by others. Therefore, although they advertise the product as a way forward for "low carbon design and decision making", it is questionable whether it could be marketable as such with such strict limitations.

The initial attempts made by the author to use the LCA Tool 1 were relatively unsuccessful due to its complexity and lack of clear instructions. The tool comprises of nine spreadsheets that are designed to work with each other to calculate a number of separate outcomes. It was difficult to identify which spreadsheets should be completed first and how to move through the several tabs within them to avoid corrupting any embedded links. During the interview with the concept developer, he admitted that he is the only person within his organisation that uses the tool to carry out analysis. It is likely that its relatively complex nature is a contributory factor to this shortage of users. The main structure of the LCA Tool 1 was developed by individuals who are not designers, in an environment that is not directly connected to the design process. Concept developer agreed that although they aimed to develop a tool that was marketable, they have only been able to demonstrate that it works at a conceptual level.

Compared to LCA Tool 1, the data input process for LCA Tool 2 was simpler to understand and follow. The principles of building up the information for the assessment are relatively similar to a 'Bill of Quantities' used in cost analysis. The web based interface allowed the user to create new projects from scratch or to copy existing projects and amend as necessary to calculate embodied carbon values. An in-house database containing data from Bath ICE and Defra data sets among others provided the embodied carbon and energy data for the calculations. The main concern associated with such in-house databases is the availability of up-to-date data. When databases are not directly connected to data providers, additional regular efforts are required to keep them updated. Consultant B, the concept designer for LCA Tool 2, acknowledged that the database maintenance costs could be an ongoing concern, particularly when the tool is not making sufficient return on the initial investment.

2.2. Issues associated with stand-alone embodied carbon assessment tools

Both these cases highlighted three fundamental concerns associated with stand-alone embodied carbon analysis tools;

- methods of generating the quantities required to carry out the calculations,
- dealing with the variations associated with a design, and
- obtaining the latest data available to carry out the analysis.

It was noted that with embodied carbon analysis, the main constraints are not the mathematical processes. This was supported by the comments made by Consultant A, as well as the information available regarding the background calculations for the LCA Tool 2. Instead, it is more dependent on the data availability and ease of data input. The literature review and the analysis of the two LCA tools supported this hypothesis [20]. Disappointingly, both the LCA tools assessed lacked the flexibility to effectively deal with these issues. Furthermore, keeping the databases up-to-date may not necessarily be a simple or an economical exercise.

3. What other options are available?

3.1. BIM software for embodied carbon assessment

The inefficiencies identified in the previous section appear to arise mainly from the lack of integration of the embodied carbon assessment into the design development process. Although the review of existing literature highlighted a number of studies which were concentrated on developing assessment tools [21]–[23], not enough of them have focused on connecting them to the design tools such as the drawing and modelling software.

In recent years, BIM software has been gathering momentum both as a platform for sharing information during the design development and as a long term building management tool. With the UK government making BIM compulsory for all public sector projects from 2016 [24], use of this technology is likely to increase over time. Although BIM is more than just a 3D model, in the early design stages, the 3D model together with its capabilities to store additional information about the design could provide a useful platform for assessing sustainability aspects. If environmental impact data about building components could then be added to the BIM model, it could be used to carry out the analysis using the quantities from the model. The values obtained could be used to compare the design options at early project stages. In addition, the direct attachment of data to 3D models could add strength to the communication of information [25] about relatively new practices such as embodied carbon assessments.

The use of BIM software to calculate embodied carbon was widely supported by both the survey respondents and the interviewees. The approval rating among the survey participants for these ideas was 81%. One of the expert interviews was with a consultant who is responsible for promoting BIM within a multinational organisation (Consultant C). He is of the opinion that its ability to assess sustainability of designs is one of biggest drivers for implementing BIM. Consultant D, a BIM software developer confirmed that BIM has the capabilities to host embodied carbon data attached to the 3D models. However, utilisation of these features is dependent on the project requirements and commercial viability of the additional analysis to the design process.

It was evident both from the literature [26], [27] and the comments by the interviewees that the potential in BIM software for developing low embodied carbon building designs is not currently explored enough by the industry. Consultant C identified six different parameters that could be used from an early design stage to assess designs; embodied and operational carbon, embodied and operational water, embodied (or capital) and operational costs. It is important to highlight that all these parameters are quantifiable characteristics associated with a design.

3.2. Plug-in tools to work with BIM software

The embodied carbon data can be added to BIM software in number of ways. One of the options explored during the interviews was the introduction of plug-in tools. A similar product is currently used by the lighting industry for developing lighting designs using the industry-developed software, Dialux. Designer E is a regular user of this software. For this particular application, plug-in tools obtained from the suppliers contain technical information about specific products that is added to a 3D model to generate lighting design. The demonstration provided by Designer E and consequent trials of the software by the author confirmed that these plug-in tools are easy to obtain and simple to add to the software. The software and the associated plug-in tools are generally available free of charge.

The use of information that can be easily added to the software that the designers are already using could be considered as a commercially savvy way of encouraging designers to use the products in designs. The way this software operates was commended by Consultant D. He confirmed that in terms of technology, it is possible to develop similar applications to provide embodied carbon details about building materials and components that could be added to BIM models. In addition to this, designers can also add their own equations to the software to automate the embodied carbon calculation process to a certain degree. However, both options require an educated user to carry out the process.

In general, the use of embodied carbon data in a BIM environment to assess early design options appears to be a practical solution that would provide the designer the information required to develop low embodied carbon designs. There are concerns about the availability and accuracy of the data. However, the current level of accuracy could be considered sufficient for design comparison purposes. As suggested by the interviewees and the literature, the data is also likely to improve over time. The key aspect to address over time is establishing a protocol for auditing the information to ensure that the data produced meets an accepted standard. This was supported by the comments of Consultant D who raised the concerns associated with establishing processes and standards to carry out the design. According to him, without well-thought-out processes and standards, it would be difficult to produce comparable analysis results.

4. Discussions

4.1. The need to improve knowledge and change attitude

It was evident from the survey and the interviews conducted that under most circumstances, it was unclear how the environmental impact assessment of designs are being carried out or who was taking the responsibility for carbon reduction. There was a certain sense of passing the responsibility to another discipline, particularly towards sustainability consultants. This was an interesting choice given that in practice, the sustainability consultants are often not involved at the early stages of a project. As identified by the literature and interviews, there are a number of factors contributing to this lack of clarity concerning responsibilities. The poor knowledge level among the designers about the concept of embodied carbon was recognised as one of the main reasons. This result supports the proposition that the carbon assessment of buildings is a fragmented process where not enough responsibility is taken by all the disciplines involved; processes such as BREEAM also act to encourage this fragmentation.

The engineering press and marketing campaigns can often suggest that sustainability is at the forefront of the thinking of all professionals involved in the design process. However, in reality this does not appear to be the case. The construction industry is heavily dependent on knowledge and experience gathered over time [28], with many industry professionals showing a tendency to stay with tried and tested methods. This reluctance for change was noted through the scoping stage discussions and supported by the experiences of the interviewees who are currently promoting LCA tools and BIM software. Unfortunately, this approach creates a mind-set that is not necessarily encouraging to new ideas and practices. The fear of losing prestige among experienced designers who may not be prepared to learn about a new subject area could be a factor that influences a design in a way that is not often assessed.

It can be argued that even when the consultants are prepared to carry out the essential extra works required to analyse embodied carbon impact of buildings, clients may not be prepared to pay the additional costs associated with the analysis. In the current economic climate where project programmes and budgets are regularly scrutinised by clients as well as designers, it is likely that commercial factors also contribute to the omission of environmental performance related analysis. This area requires further research.

4.2. BIM has the potential to deliver better options

The designers tend to use visual and numerical tools extensively during the design development. Although design reports are often produced as deliverables, they tend to be a by-product of the design process. It would be reasonable to say that numerical analysis takes priority in the design development. The main advantage of BIM software is its ability to deal with graphical, quantitative and qualitative data. Visual and numerical information generally has the potential to communicate comparative information more effectively than qualitative data. This approach could also be considered more appealing as a method of communication to designers from multiple disciplines.

As demonstrated through the interviews, the technology exists to develop methods to attach the embodied carbon calculation to the design development process using BIM software as the common platform. There are areas to be explored further such as plug-in tools, where the manufacturers and suppliers could become involved in the design process by supplying data that could be easily attached to a design. A similar approach is already in use in the lighting industry. Lightings software Dialux and its plug-in tools could be described as a successful collaboration between designers and suppliers to embrace the advances in digital technology to deliver designs more efficiently. Although some plug-in tools have been developed and trialled for BIM software such as Tally [29] and RTEI [30] for Rivet, their effectiveness in real life projects remains to be tested.

BIM software is marketed as a tool that will be used both to design and to manage buildings [24], [26]. The long-term use of this software for the operational phase of the building makes it an ideal candidate for the embodied and operational carbon data collection processes. Although BIM theoretically has the ability to be the right form of platform for developing low embodied carbon designs, care should be taken when moving towards this approach as new technology often tends to alienate a certain percentage of potential users who are not comfortable with embracing technological changes. These concerns were also supported by Consultant A. He who was under the impression that BIM was not as developed as the industry has been led to believe. Comparatively, Consultant C and Consultant D strongly supported the capabilities of BIM software to deliver this function alongside design development.

4.3. Ideas to be explored further in a wider context

From a designer's point of view, developing low embodied carbon designs could be considered as a state of mind. It is the cultural awareness that needs to be bred into the designers in a similar manner to how the awareness of health and safety was raised within the industry. Health and safety has undergone considerable changes over recent years, particularly through the introduction of Construction Design and Management (CDM) regulations. Notable levels of improvements have been achieved by placing the responsibility for health and safety on individuals as well as all parties [31]. It could be taken as a good example of changing the attitude in the industry through implementation of regulations and good practice. It is acknowledged that it has been a long process to get to this level. Therefore, if similar changes are desired in relation to developing low carbon solutions, there is a strong argument to encourage high level of commitment from the industry and regulating authorities as promptly as possible.

Value engineering is another concept that has been successfully applied by the construction industry, particularly by cost consultants, that could be adapted for carbon reduction purposes. In its current format, the aim of the exercise is usually to make the design more economical by identifying areas that could be amended or removed without heavily compromising the intended functions of a building. Some may argue that this process could quite often heavily compromise a design. However, in a commercial environment where projects are often driven by cost, it is a process that offers savings to the clients. If initial embodied carbon values are calculated for designs, 'carbon engineering' could be applied to explore the options for reducing the overall embodied carbon impact.

For designers, one of the key problems associated with carbon assessments are the limited ways it can be presented to a client in terms of costs. If the costs associated with embodied carbon could be quantified and the cost benefits of reducing embodied carbon could be demonstrated, it would provide a valuable set of information to a client that would aid decision-making. If carbon taxes were to be introduced in the future, this process would inevitably become the focus of significant attention within the industry. There are a number of studies looking at the options for 'green tax' [32] and 'carbon accounting' [33]–[35]. This may be considered as another route that regulators could take to clamp down on emissions. It can be compared to how the increases in landfill taxes have encouraged waste reduction processes.

4.4. Limitations of the research

It is acknowledged that these results may not be representative of the wider industry. It is limited to the number of participants of the survey and the interviewees. The finding may also be affected by the bias of the researcher as well as the biased opinions of the survey participants and the expert interviewees. Furthermore, the survey participants' and interviewees' understanding of their own level of appreciation of a concept may not always be compatible with widely accepted definitions.

5. Conclusions

The research found that for the sample assessed, designers are recognising the need to address environmental impacts of building and preferring to see this information in quantitative format during the design development process. There are commercially available tools looking to address these requirements. However, the two in-house tools analysed for this paper, the spreadsheet based LCA Tool 1 and the web based LCA Tool 2, were seen as lacking in flexibility to be adopted by wide range of users from early stages of the design. The extensive manual input required and validity of the databases used, both of which can have significant commercial implications, were two of the main contributory factors.

With the UK government's intentions to make BIM software use compulsory for all public sector projects, its use is becoming more popular. Therefore, it was selected to be investigated as an alternative option to using in-house stand-alone tools. Its capability to host graphical, quantitative and qualitative data makes this software more flexible compared to the aforementioned in-house tools. Furthermore, the ability to use plug-in software to add embodied carbon data gives BIM software a wider range of options for incorporating data to a 3D model to carry out calculations. However, further collaborative research between designers, suppliers, software providers and clients would be necessary to better understand these capabilities and limitations of this approach.

The research also pointed to the lack of knowledge about embodied carbon as one of issues that should be addressed. Further training could improve designers' knowledge about the embodied carbon assessments. However, this process would require the right level of commitment from educational establishments, employers as well as current and aspiring designers themselves. In addition to educating designers, the way designs are approached also need to change at a fundamental level. A new-breed of designers with the right set of skills and approach is require to effectively address the issue of developing low embodied carbon design from the start of a project. Some principles of practices such as health and safety and value engineering can be adopted to develop certain parts of this process. Furthermore, methods of quantifying the embodied carbon element in terms of the cost would provide a more widely understood set of inform to aid the decision making process.

The findings of this paper suggest that further research is required to explore the concepts investigated during the survey and interviews in greater detail. The opportunities with BIM software and plug-in tools also need to be explored further, with appropriate case studies to understand the effectiveness of this approach to develop low embodied carbon building designs. In a wider context, options for cultural changes need to be explored to identify methods to implement the development of low embodied carbon designs to the everyday-thinking of designers.

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