

THE INTEGRATION OF EARLY STAGE LIFE CYCLE ANALYSIS INTO ARCHITECTURAL PRACTICE THROUGH AN IT SUPPORTED PROCESS

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Abstract

Within the construction industry, a variety of tools undertake Life Cycle Analysis (LCA), including OneClick LCA, Tally and others recently developed. Early design decisions provide the biggest opportunity to reduce the whole life carbon (WLC) of a design. A mixed methodology approach including software appraisals, questionnaires and literature reviews found that current LCA tools do not encourage a free flowing design process and cannot analyse early stage decisions for their carbon impact. Integrating BIM and LCA at early design stages, reviewing decisions, using modern computing techniques and automated analysis is essential to addressing and reducing impacts through the construction phases.

Introduction

There is a growing base of evidence to suggest the impact of climate change is having an adverse effect on the natural and built environment. One example of addressing this is the UN adopting 17 sustainable development goals which were adopted by all United Nation Member States. These goals stated that ending poverty and other deprivations must work alongside improving health and education, reducing inequality and spurring economic growth, whilst tackling the threat of climate change (United Nations, 2015). Within the UK, the built environment is responsible for 25% of greenhouse gas emissions produced (Environmental Audit Committee, 2022). If the UK is to reach their Net Zero by 2050 goal, these figures need to be significantly reduced. Worldwide, the construction industry is currently responsible for 39% of energy related carbon emissions with 28% being from operational carbon and 11% being from embodied carbon (World Green Building Council, 2022). The construction industry has a vital part to play in addressing the climate emergency. Furthermore, the focus of WLC reduction within the construction industry is shifting from focussing on operational carbon reduction to reducing embodied carbon, this is due to the major improvements in the operational energy efficiency of the construction sector (Victoria and Perera, 2018). Operational carbon

emissions are also more regulated than embodied carbon emissions with policies such as Approved Document L in the UK, which regulates operational carbon emissions. Currently there are no Government policies within the UK that require the assessment or control of embodied carbon emissions (Building to net zero: costing carbon in construction: Government Response to the Committee's First Report, 2022). Voluntary targets have been set in the UK by construction professionals for the reduction of embodied and operational carbon, this includes targets set by the Low Energy Transformation Initiative (LETI) and the Royal Institute of British Architects. LETI is a UK based network of built environment professionals that are collaboratively working towards a zero carbon future for both the planet and the UK (leti, n.d.).

The RIBA has developed the 2030 Climate Challenge, this sets a series of targets for Architectural practices to meet with the aim to reduce embodied and operational carbon (RIBA, 2019). LETI have also published a series of guidance documents to be used by construction professionals in order to reduce the WLC of the construction industry. Architects have a key role in reducing emissions within the construction industry, with consideration and analysis across all stages of the RIBA Plan of Work. Within the design process the key design decisions that affect both operational and embodied emissions cannot currently be automatically analysed and there is no automation within the design process. The software currently available, such as Autodesk Revit and Autocad, act as an essential tool within the design process but do not encourage the reduction of emissions. Low carbon design is essential within the construction industry in order to address the climate crisis.

The objective of this paper will be to evaluate the current processes and software used within the architectural design process and use for the calculation and reduction of WLC based on a large architectural practice in the north east of England. It will also be reviewed how embodied carbon is currently calculated within architectural practice and whether it is currently integrated within the process. Consideration will be taken regarding the perception Architects and designers have regarding embodied and operational carbon

analysis across the RIBA plan of work. This will lead to discussions on how the process can be automated using IT in order to be integrated into architectural practice. In turn this will help draw conclusions on how to reduce embodied carbon within the construction industry through automation in design and integration of analysis.

The use of Building Information Modelling (BIM) within architectural practice is still developing. There are still barriers to the implementation of BIM in practice, these include lack of awareness, lack of training, training expenses and social resistance to change (Ahmed, 2018). Research has shown that the construction industry has been slow in adopting advancements and technological innovations that have enhanced workflow and productivity within other industries (Ojo and Pye, 2020). There are a variety of tools that are available that both support the utilisation of BIM and tools that incorporate LCA. These tools have not been widely implemented in practice or across the RIBA plan of work, creating a fragmented process. The RIBA plan of work organises the process of briefing, designing, constructing, maintain and operating into 8 stages (RIBA, 2024). The tools need to be seamlessly integrated into the RIBA plan of work allowing use across the lifecycle of a project. The current fragmented approach has not encouraged use of the tools during the design process where major design decision affecting embodied carbon are made.

Literature Review

Through studying relevant literature, from both academic and industry sources. The aim was to find out information regarding current software, current LCA tools, importance of early stage analysis, automation within design and the ability to interlink BIM and LCA.

Current Software and analysis tools

It is imperative that computational tools are utilised within architectural practice, both throughout the design process and for LCA. Within the construction industry there are a variety of tools that can conduct LCA of a design. These include but are not limited to Tally, One Click LCA, Ecolab, HBERT and FCBS Carbon. From this list, One Click LCA and Tally are the only tools that can be fully integrated into the BIM environment (Al-Ghamdi and Bilec, 2017). At the early design stages, these tools are not able to be utilised as there is not enough information within the design to undertake a LCA. The majority of tools that have been developed are designed for either post-construction evaluations or evaluations at the detail design stage, these tools are then used as part of scientific research as opposed to as a design tool (Meex et al., 2018).

LCA are currently a data intensive process, requiring a high level of information and computing ability by the user to calculate the embodied carbon of a design. LCA are currently used to give feedback as opposed to being able to be used as a tool to improve the design (Röck et al., 2018). Currently LCA's have not been widely

adopted into architectural practice due to the complexity of analysis, the tools are very time consuming to use and there are challenges in gathering the required data (Kamari, Kotula and Schultz, 2022).

There is a high demand for a simplified approach to LCA that Architects can use within practice, and integrate into their current workflow. This will have to have an efficient and simple approach that does not require the detailed knowledge of LCA (Hollberg and Ruth, 2016). In order for LCA to be used and accepted into practice, the tools must be seamlessly integrated into the workflow and also become embedded in the culture of the practice (Means and Guggemos, 2015).

The Royal Institute of Chartered Surveyors (RICS) have released whole life carbon assessment (WLCA) for the built environment. This document will provide guidance and become the standard for consistent and accurate carbon measurement in the built environment (RICS, 2023). Previously, there was a need to standardise embodied carbon measurement as there was a huge variation in embodied carbon figures reported, which was attributed to the variability of the assumptions made in the measurements (Victoria and Perera, 2018). The results of assessments are still dependent on a series of factors such as system boundaries which are specified in BS EN 15978. The boundary choices can make a significant difference in embodied energy calculations (Dixit et al., 2010). Another variable could include choice of material library or data sources, within the UK that could include but is not limited to The Inventory of Carbon and Energy (ICE) and the Built Environment Carbon Database (BECD).

Building performance Assessment and automation within design

Worldwide there are a variety of building performance assessments including BREEAM, LEED, DGNB, Estidama and more. The schemes have some key differences which include the weighting that they give to different environmental categories. The weighting systems take into account climate and culture (BSRIA, 2011). These systems assist in creating goals and benchmarks and assist comparing alternative methods, however these methods are rarely incorporated at the early stages of design development (Häkkinen et al., 2015).

Currently there is no continuity throughout the RIBA stages in order to assess the WLC of a building (O'Sullivan et al., 2004). As it is a fragmented approach, current tools and systems have been described as too time consuming and complicated to effectively integrate into the design process. It was stated that it is important to develop the usability of the tools, integrating methods for WLCA into the design process, utilising a semi-automated tool (Häkkinen and Belloni, 2011).

As IT use within architectural practices is still growing, especially the use of BIM, design automation needs to be

utilised. Design automation applications can show the environmental impact schemes can have, providing the opportunity to evaluate early design decisions against the WLC of a project. This can be done using a set of rules or parameters that evaluate the design (Gerth et al., 2016). Automation can also be utilised in order to reuse solutions that have been used on other projects, removing some of the routine work from the workflow of a project, allowing the designer to focus on other areas of the project (Gerth et al., 2016).

Digital tools provide the opportunity to decrease the additional work that is required to accurately undertake a life cycle assessment. Workflows have been developed to connect an LCA database such as the Inventory of Carbon and Energy (ICE) to a BIM software. For example there are cases where Dynamo for Autodesk Revit has been utilised (Hollberg, Genova and Habert, 2020). BIM and LCA have the potential to overcome the time consuming nature of undertaking a LCA, which will in turn facilitate the integration of environmental analysis, obtaining quick results about the impact of a building from an early design stage (Kamari, Kotula and Schultz, 2022). Soust-Verdauger et al. (2017) highlight significant challenges in the interoperability among the various applications, software integration of BIM and LCA and the amount of data that is required for LCA. It was also discussed that BIM-LCA integration will only be useful if the results and amount of data provided are user friendly (Soust-Verdauger, Llatas and García-Martínez, 2017). These tools are able to be used when there is a high LOD in the design.

Early Stage Analysis

The majority of Architectural practices currently rely on in-house knowledge to make design decisions regarding WLC due to lack of access to specialist knowledge or simple design tools (Meex et al., 2018). Meex et al. (2018) also stated that in the earliest design stages Architects define the WLC of a building over its whole life cycle, often unknowingly, due to the lack of availability of analytical tools. Dunant et al stated that good early stage design decisions can halve embodied carbon (Dunant et al., 2021). To achieve this, it has been stated that designers have to have a greater understanding of which material and dimensioning decisions most significantly determine a building's environmental impact and which decisions are less important (Basbagill et al., 2013). It has been discussed that the building design process does not have the tools to analyse and consider WLC in the early stages of design. The most fundamental decisions which will affect the WLC of a building are conducted at an early stage. WLC reduction is not limited to material selection at an early stage design stage. It is widely discussed that a better form factor can make a huge difference in the reduction of embodied and operational carbon (make, 2021). Other considerations that should be analysed at an early design stage include window to wall ratio,

orientation and structural grid spacings (Dunant et al., 2021). Basbagill et al. (2013) stated that considering shape and orientation during the early design stages, it is possible to reduce a designs environmental impact by 40%. According to Dunant et al. (2021), the typical building frame could have 40-60% less embodied carbon if a simple structural grid was chosen over a complex frame.

Window to wall ratio has a great impact on the operational energy of a building. Higher window to wall ratio is expected to be associated with increased heating energy due to more conductive loss through larger windows, but decreased lighting energy because bigger windows let in more daylight (Troup et al., 2019). An optimal window to wall ratio needs to be considered, this is one that minimises the sum of the energy use for heating, cooling and lighting (Goia, 2016). The optimum figure for different building typologies needs to be taken into account at early design stages. A building's orientation combined with its glazing ratio is key to minimising energy demand (LETI, 2020). LETI conducted a study that proved difference orientations of a building can almost double the space heating demand of a building (LETI, 2020).

Currently analysis is usually carried out after the detailed design stage has taken place. This is due to earlier stages of the BIM model having a low Level of Development (LOD), where generic building elements are used and accurate whole life carbon analysis cannot take place (Röck et al., 2018). Whilst analysis at a later stage gives more accurate data with the higher LOD, the ability to influence change is significantly lower. LCA should be able to take place at the earliest BIM LOD (LOD 100) in order to have the highest impact throughout the design. Changes to the developed design following later stage analysis will have larger cost implications than at an earlier stage, and the ability to influence change is lower (Gervásio et al., 2014). Gervásio et al. (2014) suggest an approach that involves a set of pre-defined construction components which incorporate embodied carbon impacts. This will provide the designer with the ability to compare options. Similar analysis is available within the H\B:ERT tool, an open source Revit tool that allows the designer to analyse building components (Hawkins Brown n.d.).

Methodology and Approach

Questionnaire

In order to gather data from a wide range of participants across a variety of stages of their careers in the field of Architecture, a questionnaire was undertaken. This included but was not limited to Architectural Technologists, Architects and Architectural Directors. Being able to gain information on the level of the participants career pinpointed the gaps in knowledge and skills within architectural practice. The questionnaire

was systematically constructed following the process of the RIBA plan of work. It was structured to review strategies for assessing carbon impacts and gaps in knowledge/software across the RIBA plan of work. The questionnaire discusses levels of knowledge of WLC, analysis conducted within practice and software used at different RIBA stages.

Review of Current Software and workflow

There has been a variety of LCA tools, utilising different carbon databases. In order to gain an understanding of the opportunities and constraints of existing tools and software, a range of LCA tools will be reviewed. It will be considered how they will be able to be implemented into practice and into the workflow of a project.

Through the sources mentioned above, a workflow within practice will be identified. The workflow will be analysed and areas will be identified that would benefit from automation and LCA using IT within the design process. This will lead to a process or framework being developed that will assist in the reduction of embodied and operational carbon over the all stages of the RIBA plan of work, utilising appropriate tools.

Results

Questionnaire

The results of the questionnaire covered a wide spread of people across various stages of their career.

The results provided an insight of when the design process progressed from 2D on paper to 3D utilising Computer Aided Design (CAD). CAD was used from RIBA Stage 2, Concept Design. The main software used according to the participants was Autodesk Revit, which is a software that supports BIM management (breakwithanarchitect, 2018).

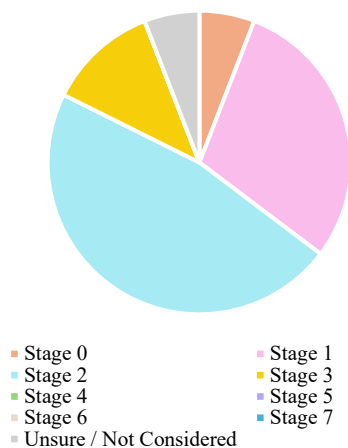


Figure 1: At what RIBA stage do you begin to use Revit

50% of participants thought that the key decisions regarding embodied carbon in a project were made at RIBA Stage 3 (Spatial Coordination). 22% stated that they considered the key decisions to be made at RIBA Stage 4 (Detailed Design).

Only one participant had conducted LCA on a project, with 78% never having conducted or outsourced an assessment. The one participant that had conducted LCA stated that they completed it at RIBA Stage 4 as it was a requirement of the project brief.

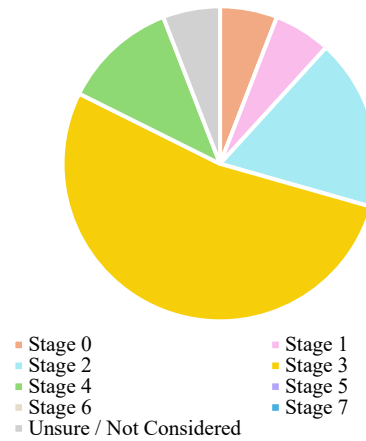


Figure 2: At what stage do you think the key decisions regarding embodied carbon are currently made on our projects

All of the participants stated that more guidance is needed within architectural practices to reduce embodied carbon at early design stages and throughout the project.

The most common response for lack of integration of embodied carbon analysis is the lack of knowledge and time. Alongside this there were comments about the lack of suitable software in order to automate the process. It was discussed that the more automated the process of analysis, the more likely it will be to be integrated into the design process. It was also commented that the main tools that are currently used do not produce live feedback and make reviewing design changes possible. Furthermore they are more mathematical as opposed to using design data, with a data heavy interface, making them unappealing to the design based users. They do not provide results that are easy to understand and are not visual.

Review of Current Software and workflow

A review of a range of tools and software was undertaken. The tools chosen are primarily aimed for use within Architectural practice, reducing the WLC of a project.

The first tool that was reviewed was OneClick LCA, this tool has the ability to extract information from a Revit model. This tool can only be utilised if the design is fully developed and the materials have been correctly set. Given the detail required, this will be used at RIBA Stage 4. It is also reliant on the Revit model being accurately and correctly modelled. Once the analysis has been conducted on the OneClick LCA web platform, it is necessary to manually check the analysis to confirm

accuracy, this is a very time consuming process. OneClick LCA can compare a variety of EPD's, and states that it has the worlds largest construction LCA database (One Click LCA® software, n.d.).

FCBS Carbon is an excel based tool and requires all information to be manually input. The tool uses data from the Inventory of Carbon and Energy (ICE) and product EPD's (portal.fcbstudios.com, n.d.). The tool can be utilised at an earlier stage of design, but quantities and material choices are still required.

Within Architectural Practice, Computer Aided Design (CAD) is utilised from RIBA Stage 2. No evidence was gathered showing that embodied carbon was analysed at this stage, or further through the project. This was supported by the literature that the sector is resistance to new innovation technologies. Work by Alwan and Ilhan Jones, 2022 claimed that within the industry, one of the main barriers is the resistance to change from the traditional working practices alongside the time required to adapt to new innovative technologies.

Discussion

The results show on the whole that there is a requirement for both early stage LCA analysis and also simpler and more accessible design tools to be put in place to implement this throughout architectural practice. This is an important development to pursue, with the goal to reduce the environmental impact of the construction industry. This study has reinforced the need for development within architectural practice focussing on linking LCA and BIM. The literature has shown that

not possible to conduct an accurate LCA at early design stages. Even though the current tools available cannot accurately measure WLC at early design stages, decisions can be made that affect the WLC of a project. Current literature shows that early stage design decisions can significantly reduce the WLC of a project. These early stage design decisions need to be analysed in order to set the design on the right trajectory to lower WLC. The comments received in the questionnaire also stated that more guidance is needed both with regard to design decisions and material choices.

The results of the questionnaire suggest that the key decisions regarding WLC are made at RIBA Stage 3. Existing literature suggests that these decisions are in fact made at RIBA Stage 2. As both sources state that the most important decisions regarding WLC are made in the early stages of the design process, it is evident that further tools and guidance is needed within the industry to assist in decision making. The early stage design decisions need to be analysed in order to provide guidance in low carbon design. The analysis needs to be undertaken as an automated process so that it can run hand in hand with the standard design process. This will encourage the new system to be widely adopted, especially if the process is neither complex or time consuming. Having design analysis from RIBA Stage 2 will assist in the reduction of WLC, before material selection takes place. The results discuss that key early design decisions effect the WLC of a project before material selection takes place.

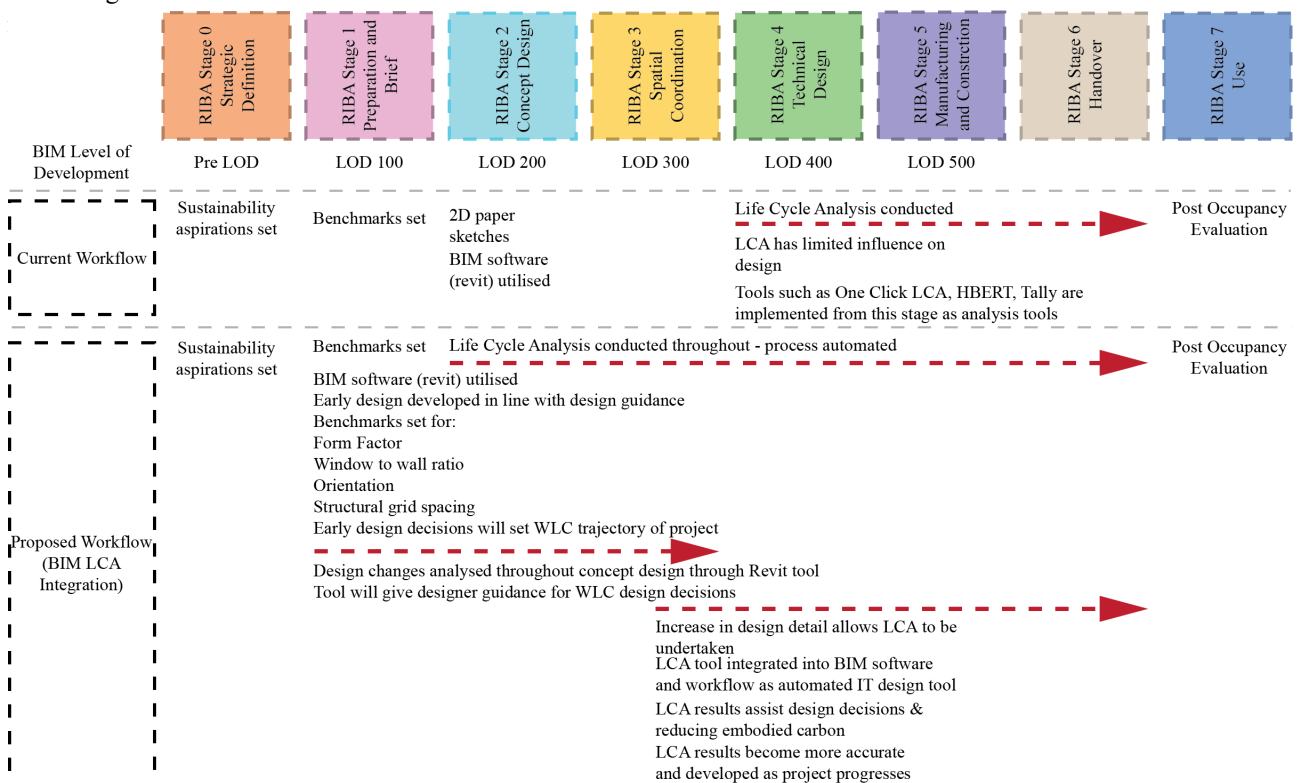


Figure 3: Existing and proposed workflow

With Revit being used from RIBA Stage 2, automation of analysis using IT tools within the design process would be able to be implemented from an early stage. Alongside this, using computer modelling from concept design stage should allow embodied carbon analysis to take place throughout the design process and through the RIBA work stages. Analysing the project from early stages will allow the design process to be influenced by constantly reviewing the information. Integrating analysis through an automated process at an early stage will assist in this decision making, increasing the ability to reduce embodied carbon from an early stage. With the industry being resistant to change from the traditional process, the tool will have to be simple to use and analyse the results, as well as not being a time consuming process.

Following analysis of both the questionnaire and existing software available it is obvious that there is a gap within Architectural Practice regarding automated LCA within the project workflow. The tools that are currently available either require a higher skill level than is available in practice or are time consuming to undertake. This is evident in the fact that only one participant had made use of a LCA tool within their projects. Furthermore, as the analysis was only conducted at RIBA Stage 4, we have to consider whether this had an impact on the final design, or whether the tool was used to only report the impact.

Conclusion

Analysis has confirmed that there is a gap in WLC design and analysis during the concept design stage or RIBA Stage 2. The tools currently available can analyse projects with a high LOD and the tools require a high skill level and are time consuming. Creating an IT based tool that is able to be utilised at an early concept design stage where we have the ability to have the biggest impact on the WLC of a project is necessary.

After reviewing relevant literature it is apparent that it is not possible to accurately undertake LCA at early stages of a design. The literature did provide an insight into the fact that early stage design decisions can have a large impact into the WLC of a project. These early stage decisions need to be analysed, this will provide guidance to the designer that the decisions made will set the project on the right trajectory to reduce the WLC. As the survey states, key decisions regarding WLC are made at RIBA 2 & 3, as this is where the major design decisions are made, setting the trajectory of the project.

A tool needs to be developed that can analyse early stage design decisions and provide the designer with feedback about the decisions they make. With the lack of detail at early stages, properties analysed will include form factor, window to wall ratio, structural grid and orientation. In line with the tool, a series of benchmarks need to be developed so that the designer understands the decisions that are being made. Following the analysis, it is not

possible to conduct an accurate LCA at early design stages.

Following the feedback, this tool will have to be automated and take information from the model and provide the designer with a graphical representation of any carbon hotspots and room for improvement. The tool will have to be digitally integrated into the workflow of a construction project, giving design guidance throughout the process. This research shows that there is a need for future tools and gives the foundations for a future tool to be developed. The analytical process conducted within architectural practice shows the need for a design based tool that utilises IT tools that are integrated into the design and construction process.

In conclusion it is apparent that there is a gap in early stage analysis. Following this initial research a tool will be developed that can be utilised from RIBA Stage 2. The tool will assess early stage design decisions such as form factor, window to wall ratio, structural grid and orientation automatically through a Revit based plugin, assisting the designer in making decisions that will affect the WLC of a project before being able to conduct LCA.

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