BUILDING INFORMATION MODELLING (BIM) AS AN ENABLER FOR WHOLE-BUILDING EMBODIED ENERGY AND CARBON CALCULATION IN EARLY-STAGE BUILDING DESIGN

AMALIA BANTELI & VICKI E. STEVENSON
Welsh School of Architecture, Cardiff University, UK

ABSTRACT

In recent years, there has been a worldwide effort to reduce carbon emissions from buildings. Operational energy (OE) reduction has been the main focus of the Industry as it accounts for a greater proportion of carbon emissions throughout the building life and is easier than embodied energy (EE) to predict. However, as OE is reduced, embodied energy and carbon emissions become more significant. Further to this, early-stage design decisions are crucial as they determine a significant portion of a building's life-cycle impacts and cannot easily be amended later in the life of a building. Currently though, there is a lack of legislation and guidance relating to embodied carbon (EC) in buildings. This, together with the UK construction industry fragmentation, creates a significant barrier to dealing with embodied carbon at the design stage. The UK Government has mandated the implementation of collaborative 3D BIM for all public-sector projects. This step aims to tackle cost and carbon emission reduction targets by encouraging the construction Industry to operate more collaboratively thereby enabling greater efficiency. Since BIM empowers communications and stores information into one single digital model it has the potential to enable whole-building EC calculations. This can facilitate EC calculation to be included in early-design stage. This paper looks at literature that relates to BIM and EC's role in early-stage design and draws conclusions on how BIM can enable EC calculation inclusion to early-stage design. It establishes a correlation between the matrix of information required for BIM and the information required for whole-building EC calculations. This research aims to reveal the actors and processes involved in providing this information and suggest the project stages that EC calculations should take place in early-stage design. The future benefit is to inform practice and policy to enable EC reduction through BIM in order to meet overall carbon targets.

Keywords: BIM, embodied energy, embodied carbon, early-stage design.

1 INTRODUCTION

Building construction material production accounts for 5–10% of total energy consumption across the European Union (EU). In the United Kingdom (UK) buildings accounted for 37% of the total UK greenhouse gas emissions (GHGs) in 2014 [1]. The UK Government's vision for 2025 is 50% reduction in GHGs in the built environment [2].

Carbon emissions from buildings is associated to the energy consumed by them. Energy in buildings can be categorised as either Embodied Energy (EE) or operational energy (OE). EE is the energy required for the construction of buildings which including the manufacture, transport and installation of building materials [3]. OE is the energy consumed during use, and relates to heating, cooling and lighting requirements in order to meet comfort levels [4].

Operational carbon (OC) emissions has been the main focus of industry (led by building regulations) as it accounts for a greater proportion of carbon emissions throughout the building life. Compared to OE, EE of buildings is estimated to account for 6–25% of the total building energy consumption over 50 years. However, this figure depends on the operational energy requirements as well as the buildings' life span [3]. Indeed, the fact that, as buildings become more energy efficient and their OE decreases, EE will have a more significant proportion of total life carbon of buildings has been widely articulated in literature [5]–[8].

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It has also been stated that in cases where buildings are designed for low/net zero energy, their EE may reach the same proportion as their OE impacts for a 50-year life time [8]–[11]. A study found EC over a 60-year life span increased for reduced OC designs for a variety of scenarios [12].

Although EE already accounts for a significant proportion of total carbon emissions of buildings, current early stage design lacks a holistic approach that is EC inclusive. There are various reasons for this which include the complexity of EC calculations that need to be performed at building element/ product level and then aggregated for whole building [8]. Other barriers to EC inclusion during early stage design are further discussed in section 2.2. Although some low OC building designs have increased EC, the two are not necessarily conflicting and carbon should be considered over the entire life cycle of the building, including EC reduction [13].

BIM promotes a collaborative way of working and embeds product and asset data in one single 3D model which can be effectively managed throughout a building's lifecycle – from earliest concept through to operation [14]. Greater collaboration also enables more informed decision making amongst the delivery teams and promotes a holistic view of the client's objectives [14].

This paper considers the barriers to EC consideration in early stage design decisions and the potential for it to be facilitated using BIM. It explores the information that is required for the EC calculations and looks at how this information can be aggregated early in the design process through BIM. The actors involved in providing this information are also considered in order to identify the relevant roles and establish clearer collaboration routes within the construction industry in relation to EC information exchange.

2 EC EMISSIONS FROM BUILDINGS

2.1 EC emission reduction benefits (growing importance)

EC reduction is important not only because of its increasing proportion in relation to OC. It can also reduce resource depletion. EC savings have the advantage of being mainly achieved during the design and construction stage at the beginning of a building's lifetime. This is important since data indicates that CO_2 saved within the next five years is of greater environmental value than CO_2 saved in 10 or more years [15].

Prediction of EC can be more precise than predicted OC as the latter is dependent on the building user behaviour which can vary significantly throughout a building's lifetime.

EC reduction is also closely associated to social and economic aspects of sustainability. One strategy for EC reduction involves local sourcing of construction materials and use of local supply chains which supports the local community through job creation [15].

However, consideration of EC is particularly critical during a project's early design stage as decisions that are made during this stage strongly determine the entire life cycle impacts of a building [9].

2.2 Barriers for including EC in building design decisions

The challenges that were found to be most dominant were lack of consistent methodology, availability of comparable data, lack of legislation, industry attitude towards EC, industry's worry of extra complexity and cost of projects in order to perform EC assessments and industry fragmentation [16]. These are addressed below.

2.2.1 Lack of consistent methodology

There are various factors that are considered in EC calculations, however, there is currently no agreed metric for these factors. This results to inconsistency among EC calculations. More information about these factors is included in section 2.4 that looks at information required for EC calculations.

2.2.2 Lack of comparable data and benchmark values

EC for construction materials is most commonly represented in kg CO_2e per kg material. Various manufacturers provide EC factors for their products in product datasheets or in Environmental Product Declarations. However, at early design stage the product manufacturer may be unknown. Apart from product specific EC values, there are also generic material databases where carbon factors of materials are compiled. Although these databases are useful as a starting point in early stage, databases have a higher level of inaccuracy as the data are taken from global sources and do not represent the precise carbon values [17]. Each database takes their information from different sources, considers different boundary levels and differ as to when they were last updated. Therefore, different databases may have different values for the same materials. Further to this there is lack of established and peer reviewed EC benchmark values for different building types against which an entire EC assessment could be compared [17].

2.2.3 Lack of legislation

The importance of resource efficiency and material environmental impact, which directly relates to EC, is mentioned in European and UK Reports, such as:

- '*By 2020 the renovation and construction of buildings and infrastructure will be made to high resource efficiency levels. The Life-cycle approach will be widely applied; all new buildings will be nearly zero-energy and highly material efficient, and 70% of non-hazardous construction and demolition waste will be recycled*' [18].
- Resource efficiency has been identified as one of the industry's main challenges in the period up to 2020 [19].
- Existing policies for buildings' energy efficiency should therefore extend to include policies for resource efficiency that consider environmental impacts through the entire building life cycle [18].
- The need for the development of a common framework of core indicators that can be used across the EU is evident. The areas that this framework needs to tackle include total energy use (embodied and operational) of construction products and processes and embodied environmental impacts of material use [13].

However, there is still no clear EC requirement in legislation [20].

In 2015, the European Commission started a study which includes consultation by stakeholders for the development of such a framework of core indicators which would have the potential to be incorporated into new and existing assessment schemes or be used independently by the entire range of the construction industry stakeholders. This framework is expected to be available in summer 2017 [21]. Apart from establishing a framework that includes these areas, another identified barrier related to legislation was the need to identify an appropriate EC assessment system [16]. Although awareness regarding the importance of EC has been raised and has led to the acknowledgement by the UK Government that EC needs to be included into the appraisal systems for new projects, there is still no clear guidance as to the appraisal system which will make this possible [22].

2.2.4 Industry attitude towards EC

Since legislation is not forth coming, industry needs to take the lead in EC inclusion to building design. However, amongst industry there is limited knowledge about the growing importance of reducing EC. Practitioners' understanding of EC in buildings is restricted to common perception and lacks a whole-life scope [23]. The industry's lack of understanding on the matter makes it impossible to set active drivers for client awareness and engagement in EC reduction. Until EC savings can be communicated, the benefits of considering EC at design will not be understood by industry and clients. Stronger links between researchers and practitioners should therefore be forged to address this [16].

2.2.5 Concern about raise of cost and complexity of projects

There is concern that EC assessment will increase the cost of a building. However, infrastructure construction examples have shown that although design costs increase, the overall cost is reduced. It is acknowledged that the building sector might be more complex and more data would be required to establish whether or not consistent cost reductions could also be achieved in the building sector [20].

2.2.6 Fragmentation of industry

In order to make improvements in resource and energy use throughout the entire life cycle of buildings, improved design, sustainable material use and higher waste recycling is required. However, this is not feasible without the active engagement of the entire chain in the construction sector [18]. There is a wide range of activities, professions and organisations within the construction sector – this fragmentation affects adaptation to new regulations due to their differences in socio-economic, organisational, cultural and technological condition. Further to this, the transition of the sector towards resource efficiency and low carbon economy is expected to bring structural changes which will require adaptation and upskilling of the sector to respond to the changing requirements [19].

2.3 Information required for EC calculations

EC measurements are related to the life-cycle boundary. There are five potential categories of life-cycle boundary considered [8], [15], [24]:

- <u>Cradle to gate:</u> considers the carbon emitted to bring the construction material from the cradle (earth) to the point it leaves the factory gate and is ready to be used in construction. This boundary includes material extraction, transport to factory and manufacture/ material processing.
- <u>Cradle to site:</u> as "Cradle to gate" plus delivery from factory to the construction site.
- <u>Cradle to complete construction</u>: as "Cradle to site" plus assembly on construction site.
- <u>Cradle to Grave:</u> as "Cradle to complete construction" plus operation and end of life processes. These include maintenance, refurbishments, demolition, waste treatment and disposals (grave).
- <u>Cradle to cradle:</u> as "Cradle to grave" plus recycling. This includes the process of making a component or product and then, at the end of its life, converting it into a new component.

It should be noted that different boundary conditions may affect the resulting carbon intensity of construction materials. This mostly applies to recyclable materials which, if assessed according to "cradle to gate", have a much higher carbon intensity than if they are assessed to "cradle to grave" or "cradle to cradle" boundary [15].

Other key factors to consider in an EC assessment include the basis and rules of measurement of building elements, assumptions made for variables such as transport and waste, life spans, replacement intervals and recycling rates as well as changes in recycling rates over the lifespan of an element [6].

Dixit et al. conducted a study which highlighted that the Life Cycle Assessment (LCA) methodology proposed in LCA ISO standards (ISO 14040:2006 and ISO 14044:2006) is not suitable for the built environment [25]. Researchers have noted that the ISO proposed LCA methodology was originally developed for products which (in relation to buildings) differ in their size, complexity and uniqueness. Further to this, it is noted that buildings also have a longer life span and undergo renovations during their lifetime [5].

EN 15978 aims to provide calculation rules for the assessment of environmental performance of buildings. Its UK implementation (BS EN 15978) has been suggested as the most likely calculation method for adoption by the UK construction industry for EC assessment [17], [26].

In the UK, there have been some attempts from the Industry to produce documents such as information papers to guide practitioners for EC calculations.

A Task Force of practitioners, academics and developers was formed in 2014 in order to raise awareness of the importance of EC in the construction industry and propose minimum standards for measurement, reporting and verification procedures. They agreed that a standard minimum reporting framework based on recognised European standards (CET TC 350 EN 15978:2011 and EN 15804:2012) should be followed. The EC assessments should cover at least product and construction stage and they should include buildings' substructure and superstructure as a minimum. Cradle to gate, which is the boundary level proposed above, is the most common life-cycle boundary used for EC measurements. There are two main reasons for this: 1) the majority of carbon datasets are cradle to gate, 2) EC emissions during the production and manufacturing of construction elements account for the largest proportion of EC emissions [17], [27]. The project-based database of EC created by the Waste Reduction Action Program (WRAP) in collaboration with the UK Green Building Council was agreed to be used as the indicative data set [15], [28].

The Royal Institute of Chartered Surveyors (RICS) information paper includes a recommended methodology for EC calculation [17]. The methodology is addressed to quantity surveyors and sets cradle to gate as the considered boundary because of lack of information at early design stages. It looks at The Royal Institute of British Architects (RIBA) work stages and adjusts the method to the specific stages. During early design stages, when specification and quantities of materials are not yet established, it is recommended to multiply the floor area of the development with specific EC benchmark values for different building types sourced from Atkins Carbon Critical Masterplanning Tool [29]. During the design development and technical design stages it recommends to calculate the mass of construction materials and multiply the results by the relevant embodied factors according to manufacturer carbon factors if available or a carbon database e.g. ICE database [17], [24]. The RICS report notes that there are no peer reviewed benchmark values available for EC emissions for different building types as monitoring EC emissions of different building types is a relatively new field of research. This information gap was filled by establishing values using the Atkins Carbon Critical Masterplanning Tool. Even though these values are not precise due to small data set and lack of consistency in assessment boundaries and also have not been verified by the industry, they can provide a benchmarking starting point. This highlights the need for greater benchmark accuracy based on data from more buildings and using a standardised assessment methodology.

2.4 Who should provide EC information

Quantity surveyors and suggests that they will be responsible for cradle to gate EC calculations by RICS. They are considered the most ideal profession to collect and report carbon information as they already produce reports that include quantities of materials for the generation of cost plans. However, in order to be able to extend the life-cycle boundary, other professions would have to provide information, such as construction process stage carbon from the contractor; use stage carbon from the mechanical engineer or life cycle specialist. Product specific figures provided by manufacturers would also be helpful whereas LCA experts would be required for more detailed studies [17].

The Green Building Council suggested that architects and structural engineers would be involved along with quantity surveyors in order to conduct initial EC discussions. They also suggest that different professions should be responsible for EC throughout the life cycle as follows: the cost consultant, or specialist carbon consultant for the project completion, the facilities manager for building in operation and the project manager in periodical refurbishment. However, since these decisions are cost associated, the final decision rests with the client [15]. It is also suggested to embed responsibilities associated with EC assessment throughout the supply chain. The subcontractors can measure, record and report on EC on steel and concrete. EC measurement in procurement and sourcing is also encouraged raising consideration on recyclable content of products, recyclable materials and leasing products during the construction period.

Although the above documents make suggestions of stakeholder involvement in providing EC information, there is still no clear responsibility allocation for EC information provision or EC calculations [6].

2.5 EC reduction strategies

The WRAP Information sheet "Cutting carbon in construction projects" [30] includes some suggestions for the design teams in order to reduce EC for projects. Some of the suggestions include more efficient building design, reducing material quantities, selecting alternative materials, waste minimisation, designing for reuse and deconstruction. This document also summarises strategies for specific building materials where there is potential for EC reduction [15].

Another point mentioned in literature was that efforts to reduce EC should firstly be focused on high impact materials (carbon hotspots) which typically account for about 80% of the overall EC footprint. Carbon critical building elements with carbon reduction potential were parts of the building substructure, superstructure, internal finishes and external works. Building Services were also mentioned as EC intensive, but with limited mitigation potential and very complex to assess [17].

3 BIM

As defined by the Construction Project Information Committee, *"Building Information Modelling is digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it forming a reliable basis for decisions during its lifecycle, from earliest conception to demolition"* [31]. The UK Government has mandated the implementation of collaborative 3D BIM for all public-sector projects from 2016 [32].

3.1 BIM as collaboration enabler

The most important letter in BIM is 'I' due to the fact that the most useful part of BIM is the information storage within the BIM model [33]. BIM is not merely a technological advancement but rather a procedural shift within the construction industry [34]. This is reflected in the definition given for BIM in the Digital Britain report: '*BIM has been described as a game-changing Information and Communications Technology (ICT) and cultural process for the construction sector*' [14]. BIM facilitates project data management throughout the building's life cycle [7] which results in benefits which include increased efficiency and reductions in clashes, construction time, carbon and cost [35]. Research has demonstrated that amongst the benefits that BIM brings, facilitation of stakeholder collaboration has the greatest impact [36]. As previously mentioned, the UK construction industry is characterised by fragmentation resulting in inefficient communication and collaboration amongst stakeholders. Early collaboration of stakeholders and front loaded efforts at early design stage has been considered to address fragmentation and enable more efficient collaboration [37].

3.2 BIM and whole building EC in early-stage design

The 3D BIM model is a single data source which includes information for the entire life-cycle of a building. In the model, objects' geometric and non-geometric data is stored and relationships of different objects are established [37]. Therefore, changes on an object's information are reflected on all related objects and the entire building information is reconfigured [38]. As information stored in the BIM model relates to various design aspects and is relevant to the entire building life-cycle, a holistic view of the design is provided which can be inclusive of multiple design considerations simultaneously. This enables informed decisions to be made, especially at an early design stage when design decisions determine a great amount of a building's life-cycle impacts [39]. With carbon data of elements incorporated into the BIM model, the whole building EC can be estimated and evaluation of both OE and EE can be performed over the life-cycle of a project [6]. Further to this, the aggregation of carbon calculations from element to building level using the BIM model can significantly reduce the time that is required to perform whole building EC calculations using traditional design methods [8].

3.3 BIM information collection and role identification

In order to improve productivity through BIM use, a BIM implementation strategy is required [37]. During the initial stages of the project when goals and stakeholders' requirements are defined, essential information for the BIM model development and further management should be provided [37]. In literature the importance of creating a BIM library at early design stage in order to secure essential data for BIM model development has been emphasised [14], [37]. In conjunction to a BIM data repository, a BIM framework that includes internal and external collaboration and synchronises with current work processes is required [40]. Research has demonstrated that setting clear roles for key project life stakeholders and establishing specific information exchange points throughout the project is essential for effective BIM use [37].

Considering all the above it is clear that in order to implement BIM and use it efficiently, a BIM implementation standard is required. Although there is currently no universal BIM standard, in the UK standards and protocols have been developed by UK construction professional organisations. RIBA has created a BIM Overlay document to the RIBA Plan of Work [41]. In this document, the key tasks are linked to BIM activities for the project work stages. Although this is a very useful document, it only focuses on core activities and has no information about responsibility of project stakeholders against them.

The Scope of Services Handbook [42] created by the Construction Industry Council (CIC) lists services required in a project and indicates generic roles that need to provide them. It includes the Specific Scope Schedule where primary responsibility for the definition of components can be allocated against project stages. The CIC BIM Protocol [43] looks at BIM model creation at defined project stages by members of the project team. The Protocol also defines the level of detail (LOD) of the model at each stage. In this document, the Model Production and Delivery Tables (MPDTs) are introduced, which are key elements that allocate responsibility of BIM model preparation and set the LOD of the models at each project stage. An information manager is also required to be assigned for the project who will be responsible for the implementation of the BIM Protocol and the MPDT updating. The information manager is also responsible for managing the information exchanges and assigning project outputs such as Data Drops. Data Drops take place in accordance with the Employer's Information Requirements (EIR) and the BIM Execution Plan (BEP) [43]. The data that is required in each project data drop is defined by the Plain Language questions which address performance requirements in order to comply with the project brief and wider regulatory requirements [44]. A clearly defined data drop schedule facilitates the effective information requirement communication. The EIR document is a key element of the Project BIM Implementation as it establishes and communicates information requirements [44]. It is used to set out the models that are required and the models' purposes. PAS 1192-2:2013 [45] provides guidance for information management requirements of BIM projects. Although types of roles that should be considered and likely responsibilities are identified, PAS 1192-2:2013 should be read in conjunction with other contract documentation such as the RIBA Plan of Work [46] and the Schedule of Services [42] and appropriateness of roles should be examined and reconfigured for each project [45]. In PAS 1192-2:2013 [45], levels of model detail and model information are included in tables for each project stage. In the Parametric Information model, embodied and operational carbon, energy and resource needs are required to be defined at Brief, Production and Installation stage [45].

3.4 Case Studies of EC calculation at early design stage through BIM

There are examples identified in literature that describe how EC calculation has been included to early design stages through BIM. Some are based purely on modelling or hypothetical case studies, whereas others include real-life projects. In one example, BIM was used to create various structural system alternative models and assess their initial EC in order to conclude to the design with the lowest initial EC [7]. Other research has examined the incorporation of EC information to a BIM model so that both EC and OC can be considered at the same time in different design solutions. The model is described along with its application to a case study project, a new-built school building in the North East of England [6]. A hypothetical case study was used in a research that was aiming to test a Housing Information Modelling Framework developed for Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) based housing refurbishment solutions [37].

All the case studies mentioned above concluded that BIM can facilitate EC inclusive design decision making by enabling design parameter alterations of BIM models and testing design alternatives. Further to this, BIM provides a holistic view of the projects since the same model considers the entire life-cycle which enables more informed decision making at early design stages [6], [7], [37].

4 CONCLUSIONS

Literature relating to EC and BIM was reviewed in this paper in order to draw conclusions on how BIM can enable EC calculation inclusion to early-stage design. This research focuses on early design stage as decisions made during this stage determine a significant portion of a building's life-cycle impacts and cannot easily be amended later in the life of a building.

EC's contribution to buildings' total carbon emissions is growing as buildings become more energy efficient and tackling building EC emissions has immediate benefits that are not only environmental but also economic and social, contributing to broader sustainability targets. However, there are various barriers in performing EC calculations, which include lack of consistency in method, of availability of EC data and benchmarks, of legislation, industry's attitude towards EC and worry that its calculation will add complexity and cost on projects and fragmentation of the construction industry.

Looking at the above barriers and relating them to BIM and its implementation, it can be seen that BIM can facilitate EC calculations for projects in many ways.

BIM can facilitate stakeholder collaboration and therefore improve the observed fragmentation and lack of communication amongst the construction industry. As BIM collates building elements' information into a single model, it enables the aggregation EC values from element to building level without any complexity added to the process. This reduces the time required for whole building EC calculations and therefore addresses the industry's concern of added complexity due to EC assessment. It also enables simultaneous consideration of multiple design aspects, so evaluation of both operational and embodied carbon is facilitated.

With regards to information required to perform EC calculations and the stakeholders involved in it, the UK BIM standards and protocols developed by UK construction professional organisations set key information exchange points throughout the building life-cycle and stakeholders' responsibilities for these exchanges.

Finally, with regards to the industry's lack of knowledge about the importance of EC in securing whole building carbon emission reduction, literature has suggested that, in order to address this, stronger links between researchers and practitioners should be forged [16].

5 FURTHER RESEARCH

From literature it has been revealed that BIM research has focused on 'after BIM' assessment approach, where achievements through BIM implementation are focused on finalised projects. On the other hand, there is a research gap on real time BIM projects, especially in pre-construction stages [47]. This research aims to address this gap by looking at real time BIM application at early stage design in relation to EC. The role of EC in the decision process is going to be investigated as well as methodologies used for its calculation. The actors and information exchanges for these calculations are going to be established by looking at real-time project case studies with and without BIM use to establish the differences of these aspects in traditional and BIM enabled projects. Grounded theory will be applied for data collection and analysis during which semi-structured interviews, project meeting observations and meetings with key informants will be conducted for data collection. For the data analysis, qualitative data analysis software will be used.

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