Building Information Modelling (BIM) application in relation to embodied energy and carbon (EEC) considerations during design: A practitioner perspective

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Abstract: Buildings' carbon emission reduction efforts in buildings have mainly been focused on operational energy reduction and, as operational energy is reduced, embodied energy and carbon (EEC) becomes more significant. However, there is currently a lack of legislation and guidance relating to embodied carbon in buildings. This, together with the United Kingdom (UK) construction industry fragmentation, creates a significant barrier to dealing with EEC during building design. In this context, Building Information Modelling (BIM) empowers communications and stores information into one single digital model and has therefore potential to facilitate EEC considerations to be included in building design.
This research takes a qualitative approach and looks at the design process in relation to EEC considerations and BIM application and how the latter can facilitate the inclusion of EEC in design considerations. Through semi-structured interviews with the construction industry professionals, this research investigates BIM application in relation to EEC information during design. EEC's current role in building design and the drivers and challenges EEC considerations are being mapped. EEC information processes and how BIM facilitates EEC information exchange and storage as well as the actors involved are revealed. The overall aim of this research is to inform practice and policy to enable EEC reduction through BIM and meet overall carbon targets.

Keywords: BIM, embodied energy, embodied carbon, building design process, industry perspective

Introduction

Buildings are great contributors to carbon emissions and account for 36% of CO2 emissions in the European Union (European Commission 2018). There is therefore a worldwide effort to reduce carbon emissions from buildings. In the UK, the Government's vision is to reduce greenhouse gas emissions in the built environment by 50% by the year 2025 (HM Government 2013). Buildings' carbon emissions can be split into two categories, Embodied Carbon (EC) and Operational Carbon (OC). EC relates to the building construction which includes the manufacture, transport and installation of building materials (Sassi 2006) whereas OC relates to the building operation, which includes heating cooling and lighting requirements in order to meet comfort levels (Yohanis and Norton 2006).

Historically, OC accounts for a greater proportion of the overall building lifecycle carbon emissions and therefore carbon reduction efforts in the built environment have mainly been focused on OC. However, as buildings become more efficient and their OC decreases, EC will have an increased proportion of the overall building lifecycle carbon (Capper et al. 2012; Shrivastava and Chini 2012; Iddon and Firth 2013; Doran 2015). For low OC designs, EC has also been observed to increase not only as a proportion of the overall lifecycle carbon, but as an actual carbon figure due to increased use of materials for achieving low OC building designs (Winther and Hestnes 1999; Thormark 2002; NHBC Foundation 2011; Basbagill et al. 2013; Doran 2015).

Although EC becomes more important as OC is being reduced, there is currently a lack of legislation, consistent methodology and availability of comparable data in relation to EC (Capper et al. 2012; Royal Institution of Chartered Surveyors 2012; Sophie Chisholm 2015).

Further to this, the UK construction industry attitude and limited knowledge about EC as well as the industry's observed fragmentation, creates a significant barrier to dealing with EEC during building design.

Building Information Modelling (BIM) has been introduced to the construction Industry as a new collaborative way of working that enables information storage and exchange within the BIM model (Mahdjoubi et al. 2015), facilitates data management (Shrivastava and Chini 2012) and most importantly facilitates stakeholder collaboration by providing a procedural shift (Succar 2009, 2013; HM Government 2015).

This paper presents the initial findings of a wider research project which investigates the potential of BIM to facilitate EC to be included into building design. This research takes an ethnographic approach that uses building projects at their design stage as case studies and includes interviews, meeting attendance and document analysis as the main data collection methods. In this paper, the findings from initial interviews held with industry professionals in the building construction industry are presented. Through these interviews, EC's current role in building design and methodologies used for its calculation are investigated and the challenges in the process are revealed. The potential for EC inclusion in the design process through BIM application is explored from a participant point of view.

Method

This research included interviews with construction industry professionals which discussed the professionals' perceptions about the role of EEC in building design, what motivates professionals to include EC as a consideration in design and how this changes for different project aspects, such as procurement routes, building uses and different clients. The information used for EC calculation of projects is also investigated focusing on when information exchanges that relate to EC take place, who gets involved in these information exchanges and what sources are used. The current drivers and challenges encountered by professionals in the process of information exchange and calculations for EC are outlined. Finally the BIM application and its potential to facilitate the inclusion of EC in building design is presented from a practitioner point of view. The interview topics are included table 1.

Table 1 Interview topics

Interview topics					
Participant background information	Role of EC in design decisions and drivers	EC information exchanges and sources	Challenges/ Barriers for EC considerations in design	BIM Application in relation to EC	BIM potential to facilitate EC to be included in design

Four one hour semi-structured interviews were conducted. One interview was conducted face to face, while the others were conducted via real-time video conferencing tool called 'Blackboard Collaborate' and only included voice and not video. The professionals that participated in the completed interviews were two Life Cycle Assessment (LCA) consultants, one general sustainability consultant with expertise on BREEAM assessments and one architect. A future phase of interviews is planned to include structural engineers, quantity surveyors and BIM experts. Participant background information includes profession, company type, and types of projects and clients are included in table 2. The interviews were transcribed and the data was analysed using a qualitative data analysis computer software

(NVivo 11). Thematic coding was used to compare participants responses in relation to the interview topics (table 1) and new codes emerged from the participants' responses.

Table 2 Participant background information

Participant	Profession	Years of experience	Company Type	Project types	Client types
1	LCA Consultant	10 years	Global Sustainability Consultancy	All	Mostly big private developers
2	LCA Consultant	5 years	Environmental Consultancy with focus on LCA (SME)*	Mostly commercial	Mostly private clients
3	Sustainability Consultant	15 years	Sustainable Design Consultancy (Micro-enterprise)	All	Both private and public
4	Architect	8 years	Architectural Practice (SME)*	Most types excluding small domestic	Both private and public

* SME: Small Medium Enterprise

Interview Results

The role of EC in design decisions and what drives EC considerations

The role of EC in design decisions and the parameters that affect it were considered for different procurement routes, types of building projects and clients. It was found that the role of EC is mostly influenced by the client rather than the procurement route of the project according to all interviewees. Even for Design and Build procurement where the contractor has more control over the final product delivered, contracted deliverables and targets still need to be met. The contract and targets therefore play the most important role and are set by the client at the beginning of the project; interviewee 2: *'As long as the right conditions are set by the client either in the form of contractual obligation but also the particular type of team relationships and hierarchy and organisation each project follows it is effectively down to that',* interviewee 4: *'It depends what's in the contract, if a specific requirement for EC is in the contract then the contractors can' really change that. So Design and build is usually thought of as weak in terms of the contractors coming and doing whatever they want but it really depends'*. In terms of types of projects, the role of EC in design does not change for different building uses, which was the belief of interviewees 1,2 and 4, although Universities were found to demonstrate a high standard in terms of their sustainability ambitions for their buildings according to interviewee 3: *'Universities again often have higher education funding council, there is a metric about rewarding about broad sustainability criteria, if you have a carbon management plan, what BREEAM rating, what your policies are. That can be very high level and can range from a variety of sustainability criteria. But an easy one is to say all new buildings will be BREEAM excellent, and I think that is why probably most universities have that in some degree'*. Another participant found that for big projects, the larger developers/ clients involved could afford the appointment of a carbon consultant which facilitated carbon

calculations and there was a policy for EC in place in relation to smaller projects and clients, interviewee 4: *'I would say the larger the project the easier because typically with all of these projects we have had a carbon consultant involved who has assisted with the calculations, so the larger the project the more likely that the client will have a fee that they can pay to a carbon consultant. If it is a very small project, chances are that you wouldn't really be able to add a consultant for something so specialist'*. Considering all the above, clients were found to be the most influential parameter of a project as they set up the contractual agreements, carbon policies and carbon consultant appointment for the projects.

At the moment sustainability in projects is mostly driven by BREEAM rating achievement ambition and Part L regulations and therefore mostly focuses on OC, interviewee 4: *'most of sustainability decisions that are made are based around BREEAM requirements, planning requirements and still most of the energy and sustainability work is done in terms of OE and part L regulations'*. EC calculations at the moment are rare and are most commonly performed after the completion of the project as an after exercise and very rarely play part of the building design process, interviewee 3: *'Most of my work at the moment has come thorough retrospective review'*. When they do take part of the design considerations and they are included in the brief as a target, they have equal priority with the other sustainability targets by the design team, interviewee 4: *'You have to meet all of the criteria that are included in the targets, there is no priority'*. However, since it has no regulatory impact, it often doesn't get the same priority by the clients; interviewee 4: *'I would say that if something has a specific cost implication, that is more likely to be value engineered out than something else. But that is usually a client issue rather than an architect issue.'*

Early engagement of sustainability consultants with the design team was considered critical by the LCA and sustainability consultants that participated in the interviews (interviewees 1, 2 and 3). They suggested that their engagement should start at least from concept design, with one interviewee stating that the ideal would be as early as site selection of the project, interviewee 1: *'it is very important to get there as early as possible. Some of the recommendations could be relevant to the building site selection'*. Apart from early engagement of the carbon/ sustainability consultant, it was also deemed important that the contractor and the main suppliers also become involved early on so that they can all work collectively towards the carbon reduction targets, interviewee 2: *'bringing in the main contractor but also tendering contractors or suppliers like sub-contractors from early on in the design process in order to engage with them at an early stage, […]. And then working side by side and hand in hand with the entire team'*.

EC information exchanges and sources

EC information exchanges were investigated in terms of when EC considerations are introduced to the design, the professionals involved in the information exchange for EC calculations and the sources of information used for its calculation.

In terms of when EC considerations are introduced, interviewees 1 and 3 mentioned that this would not be during the design stage but rather during or after the construction phase, interviewee 1: *'It is usually fairly late, at the end of when the building is built or during construction. I don't think I have ever gotten involved at the design stage',* interviewee 3: *'Most of my work at the moment has come thorough retrospective review'*. For projects that include EC into design considerations, this would most commonly happen at the end of developed design stage or even at the end of technical design stage when the design has entered a more detailed phase, interviewee 4: *'I think that for most projects in the industry it*

would be at the end of Stage 3 maybe or even at the end of Stage 4'. However, it was mentioned that for projects with high sustainability aspirations, EC considerations would start from concept design, interviewee 2: *'So if it is a project that has high environmental aspirations we would get involved fairly early, around later than concept design RIBA Stage 2'*. The stages mentioned above relate to building stages as defined by the Royal Institute of British Architects (RIBA) in their Plan of works document, Figure 1. According to the RIBA plan of works green overlay, Stage 2 is the recommended stage for EC considerations to be introduced (Royal Institute of British Architects 2011).

Figure 1 RIBA project stages (Royal Institution of British Architects 2013).

The professionals who perform the carbon calculations are most commonly carbon/ sustainability consultants appointed by the client. The professionals who are involved in the information exchange process are initially the architects and the design team that provide material information and specifications. This is then either directly communicated with the carbon consultant, or with the cost consultant/ quantity surveyor who gathers material quantity information and communicates it to the carbon/ sustainability consultant. In cases where this process is completed after the project is built, the design team may not still be available, so the carbon consultant gather the information from the main contractor in the form of drawings. Section drawings have been found very useful as they provide material thicknesses.

The boundary conditions considered were cradle to construction at a minimum but most commonly the boundary condition considered by the interviewees was cradle to grave, which is the boundary condition required for the Royal Institute of Chartered Surveyors (RICS) new professional statement document. This professional statement document provides members with mandatory calculation and reporting requirements about whole life cycle assessment of buildings based on the EN 15978 standard principles (Royal Institution of Chartered Surveyors 2017). With regards to EC data sources, the professionals used independent EC databases or databases that related to specific EC calculation tools as well as Environmental Product Declarations (EPDs).

Challenges in including EC in building design

Current UK building legislation on conservation of fuel and power (Part L) and BREEAM 2014[1], focus heavily on OC. This has led to lack of knowledge and understanding of the overall carbon building impact by the building professionals; interviewee 3: *'If you ask how sustainable your building is they will talk about energy and renewables, not other aspects of building design'.* This lack of legislation for EC requirements also creates a lack of a market drive for the industry to start considering it, interviewee 4: *'Essentially there isn't a market driver for EC so the people that are doing it tend to be either for their own ambition or as part of a sustainability policy but that usually means that any specific targets can be eased slightly if*

[1] BREEAM is the most commonly used building rating system in the UK and version 2014 is what the industry has been using in the last four years. A new version of BREEAM replaced the 2014 version in March 2018, hence the new version has very recently been introduced to the industry.

need because there is no outside independent review'. This this lack of market drive and knowledge has resulted in limited expertise within the construction industry professionals for EC calculations, interviewee 3: *'There aren't many people that do LCA at the moment, there is very little guidance as to what you should do and there is a big risk that people that are actually doing it are doing it completely incorrectly'.* Further to this, there is lack of training and a scheme to certify professionals, interviewee 3: *'The emphasis is on lack of training, if you look at energy related work, other (professional) bodies have a method to becoming an expert to it for information to be compliant. That is the missing step I think with LCA. Until you have a badge though, to specify certified training to get it, you are not sure.'*

The main challenge that all interview participants found with EC calculations was the lack of accuracy in secondary data available in EC databases when primary data for the building materials is not available, interviewee 1: *'You can only get so much primary data from the client and the supply chain, so a lot of the lifecycle has to be filled in with secondary data', 'Secondary data are then used to fill the gaps with variant degrees of quality'.* In the UK, it was mentioned that the IMPACT database which is linked to the BREEAM standard doesn't include specific product data but averaged data for products available in the UK. Distances used for the calculations also use averaged UK assumed values. The methodology for the EC calculations was found to be straight forward by most of the respondents apart from one who found that the current guidance only provides a 'checklist' rather than a detailed method, interviewee 3: *'how do you know what is right and what is wrong? It is a checklist but not a detailed method'*.

Another challenge mentioned that related to uncertainty was the change of materials from design to what is actually getting built. It was found that there is lack of material specification by the design team which results in uncertainty as to what the end material used will actually be *'So if an architect puts in a specifications for a system there is little room for deviation. But what normally happens though that it is either a generic statement or it will be we will specify a system, or similar, or approved and that gives the contractor flexibility as to what to install'.* Further to this, even when materials are given specifications by the design team, if the project carbon target relates to an overall carbon figure for the entire building, which is often the case, then contractors still have flexibility to change the design team's specified material if they manage to achieve the building's overall carbon target by reducing the carbon impact of another element.

Finally an important challenge was found to be the lack of integration of the carbon consultant within the design team *'establishing the role of carbon assessment where the whole life environmental assessment is integrated and works side by side. The soft side is very important rather than just the technical one. It is important to stay integrated and to ensure that you are in touch with the project progress and it's not just an assessment that just happens and is carried out by an external body and there is no interaction whatsoever', 'I attend meetings to be present and see how design is progressing. And I am in a position to know what they are talking about. If you don't do that you may miss it, it is very easy for design to 'run away'. You could miss a process to evaluate and work with the engineer to report on it. So you need to be mindful to when decisions are made and you need to be embedded in the project team'.*

BIM Application

BIM application includes both the use of technology and a use of a BIM model but also introduces a procedural change in the construction industry as it facilitates project whole life

cycle data management (Succar 2009; Shrivastava and Chini 2012). The UK Government has mandated collaborative 3D BIM (BIM Level 2) for all public sector projects from 2016 (HM Government 2012). This has resulted in most buildings currently being at that BIM level, however as stated by one of the interview respondents, interviewee 3: *'There is a variety of levels within level 2 and that really comes down to what do you need it (BIM) for.'*

It was mentioned that there is ambiguity and lack of standardisation about the BIM model requirements included in the BIM Protocol, interviewee 3: *'the key question is what is the expectation of the client - that tends to be the driver'.* This was confirmed by another respondent who mentioned that the EC requirements that get included in the Employer Information Requirements (EIR) document come from the client, however, it is the design team that puts the EIR document together, and this is not done until RIBA Stage 2-3. Although the EIR was mentioned to include EC requirements, these only usually relate to an overall building carbon figure and don't relate to information required within the BIM model; interviewee 4: *'Our clients aren't interested in the EC of specific components they are interested in the building they'll be interested in the analysis and a final number, which may be included in the EIR but it wouldn't be part of the model'.* Further to this, since the cost consultants are usually involved in the EC information exchange process, it was mentioned that pdf documents were used for EC information by the cost consultants rather than the BIM model due to lack of familiarity with BIM data. Only one respondent mentioned that they try to establish a link between BIM and the EC information collection process, interviewee 2: *'We are trying to interrelate interlink and interact and to have an interface between carbon and BIM and see how they can work together and how BIM can be utilised to extract data that would feed into the carbon calculated process in a streamlined fashion that would facilitate automation.'.* Although this was mentioned as a future intention, this is not current practice, interviewee 2: *'BIM is very catchy and has a lot of potential but whether it is able to what you want is a different story.'*

One of the respondents mentioned that one problem encountered in BIM models is that they include building block elements that are not broken down into specific materials, interviewee 3: *'BIM models have an arbitrary volume that is just a block. So with LCA it is not the block, it is the materials that create this block element that you need information for. So at the moment we have an industry that uses this BIM model that 9 out of 10 doesn't split down these individual materials of the block elements'. T*he importance of the right information in the BIM model in relation to metal materials was also highlighted, interviewee 3: *'So if you take the BIM analogy, the area of your external wall, then you are massively overestimating the volume of metal which is not true.'* Although structural frames are ordered in kilograms and therefore the weight information is easily available, secondary support system metal weight information is not available. The respondent believed that the BIM model can't be trusted to automatically populate quantity information required for EC calculations, interviewee 3: *'I don't trust the BIM model, I like to manually understand what my volumes, my areas my weights I can trust the section drawing, what I don't trust is the BIM model to automatically populate all these items, I know some aspects are volumes and not the materials in it'*. Concern was expressed that with BREEAM 2018, more people will start using the BIM model as an EC information resource, interviewee 3: 'people *won't have the time to even consider that, they will take a BIM model because they are told to, BIM is telling me that and they'll put it through. That's my biggest worry that there's going to be a lot of information coming through that is going to be completely spurious not through anyone's*

fault.'. It was also stated that there is no checking mechanism for the BIM model inputs or the supporting documentation for the assessments, there is only checking of the final figure.

BIM potential to facilitate EC inclusion to building design

All respondents saw potential in BIM facilitating EC inclusion in building design. Two respondents based their opinion on the BIM model's ability to store EC data and material quantities within the model which could feed into the EC calculation process resulting in automation and enabling an iterative process for EC reduction of building designs, interviewee 4: *'With the BIM model you have all of the quantities and you could in theory have a database inputted in a parameter and you can automatically get a calculation out of that and you can get very quick iterative processes',* interviewee 2: *'it could help at early stage iterations when you have more generic figures attached to certain components and look at a few major variants to form the design'*. One respondent added that this could also enable visualisation of EC results and better communication of these results with clients, interviewee 2: *'this could add to visualisation and communication with the clients'.* Apart from automation of the EC calculation process, one respondent added that the EC data input in the BIM model could also be facilitated by technology, in the form of an application which would simplify the data input process, interviewee 1: *'Perhaps software can be related to data collection to make it as easy as possible'*.

Although three of the respondents focused on the technological side of BIM in terms of its potential to facilitate the inclusion of EC in building design (interviewees 1, 2 and 4), none referred to the information management that BIM contractual documents aim to facilitate. In relation to information management, one of the respondents mentioned the following; interviewee 4: *'current process is fine, it is not that a complicated a methodology it is more about speeding it up and getting better accuracy'.* On the other hand, one of the respondents mentioned the software currently available has a lot more potential, but the data input from the practitioners is what requires improvement, interviewee 3: *'I think that the software is there and is very very good, I think it is the front end which is lacking.'*

EC growing importance

All of the respondents acknowledged the growing importance of EC in the overall carbon impact of buildings. They all believed that although there is currently no legislation relating to EC and the market isn't currently ready to have specific regulatory targets relating to EC, in the coming years there will be regulations put into place, with opinions ranging that this will be introduced in 3-20 years' time, interviewee 2: *'I think that is not too far off, within a frame of 3-5 years' time we will be seeing regulations in some form',* interviewee 1: *'I am sure it will get to a stage, I don't think it's soon, in 15 20 years that we will start seeing some EC legislation'*. At the moment even in the lack of a top down approach, the market is attempting to raise their competitiveness by producing EPDs for their products; interviewee 1: *'a lot being done on individual product level and on EPDs to communicate their impact against their competitors and in the hope that this will get picked up by the procurement team',* but also professionals are raising their competitiveness by adding EC considerations in their project delivery; interviewee 2: *'Contractors are doing it to a degree for their own sake and corporate responsibility as well which also adds to their marketability from a commercial perspective […]'.* Another aspect of the reason why professionals are voluntarily shifting their focus and try to include EC is for ensuring that projects are going to be meeting future requirements; interviewee 2: *'it is also about security futureproofing against future regulations and against*

resources , the continuously depleting resources that make resource efficiency more and more important'. Interviewee 3 also highlighted that the growing importance of EC is also acknowledged in the new version of BREEAM, which states that EC is increasingly important in terms of reducing the overall emissions that lead to climate change (BRE 2017).

Conclusions and further research

In this paper the results of the initial data collection of this research have been presented which included interviews with construction industry professionals and looked at the role of EC in design and methods for its calculation, the challenges that professionals face in the process as well as BIM application and potential in relation to EC reduction considerations.

The role of EC was found to be mostly dependent on the client aspirations whereas the type of procurement route and type of project didn't play an important part in the role of EC in design. Larger clients/ developers are more commonly the ones with high EC reduction aspirations however at the moment the role of EC is still very small in relation to OC and it is very rarely considered at an early design stage. However, early engagement of the EC consultants with the project, which was suggested to start during concept design was considered critical and it was suggested that all the professionals involved should come together from as early as possible to work collectively towards the carbon reduction targets.

Team integration was one of the challenges identified by the professionals in relation to EC considerations. Lack of EC legislation also brought challenges that relate EC which is a lack of market drive and lack of available expertise and knowledge. There is also no certification and training for EC calculations and this raises uncertainty for professionals who perform EC calculations. Another challenge mentioned was the poor accuracy of secondary data that is included in EC databases. Finally it was highlighted that materials may change from design to construction which is due to either lack of specification set by the design team or because of the flexibility the contractors have if the carbon target is set for the overall building and not the individual component of each element. This again, comes down to the client and what has been agreed within the contract, it is therefore important to incentivise clients and drive the market so that more specific requirements are set to the construction industry by clients.

The new BREEAM version and other available guidance and initiatives like the London Planning policy include EC considerations and that is helping to get the market ready for potential future EC regulations (BRE 2017; Greater London Authority 2017). Even though the EC requirements set by the new BREEAM version were considered limited by the interview respondents, they were found to provide a stepping stone for both building professionals and clients to raise their EC reduction target ambition.

In relation to BIM, professionals found that most of the industry has reached level 2, which is the level that the UK Government has mandated for public buildings, but there is still no standardisation in BIM processes and data input in the BIM model. Although most professionals believed that BIM's potential to facilitate EC considerations lie within the BIM model's capability to enable automation of the EC calculation process and better communication of EC results through visualisation, there was also the reluctance to trust the BIM model due to the lack of standardisation and the variation of the data that is inputted in the model. Therefore, in order for the BIM model to become a tool that can be used for facilitation of the EC process, better data input to the BIM model is required. This effectively needs to be set within the contractual agreements that BIM entails, such as the BIM Protocol and the EIR document.

The above conclusions were drown from a small sample of participants, which included 2 LCA consultants, 1 Sustainability consultant and 1 architect, 4 practitioners in total. Therefore, the above results can't be generalised to be considered as representative of the UK construction industry. The conclusions from this research form a preliminary part of a wider study which investigates the design process in relation to BIM and how its application can facilitate the inclusion of EEC in design considerations. This study takes an ethnographic approach which includes in-progress building design observation through the immersion of the researcher in the field. Three projects during design stage are included as case studies where the design process is investigated in relation to EC and BIM. Through interviews with the professionals involved in the projects, project meeting observation and document analysis, this research investigates BIM application in relation to EC information during design.

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