EMBODIED ENERGY CONSIDERATIONS IN A BIM-ENABLED BUILDING DESIGN PROCESS: AN ETHNOGRAPHIC CASE STUDY

Built environment carbon emission reductions have been focused on operational energy reduction. Successes in this area have increased the significance of embodied energy and carbon (EC); however, this is not addressed by legislation. United Kingdom (UK) construction industry fragmentation creates further challenges that undermine the consideration of EC. It has been hypothesised that Building Information Modelling (BIM) empowers information management and collaboration amongst professionals, thereby potentially facilitating consideration of EC during building design. As both BIM and EC pose new challenges to design teams, this research investigates the role of EC in building design and how this is realised in practice, particularly for a BIM-enabled project. This investigation aims to identify the factors affecting EC considerations and reveal how relevant targets are set and realised in a BIM-enabled building design process. This will inform practice and policy to enable EC consideration in building design for BIM-enabled projects. An ethnographic approach was adopted which included interviews, meeting attendance and document analysis to investigate: 1) EC considerations in the design process, 2) the role of building professionals involved in the process and 3) what affects EC considerations and information management through BIM. This was applied to a UK BIM-enabled building project case study at its design stage. The initial investigation considered: 1) barriers and enablers for EC target setting and realisation and 2) BIM application and information management. These results were classified in relation to people, process and tools. A socio-technical perspective was adopted as a lens to generate conclusions and inform further data analysis. Future research will include three further case studies, enabling cross-case comparison of the factors affecting EC considerations in BIM-enabled projects.

Keywords: BIM, socio-technical theory, design process, embodied energy, ethnography.

INTRODUCTION

Carbon from buildings can be distinguished into two main categories: operational and embodied (OC and EC respectively). The former relates to the building's operation which includes heating, cooling and lighting to provide comfort (Yohanis and Norton 2006). The latter relates to building construction, which includes the manufacture, transport and installation of building materials (Sassi 2006). Until today, OC has been the main focus of carbon reduction efforts as it has historically accounted for a greater proportion of the overall building lifecycle carbon emissions. However, as more efficient building designs have a reduced OC, their EC has an increased proportion in their overall building lifecycle carbon (Capper et al. 2012; Shrivastava and Chini 2012). Further to this, EC has also been observed to increase not only as a proportion, but also as an actual carbon figure for reduced OC building designs (Basbagill et al. 2013). Although the importance of EC is growing, there is still lack of a legislative EC reduction requirement in the UK. Industry guidance on Whole life carbon assessment for the built environment which includes EC assessment has now become available through a professional statement by the Royal Institution of Chartered Surveyors (RICS 2017). However, EC remains a low or non-existent consideration for building design (Orr et al. 2019). The various barriers to tackling EC have been discussed more extensively in (Banteli and Stevenson 2017). These include the UK AEC industry's observed diversity and fragmentation and EC assessment complexity. In recent years, Building Information Modelling (BIM) has been introduced to the UK construction industry as a new collaborative way of working. It is defined as both a process and a tool to enhance stakeholder collaboration through improved data management and a single digital model that is accessible to all professionals throughout the building's life cycle (Shrivastava and Chini 2012). Thus, BIM is considered to improve information management across the design team and reduce the complexity of addressing EC (Capper et al. 2012). Current literature relating to both EC and BIM has predominantly focused on the technical aspects of EC assessment facilitation through the use of the BIM model. However, there is a lack of research taking a holistic approach that adopts a socio-technical perspective. This paper investigates EC facilitation through BIM by asking the question: 'How are EC considerations set and realised in a BIM-enabled building design process?' It uses an ethnographic case study of a building project and draws observations during the design stage. The results have been analysed through a socio-technical perspective that considers people, process and tools and gives new insights about the interactions between these three themes.

THEORY

Socio-technical system (STS) theory was originally developed at the Tavistock Institute of Human Relations and focuses on the interdependencies between people, technology and environment (Appelbaum 1997). Socio-technical theory was initially used to design jobs and work systems. As technology has been incorporated to all industries and STS applicability extended to almost any organizational situation, STS has been widely applied to most industrialised nations (Appelbaum 1997).

BIM has been considered as a collaborative environment where people and information work together through defined processes and technology (RICS 2014). Therefore, by definition, BIM is not merely a software application as it involves social and technical characteristics. There is an extensive body of literature that focuses on the technology side of BIM. The studies that take an STS approach mostly focus on BIM implementation and its barriers (Alreshidi et al. 2017). Oesterreich and Teuteberg (2019) use STS to analyse barriers to BIM adoption and indeed to the causes of these barriers. They use an STS social and technical sub-system framework that consists of 'people and structure' (social) and 'processes, technology and tasks' (technical) components. The study demonstrates that although many barriers are task or technology related, the causes of those barriers show a significant shift towards social aspects of the system, mainly people and social arrangements (structure) within the construction industry (Oesterreich and Teuteberg 2019).

New environmental problems that have taken a global focus in the last decades have been characterised as socio-technical due to their complexity and the fact that they entail new technologies and changes in policy as well as user practices and cultural meanings (Verbong and Geels 2010). Tackling EC in building design can be considered as part of these new environmental problems. EC has mostly been addressed in literature as a technical problem, with studies focusing on estimation methodologies databases and tools (Azari and Abbasabadi 2018). However, there are exceptions. Moncaster et al. (2019) used a socio-technical perspective to consider contexts that influence design decisions that aim at EC reduction. The study focused on enablers at the policy and project levels for case studies that are innovation examples in reducing EC building impacts. At the policy level, in the lack of national UK regulations, regional authorities played an important role in EC target setting for the project. At the project level, professional leadership shown by the design team resulted in the use of structural timber instead of a steel frame material. Orr et al. (2019)'s study is also an exception to the technical focus of EC related literature and focuses on practitioners' views on material efficiency. The study used a survey addressed to engineering (structural and civil) practitioners to examine the culture and practices in design relating to material efficiency. The results showed that EC is not a high priority in structural design and a lack of consensus across the sector regarding material efficiency.

Other studies that looked at the technological transition for sustainable building construction (Rohracher 2001) and transitions in environmental sustainability, energy systems and policy have also been analysed through the STS approach (Markard et al. 2016; Geels et al. 2017). As both BIM application and EC considerations in building design form new challenges for the construction industry, a transition in current practices is required. However, literature that combines BIM and EC has taken a technical approach and has focused on incorporating carbon data into the BIM model (Capper et al. 2012), BIM and Life Cycle Assessment (LCA) tool interoperability (Soust-Verdaguer et al. 2017), comparisons of EC results from LCA tools and BIM plugins (Bueno and Fabricio 2018), and visualisation of environmental potentials of building designs through BIM (Röck et al. 2018). There is a lack in the literature that considers BIM and EC under a socio-technical perspective.

This research aims to address this gap by adopting a socio-technical approach to analyse the elements that affect EC target setting and realisation in BIM-enabled building design. As both BIM application and EC considerations in design require a transition in current practice, STS is deemed a suitable theoretical lens for studying this transition. "People, Process and Technology" are part of Leavitt's socio-technical Diamond model for creating change in an organization and have been identified as key elements for process improvement (Leavitt et al. 1962). Therefore, this research considers people, process and technology to enable a holistic view of EC considerations in a BIM-enabled building design.

METHOD

The main characteristic of ethnography is that it aims to create a deep understanding of behaviour within a specific context. It is particularly useful when exploring unknown or new behaviours and investigates the meanings that are shared within this context that are considered salient in understanding group behaviours (Punch 1998). This research looks at EC considerations in BIM-enabled building design through a socio-technical perspective, which hasn't been addressed so far. Therefore, an ethnographic approach was adopted to explore the nuances and create a deep understanding of the observed phenomenon. Since this study particularly focuses on EC and BIM application during the building design process, the case study was selected through purposive sampling to ensure that the building project enables an investigation of these two aspects (Miles 1984). The selected case study has a target to achieve BREEAM 2014 Excellent and although EC is not a separate target, it forms a part of the overall BREEAM target. Defined as BIM Level 2 project, it is an educational building project in South Wales classified as D1 Non-residential institutions according to the Town and Country Planning (Use Classes) Order 1987. The client is a Higher Education Institution, which is classified as a non-profit institution serving households. The researcher engaged with the project for 14 months, from the end of the project's brief stage/ beginning of concept design stage until the end of the design stage/ start of the construction stage. The fieldwork included attendance of key project meetings, document analysis and interviews with relevant project stakeholders. Overall, the researcher attended 12 meetings resulting in 40 hours of meeting observation which covered the project design team and progress meetings as well as any meetings that related to sustainability and BIM. During the meetings, the researcher made notes of what was being discussed. For a further 4 meetings when attendance was not feasible, meeting minutes were analysed. Project document analysis included the feasibility report, end of design stages reports (2 documents which included project brief), BREEAM end of design stages reports (3 documents), the BIM execution plan, the Master Information Delivery Plan, the Model Production Delivery Plan, the Architectural Outline Specification, the Design and Access Statement and National Building Specification material specifications (55 documents). Acquiring information from key stakeholders didn't always take the form of a formal interview, but rather as informal discussions during the meeting breaks or emails. These discussions involved the client, architects and sustainability consultant and took place at least once per design stage. The research data collected during this research have been anonymised.

RESULTS AND ANALYSIS

Analysis of the data included organising them into three main topic areas, 'EC considerations and target setting', 'EC target realisation' and 'BIM application and information management'. During the analysis, three main themes emerged: People, Process and Tools. This relates to the key elements "People, Process and Technology". In this research, Technology has been replaced with Tools to encompass other technical tools such as secondary data lists and benchmarks. Informed by the data analysis, the broad themes of People, Process and Tools were broken down into sub-areas as follows:

- People (Pe): This area refers to the client and the professionals that comprise the design team. This area is further divided into sub-areas of (i) collaboration (C) between the teams and the client, (ii) skills, knowledge and expertise (S), and (iii) values/ professional ethics (V).
- Process (Pr): This area refers to the available standards, protocols, rating schemes, guidance documents, as well as building contracts, project management and scheduling. This area is further divided into sub-areas of (i) high-level (H) and (ii) project level (P).
- Tools (T): This area refers to (i) software (S), and (ii) information sets such as benchmarks, datasets (I).

The results are grouped into themes in Figure 1. The interrelations of results amongst different themes are also presented in this figure.

People

Values

The client is responsible for team appointments which highly influences sustainability considerations for a project. Team appointments for the project informally considered sustainability input that the professionals could bring to the project. According to the Sustainability Consultant (SC): *'So there won't be anything in the brief that says 'you need to have sustainability criteria' but they have been appointed because they have that. The whole project team is working towards the same aim.'* (SC, Concept Design Stage). Although this project's team appointments considered sustainability expertise and included an SC from an early stage, EC was not a high consideration for the project and building's whole life carbon impacts were not considered at all due to SC's lack in Life Cycle Analysis (LCA) expertise.

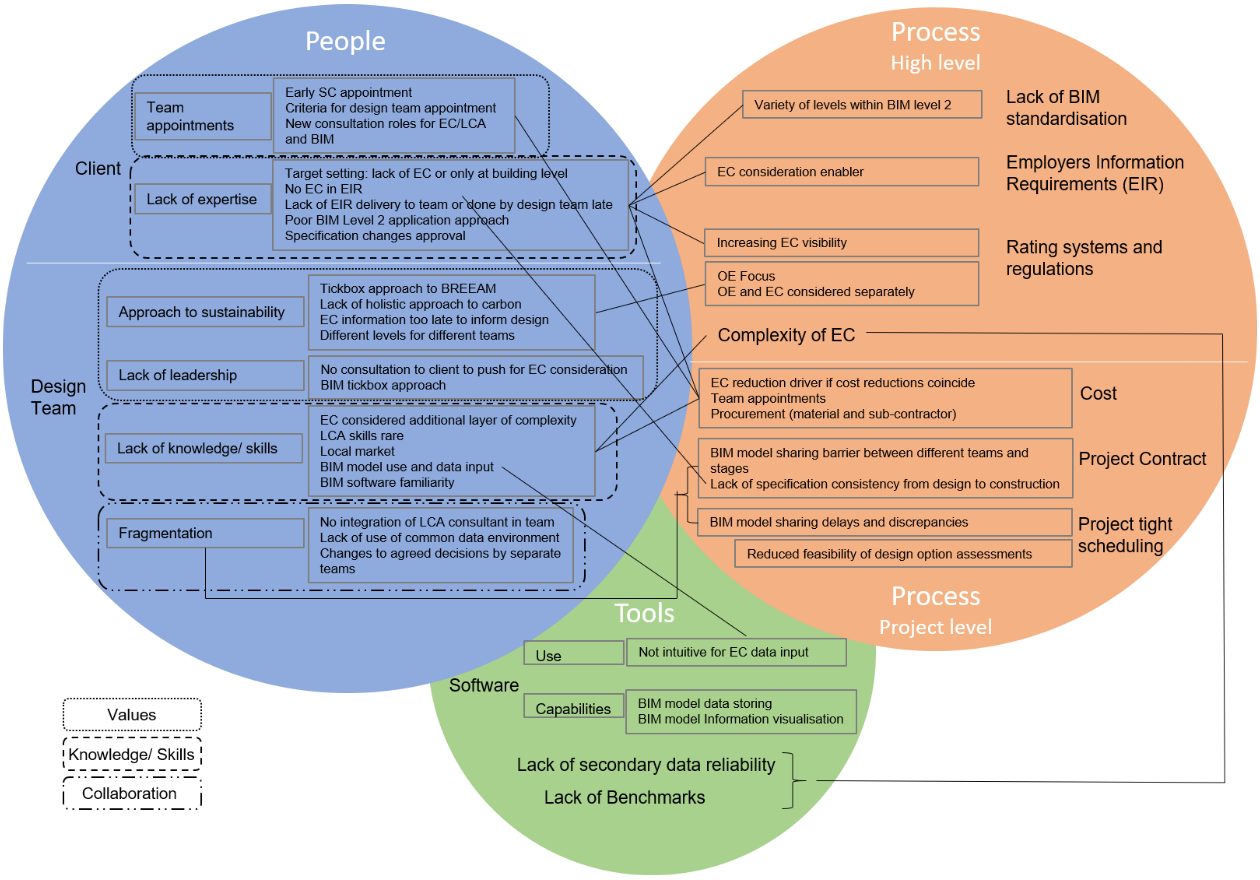

Figure 1People Process and Tools themes and interactions

Although the appointment of an LCA consultant was requested by the SC at the end of Concept Design Stage, this was not provided. A "BIM and Information lead" appointment requested by the design team at Concept Design was also not provided. The BREEAM target was the main sustainability driver, with a "lowest capital cost" approach taken to achieve the target. The SC's role was to achieve the BREEAM target 'comfortably': *'We've got the realistic opportunity to go up to 80%, but we need 70% so my overarching role is to get us comfortably to 70%. Also mindful that there are options that cost a lot and others that don't, and that's what I bring to the table, so I will comfortably get us a rating of 70%, it's how we collectively play with these figures'* (SC, Concept Design Stage). The architects held consultation sessions with the client and users and to ensure that the design would respond to their requirements. However, this opportunity was not taken to discuss sustainability priorities beyond compliance with the BREEAM target.

Skills, Knowledge and Expertise

The client is responsible for setting targets for EC and BIM approach; however, may not have sufficient knowledge, understanding or expertise to do this. In this project, this resulted in a lack of Employer's Information Requirements (EIR) and EC targets, as well as a poor BIM approach. The project design team demonstrated a variation to sustainability approaches from the different professions. The structural engineer team considered EC impacts from an early design stage; however, prioritised cost and local supply chain familiarity over reduced EC. The architects only mentioned EC impacts for specific building elements at the final design stage and did not let it inform the design. This may be because of the lack of knowledge and skills related to EC, which resulted in EC being considered as an additional layer of complexity and cost to the project delivery. EC was not included as a requirement for material specification by the design team at the end of the design stage (Architectural Outline Specification document). Therefore, the client will be responsible for approving any material changes proposed by the contractor during construction. This returns the responsibility of the final material selection to the client, who is not expected to have any specific sustainability knowledge. Similar issues were experienced in relation to the BIM model which was only used for spatial coordination. One aspect where BIM has been expected to facilitate EC consideration in projects is through providing reliable material quantities. However, the Quantity Surveyor team lacked familiarity with BIM software; therefore, the SC did not consider the material quantities in the BIM model accurate enough to be used in EC assessment of building elements for this project.

Collaboration
Fragmentation was observed in the design team and the common data environment for the project was not used, possibly due to late introduction. In particular, agreed decisions were later changed by separate teams.

Process

Higher Level
The poor BIM approach adopted in the case study can be related to the lack of standardisation which allows for flexibility in the way that Level 2 BIM is realised in building projects. Although EIRs have been identified as a potential enabler for EC inclusion in targets and project design, EIR creation falls within the responsibility of the client. EIR creation depends on the client's expertise to firstly deliver these requirements and secondly to include EC considerations and targets within the EIR. The heavy focus of regulations and building rating systems on Operational Energy (OE), and the separate consideration of OE and EC is a barrier to a holistic approach to carbon reduction by the design team. Although the case study had a proactive and consistent approach to BREEAM target achievement, EC considerations were low during the target setting and were considered too late to inform design. LCA was mentioned as an intention but was not actioned. This shows that even when following a consistent approach to BREEAM, it is not sufficient for EC to be thoroughly included and realised for the project.

Project level
The main themes that stood out in the case study were project cost, contract and scheduling. The project cost was identified to be an important factor that affected EC reduction efforts, team appointments and project procurement. In relation to EC reduction, cost was found to be an enabler if cost reductions were coinciding with carbon reductions. However, for the team appointments and procurement, when further costs would be incurred due to new role appointments (for LCA and BIM) or material and sub-contractor selection, cost was a barrier for EC reduction. With regards to selecting structural timber as a material, it was mentioned: *'[structural timber is] not yet commonplace in the UK and requiring new site skills, anticipated costs are higher than the more traditional concrete and steel options. Providing a timber option was therefore discounted at early Stage 2 design development'* (Concept Design end of report). The project contract caused a barrier to BIM model sharing between different design teams at different design stages due to legal implications of novation. In regards to specification, the lack of consistency between what is specified by the design team and what is actually built by the contractor was also a barrier that was related to the project contract. Tight project scheduling resulted in delays of sharing the BIM model and caused discrepancies between the different professional teams. It also resulted in reduced feasibility of undertaking cost assessments for alternative design options. Project contract and

scheduling further contributed to the fragmentation observed amongst the different professions of the design team.

Tools

Although BIM software tool capabilities of data storing and information visualisation were identified and considered as an enabler for EC considerations, the complexity of their use and the lack of an intuitive way to add the required information and to produce meaningful results was considered a barrier by the design team: *''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'* (SC interview, Concept Design Stage). This can be linked to the theme of skills as the design team lacked the skills related to BIM model use and data input. The SC highlighted lack of reliable secondary data and benchmarks for EC as a barrier for EC considerations during the design process: *'we cannot specific targeting, because we don't have a benchmark to compare against'* (SC interview, Concept Design Stage). This can also be related to the complexity of EC calculation and assessment process.

DISCUSSION

The client is very important in both EC considerations and BIM application as project target setting, BIM EIRs and project team appointments are dependent on them. The importance of clients was also acknowledged by Orr et al. (2019) in their investigation on efficient material use for the EC reduction in buildings. They highlight the need to align incentives of clients, design team and policy makers in order to achieve reduced EC in building structures. The need to incentivise and also educate clients was acknowledged by Schweber and Schweber and Haroglu (2014). They urged policy makers to adopt a capacity building approach for enabling sustainable building construction. As seen in the findings of this study, clients might lack sustainability expertise and tend to prioritise decisions on the basis of reducing the capital cost of the project. This could result in the lack of setting EC target, EIRs and required BIM and LCA consultant appointments. This demonstrates discrepancy between what is expected by standards and guidance documents, and what actually happens in a real context. This discrepancy is also evident for the Quantity Surveyors who are expected to be the profession most involved in tackling EC due to their familiarity with project material quantities (RICS 2012). However, in the case study, they were found to be the least involved in EC considerations and lacking BIM software familiarity for the inclusion of material quantities in the model.

Considering the lack of client expertise, design team appointments are important for enabling the inclusion of sustainability in building design. In particular, early appointment of a SC has been considered critical for the inclusion of EC in design considerations (Banteli et al. 2018). However, the design team in the case study has shown lack of leadership in providing consultation to the client to push for a more thorough approach to EC reduction and a stronger BIM implementation. Their EC and BIM actions were characterised by a lowest capital cost approach to BREEAM target realisation and BIM information management. This was also encountered in Schweber and Haroglu's (2014) study of BREEAM assessment during the design process, where interviewees characterised the BREEAM assessment process as a 'box-ticking' exercise. This demonstrates that high level (or top-down) processes alone are not enough to enable the change required, and design team professionals need to adopt a 'middle-agent' approach to influence EC inclusion in design considerations and a stronger BIM application. This approach was also suggested by Janda and Parag (2013) where building professionals were considered as middle agents of change to implementing low carbon innovations and practices. The contribution of individual team members in driving innovation was also demonstrated in the study by Moncaster et al. (2019) where the design team pushed for innovative use of materials for EC impact reduction. Innovation that emerges in niches through dedicated actors has been highlighted in the socio-technical transitions literature (Verbong and Geels 2010). However, variations to sustainability approaches from the different professions of the design team, as observed during the fieldwork, hindered a unified approach to the reduction of the case study's carbon impacts. Lack of consensus in relation to material efficiency for EC reduction has also been identified amongst engineering practitioners (Orr et al. 2019).

At Project level of the Process theme, cost and scheduling need to be reconsidered as they have been found to have several implications on EC considerations. Project costs need to be revised to enable new roles and required expertise (BIM manager, LCA consultant) to be appointed. This could enable better information management of projects to enhance collaboration amongst the design team (as BIM was intended to do), and undertaking a whole building life cycle carbon approach. Project schedule needs to be revised to enable alternative design options to be assessed in relation to both carbon and cost, during all design stages. All of the above issues link back to the skills and values of client and project manager, who need to include these considerations when budget and project timetabling is devised.

Lack of benchmarks and reliable secondary EC databases have been found to cause complexity in the overall EC calculation process. The BIM model has the potential to address this complexity and facilitate the whole building EC calculation, as it can aggregate EC impacts from element level to whole-building level (Capper et al. 2012). However, unmanaged and fragmented model data input can make the BIM model unreliable. The professionals' unfamiliarity with the software hinders its use and contract implications hinder BIM model sharing between teams.

As seen from the above discussion, 'People' appears to be the predominant theme affecting EC target setting and realisation as well as BIM application. Process and Tool elements can become barriers or enablers depending on how people enact and use them. This was also conveyed by Alreshidi et al. (2017), where the focus on 'actors' was considered crucial for successful BIM governance. Oesterreich and Teuteberg (2019) also found that for BIM adoption barriers concerning tasks and technology, the cause of those barriers was traced back to social dimensions that related to people and organisational structure.

CONCLUSIONS

Following the socio-technical approach, this study has given new insights into how EC considerations are set and realised in a BIM-enabled process. It has offered a holistic view which considered the role of people, process and tools in EC target setting and realisation, as well as BIM application and information management. The study identified links between the themes of 'People', 'Processes' and 'Tools' and highlighted the importance of 'People' for the effective use of tools and processes that can facilitate EC considerations in building design through BIM application. It has also highlighted the need for design teams to act as 'middle agents' and 'actors of influence' for educating the client in relation to EC target setting and BIM application. Further, the design team might need to provide consultation in relation to project budget and timetabling to enable new roles for the required expertise to be appointed and alternative design options to be assessed in relation to cost and carbon. Using a real-life context, the study also revealed discrepancies between expected practices by guidelines and standards relating to EC and BIM, and what is observed in practice. This calls for future EC reduction policy and BIM standards to adopt a more pragmatic approach by establishing a better understanding of current industry practices and capabilities. The study therefore contributes to both practice and policy by providing insights into how EC considerations are set and realised in a BIM-enabled building design process. Finally, the study also contributes to the STS theory by using key elements from Leavitt's socio-technical Diamond model as themes and introducing sub-areas for the 'People' and 'Process' themes to analyse the research findings.

Further investigation

Future research will include three further case studies, enabling cross-case comparison of the factors affecting EC considerations in BIM-enabled projects. Purposive case study selection will ensure that the case studies are all at BIM Level 2 but differ in their approach to EC considerations. A cross-case comparison will be conducted to identify similarities and differences between case studies and enable further understanding of what affects EC considerations during target setting and realising those targets in BIM-enabled projects. As different levels within themes have been identified, the application of multi-level perspective for further data analysis will be considered.

REFERENCES

Alreshidi, E. et al. 2017. Factors for effective BIM governance. *Journal of Building Engineering* 10, pp. 89-101. doi: https://doi.org/10.1016/j.jobe.2017.02.006

Appelbaum, S. H. 1997. Socio-technical systems theory: an intervention strategy for organizational development. *Management Decision* 35(6), pp. 452-463. doi: 10.1108/00251749710173823

Azari, R. and Abbasabadi, N. 2018. Embodied energy of buildings: A review of data, methods, challenges, and research trends. Energy and Buildings 168, pp. 225-235. doi: https://doi.org/10.1016/j.enbuild.2018.03.003

Banteli, A. and Stevenson, V. 2017. Building information modelling (BIM) as an enabler for whole building embodied energy and carbon calculation in early stage building design. *WIT Transaction on The Built Environment* 169, pp. 89-100.

Banteli, A. et al. 2018. Building Information Modelling (BIM) application in relation to embodied energy and carbon (EEC) considerations during design: A practitioner perspective. *Sustainable Design in the Built Environment.* London.

Basbagill, J. et al. 2013. Application of life-cycle assessment to early stage building design for reduced embodied environmental impacts. *Building and Environment* 60, pp. 81-92. doi: https://doi.org/10.1016/j.buildenv.2012.11.009

Bueno, C. and Fabricio, M. M. 2018. Comparative analysis between a complete LCA study and results from a BIM-LCA plug-in. *Automation in Construction* 90, pp. 188-200. doi: https://doi.org/10.1016/j.autcon.2018.02.028

Capper, G. et al. 2012. Incorporating embodied energy in the BIM process. *CIBSE ASHRAE Technical Symposium.* Imperial College, London UK.

Geels, F. W. et al. 2017. The Socio-Technical Dynamics of Low-Carbon Transitions. *Joule* 1(3), pp. 463-479. doi: https://doi.org/10.1016/j.joule.2017.09.018

Janda, K. B. and Parag, Y. 2013. A middle-out approach for improving energy performance in buildings. *Building Research & Information* 41(1), pp. 39-50. doi: 10.1080/09613218.2013.743396

Leavitt, H. J. et al. eds.*Cooper, W.W.* 1962. *New perspectives in organization research*. *Research in Organizations.* Carnegie Institute of Technology, Wiley.

Markard, J. et al. 2016. Socio-technical transitions and policy change – Advocacy coalitions in Swiss energy policy. *Environmental Innovation and Societal Transitions* 18, pp. 215-237. doi: https://doi.org/10.1016/j.eist.2015.05.003

Miles, M. B. 1984. *Qualitative data analysis:a sourcebook of new methods*. London: SAGE.

Moncaster, A. M. et al. 2019. Widening understanding of low embodied impact buildings: Results and recommendations from 80 multi-national quantitative and qualitative case studies. *Journal of Cleaner Production* 235, pp. 378-393. doi: https://doi.org/10.1016/j.jclepro.2019.06.233

Oesterreich, T. D. and Teuteberg, F. 2019. Behind the scenes: Understanding the socio-technical barriers to BIM adoption through the theoretical lens of information systems research. *Technological Forecasting and Social Change* 146(C), pp. 413-431.

Orr, J. et al. 2019. Minimising energy in construction: Practitioners' views on material efficiency. *Resources, Conservation and Recycling* 140, pp. 125-136. doi: https://doi.org/10.1016/j.resconrec.2018.09.015

Punch, K. 1998. *Introduction to social research : quantitative and qualitative approaches*. London: SAGE.

RICS. 2012. *Methodology to calculate embodied carbon of materials*.

RICS. 2014. *What is BIM?* http://www.rics.org/uk/knowledge/glossary/bim-intro: Available at: [Accessed: 9 April].

RICS. 2017. *Whole life carbon assessment for the built environment*. London UK

Rohracher, H. 2001. Managing the Technological Transition to Sustainable Construction of Buildings: A Socio-Technical Perspective. *Technology Analysis & Strategic Management* 13(1), pp. 137-150. doi: 10.1080/09537320120040491

Röck, M. et al. 2018. LCA and BIM: Visualization of environmental potentials in building construction at early design stages. *Building and Environment* 140, pp. 153-161. doi: https://doi.org/10.1016/j.buildenv.2018.05.006

Sassi, P. 2006. *Strategies for Sustainable Architecture*. London: Taylor & Francis.

Schweber, L. and Haroglu, H. 2014. Comparing the fit between BREEAM assessment and design processes. *Building Research & Information* 42(3), pp. 300-317. doi: 10.1080/09613218.2014.889490

Shrivastava, S. and Chini, A. 2012. Using Building Information Modeling to Assess the Initial Embodied Energy of a Building. *International Journal of Construction Management* 12(1), pp. 51-63. doi: 10.1080/15623599.2012.10773184

Soust-Verdaguer, B. et al. 2017. Critical review of bim-based LCA method to buildings. *Energy and Buildings* 136, pp. 110-120. doi: https://doi.org/10.1016/j.enbuild.2016.12.009

Verbong, G. P. J. and Geels, F. W. 2010. Exploring sustainability transitions in the electricity sector with socio-technical pathways. *Technological Forecasting and Social Change* 77(8), pp. 1214-1221. doi: https://doi.org/10.1016/j.techfore.2010.04.008

Yohanis, Y. G. and Norton, B. 2006. Including embodied energy considerations at the conceptual stage of building design. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy* 220(3), pp. 271-288. doi: 10.1243/095765006X76009