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Delivering improved initial embodied energy efficiency during construction

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ABSTRACT

Energy use during the material, transportation and construction phases up to project practical completion is known as initial embodied energy. Contractors have the opportunity to capture initial embodied energy data and influence performance due to their significant involvement in project procurement and delivery. In this case study practical challenges and opportunities were addressed for delivering improved initial embodied energy efficiency during construction. A revised framework was applied to a live industrial warehouse project to assess the initial embodied energy performance of assorted construction activities, packages and sub-contractors. The practices employed by the contractor on-site were explored and then improved. Results show that material phase impacts represented 95.1% of the total initial embodied energy consumption whereby construction packages predominately containing steel and concrete-based materials (i.e. ground and upper floor, external slab and frame) were most significant. The overall initial embodied impact was deemed greater than the operational impact at the end of the buildings 25-year lifespan. Findings suggest that future project benchmarks and targets should be normalised per site area, as these impacts were found to be significant in this particular case.

1. Introduction

The UK non-domestic sector is accountable for 18% of the UK's total CO_2 emissions, hence providing significant opportunities for CO_2 emission and energy consumption reduction (BIS, 2010; Carbon Connect, 2011; Carbon Trust, 2009). Project life cycle energy is derived from operational and embodied energy. Operational energy relates to the energy use during building occupier activity whereas embodied energy relates to the indirect and direct energy inputs required for various forms of construction. Initial embodied energy specifically relates to the energy use during the material, transportation and construction phases up to project practical completion (Cole, 1999; Davies, Emmitt, & Firth, 2014; Dixit, Fernandez-Solis, Lavy, & Culp, 2010). Many previous studies have focused on improving operational energy efficiency through developing standardised methods of data capture, benchmarks and exploring common discrepancies between design and actual operational energy performance within buildings (Cabeza, Rincon, Vilarino, Perez, & Castell, 2014; de Wilde, 2014; Firth, Lomas, Wright, & Wall, 2008; Gill, Tierney, Pegg, & Allan, 2011; Menezes, Cripps, Bouchlaghem, & Buswell, 2011; Menezes, Nkonge, Cripps, Bouchlaghem, & Buswell, 2012). However, at present the concept of addressing initial embodied energy is not as advanced within the industry.

Opportunities to address project life cycle energy are typically identified through a life cycle assessment (LCA). Seemingly the availability and accuracy of LCA data is dependent upon many various project factors such as type, scale, location and duration and the decisions undertaken by practitioners in terms of system boundary, data source and calculation method selection (Dixit, Fernandez-Solis, Lavy, & Culp, 2012; Optis & Wild, 2010). Variation amongst these project factors and decisions make it difficult for practitioners to compare data and highlight consistency within results (Cabeza et al., 2013; Ding & Forsythe, 2013; Treloar, Love, & Iyer-Raniga, 2000).

Understanding the significance of individual project life cycle phases and the relationship between them seems essential for project stakeholders to reduce overall project life cycle energy (Blengini & Di Carol, 2010; Davies, Emmitt, Firth, & Kerr, 2013b; Langston & Langston, 2008; Optis & Wild, 2010; Sodagar & Fieldson, 2008). Some studies have suggested Building Information

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Modelling (BIM) will support project stakeholders in the future to identify opportunities to improve energy efficiency through the creation and use of intelligent databases and 3D models (Goedert & Meadati, 2008; Mah, Manrique, Yu, Al-Hussein, & Nasseri, 2010; Vilkner, Wodzicki, Hatfield, & Scarangello, 2007). However, there appears to be limited comprehensive data available (Davies et al., 2013b), no coherent method for data capture (BIS, 2010; Dixit et al., 2012), and little incentive for project stakeholders (Hamilton-MacLaren, Loveday, & Mourshed, 2009) to reduce initial embodied energy.

The majority of existing studies have not explored practical approaches to initial embodied energy assessment or addressed the significance of construction packages and activities in terms of individual life cycle phases. Despite the need for improved data and benchmarks (BIS, 2010; Ko, 2010) there appears to be no clear understanding of which project stakeholders are best equip to capture this data and experience the risk and rewards for targeting improved initial embodied energy efficiency (Treasury, 2013; RICS, 2012; UK-GBC, 2012). Evidently, project stakeholders may decide going forward to develop internal bespoke methods, based upon own current practices and data, to facilitate initial embodied energy assessment rather than use existing LCA tools (e.g. ATHENA® Impact Estimator, EIO-LCA, Eco-LCA, Ecoinvent) and databases (e.g. DEAM™, GaBi, CFP, IBO, Synergia, ICE, Defra Guide) due to knowledge, user-friendliness and resource availability (Davies et al., 2013b, 2014; Scheuer, Keoleian, & Reppe, 2003; Srinivasan, Ingwersen, Trucco, Ries, & Campbell, 2014; Takano, Winter, Hughes, & Linkosalmi, 2014; Van Ooteghem & Xu, 2012). In particular contractors have a vested interest in initial embodied energy and have access to primary data due to their significant involvement in project procurement and delivery (Davies, Emmitt, & Firth, 2013a; Davies et al., 2013b; Goggins, Keane, & Kelly, 2010; Li, Zhu, & Zhang, 2010; Monahan & Powell, 2011; RICS, 2010). The study aimed to address the practical challenges and opportunities for delivering improved initial embodied energy efficiency during construction. A literature review helped develop a revised framework intended to assess the initial embodied energy performance of construction activities, packages and sub-contractors relative to a UK industrial warehouse project. The revised framework was applied to a live project to facilitate the capture of primary data.

1.1. Initial embodied energy phases

1.1.1. Material phase (cradle-to-factory gate)

Material phase impacts are derived from the consumption of energy (e.g. petrol, diesel, gas, electricity) during the procurement and manufacture of raw materials into finished building materials, products and services. The Inventory of Carbon and Energy (ICE) is a commonly used dataset which highlights the embodied carbon and energy of materials typically used within construction (e.g. concrete, glass, plastic, steel, and timber) (BSRIA, 2011). The embodied coefficients detailed within the dataset are typically used by practitioners in conjunction with material characteristics (i.e. size, volume and weight) derived from a project's bill of quantities and design drawings (Davies et al., 2013b, 2014; Hamilton-MacLaren et al., 2009; Mah et al., 2010; Scheuer et al., 2003). Regardless of project type and location, many previous studies have highlighted the significance of material phase impacts and in particular emphasised the importance of building frame and envelop design in order to help reduce initial embodied energy consumption (Cole & Kernan, 1996; Kofoworola & Gheewala, 2009; Rai, Sodagar, Fieldson, & Hu, 2011; Van Ooteghem & Xu, 2012).

1.1.2. Transportation phase (factory gate-to-site gate)

Transportation phase impacts are derived from the consumption of energy (e.g. petrol, diesel) during transport of material, plant and equipment, and operatives to and from site during the construction phase of a project. Some studies have previously used the publically available data within the 2012 Guidelines to Defra/DECC's GHG Conversation Factors Company Reporting document (Defra Guide) to assess these impacts (Davies et al., 2014; Williams, Elghali, Wheeler, & France, 2011). The Defra Guide contains a series of GHG conversion factors to allow various activities (i.e. litres of fuel used, number of miles travelled) to be converted into kilograms of carbon dioxide equivalent ($kgCO_2e$) (DEFRA, 2012). Typically to assess these impacts mode and distance of transport data is captured post-construction from various contractor current practices (e.g. sign-in sheets, delivery records) as this data is only available once the construction phase has commenced (Davies et al., 2013b, 2014; Hamilton-MacLaren et al., 2009; RICS, 2012). Seemingly, the majority of previous LCA studies have either: assumed or ignored certain transport data such as distance travelled (Adalberth, 1997; Cole, 1999); reported this impact collectively with other life cycle phase impacts such as the construction phase (Cole & Kernan, 1996; Kofoworola & Gheewala, 2009); or overlooked this impact all together (Gustavsson, Joelsson, & Sathre, 2010; Halcrow Yolles, 2010; Iddon & Firth, 2013). Consequently, there is an apparent view within literature that reducing this impact will not result in significant energy reductions for a project or wider industry (Hamilton-MacLaren et al., 2009; RICS, 2012).

1.1.3. Construction phase (site gate-to-practical completion)

Construction phase impacts are derived from the consumption of energy (e.g. petrol, diesel, gas, electricity) during the installation of building materials, products and services up to project practical completion. Typically to assess these impacts, along with the Defra Guide, construction activity duration, plant and equipment selection, and fuel usage data is captured post-construction from various contractor current practices (e.g. programme of works, plant register), as this data is only available once the construction phase has commenced (Davies et al., 2013b, 2014; RICS, 2012). Currently there is a lack of detailed, accurate data within literature which reflects the impact of the construction phase across various projects (Hamilton-MacLaren et al., 2009), especially as significant time, money and effort are required by practitioners to capture and assess this data. Hence, construction phase impacts are commonly assumed, or even ignored, by practitioners as the impact is viewed to be insignificant in comparison to total project life cycle energy (Gustavsson & Joelsson, 2010; Iddon & Firth, 2013; Pajchrowski, Noskowiak, Lewandowska, & Strykowski, 2014).

2. Method

A case study approach was adopted as this provided a useful vehicle for monitoring activities on site in relation to initial embodied energy. One of the researchers was employed by a principal contractor thus providing the opportunity to capture primary data throughout the entire construction phase of the project (lasting 30 weeks). The contractor provided an appropriate sample due to their use of current forms of environmental measurement (i.e. Building Research Establishment Environmental Assessment Method, BREEAM) (BRE, 2011) and overall desire to improve project environmental performance; thus supporting the research by allowing access to primary data.

The case study project was a large design and build industrial warehouse located in the south of England. The project contained two pod offices, a single storey mezzanine office and a large chamber for ambient (10 °C) operating and storage use. The main building comprised: prefabricated steel structure; composite roof and cladding panels; precast concrete retaining wall; glazed façade