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Reducing embodied carbon during the design process of buildings

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ABSTRACT

To achieve low-carbon buildings, or buildings with low greenhouse (GHG) emissions, planning must begin during the design phase of a building project. This paper evaluates the current methods as support for the design of low-carbon buildings and the significance of different design phases from the perspective of embodied carbon. Through evaluation of relevant literature, interviews with practicing architects, and a building case study, we recommend to proceed gradually across all design phases for achieving low-carbon building design. This should take place in a systematic way that describes the status, coverage, and accuracy of GHG assessments in each design stage. Furthermore, we outline the framework with the use of the Royal Institute of British Architects (RIBA) stages of design, and for each stage, we identified the objectives, typical deliverables, and milestones necessary for ensuring carbon efficiency. This will require integration of the roles and responsibilities of the relevant stakeholders, including the client, project manager, architect, structural engineer, and Heating Ventilation and Air Conditioning (HVAC) engineer.

1. Introduction

The building sector is the largest single contributor to global greenhouse gas (GHG) emissions. The Intergovernmental Panel on Climate Change (IPCC) synthesis report [1] also lists buildings as having the greatest estimated economic mitigation potential of all the sector-linked solutions that were investigated. The IPCC suggests that measures to reduce GHG emissions from buildings include: reducing embodied energy in buildings, reducing energy consumption of buildings, and switching to low-carbon fuels [2].

Sustainable development of buildings brings about the required performance and function with the minimum adverse environmental impact [3]. Sustainable building processes can be defined as those in which the overall quality of the process enables the delivery of sustainable buildings in a way that meets the needs of all people involved [4].

Current building processes need to be changed to become sustainable; this will require significant improvements in the current plan of work and in the use of assessment tools. Sustainability assessment is no longer used only for marketing purposes, but the definition of project objectives is increasingly guided by the sustainability content, especially in public building processes [5–7]. This may require changing the way in which sustainability assessments are performed. The examination of sustainability at the end of the planning phase does not support design for sustainable buildings, therefore the "optimization" of sustainability must take place during the design phase.

This paper considers low-carbon design as one of the most important aspects of sustainable building design and focuses on the design process to reduce embodied carbon. The extraction, processing, manufacture, transportation, assembly and use of a product utilizes energy and induces harmful emissions, including CO_2 and other GHGs. With the exception of the generally more evident energy in-use, these impacts are regarded as the hidden or embodied burdens [8]. While there are several methods and tools for the assessment of energy consumption during the operational phase (as summarized by Schlueter and Thesseling [9]) embodied energy and carbon are not, in general practice, a consideration when a building is designed and constructed [8].

While the importance of decision making at an early stage of design has been widely studied and acknowledged, there is limited research on how to account for embodied carbon as a building is designed. This paper seeks to fill knowledge gaps in the literature and aims to support building designers and relevant decision makers on how to account for embodied carbon during the design stage in a step-by-step process.

The hypotheses of the paper are that: (1) important design decisions are done in the early stages of design and design alternatives need to be compared, even though complete building data

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is not yet available. (2) Design for low-carbon buildings requires the calculation of embodied GHGs gradually over the course of the building design. By a gradual approach, we mean a step-by-step process which should take place systematically describing the status, coverage and accuracy of GHG assessment in each design stage. (3) In each design stage the designer should be able to understand the significance of the preliminary calculations.

2. Objectives

The objective of this paper is to provide key guidance with the help of a systematic procedure required for designing low-carbon buildings, with a focus on embodied GHG emissions. These GHG emissions are induced because of the production processes of construction products (product stage emissions) and in further life cycle stages of construction products (installation into the building, use and maintenance, replacements, demolition, waste processing for re-use, recovery, recycling and disposal) [10,11]. The motivation for this paper is to address the need to apply sustainability related decision making as early as during the preliminary feasibility and preparation work and continuing throughout the initial design phases.

The objectives are as follows:

1. To assess the potentials and drawbacks of the current methods, standards and tools provided as aids for the design for low-carbon buildings.
2. To assess the significance of different design phases from the perspective of embodied carbon.
3. To describe a framework for a gradual low-carbon design approach to consider embodied carbon of buildings throughout the design process phases, mapped with the use of the RIBA Plan of Work [12] and ARK12 Finnish Plan of Work [13].
4. To draw conclusions and recommendations on the information, methods and standards needed.

3. Methodology

The study consists of: a review of relevant literature, interviews of principal designers in Finnish architectural offices, and a case study of a building. In the study of literature, we used qualitative research by comparing the findings in the literature in contrast to our hypotheses. The purpose of the semi-structured interviews was to understand at which phase of a building project are selections made for main building components and by whom. The purpose of the case study was to evaluate the relative importance of different building parts to the total embodied carbon of a building.

Environmental or sustainability rating systems such as LEED [18] and BREEAM [19] help designers in sustainable building design by providing indicators and benchmarks. Their main function is to enable the benchmarking of buildings. As a limitation of this article, rating systems are not the focus of this paper, but rather the focus is on the methods that can help the designer to attain the benchmarks – especially low-carbon design. Another limitation of this study is that the interviews are primarily conducted in Finland and the case study building is also constructed and designed based on Finnish regulations. However, it will benefit a larger audience as the architectural practices around the world have overlapping processes.

3.1. Study of literature

Through our literature review, we aimed at finding information for the following issues: (a) importance of embodied GHGs compared to total GHGs induced by buildings; (b) importance of the early stages of design with regard to embodied GHGs; (c) potential and drawbacks of current approaches, methods, standards and tools to aid the design low-carbon buildings; and (d) availability of data, process descriptions and frameworks for sustainable building design.

3.2. Interviews

The architectural offices were selected randomly with no prior preference or bias of the authors; but they were required to be a member of Association of Finnish Architects offices [Arkkitehtitoimistojen Liitto (ATL)]. ATL comprises more than 240 registered architectural companies across Finland. To be a member of the association, the architectural company must demonstrate the highest professional training and solid experience of working in the industry [www.atl.fi]. Twelve architectural companies were contacted to carry out a semi-structured interview, out of which seven responded positively (58.5% response rate). Being a member of ATL, these seven offices are representative of quality architecture being practiced in Finland; they have a minimum of two to a maximum of forty five full-time architects working on a variety of projects. The seven architectural companies have a collective total of over 200 reference projects that were listed as their best designs on their websites. The design projects included in the interviews conducted for this study were mostly won through national design competitions.

Interviews were conducted between August and October 2013; six were face to face and one was via teleconference. The interview durations varied from 40 to 90 min. All the interviewees are the principal architects in their respective companies and have more than ten years of experience in industry. The architects chose to share information of the projects, where they had the right or the permission of the client to share the details discussed in this article. Table 1 lists twelve buildings with type, location, floor area and the name of respective offices interviewed. The seven principal designers were asked to select a recently designed and commissioned project that is representative of different architectural form and function of the building. This was done to capture the variation in the roles of key decision makers in different types of projects. They were asked to give their responses with help of an Excel spreadsheet to quantitatively assess the role of each actor in each phase of their selected project. This process was repeated individually for each building project evaluated as presented in Table 1. To gauge the general perception of the interviewee on the decision making process, we then asked the participants to elaborate more upon their responses and give reasoning based on the already collected quantitative data about the issues that generally affect the decision making of materials selection. This semi-structured interview approach was found necessary to increase the depth and interpretation of the results especially when such research may involve personal opinions and project specific experiences in construction industry [14]. Desktop analysis was employed to analyze the data collected by the semi-structured interviews. Furthermore, Section 5 presents the results of the interviews.

3.3. Building case study

Based on insight gathered from the interviews, we identified the key decision makers at each design stage according to the RIBA plan of work and ARK12 (Finnish plan of work) (Table 2). Each design stage typically corresponds to a building part, where decisions are made for that part or for many parts in parallel. For example, decisions about the building frame are made during the