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A multidisciplinary approach to sustainable building material selection: A case study in a Finnish context

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A B S T R A C T

This study demonstrated the influence of building material selection on the environmental and economic parameters of a building in a Finnish context. The effects of the choice were studied for the three building component categories: structural frame, inner components (i.e. insulation and sheathing) and surface components (i.e. exterior cladding and flooring), in a comparative manner on a reference building. The aim was to illustrate the features of the building materials in a relative manner from several aspects in order to help multi-criteria decision-making for professionals associated with the construction industry.

The results showed that the value of alternative materials varies depending on the aspects. It was also revealed that the environmental parameters need to be taken into account over economic aspect, since in many cases they vary much between the alternatives considered. The selection of the structural frame material has greater influence than the other two component categories, and the inner components need to be considered rather than the surface components, even though they are not visible when a building is completed. This paper indicates the importance of expressing and understanding the diversity of the materials. It would be important for sustainable building design to select suitable materials according to the purpose and their features on a case-by-case basis. In order to broaden the range of choice, the market system needs to be developed as well.

1. Introduction

The building sector contributes significantly to Humankind's environmental footprint, accounting for about 40% of total primary energy consumption in the European Union for instance [1]. A reduction in the environmental impact of a building during its life cycle is therefore an important target in terms of sustainable development and in this context there has been considerable effort over the past few decades to investigate the life cycle energy use and impacts of buildings. During their life cycle, buildings need energy for their construction (embodied energy) as well as their functioning (operational energy). In efforts to reduce the life cycle energy consumption and impacts of buildings, most attention has thus far been paid to the operation phase. The performance of a building (e.g. thermal insulation performance and air tightness) has been improved and the efficiency of building service equipment has also been actively developed. As a result of such efforts, the impact from the operation phase has been mitigated and the relative importance of the other life cycle stages has increased. Several researchers have conducted statistical analyses on previous building life cycle assessment (LCA) studies to review the relationship between operational and embodied impacts [2–8]. The studies commonly concluded that, in general, the operation still accounts for the major part of the life cycle energy use and environmental impact of buildings, but the proportion of the embodied energy and impact is increasing especially in the case of low energy buildings. Although there were the methodological differences between the case studies reviewed, it was reported that the share of embodied energy in the life cycle energy use (service life of 50 years) accounts for up to 46% in the case of low energy building and up to 38% in the case of conventional buildings [6]. Furthermore, it has been shown that embodied carbon emission could account for up to 68% of 60 year life cycle emissions [2].

To reduce the embodied impacts, the proper choice of building materials is important [9]; however, in a building LCA there is an apparent dilemma. In the design process, the flexibility in the choice of the design parameters is not consistent with the accuracy and amount of available information for the LCA [10]. However, the

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major proportion of the life cycle impacts of a building are determined by decisions made in the early design phase [11], so in practice, therefore, designers have to make important decisions at the beginning of design process with incomplete information. Several researchers have tried to address this problem by developing an index of building materials to help designers arrive at an optimal design solution for a sustainable building [12–15]. For four building elements (Substructure, Shell, Interiors and Services), Basbagill et al. [12] investigated the influence of material choice and thickness on a building's embodied impact. They noted that the largest influences arose from the cladding materials, piles, glazing material and flooring material, whilst changes to materials and thicknesses were not important for the building service components. Yasantha Abeysundara et al. [13] compared materials in five building elements (Foundation, Roof, Ceiling, Door and Window, and Floor) from an environmental, economic and social aspect in a life cycle perspective. They described the best and worst material combination in terms of embodied impacts for each building element as a matrix, and an existing school building in Sri Lanka was compared with the best and worst material combinations. Emmanuel [14] compared the five most common wall materials in Sri Lanka in terms of three parameters: embodied energy, life-cycle costs and re-usability, and summarized the results as an environmental sustainability index. Thormark [15] observed how material choice affects both embodied energy and recycling potential in an energy efficient apartment block in Sweden. He found that embodied energy could be decreased by approximately 17% or increased by about 6% by implementing a simple material change. It was also emphasised that the recycling aspect is a rather important factor in reducing life cycle energy use in buildings. Although there are limitations in these studies (e.g. the number of material combinations and geographical representativeness of the materials studied), they indicate that presenting information about building materials in a comparative manner can be used as a decision support tool to help designers and constructors make reasonable decisions about material choices for sustainable buildings. In particular, a multidisciplinary approach covering a number of indicators (e.g. energy consumption, global warming potential (GWP) and cost) [13,14] seems to be relevant, since a multi-parametric perspective is significant for decision-making in building design.

2. Objectives and scope

The aim of this study was to demonstrate how the choice of building material affects the following indicators in the material production phase of a building in a Finnish context:

- Resource use
- Embodied energy
- Energy content
- Embodied greenhouse gas emission
- Carbon storage
- Material cost

The effects of different material use on these indicators was analysed for the three building component categories: structural frame, inner components and surface components, in a comparative manner on a reference building. In addition to the differences in the materials in each building component category, the dominance of each building element (e.g. exterior wall) depending on the structural frame materials and the contribution of the component categories to the end results were investigated. The aim was to describe the features of the building materials in a relative manner from several aspects in order to help multi-criteria decision-making for professionals associated with the construction industry.

3. Method

3.1. Reference building

The building studied was a three story townhouse planned in Helsinki. The building consisted of five houses in a row. Fig. 1 shows the basic plan and section of the building with an indication of the building elements (e.g. exterior wall, party wall, interior wall, exterior floor, interior floor etc.), whilst Table 1 shows the area of each building element used in the calculation. Windows and doors were excluded from the calculation since they were the same in all cases. It was also confirmed that the influence of these components on the assessment result were marginal, so that their exclusion was not critical in this case.

The townhouse concept has attracted considerable attention lately as a new urban housing typology in Helsinki and is based on a conscious policy by the city planning department [16]. Thus this building was selected as the study object, although it was a blueprint for the new townhouse concept.

3.2. Indicators

3.2.1. Resource use (RU)

The mass of the renewable and non-renewable resources used as the raw material forming the building components was calculated as an indicator of resource use (RU-R and RU-NR).

3.2.2. Embodied energy (EE)

Primary energy consumed in the production phase of the building, from raw material extraction to completion of a product ready for delivery at the factory gate, was calculated as embodied energy with the ecoinvent database [17]. Embodied energy originating from renewable (EE-R) and non-renewable resources (EE-NR) were presented separately.

3.2.3. Energy content (EC)

As described in EN 16485 [18], the energy content of products used in the building was regarded as a specific inherent property and counted as the energy recovery potential of the building. The value was calculated with ecoinvent and literature [20].

3.2.4. Embodied greenhouse gas emissions (GHG)

Greenhouse gas (GHG) emissions for the production phase of the building were assessed as embodied GHG with ecoinvent. GHG emission from biogenic fuel combustion was regarded as zero emission based on the idea of biogenic carbon neutrality [18]. Thus embodied GHG means only the emission from fossil fuel combustion in this study.

3.2.5. Carbon storage (CS)

As mentioned previously, biogenic GHG is regarded as having a zero balance over the life cycle of wood products. In that sense, carbon storage in wood products may be a virtual value. However, it would be a clear benefit to store carbon in a product that delays the emission of CO_2 for a certain period at least. Therefore, the temporal carbon storage in wood products used is accounted for according to EN 16449 [19] as an environmental benefit of the building.

3.2.6. Material cost (cost)

Cost is one of the main criteria for material choice in practice so that it should be taken into consideration together with environmental features of products. Initial material cost was counted based on data in references [21] and [22]. The consistency of these two information sources was confirmed by comparing the price of same products.