UK experience of the use of timber as a low embodied carbon structural material

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Abstract: *As buildings become more energy efficient in their operation, embodied energy and carbon become increasingly important. However, there is limited information to allow accurate comparisons of products. Moreover, construction projects are quite complex, not only regarding environmental issues, but also processes and stakeholders. The study of timber as a structural material in the UK is used in this paper to illustrate these factors. The paper brings together five studies and it considers the decisions and processes affecting the use of timber. The EE and EC of timber throughout its lifecycle are identified, including a discussion of assumptions. The impact of various decisions is assessed and the paper concludes by identifying technical and social factors for the focus of policy makers and the industry.*

Timber, embodied energy, embodied carbon, building structure

Introduction

As buildings' operational energy (OE) performance improves, embodied energy (EE) and embodied carbon (EC) become increasingly important. Research focusing on the comparison of OE and EE [1] shows that for conventional buildings, EE represents between 2% and 38% of the energy use over their lifetime periods. This becomes 9% to 46% for low-energy buildings and even 100% for 'zero carbon' ones. Hence, accounting for embodied burdens in construction practices is crucial. However, the lack of information, the loyalty to conventional construction methods and the decision-making processes prevent this change from occurring.

The aim of this paper is to expand on and clarify information regarding the use of timber as a structural material in the UK. This includes an analysis of the EE and EC of timber versus steel and concrete, with details of its End-of-Life (EoL) scenarios and a discussion of the potential advantages of timber construction. Finally, barriers to its wider use are investigated.

This paper is structured as follows. The second section provides contextual information and the third one describes the research methodology. The fourth and fifth sections identify the most carbon intensive lifecycle stages and building elements. The sixth section describes the advantages of timber and the seventh explains factors affecting its use. The final section emphasises the uncertainties of the research, summarising findings for different stakeholders.

Background

Buildings' construction and use are significant contributors to carbon emissions, being liable for almost 25% of worldwide emissions [2]. A further 5% is attributed to cement manufacture

[3]. Therefore, there is extensive research on the comparison of timber and lightweight construction versus concrete and heavyweight construction. Monahan [4] explains that brick and concrete construction is of higher EE compared to timber. Moreover, research in New Zealand [5] concluded that significant reductions in EC would result from a shift from steel and concrete to timber, provided that timber is sustainably produced.

The European Standard TC350 provides a calculation method for the whole-life performance of buildings, focusing on cradle-to-grave, with an optional stage beyond this. Cradle-to grave includes: product, construction process (including transport and construction), use and EoL [6]. However, the materials' country of origin and databases used can have a significant impact, while systems boundaries can be debatable. For example, defining the lifespan of the building as 25 or as 50 years can increase the initial EE by 59% or 148% respectively [7].

The calculation of EE and EC for timber construction, poses two very challenging issues: carbon sequestration and EoL scenarios. There are controversial opinions on including carbon sequestration for EC calculations of timber [8, 9]. Weight [9] considers the provenance of timber as the most important influence in sequestration and EC calculation for timber. Regarding EoL, Symons [8] addresses recycling, incineration and landfill. When recycling, the carbon 'credit' gained during sequestration remains intact. On the other hand, when timber is incinerated with full combustion, carbon of the same amount originally sequestered, is released into the atmosphere. The energy stored in the timber is released and can be recovered, hence an energy credit can be taken. Finally, in landfill, the carbon stored in timber is released as CO_2 or methane. The EoL scenarios depend on the country and landfill use; thus the comparison of various studies in different geographic contexts, is very challenging.

Methodology

As explained above, boundaries and lifecycle stages may vary between different studies. This paper discusses the boundaries and assumptions for EE and EC, focusing on timber compared to conventional materials. Structural timber use is currently limited in the UK, unlike concrete and steel. The paper is primarily based on studies conducted by five groups of researchers:

- Darby et al.[10]: an assessment of timber's EC and storage capacity as a structural material for a new building. The research focuses on Cross Laminated Timber (CLT) used for a multi-storey building, carbon storage during the building's life and the impact of EoL scenarios on EC. CLT is solid timber panels manufactured off site, with very low waste and a very quick erection time.
- Gavotsis [11]: OE and EE analysis of a new school building, using prefabricated timber beams. The study includes all stages of building lifespan, from product to EoL.
- Monahan [4]: timber frame versus conventional masonry at a housing development, focusing on EE and EC of the product and the construction stages.
- Moncaster [12]: decision-making and stakeholders' influence on the use of timber as a structural material for two school buildings.

- Vukotic et al. [13]: timber versus steel: an assessment of building structures' EE. The study includes all stages of a building lifespan, from product to EoL.

Carbon intensive stages of buildings' lifecycle
As Gavotsis [11] describes, research has identified the product stage as being responsible for the greatest percentage of EE and EC in buildings. In his study, the product and refurbishment stages contribute to EC with 50% and 31% respectively. Transport, construction and EoL are only liable for 8%, 7% and 4% respectively. Within this 50%, minerals come first, followed by plastics, metals and timber. Monahan [4] finds that for the timber frame scenario, 82% of the EC is due to the materials, excluding waste. The rest is due to transport and construction. Vukotic et al.[13] also calculate that for both the steel and the timber frame options, the product stage is the most significant, with 90% and 77% of total EC respectively. Different calculation methods, with differing temporal and material boundaries, highly influence the outcome, therefore the comparison of different cases should be made with caution.

Monahan [4] identifies waste as an important contributor to EE; the construction industry is responsible for more than one third of total waste in the UK; half of this is recycled or reused. She explains that 10 to 15% of materials brought on site are exported as waste, due to over-ordering. A potential solution is off site manufacturing, which produces lower waste than on site construction [14]. The Waste Resources and Action Programme estimates that the waste reduction through substituting traditional with prefabricated systems is 20% to 40% [14].

Finally, in the carbon sequestration calculations by Darby et al. [10], it has been demonstrated that if 100% carbon sequestration is assumed, the EC of the CLT frame building is 1006 tCO_2e lower than the RC frame equivalent, approximately equal to the carbon footprint of all building occupants for a year. If no sequestration is assumed, the CLT frame building is liable for 186 tCO_2e more EC than the RC. However, since the softwood spruce timber used for the CLT frame is produced usually on a 40 to 60 year period rotation [15] and is sourced from sustainably managed forests, Darby [10] suggests assuming 100% sequestration.

In conclusion, material production is the most important stage in a building's lifecycle and it is also likely the stage that provides a very high potential to reduce EE and EC.

Carbon intensive building elements and materials
Since the product stage is so significant in a building's lifecycle, it is worth comparing building elements and materials, to identify the potential of various strategies in reducing EC.

Gavotsis [11] identifies the superstructure as responsible for half the EC, followed by the ground floor slab and the foundations. In his study, concrete is the principal material for the foundation and slab, while the superstructure is mainly made of timber.

Monahan [4] compares two distinct building scenarios in her research:

- A timber frame structure assembled off site, with timber façade: the substructure, foundations, first floor and roof are constructed using concrete.

- A conventional masonry construction: the materials are heavier than those in the previous scenario and thus an increased substructure was needed.

The latter construction method increases EC by 34% and EE by 26% compared to the former one. Both Monahan [4] and Gavotsis [11] in their timber frame buildings calculate that the substructure, foundations and ground floor slab together are responsible for half the EC. In Monahan's conventional masonry construction, this percentage drops to 37%, due to more carbon intensive materials being used in other components [4]. For both scenarios of this study, the principle material contributor to EC is minerals[1], mainly concrete. In the timber frame scenario, the majority of minerals are used for the substructure and foundations. These elements are responsible for 45% of materials' emissions, with concrete accounting for 81% of minerals' EC. In the conventional masonry scenario, materials account for 86% of the total EC, with minerals being liable for 77% of this [4].

In the research by Vukotic et al. [13], it is assumed that both timber and steel scenarios require identical concrete foundations and slab, hence resulting in very similar EE; in the timber scenario, materials account for 79% of EE, as opposed to 88% in the steel scenario.

The analysis in this section suggested that building elements where materials with high embodied intensity such as concrete are typically used, are worth improving, by integrating the use of less carbon intensive materials, such as timber. Monahan cites the case of alternative wall elements of different weight, hence requiring different load bearing structures [4]. This could further increase the carbon benefits of timber; as a lighter wall element, it requires less materials for the building's concrete substructure and foundations.

Advantages of timber construction

The previous two sections identified the advantages of timber versus steel and concrete in terms of EE and EC. However, timber can potentially involve more aspects that are positive. The use of CLT is related to dimensional stability; good fire resistance; easiness of achieving airtight construction; good insulation properties [10]. Moreover, according to Darby et al. [10], CLT construction is quicker, with an erection time of 10 weeks for a multi-storey building, versus 14 weeks for the reinforced concrete (RC) construction of the same building.

Furthermore, in one of the projects described by Moncaster [12], CLT construction presents numerous advantages for the contractor, namely improved health and safety on site, decreased cost due to reduced construction time, improved cleanliness, quietness and accessibility due to absence of scaffolding. Finally, the developer may use the decreased EE of timber to their advantage, as it happened in Bridport House [10], where the planning authorities agreed to reduce the requirement for on site renewable energy by 10% [16].

Factors influencing the choice of timber as a structural material

The sections above demonstrated the advantages of timber replacing steel or concrete as a structural material. However, its use in the UK is still very limited.

[1] Minerals in this study included cement, gravel, sand and concrete products.

Lifecycle assessment is a challenging process, due to the numerous parameters involved. One of the messages of the Carbon Week 2014 was the need to improve consistency and transparency [17]. The lack of these characteristics impedes the wider adoption of timber.

This section analyses the decision-making regarding sustainability in school buildings described by Moncaster [12]. It identifies barriers and incentives to the use of timber, with a focus on politics and attitudes towards sustainability by professionals and stakeholders.

The involvement of stakeholders in decision making regarding sustainability can be crucial. Projects are usually shaped through the requirements of clients, but their decisions are strongly influenced by the information provided by the design team. While ‘sustainability’ is often expressed as a priority, it is open to interpretation. Expertise in sustainability is a powerful opportunity at the moment; hence many professionals promote their area as ‘sustainable’ [12]. In one of the schools [12], there was a disagreement on the interpretation of sustainability and each professional had reasons to suggest different strategies. Services engineers considered renewables as a synonym of sustainability, while the structural engineer highlighted the importance of EC. CLT was used as a structural material, partly due to the structural engineer who produced calculations on the EC of timber and concrete. On the other hand, the quantity surveyor, was against timber, due to the difficulty of costing an innovative at the time structural material and a fear that his expertise might be doubted.

The sustainability assessment and the tools used are also important. In the case analysed above, both the structural engineer and the architect, felt that BREEAM was limited as a tool, since it did not support the use of structural timber [12]. In most cases, tools have a significant influence, by including, excluding or interpreting options. According to Guy and Shove ‘design tools do not simply translate between the languages of science and practice. Like it or not, they have hidden agendas and qualities of their own’ [18] (quoted in Moncaster [12]).

Finally, policy is a factor that can hinder or promote the use of specific materials. Moncaster [12] suggests that omitting EC from the definition of ‘zero carbon’ reflects the priority of the politicians to encourage work in construction. Industry experts consulted also reflect these priorities; key policy documents which led to the current UK Building Regulations were based on reports by Barker [19] and Callcutt [20] and responded to powerful lobbies such as the cement and concrete industries, rather than reduced carbon [12]. Hence, the choice to use a material on a broader basis, is not only a project-specific decision; political priorities and policies can be included in this decision-making process as equally important elements.

Discussion and conclusions

It has been demonstrated that the use of structural timber decreases EE and EC compared to conventional materials. Concrete typically used for structural elements of buildings has been proven to be a major contributor in terms of EE and EC. Therefore, its replacement by timber can have an effect on EC reduction in buildings; this is an important finding, enabling designers to make more informed decisions. Moreover, timber is a clean, safe material, improving the construction times and its use can involve multiple advantages for contractors.

However, the multitude of parameters and assumptions involved complicates the analysis and comparison between materials and construction methods. Besides, there is an inherent difficulty in predicting the EoL of products. As Vukotic et al. [13] describe, EoL refers to a projection of the future; with practices and technologies likely to change, it is very hard to identify the demolition, disposal and recovery practices so much time in advance.

Furthermore, it is worth studying in detail the effect that materials have, not only on EE as described in the previous sections, but also on OE. As Monahan describes [4], concrete has higher thermal mass and can thus assist in reducing heating and cooling loads, which does not happen in the case of timber; nevertheless, this is not easily quantifiable. Future work may involve the application of timber, steel and concrete as alternative structural materials on a specific building, in order to assess both OE and EE and to compare additional quantifiable or non-quantifiable benefits of each construction method.

Despite the advantages of structural timber, it is not currently broadly used in the UK. Decision-making processes, the professionals' expertise in sustainability, new materials and embodied burdens, as well as lack of knowledge, hinder the broader use of timber. This paper contributes to the knowledge around timber construction in the UK and informs the industry on its potential and on relevant technical or socio-political barriers. Moreover, given the significance of reducing carbon emissions, it is crucial to inform policy makers on the use of non-conventional materials. The description of timber's share in EE, its EoL scenarios and finally the factors complicating its use in the UK, can be valuable for policy makers and the industry, contributing to the promotion of alternative construction methods.

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