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UK apartment construction impact on carbon life cycle calculations

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Abstract

There is no fixed method to analyse the global warming (carbon) impact of a building envelope over its life time, however guidance is given in BS EN 15978 [1].The paper assesses the Life Cycle stages and components in 3 archetypal construction typologies for an apartment building assessed with the BRE Green Guide [2] as a comparator. There is a difference of a factor of 4 between construction types and the position of units within an apartment block. Replacement and recycling factors significantly affect the end results with steel being highly recyclable, concrete advantageous in longevity and timber sequestering carbon at early stages. Timber does have an increased number of replacements during the life span and significant impacts at end of life stages. The BRE quantification does not take into account foundations leading to a climate change impact 3 times lower than a bottom up analysis for a steel building.

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Keywords: LCA; Apartment buildings; Building Lifespan; Future Carbon Use

1. Introduction

Architects should design buildings with their life span as a primary consideration. This is not addressed by current UK regulations which only consider a single year of energy use based on historic weather data. As future climate threatens the resilience of the built environment, it is important that a building's Life Cycle (LC) and Green House Gas (GHG) assessments account for climate change. As a building contains hundreds of products within its

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assembly, it is impractical for a designer to conduct an analysis using the BS:EN 15978 [1] modular framework (shown in Fig 1) at the early stages of a design process. Additional problems include the lack of a standardised methodology in quantifying the impact of dwellings within apartment blocks such as the measurement of shared features.

Product stage			Construction		Use stage							End of life			
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4
raw material suppy	Transport	Manufacturing	Transport	Construction Installation Process	Use	Maintenance	Repair	Replacement	Refurbishment	Operational Energy	Operational Water	Deconstruction Demolition	Transport	Waste processing	Disposal

Fig. 1. Stages within BS:EN 15978 [1] by author

Building construction materials need to be assessed across a range of LC stages otherwise incorrect assumptions on design decisions are made, especially where a material is to be replaced several times over the building's life. Within this study archetypal buildings are used for comparison of the GHG impact within an apartment block. In considering the LC operational carbon it is important to determine the change in heating and overheating likely to occur due to climate change. Overheating is assessed using the CIBSE TM52 [3] methodology for naturally ventilated buildings as detailed in a previous study [4]. The assessment uses future weather files from Eames et al [5] within a dynamic model to account for different constructions. The study demonstrated the likely date for active cooling to be adopted and determines the subsequent GHG impact on construction types.

This study aims to assess typical apartment buildings using current LC protocols as given by Building Research Establishment (BRE) [2] against a bottom up methodology. The bottom up study uses a comprehensive set of LC stages, where practical, to determine their importance in a GHG calculation of a building. In determining the GHG of differing constructions the effect on other building components and the main features that influence the LC solution for a given life span are identified.

2. Background

The BRE provides voluntary building standards in the UK, part of which contain a LC methodology for a 60 year period. The GHG of constructions is quantified in publications [2] with longer life spans used in PAS 2050:2011 [6] at 100 years and specifications for long life buildings can be 125 years. The apartment life span primarily impacts the operational carbon and replacement factors of materials within a building.

Previous studies have quantified the Embodied Carbon of foundations [7] but do not deal with the superstructure or other systems for the whole building; a holistic picture is required so that design dependencies of different building elements can be understood. Pad, strip and pile foundation typologies are quantified, as part of the building study, dependant on the construction weight of the apartment building considered. The assessment assumes good ground conditions rather than site specifics where surveys and investigations influence the final structural solution.

Environmental Product Declarations (EPD) [8] are used as the GHG dataset for construction materials directly from manufacturers. As timber EPDs account for sequestration [9], it is investigated compared to heavyweight materials [10]. Thermal mass has been shown to delay the installation of active cooling in a future climate thus avoiding operational GHG compared to a lightweight construction. The practicality of the inclusion of all the LC stages in the study are discussed in the methodology.

Three and 6 storey apartment buildings are evaluated with a core serving two apartments per floor, a typical arrangement for many multi occupancy buildings shown in Figure 2. In the case of the 6 storey solution a lift is added to show the influence on the LC calculations. Solutions comply with UK building regulations although the 6 storey timber building assessed would not comply due to a lack of structural redundancy required for disproportionate collapse regulations.

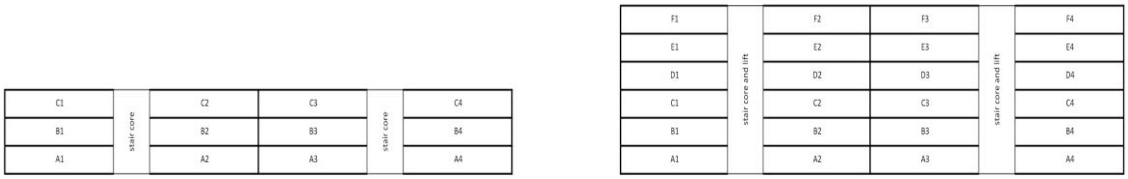

Fig. 2. Unit nomenclature used to identify apartments within the blocks modeled

3. Methodology

Each individual apartment floor plate is similar to those dynamically modeled in a previous study [4] allowing the Gross Internal Floor Area (GIFA) to remain constant whilst the Gross External Floor Area (GEFA) changes according to the construction build up used. The U values of the constructions is similar by compensating on the thickness of the insulation layers. The dwellings are organised as shown in Fig. 2 in 3 and 6 storey blocks, individually named to assess the importance of the dwelling position within the block. A floor to ceiling height of 2.5m is used in line with PassivHaus Planning Package (PHPP) default calculations. The 3 structural types are studied to reflect the majority of the UK apartment market. Table 1 shows how each typology influences the construction of other elements used within the building.

Table 1 Construction specification of each model

Structure	Timber	Steel	Concrete
stairs	wood	sheet steel	precast concrete
lift core	cement board	cement board	concrete block
foundation			
3st	450 concrete strip	concrete pad	600 concrete strip
6st	600 concrete strip	precast pile	precast pile
ground floor	concrete slab	concrete slab	concrete slab
party floor	timber I joists	steel web	hollowcore
ext wall	timber, insulation, sw boards	met sec, insulation, cement board	block, insulation, block
internal wall	timber	met sec	timber
windows	double glazed timber	double glazed timber	double glazed timber

It should be noted that all timber is Forest Stewardship Council (FSC) certified and the concrete used is 50% cement replacement in line with industry norms. All metals used are also to current industry recycled content levels including concrete reinforcement. The BRE model is used for the 3 storey buildings of differing structures with identical input values to ensure consistency. The basis of the elemental calculation is as follows:

LC Stages A1-A3 the GHG is quantified using EPDs from manufacturers. Taking the weight of elements stage A4 is established by using 30km road transport in 10 tonne truck loads. In addition, the timber is sourced from Poland (with associated road transport) and steel from China (a combination of container ship and road transport) these parameters avoid the investigation of individual supply chains. Stage A5 is approximated as 6 months of a digger on site for strip and pad foundations or a piling rig for 3 months. Other equipment used includes 6 months for a forklift and 6 months of 10 power tools, with additional 6 months of power tools for concrete structure with a cement mixer for 6 months. Construction timescales and equipment used are doubled for 6 storey structures apart from the piling rig. These approximations are based on observations, experience and construction site records. This is compared to Office of National Statistics (ONS) data on GHG of the construction industry to determine the comparison between a stage A5 top down analysis and a bottom up methodology.

Stages B1 to B3 are not included in the study as these would require observed facility management records and site assessments. Instead B4 is used with replacement rates based on Williams et al [11]; within this stage buildability (replacing dependant elements) and disposal are considered in the calculation. Stage B6 is based on a future climate study [4] by assessing the reduction in heating carbon. The study also assesses the increased overheating periods to estimate the date of adoption of active cooling systems and its associated GHG usage. Hot water and appliance loads are obtained from a PHPP calculation for an individual flat. In addition, an annual reduction of 2% in grid carbon is calculated as an extrapolation of the last 10 years UK electrical grid figures [12] to account for the adoption of renewables in future grid decarbonisation. A sensitivity analysis is conducted in this study using an unchanged future grid GHG value and a 1% annual reduction. Stage B7 is ignored as this has little GHG impact but has a greater weighting within other LC indicators.

Stage C1 is established as 3 months deconstruction for a concrete/steel building and 2 months for a timber building. The basis of the calculation of stage C2 is by mass and uses a distance of 30km in the UK to a recycling plant or landfill. C3 recycling rates are taken from WRAP Net Waste Tool figures [13] assigning a proportion of the original GHG dependant on the recyclability of the material. This stage has not been calculated from EPDs figures which give an optimistic end of use scenarios such as the use of waste to energy [9]. C4 is the residual amount of material land filled and classified as inert or degradable with their associated GHG outcome. D stage of the LC dealing with reuse is ignored as this is beyond the scope of the study boundaries. From the data produced a ranking of construction elements and LC stages of importance is given.

4. Results

BRE Green Guide gives a single figure for GHG of an assembly over 60 years and does not deal with foundation or operational carbon results. Fig 3a shows a clear recommendation of structures to be used by designers to reduce LC impacts. For a concrete building the internal floors dominate with 50% followed by roof 30% and ground floor 12% of the overall figure. In contrast to figures in Fig 3b the values of the BRE result are low for 12 dwellings.

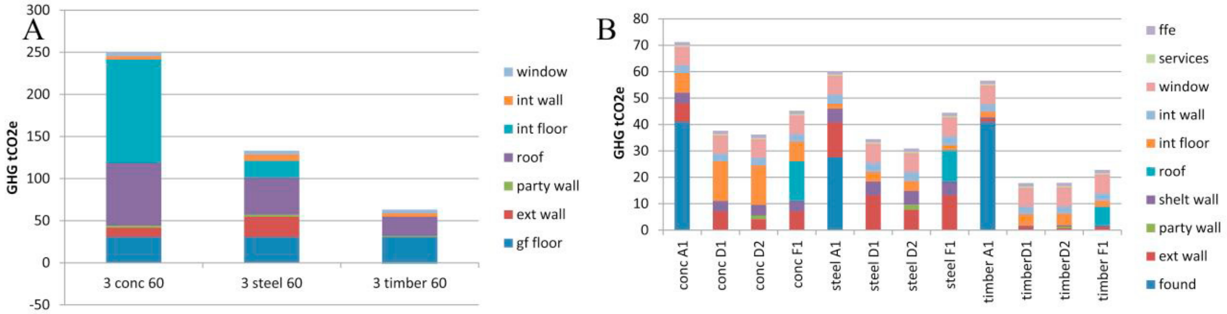

Fig. 3. (A) GHG figures for BRE assessment, (B) on a unit assessment

The construction in Fig 3b shows a variance of a factor of 4 between different unit types of the same GIFA. For a steel building using the A1 ground floor unit as a base case is 57% for D1, 51% for D2 and 74% for F1 roof apartment. The trend in all the construction variants is the roof and foundation play a major role in the LC result.

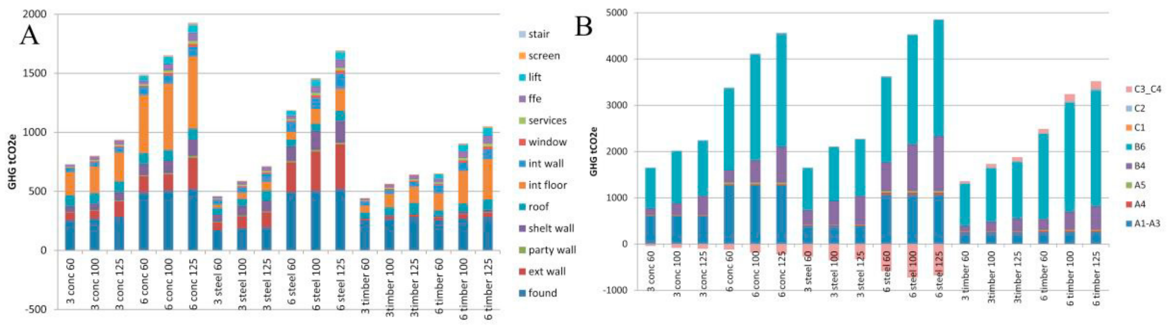

Fig. 4. (A) apartment block by component, (B) apartment block by stage

Figure 4 shows a 6 storey building has a higher LC impact however this is more than compensated by the amount of dwellings the block contains. Fig 4a excludes operational and transport GHG but similar patterns are evident with the foundations (35-58%), roof (13-11%) and internal floors (27-6%) dominating the results for a 3 storey building of identical GIFA. The steel construction does have significant expenditure on its external walls 14% of the overall amount and interior walls 9% due to the amount of steel content. The variation in external wall materials is a factor of 4.5 from a timber to steel lightweight metal section (met sec) wall for a 3 storey building of identical GIFA.

Figure 4b shows the impact of all LC stages on each of the building types. The operational B6 stage contributes 60% of the building's overall GHG expenditure, which highlights a potential area of influence to the designer. About 30% is in the A1-A3 stage which has the most impact on the environment as this stage typically lasting 1-2 years rather than the longer timeframe of the operational GHG used in stage B of a LC study. Replacement accounts for around 12% of the overall value adding to arguments that buildings should be built for longevity rather than demolition (C1) and expending GHG of stage A of the LC again.

Currently only 5% of the GHG proportion of a building is recovered (concrete piling is excluded due to difficulty of extraction). This is larger for a steel building but the full extent of the subsequent supply chain to a new building product (with possible recycling in China) and its proportional mixing with virgin material has not been assessed in this study. This would result in a lower steel recycling advantage by approximately 50%.

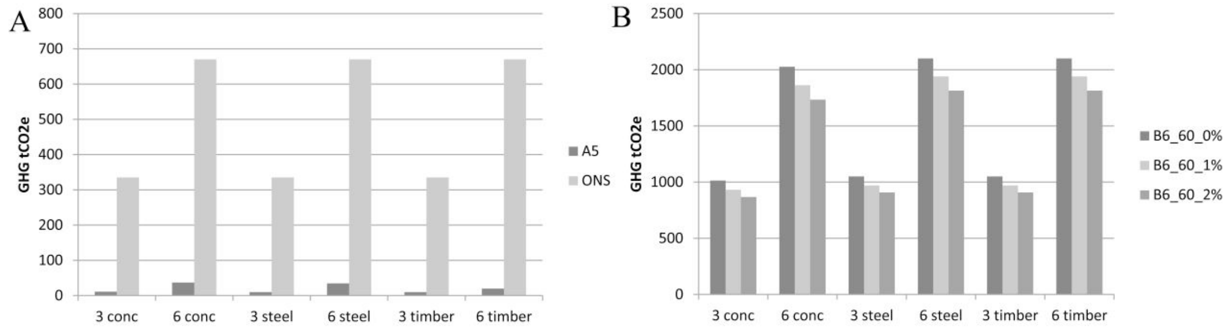

Fig. 5. A stage A5 comparison, B grid decarbonisation sensitivity

In Fig 5a shows the use of ONS data leads to a 10-fold increase in the amount that is estimated for stage A5 site energy. As a top down analysis, this is reasonable result as it considers truncated LC errors. However, the ONS figures cannot be further scrutinised (due to a lack of itemised data) and are used on an area basis regardless of building construction. The grid decarbonisation in Fig 5b shows a linear trend which is consistent across all cases and does not affect the ranking of results (although the GHG savings are significant). This does not adversely change the proportions of the LC stages given in Fig 4b.

5. Future implementation

The transportation in supply and recycling chains have been approximated in this study along with the omission of the maintenance and repair of buildings. This may lower the GHG values for heavier weight buildings in comparison to a timber building. The variation in site carbon varies significantly with ONS data and needs further analysis to find a comparable methodology with the other stages analysed in this study.

The implementation of stage D and its methodology for the transferable reuse of materials is critical in properly assessing the impact of stage C and could be a valuable addition to the guidelines outside of use of current 'Cradle to Gate' studies.

6. Conclusion

The BRE methodology shows low GHG values for building components but has the correct order of design concerns, apart from the foundation element. In contrast the GHG of differing structural materials is inconclusive in an elemental study, with the combination of LC stages influencing results significantly. The foundation typology does cause considerable GHG expenditure leading to arguments for taller buildings to expend the GHG of piling across more dwellings. Other aspects such as internal floor construction may be resolved by using a hybrid design approach using differing structural and non structural materials within the block.

The analysis of dwellings of a similar GIFA shows a large variation depending on construction and location of an apartment but does not lead to useful results when shared services are accounted for. The results show a steel building is the worst solution, as a result of the transportation distances required from international sources, but does gain credits from its recyclability. Timber buildings perform best although the sequestered carbon is largely released back into the environment at its disposal stage. Buildings should be built for longevity as demonstrated by concrete structures with the proportional increase in GHG being compensated by its long life characteristics.

Given the incremental decrease of grid carbon more needs to be done in terms of reducing the amount of operational carbon in buildings. Appliance and hot water loads are not adequately addressed by current regulations or PassivHaus standards are an area where the designer can influence. The results show a framework for a toolkit is possible demonstrating the significance of design features even if the results given do not show a distinct preference of one type of construction material over the life spans studied. Results both by life cycle stage and material need to be considered in parallel to form a true picture of GHG implications to be understood by building designers.

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