Study of the Embodied Carbon in Traditional Masonry Construction vs Timber Frame Construction in Housing

Authors | J Walsh & B McAulliffe
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jwpm Jeremy Walsh Project Management

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1.0 Introduction

1.1 Scope and Introduction of the Report

The “Effort Sharing Regulation” (ESR) [1], sets out binding annual greenhouse gas emission targets for EU Member States for each year for the period 2021-2030. These targets cover sectors of the economy that fall outside the scope of the EU Emissions Trading System (EU ETS) [2]. These sectors, including transport, buildings, agriculture and waste management, account for almost 60% of total EU emissions and 74% for Ireland. The ESR, and the Irish Government in the *National Energy and Climate Plan 2021-2030* [3], enshrines a greenhouse gas emissions reduction target for Ireland of 30% by 2030 relative to 2005 levels and whilst there are no individual targets for each sector it is clear that the building industry must play its part.

The built environment is a major contributor to greenhouse gas emissions with the energy associated with building use accounting for 24% of energy-related CO_2 emissions in Ireland in 2018; [4]. The emissions associated with the manufacturing, transportation, construction and end of life phases, commonly referred to as embodied carbon, contribute around 11% of all global carbon emissions.

As the levels of insulation and associated construction thickness have increased to comply with the necessary improvements in the building regulations (Part L, [5]) the embodied energy and associated embodied carbon, in absolute terms and as a proportion of the overall lifecycle energy of a building is rising. Furthermore, as the operational energy performance of new buildings is improving to the point where there is diminishing returns by improving element u-values and airtightness it is logical that focus would progress to how the embodied energy of a building, estimated to reach 50% of building lifecycle carbon emissions by 2050, can be reduced.

A better understanding of the embodied carbon associated with building materials and construction types will allow building designers and developers to build lower carbon homes. This study aims to compare the embodied energy of the two most typically used construction types, namely tradition masonry construction and timber frame, by using a life cycle assessment tool. By selecting two near Zero Energy Building (NZEB) compliant houses in the same housing estate and not including building finishes in the analysis we aim to compare the construction types. The results will also be used to look at ways of improving the selection of construction methods and the specification of building materials to help reduce the industry’s carbon footprint. The purpose of this study was to inform future inhouse decisions on the specifications of building materials and construction types.

2.0 Background

2.1 One Click LCA

One Click LCA [6] is a life cycle assessment (LCA) calculating software created by Bionnova LTD. The software carries out a life cycle assessments using tools that are built for certain standards, for example; BREEAM and LEED. For this report, the buildings' LCAs are calculated using the LCA tool according to *EN 15978 - Sustainability Of Construction Works - Assessment Of Environmental Performance Of Buildings - Calculation Method*. This standard describes the calculation method, based on life cycle assessment and other quantified environmental information, to assess the environmental performance of a building.

The software has a large database of Environmental Product Declarations (EPD), a document which transparently communicates the environmental performance or impact of any product or material over its lifetime, for products and building materials from a wide range of countries. All EPDs used in this report were published in accordance with standards *EN15804 - Sustainability Of Construction Works - Environmental Product Declarations - Core Rules For The Product Category Of Construction Products and or ISO 14040 - Environmental management — Life cycle assessment — Principles and framework, see Appendix B.*

2.2 Life Cycle Assessment (LCA)

An LCA calculates the total impact a product, service or system has on the environment throughout its whole lifespan. This includes the raw materials, extraction of materials, energy consumption, manufacturing, transportation, use of the product, recycling, disposal and end of life.

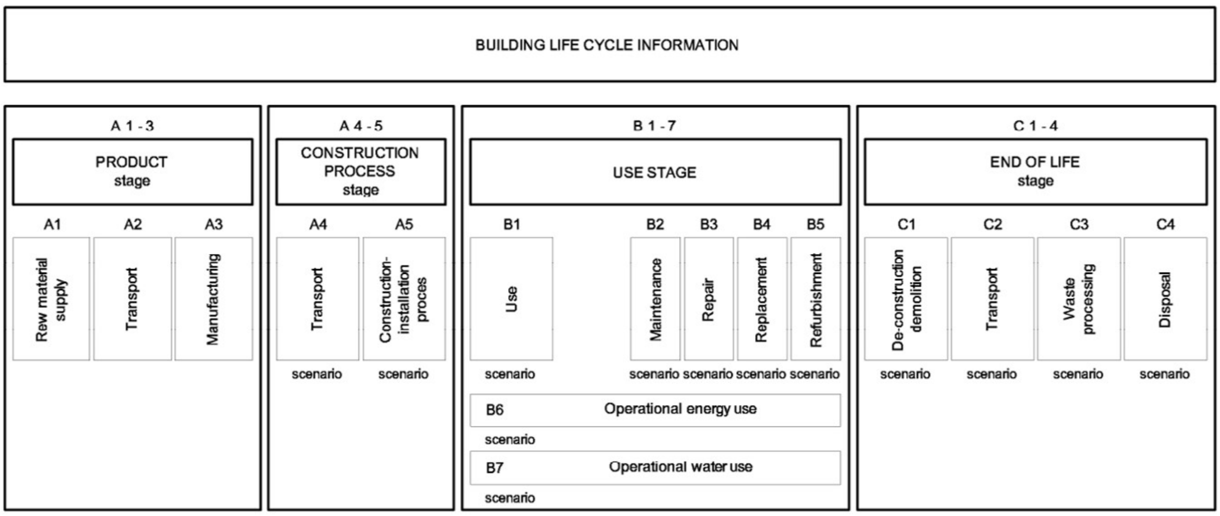


Figure 1. Life Cycle Assessment Stages (I.S. EN 15978:2011)

Figure 1 shows the life cycle stages used when calculating the LCA of a building in accordance with *EN 15978*. The Product stage A1-A3 includes the supply, transport and manufacture of the resource, known as 'Cradle to Gate', this represents the impacts from sourcing the material to being ready to export from the factory after manufacture.

Stages A4-A5 are the transport to the building site and the effects the construction process has for the specific material.

The Use or Operational stage B1-B7 refers to the environmental impacts throughout the lifespan of the product, including; the use of the specific product, repair and replacement, energy usage and water consumption.

The End of Life Stage C1-C4 calculates the effects the product has after it cannot be used any longer for example; demolition, transport, waste processing and disposal.

Stage D is the benefits that the product can supply to the environment such as recycling so the same product does not need to be manufactured again, however, this stage is not included in the total LCA of the product and is only used as supplementary information that may or may not be subtracted from the total depending on the reusability of the product.

The environmental impact categories calculated by an LCA are;

Global Warming Potential (GWP)	kg CO_2e
Acidification Potential	kg SO2e
Eutrophication Potential	kg PO4e
Ozone depletion potential	kg CFC11e
Formation of ozone of lower atmosphere	kg Ethene
Total use of primary energy ex. raw materials	MJ

The main focus of this report will be on the GWP of the building as this is the most widely used category for comparing environmental impacts of systems.

Each EPD has a calculated LCA for the specific product or resource, after all the materials and products used in a building are inputted into the One Click LCA software, the LCAs of each item are summed together to get a total LCA of all the materials used in the building from 'Cradle to Grave' (Stages A to C). This is not the final total of the building's LCA but only the impacts of the inputted materials.

The building itself has its own LCA, stages A1-A5 represent all the sourcing, manufacturing, transport and construction process of the materials, B1-B5 take all maintenance and replacements throughout the lifespan of the building into account, B6 and B7 calculate the operational energy and water consumption effects over the lifespan and C1-C4 predict the deconstruction impacts of the building at the end of its life.

The software combines all the inputted data and outputs the subtotals and total environmental impacts of the building for each environmental category, it also gives helpful breakdowns of impacts such as the effects of each LCA stage and each type of material used.

2.3 NZEB Requirements for New Domestic Buildings

In 2019 the *Technical Guidance Document L- Conservation of Fuel and Energy – Dwellings* [5] was updated so that all new dwelling houses will have a 25% energy performance improvement from the 2011 building regulations, making the new dwellings Nearly Zero Energy Buildings (NZEB). All new dwellings occupied after the 31st December 2020 must comply with this NZEB standard and are limited to a maximum energy performance coefficient of 0.3, a maximum carbon performance of 0.35 and a renewable energy ratio of 20%. Both buildings in this report are NZEB compliant which significantly reduces their operational CO_2e emissions compared to similar sized dwellings prior to the new regulations.

3.0 Details of Buildings

3.1 Location

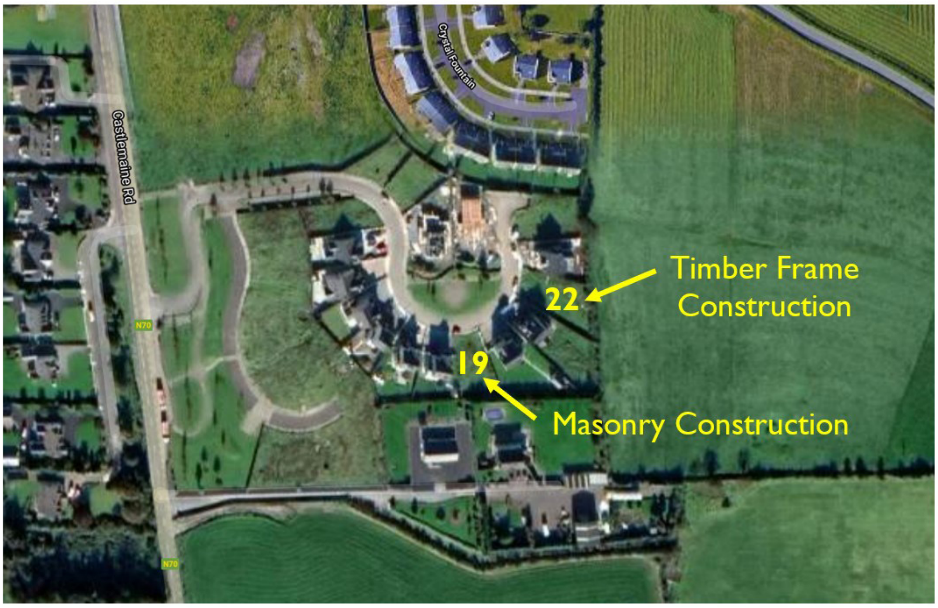


Figure 2. Map of Dromcairn

Both buildings are situated in Dromcairn Housing estate, Skehanagh, Tralee, Co. Kerry which is in the outskirts of Tralee town. As shown in *Figure 2* house number 19 is the traditional masonry construction building and number 22 is the house built using timber frame construction. Because the two buildings were built in the same place, ground conditions, common material transportation distances, service connections and labour transportation can be considered the same for both constructions.

3.2 Site Layouts

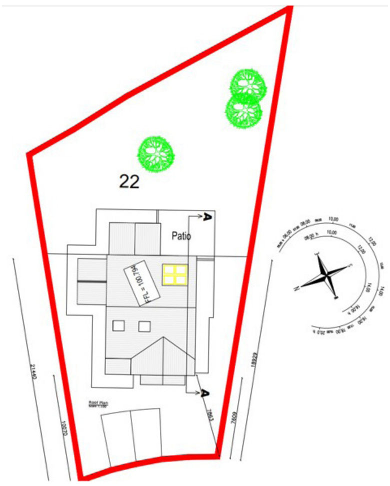


Figure 3. Timber Frame Construction Site Layout

Figure 4. Masonry Construction Site Layout

As shown in *Figure 3* and *Figure 4* both site layouts are similar apart from the masonry construction site has a smaller area (469m^2) in comparison to the timber frame construction site (664m^2). External site works and finishes were not accounted for when calculating the embodied carbon of both projects, so the greater area of the timber frame site does not affect the results.

3.3 Plans

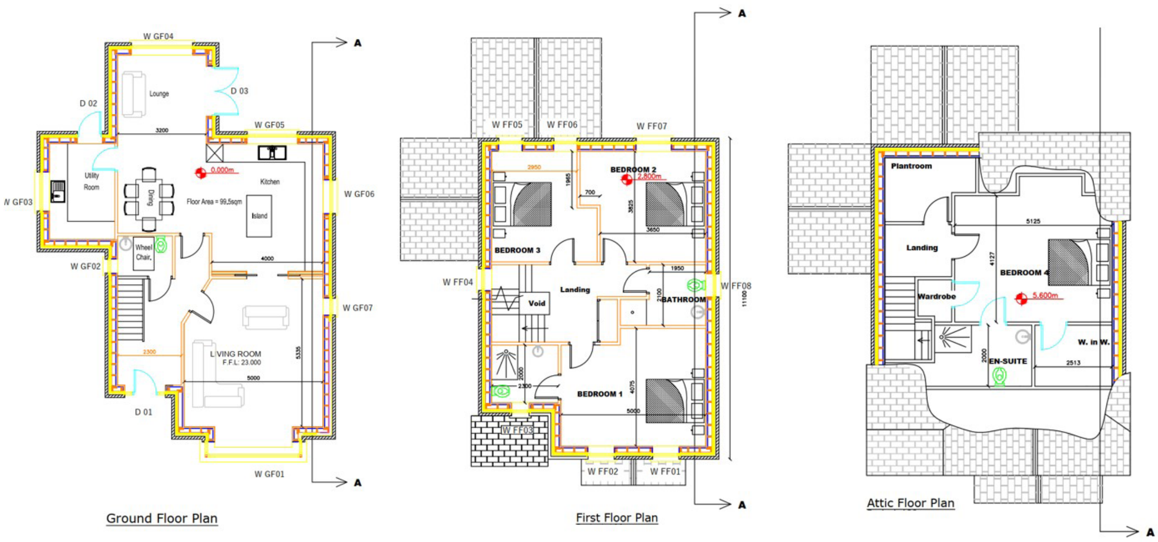


Figure 5. Timber Frame Construction Plans

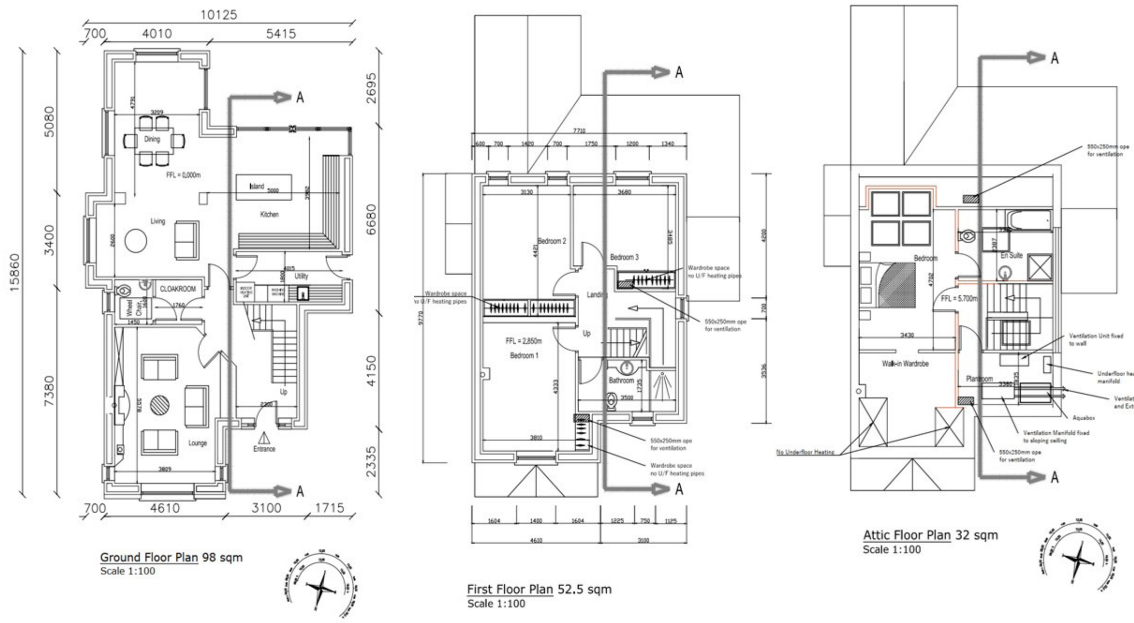


Figure 6. Masonry Construction Plans

The timber frame construction house is a two and a half storey building with 4 bedrooms and 4 bathrooms, *Figure 5* shows the ground, first and attic floors of the building with respective floor areas of 92.6m², 71.9m², and 51m², 215.5m² (GIFA, Gross Internal Floor Area) in total.

The masonry construction house is also a two and a half storey building with 4 bedrooms and 3 bathrooms, *Figure 6* shows the ground, first and attic floors of the building with respective floor areas of 96.9m², 57.8m² and 45.8m², 200.5m² (GIFA) in total.

Both ground floors have a similar floor area and room layout, the main difference between the upper floors is that the timber frame house has two bathrooms on the first and has larger floor areas in comparison to the masonry house.

3.4 Elevations

Figure 7. Masonry Construction Elevations

Figure 8. Timber Frame Construction Elevations

The elevations of both buildings can be viewed in *Figure 7* and *Figure 8*. There is very little difference between the two sets of elevations apart from the masonry building having more window area (36m^2) than the timber frame building (22m^2) plus the timber frame building also has no chimney. Both have a similar amount of decorative stonework on their front elevations.

3.5 Construction Details

3.5.1 Masonry Construction Build-up

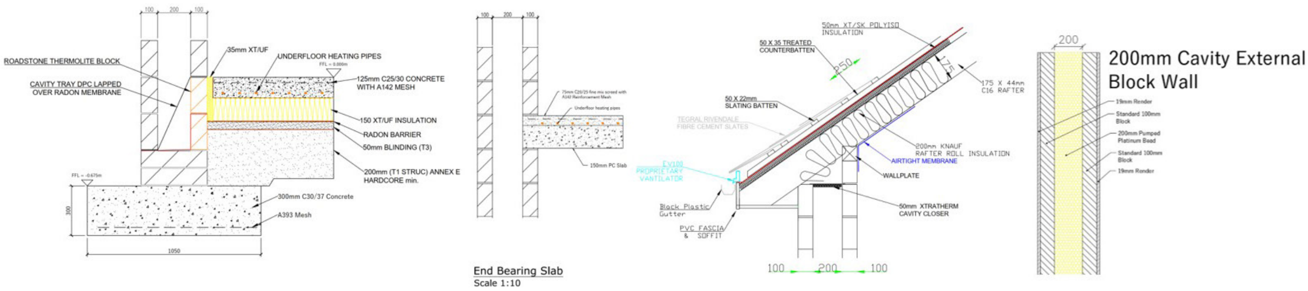


Figure 9. Masonry Construction Details

The substructure of the building is made up of a 1050x300mm strip foundation of C30/37 concrete reinforced with A393 mesh with three courses of blockwork in the sub-walls. 125mm of poured C25/30 concrete with A142 reinforcing mesh makes up the ground floor slab, there is 200mm EPS 70, a radon membrane, 50mm sand blinding and at least 200mm of Annex E Hardcore beneath the concrete slab. There is a 600x300mm strip foundation beneath the internal block walls.

The external block walls have sand and cement render externally and internally, the 200mm cavity between the 100mm standard concrete blocks is filled with pumped platinum cavity bead insulation (thermal conductivity: 0.035 W/mK).

The pitched timber cut roof is made up of Fibre cement slates, slating and counter battens, roofing felt, 50mm of PIR sarking insulation and 200mm of mineral wool insulation between 174x44mm rafters.

150mm precast concrete slabs and 75mm of C20/25 concrete screed reinforced with A142 mesh make up the two intermediate floors.

A total of 2 tons of structural steel beams were used. There is 36m^2 of triple glazed PVC windows and 4.5m^2 of skylight windows.

3.5.2 Timber Frame Construction Build-up

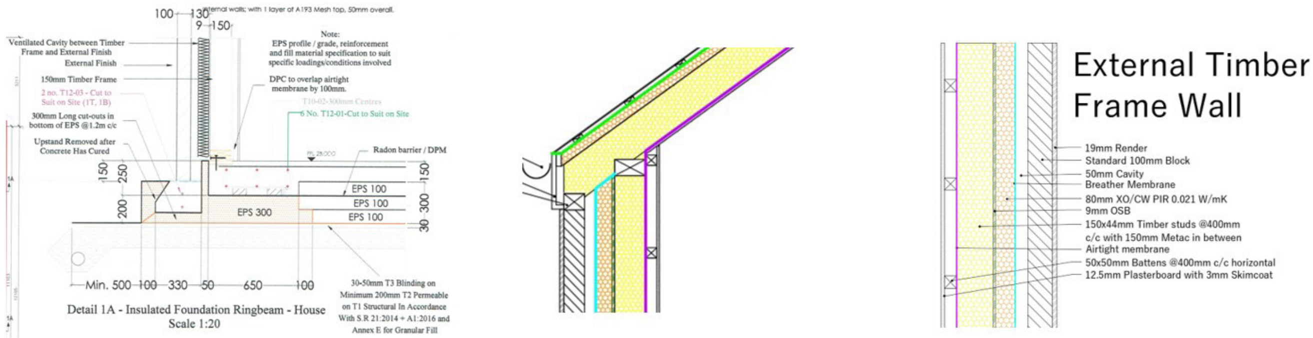


Figure 10. Timber Frame Construction Details

A passive raft slab foundation is used in this construction, the ground floor is made up of 150mm of C35 concrete reinforced with A193 mesh, 300mm of EPS 100, a radon barrier, 50mm of sand blinding and at least 200mm of Annex E hardcore. Beneath the external concrete block leaf, there is a 300x200mm reinforced concrete footing and a reinforcing steel cage is put in the thickened concrete floor slab beneath the timber frame load-bearing perimeter. EPS 300, an EPS insulation with a higher load-bearing capacity, is used beneath the perimeter walls replacing the EPS 100.

The external wall consists of sand and cement rendered 100mm standard block, 50mm cavity, breather membrane, 80mm PIR insulation, 9mm OSB board, 150mm mineral wool insulation between 150x44mm timber studs at 400mm c/c, airtightness membrane, 50x50mm battens and 12.5mm plasterboard.

The pitched timber cut roof make-up is the same as the masonry construction roof.

The intermediate floors are made up with 18mm OSB board on space joists with a depth of 254mm, 50x50mm battens and 12.5mm plasterboard are hung from the joists.

There is 510kg of steel beams in the building, 22m^2 of triple glazed PVC windows and 3m^2 of skylight windows.

Table 1 displays some design parameters for both buildings including the U-values of the floors, walls, roofs and window, the timber frame construction has better U-values as its floors and walls have more resistance to heat transfer with the extra insulation.

	MASONRY CONSTRUCTION	TIMBER FRAME CONSTRUCTION
Number of Floors	3	3
Gross Internal Floor Area (m²)	200.5	215.5
External Wall Area, Without Openings (m²)	260	265
Openings (m²)	40	31
External Wall Width (mm)	438	470
Thermal Mass	Medium-High	Low
U-Value (W/m²K)		
Floor	0.16	0.11
Wall	0.18	0.12
Roof	0.14	0.14
Windows	0.70	0.70

Table 1. Construction Details Comparison

4.0 Material Calculation

The material quantities for both projects were calculated by going through all the invoices issued and summing up the quantity of each material ordered to the site during the construction period. Theory estimates were also collected by calculating the quantity of material needed based on the building drawings. The quantities calculated from the invoices were then cross-checked with these estimates to confirm that there was no quantity of material or invoice accidentally neglected. *Figure 11* and *Figure 12* show the quantities of the main embodied carbon contributing materials for both constructions.

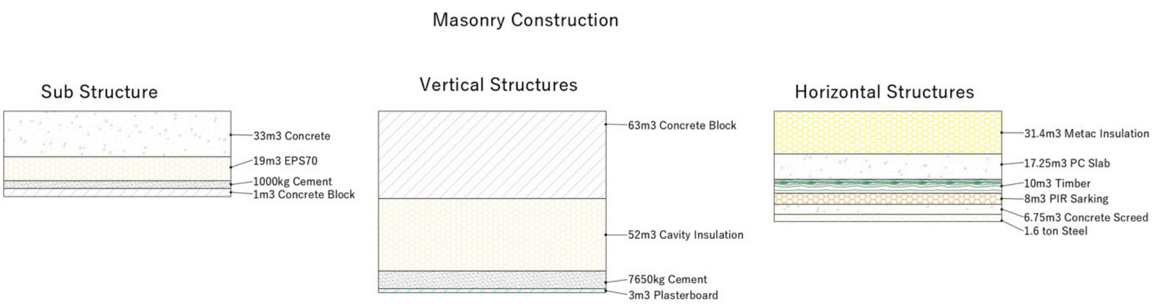


Figure 11. Masonry Construction Main Materials

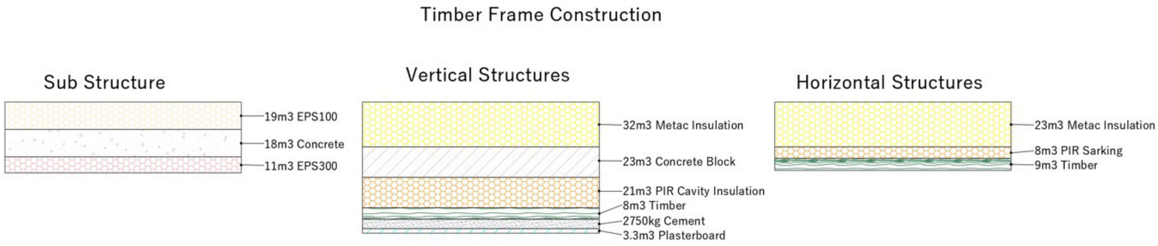


Figure 12. Timber Frame Construction Main Materials

Not every material in each building was included in the calculations for comparability reasons between the two buildings, for example; no materials after the builder's finish (Floor finishes, tiling etc.), no services (plumbing, electrical, ventilation, etc.) because these would vary on the clients' specifications. Below is a list of all types of materials that were included:

- Blocks
- Cement
- Concrete (All ready-mix concrete used has 30% recycled binders in cement)
- Hardcore
- Insulation
- Plasterboards
- Radon, DPC, Airtight, Breather, Roofing Membranes
- Sand
- Slates
- Steel
- Timber
- Windows, Skylights and Doors

As shown in *Appendix A*, most materials' volume or mass was calculated and inputted into the One-Click LCA software. For both constructions, materials were inputted in their respective subdivisions of the building; *Foundations and Substructure, Vertical Structures and Façade, Horizontal Structures and Other Structures*, this gives the option to observe which aspects of each building contributed the most embodied energy to the project.

In section *5.0 Results* the calculated results of both projects can be viewed, the software is capable of calculating the total impacts, a breakdown of the impacts caused by the various construction sections and the total impacts of each type of material. For this report, the global warming impacts in kg CO_2e are focused on but the software also calculates acidification, eutrophication, ozone depletion potential and formation of ozone of lower atmosphere impacts of all the materials used.

4.1 Building Materials

All the selected materials were inputted in the software's *Building Materials* section, the software has a large database of material EPDs (Environmental Product Declaration) provided by manufacturers all over the world. When selecting a material, the exact material EPD was used when inputting the quantity, in the event where the specific material did not have its own EPD, the closest substitute for that material was used.

These substitutes were selected based on their location, similarity to the material actually used and their global warming potential impacts were cross-checked with other similar materials so that this substitute material resembled the correct material as accurately as possible. Local EPDs were difficult to find for some materials such as standard concrete blocks and structural timber which are widely produced in Ireland and used in Irish construction but UK versions were used in their absence on the OneClick software. This shows that few companies have published EPDs for some of their most commonly used products.

Where manufacture to site distances were known, the transport distance was manually inputted, however, most distances were not known for each material so the software's default regional estimates were used for the majority of materials. In the interest of comparison, this did not affect results as both sites were at the same location and the software's estimates can be considered a constant for each material selected, it may affect the overall individual embodied energy of each building but as discussed later in the next section, transportation has a relatively low percentage of the overall impacts.

The service life of each inputted material was automatically calculated by the software using the materials EPD. The software calculates the foundation materials lifespan as permanent and all other materials have the same lifespan as the inputted calculation period for each building unless a material has a shorter service life, in which case the material must be replaced, possibly doubling or tripling the quantity needed depending on its service life.

4.2 Energy Consumption

Energy Consumption calculates the total environmental impact the building will create over the calculation period based on the buildings annual use of electricity and fuels. Both buildings' main heating supply will be from electricity so all energy consumption will be supplied by the national grid. An NZEB (Nearly Zero Energy Building) Compliance Report using the Dwelling Energy Assessment Procedure (DEAP) software was carried out on the masonry construction house using a 'medium-high' thermal mass, from this an accurate estimate of the building's annual energy usage (33.45 kWh/m^2/yr) and annual CO_2 emissions (6.58 kg/m^2/yr) can be found. Using the CO_2 emissions value, the total carbon produced by the building over the calculation period can be calculated and inputted in the software. The NZEB Report calculation for the masonry construction was redone using a 'low' thermal mass and the produced carbon per m^2 was 6.8 kg/m^2/yr, this value was used to calculate the timber frame building's annual energy consumption emissions.

The timber frame house has better elemental u-values and therefore likely lower heating energy use, for the purposes of this study it was decided to compare the effect of a high thermal mass versus a low thermal mass.

4.3 Water Consumption

The annual *Water Consumption* values inputted for each building were based on the national average for a dwelling house with four occupants, which is 133 m^3/yr [7].

4.4 Construction Site Operations

Construction Site Operations were calculated using the software's formula; *Average site impacts - temperate climate (North) (per GFA)*. This uses the inputted Gross Floor Area (GFA) of the building to calculate the estimated carbon emissions produced during the construction period, construction waste, electricity use and diesel are all included in this calculation.

4.5 Building Area

The *Building Area* is inputted using the gross internal floor area of the building, this value is used when calculating the CO_2 emissions equivalent per square meter for each project.

4.6 Calculation Period

The *Calculation Period* inputted for both buildings was 60 years which is based on the typical design life of a building.

5.0 Results

The following results are calculated only from the inputted materials on the One Click LCA software, see *Appendix A*. This does not resemble a full LCA for each building, as discussed previously; finishes, services, etc. were not included in the calculations for comparison purposes. However, the inputted materials were used to construct both buildings to the same stage, excluding services.

5.1 Masonry Construction Results

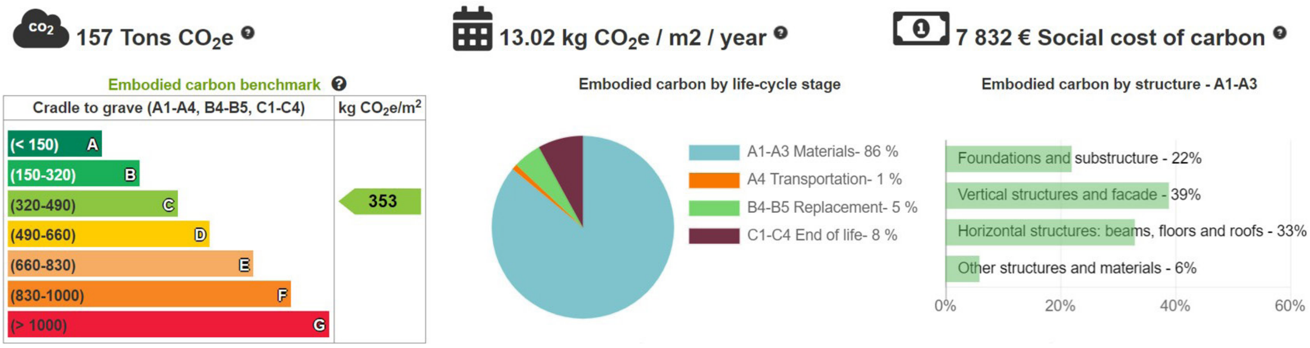


Figure 13. Construction Details Comparison

The masonry building will produce 13.02 kg CO_2e/m^2/year (Figure 13) which works out at 2613 kg CO_2e/year. For a cradle to grave life-cycle (A1-A4, B4-B5, C1-C4) the building produces 353 kg CO_2e/m^2 which grants a OneClick LCA Embodied Carbon Benchmark C rating (*based on CH Q1 2020 United Kingdom*). Stages A1-A3 - Materials make up 86% of the overall Cradle to Grave Life-cycle, 8% is generated by C1-C4 – End of Life while just 5% and 1% by stages B4-B5 – Replacement and A4 – Transportation respectively. Vertical Structures contribute the largest amount of carbon with 39% of the total from all materials, followed by Horizontal Structures and Substructure with 33% and 22% respectively.

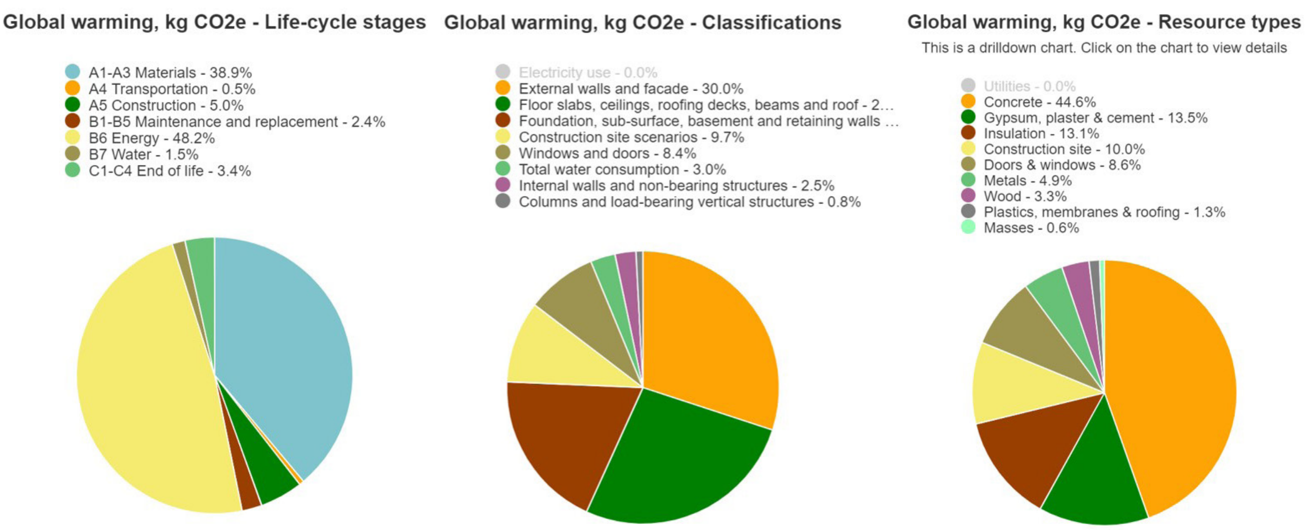


Figure 14. Masonry Construction Global Warming - Life-Cycle Stages, Classifications, Resource Types

It is clear from *Figure 14* that stage B6-Energy is the largest contributor of carbon and this is to be expected as the energy used by the building reoccurs each year of the calculation period which is 1258 kg CO_2e annually. However, the carbon contribution of stages A1-A3 materials is a significant 38.9%. The main contributing resource type is concrete with 44.6% of the total carbon produced by all resources excluding electricity.

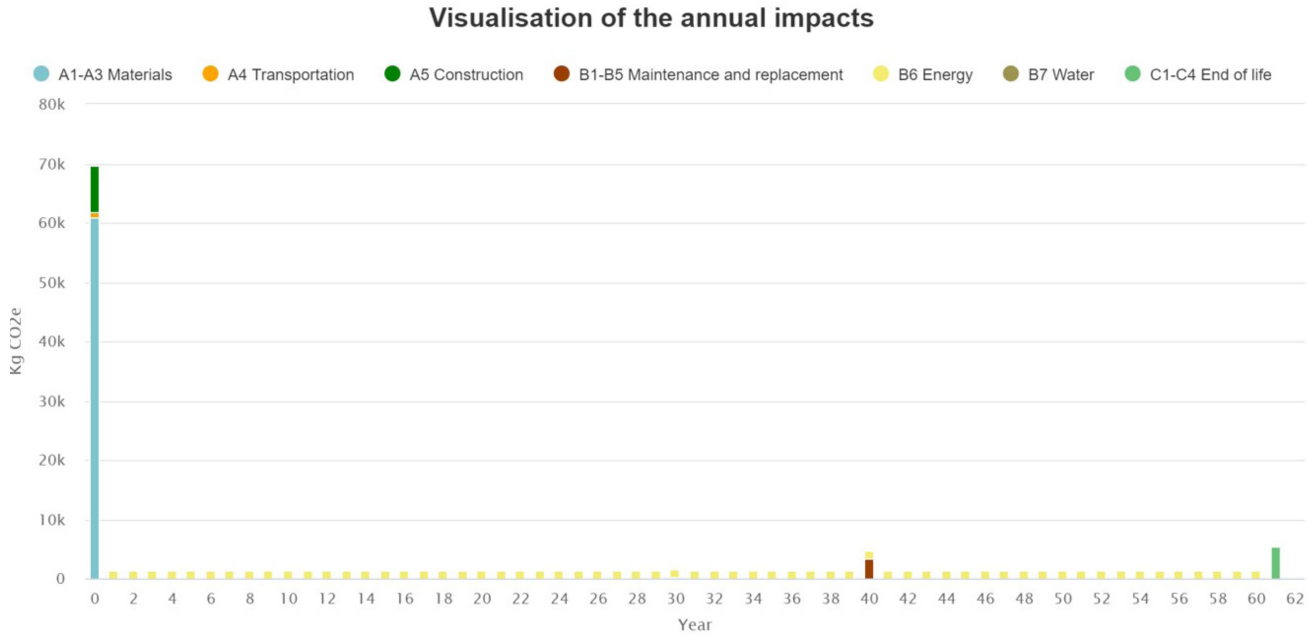


Figure 15. Masonry Construction Annual Impacts

Figure 15 shows the annual impacts produced by the building over the 60 years, there is a constant energy use each year from start to finish, after 40 years the windows and some other materials need to be changed at their service life's end creating a small spike in carbon emissions. It is assumed that after 60 years the building's materials will be demolished, disposed of and recycled if possible.

It should be noted that the amount of carbon emissions created per kWh of electricity produced by the grid could decrease significantly over the next 60 years as the country has targets to produce more renewable energy thus effectively reducing the total CO_2e generated from the building's operational energy usage.

5.2 Timber Frame Construction Results

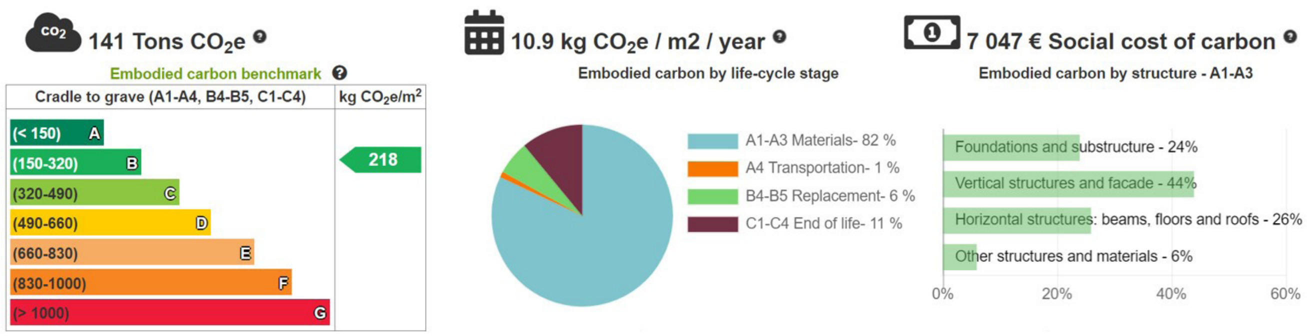


Figure 16. Timber Frame Results Summary

The Timber Frame building will produce 10.9 $kgCO_2e/m^2/year$ (*Figure 16*) which works out at 2349 $kgCO_2e/year$. For a cradle to grave life-cycle, the building produces 218 kg CO_2e/m^2 which grants a

OneClick LCA Embodied Carbon Benchmark B rating based on *CH Q1 2020 United Kingdom*. Stages A1-A3 make up 82% of the overall Cradle to Grave Life-cycle, 11% is generated by C1-C5, 6% for B4-B5 and just 1% by stage A4. Vertical Structures contribute the largest amount of carbon with 44% of total carbon from all materials, followed by Horizontal Structures with 26% and Substructure with 24% respectively.

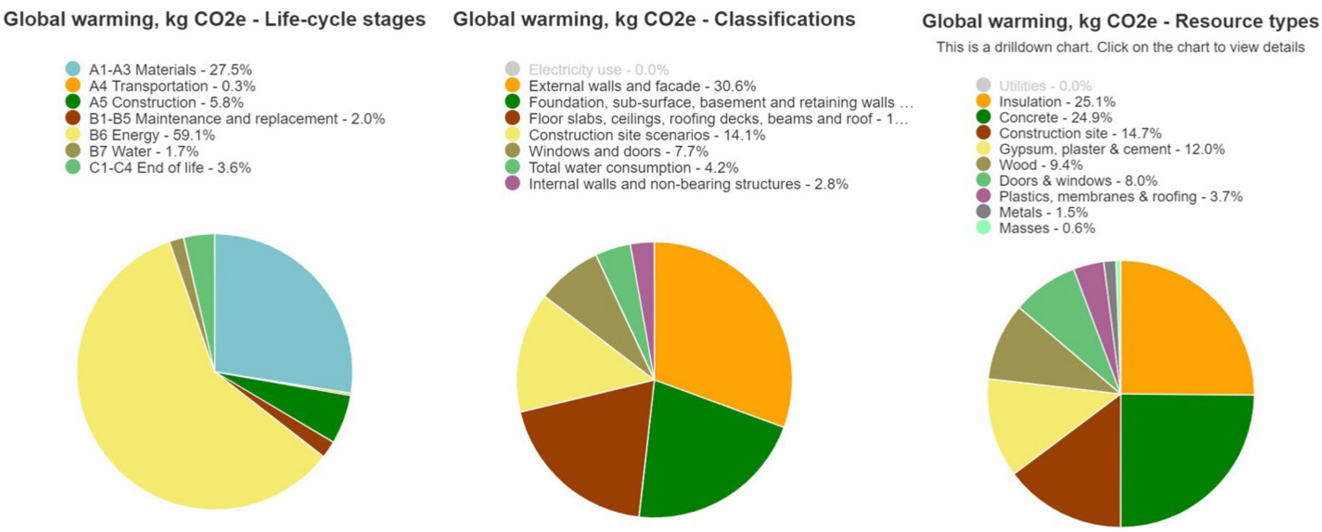


Figure 17. Timber Frame Global Warming - Life-Cycle Stages, Classification, Resource Types

It is clear from *Figure 17* that stage B6-Energy is the largest contributor (59.1%) which is 1389 kg CO_2e annually. The main contributing resource types are concrete and insulation with 24.9% and 25.1% of the total carbon produced by all resources excluding electricity.

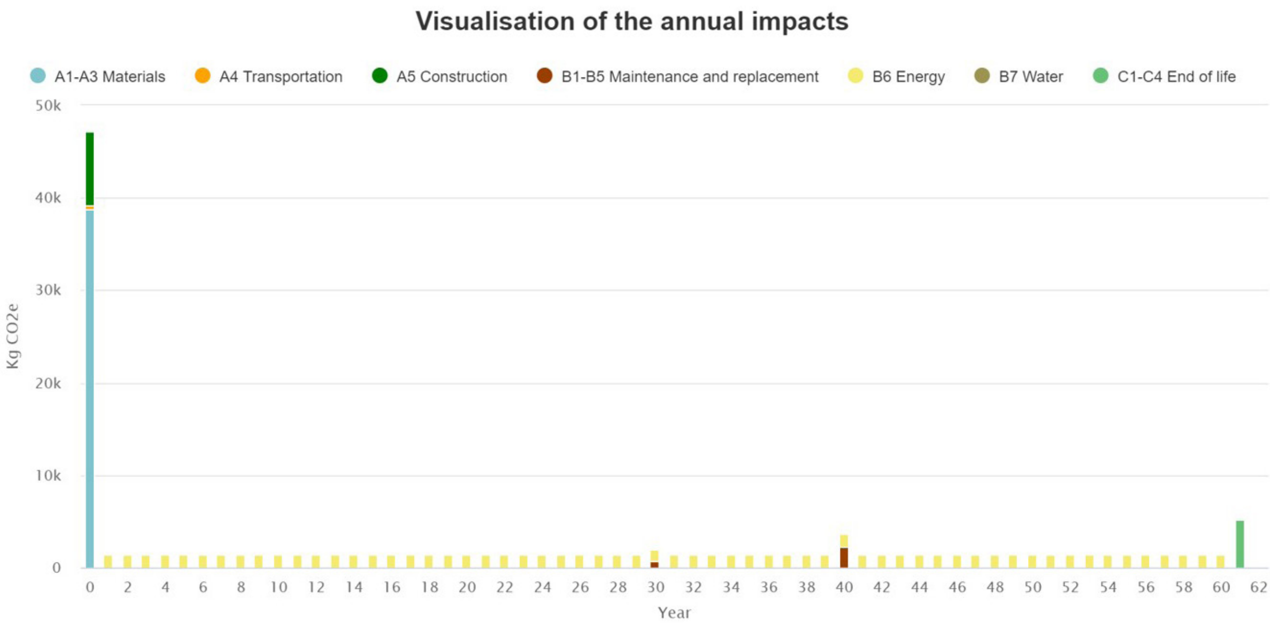
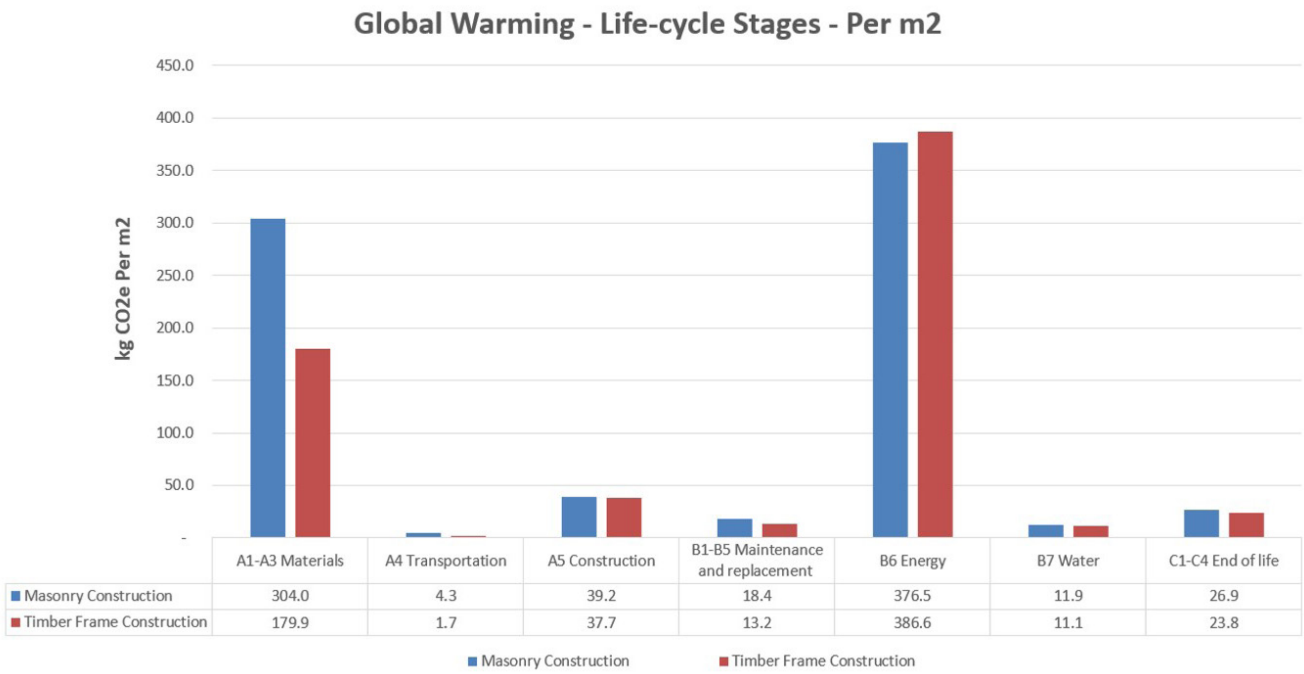


Figure 18. Timber Frame Annual Impacts

Similarly, to the masonry construction *Figure 18* shows the annual impacts produced by the building over the 60 years, there is a constant energy use each year from start to finish, after 40 years the windows and some other materials need to be changed as their service life's end creating a small spike in carbon emissions.

5.3 Results Comparison



	A1-A3 Materials	A4 Transportation	A5 Construction	B1-B5 Maintenance and replacement	B6 Energy	B7 Water	C1-C4 End of life
Masonry Construction	304.0	4.3	39.2	18.4	376.5	11.9	26.9
Timber Frame Construction	179.9	1.7	37.7	13.2	386.6	11.1	23.8

Figure 19. Life-Cycle Stages Comparison

Figure 19 displays the global warming potential per m^2 of both constructions with respect to their life-cycle stages, this chart clearly shows how both projects have similar carbon for all life-cycle stages apart from stages *A1-A3 Materials*. As discussed in Section 4.2, the energy use of both houses are similar and based on a DEAP calculation carried out on the masonry construction the timber frame building has slightly higher B6 emissions per m^2 due to a lower thermal mass, but the main focus when comparing the two constructions is the materials stage. The building materials used in the timber frame construction produce 41% less carbon per m^2 than the masonry construction materials, a saving of 124.1 kg CO_2e per m^2, which is equivalent to 46L of consumed diesel per m^2 of floor area [8].

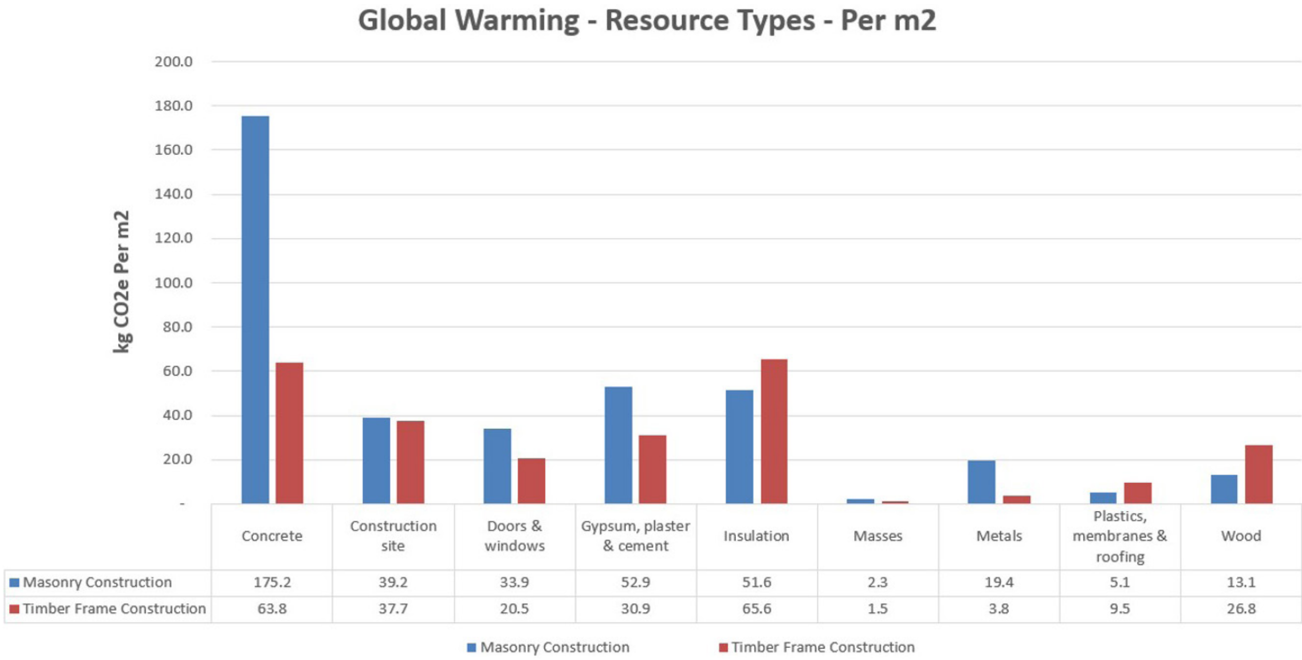
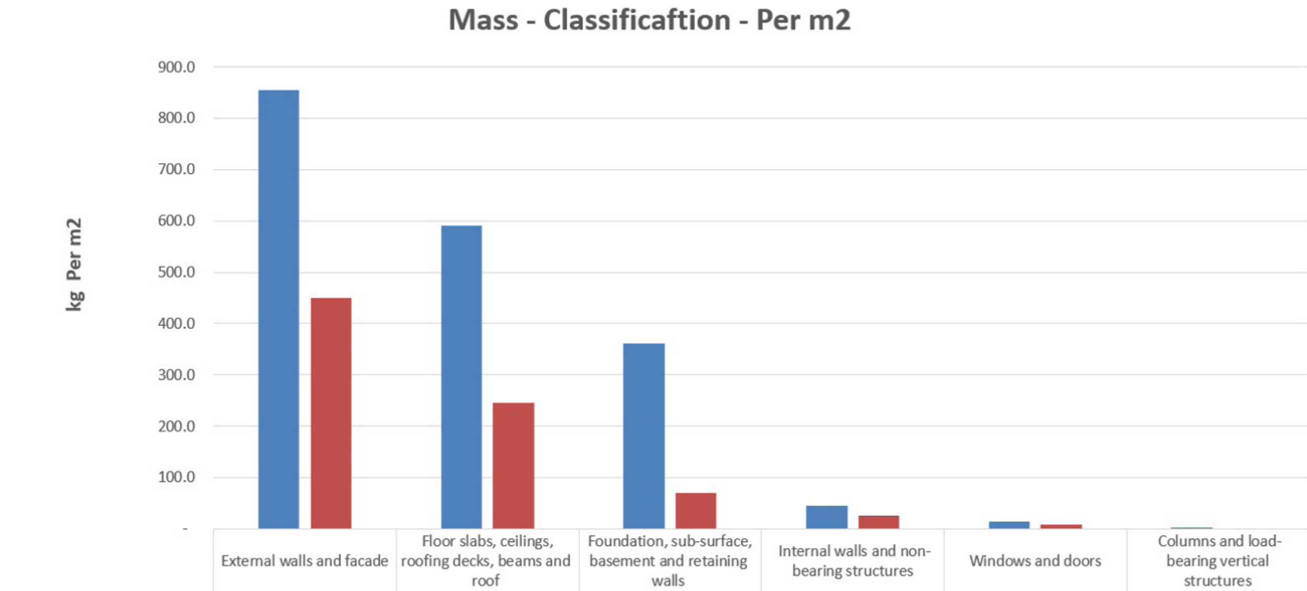


Figure 20. Resource Types Comparison

Figure 20 compares the CO_2 equivalent emissions per m^2 produced by each resource type in both constructions. Concrete is the resource with the largest difference between the two constructions, with the timber frame construction using 36% of the concrete used in the masonry construction. The timber frame construction used double the amount of timber and 20% more insulation compared to the masonry which amounts to 23.9 kg CO_2e per m^2 more than the masonry construction for the two resource types but the masonry building produced 111.4 kg CO_2e per m^2 more than the timber frame for concrete alone. This suggests that replacing concrete with wood significantly reduces the CO_2 equivalent emissions produced by building materials.

The masonry construction has a larger window area and produces slightly more CO_2e, this factor is independent of construction type of the building and is only due to the design of the house. More plaster and cement is needed for the masonry building as it has an extra concrete block leaf compared to just one in the timber frame house.
Because the masonry construction is heavier than the timber frame more steel beams are required which further increases the CO_2e emissions of the construction.

Both buildings produce high emissions from insulation resources, 13% of the masonry construction and 25% of the timber frame construction, these emissions could be significantly reduced if more sustainable insulation materials were selected, cellulose for example which produces 11.21 kg CO_2e/m^3 in comparison to glass wool, EPS 70/100 and PIR insulation which produce 28.17 kg CO_2e/m^3, 66.26/86.58 kg CO_2e/m^3 and 169.38 kg CO_2e/m^3 respectively.



	External walls and facade	Floor slabs, ceilings, roofing decks, beams and roof	Foundation, sub-surface, basement and retaining walls	Internal walls and non-bearing structures	Windows and doors	Columns and load-bearing vertical structures
Masonry Construction	854.8	590.7	360.9	44.4	13.5	1.3
Timber Frame Construction	450.0	245.8	69.7	25.2	8.7	-

Figure 21. Mass Comparison

As expected, the masonry construction has a much greater mass compared to the timber frame construction, 1865 kg per m^2 to 800 kg per m^2 respectively, which is more than double that of the timber frame building. Because the timber frame construction is lighter, its foundations can be lighter which is another factor why much less concrete is used in the building compared to the amount of concrete in the masonry construction foundation.

Life-cycle assessment results

<table>
<tr><th></th><th>Result category</th><th>Global warming kg CO_2e ⓘ</th><th>Acidification kg SO2e ⓘ</th><th>Eutrophication kg PO4e ⓘ</th><th>Ozone depletion potential kg CFC11e ⓘ</th><th>Formation of ozone of lower atmosphere kg Ethenee ⓘ</th><th>Total use of primary energy ex. raw materials MJ ⓘ</th><th></th></tr>
<tr><td>A1-A3</td><td>Construction Materials</td><td>60 952,54 | +57 %</td><td>170,26 | +29 %</td><td>23,19 | +19 %</td><td>0 | +72 %</td><td>35,07 | +28 %</td><td>568 824,53 | +13 %</td><td>Details</td></tr>
<tr><td>A4</td><td>Transportation to site</td><td>852,18 | +140 %</td><td>2,52 | +82 %</td><td>0,54 | +80 %</td><td>0 | +130 %</td><td>0,09 | +210 %</td><td>18 393,3 | +100 %</td><td>Details</td></tr>
<tr><td>A5a</td><td>Site operations & site waste handling</td><td>7 858,96 | -3,4 %</td><td>28,43 | -3,4 %</td><td>17,23 | -3,4 %</td><td>0 | -3,4 %</td><td>0,96 | -3,4 %</td><td>146 807,02 | -3,4 %</td><td>Details</td></tr>
<tr><td>A5b</td><td>Site waste transportation</td><td></td><td></td><td></td><td></td><td></td><td></td><td>Details</td></tr>
<tr><td>A5</td><td>Construction/installation process</td><td>7 858,96 | -3,4 %</td><td>28,43 | -3,4 %</td><td>17,23 | -3,4 %</td><td>0 | -3,4 %</td><td>0,96 | -3,4 %</td><td>146 807,02 | -3,4 %</td><td>Details</td></tr>
<tr><td>B1-B5</td><td>Maintenance and material replacement</td><td>3 688,15 | +30 %</td><td>14,85 | +36 %</td><td>1,82 | +45 %</td><td>0 | +47 %</td><td>1,19 | +19 %</td><td>20 733,43 | -35 %</td><td>Details</td></tr>
<tr><td>B6</td><td>Energy use</td><td>75 497,53 | -9,4 %</td><td>267,52 | -9,4 %</td><td>40,22 | -9,4 %</td><td>0,01 | -9,4 %</td><td>14,16 | -9,4 %</td><td>1 255 275,97 | -9,4 %</td><td>Details</td></tr>
<tr><td>B7</td><td>Water use</td><td>2 394 | 0 %</td><td>12,96 | 0 %</td><td>6,56 | 0 %</td><td>0 | 0 %</td><td>0,58 | 0 %</td><td>50 613,01 | 0 %</td><td>Details</td></tr>
<tr><td>C1-C4</td><td>Deconstruction</td><td>5 400,62 | +5,3 %</td><td>9,47 | +50 %</td><td>2,21 | +42 %</td><td>0 | +90 %</td><td>0,63 | +35 %</td><td>43 580,82 | +70 %</td><td>Details</td></tr>
<tr><td>D</td><td>External impacts (not included in totals)</td><td>−14 165,35 | +6,8 %</td><td>−25,2 | +43 %</td><td>−7,2 | +85 %</td><td>−0 | +160 %</td><td>−2,24 | +39 %</td><td>−167 067,97 | -19 %</td><td>Details</td></tr>
<tr><td></td><td>Total</td><td>156 644</td><td>506</td><td>91,77</td><td>0,01</td><td>52,69</td><td>2 104 228,08</td><td></td></tr>
<tr><td></td><td>Comparing total results with: 5 - Timber Frame Construction</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>5 - Timber Frame Construction Total</td><td>140 932,27</td><td>488,53</td><td>91,37</td><td>0,01</td><td>46,17</td><td>2 155 482,54</td><td></td></tr>
<tr><td></td><td>5 - Masonry Construction compared with 5 - Timber Frame Construction</td><td>+11 %</td><td>+3,6 %</td><td>0,4 %</td><td>+1,6 %</td><td>+14 %</td><td>−2,4 %</td><td></td></tr>
</table>

Figure 22. Masonry Construction Results in Comparison to Timber Frame Construction

Figure 22 shows the Life-Cycle Assessment of the masonry construction compared to the timber frame construction with respect to the different environmental impact categories though not adjusted per m^2. The masonry construction materials have a greater impact for all categories, this shows that a timber frame building is more environmentally friendly in all categories rather than just the GWP (Global Warming Potential). Note, end of life scenarios are based on the current version of the EPD used for each material, in future this may vary as more systems are put in place to ensure material recycling wherever possible and reducing waste disposal carbon costs.

Biogenic storage of biomaterials (wood) is not used in the calculations by the OneClick LCA software because the current, most common method of dealing with timber waste is incineration. This means that the carbon is stored for the buildings lifetime but is released back into the atmosphere during the end of life stage, however, if the wood was guaranteed to be recycled and reused then the biogenic storage could be subtracted from the total embodied carbon of the building. The biogenic storage from the timber used in the masonry and timber frame constructions is 42 kg CO_2e per m^2 and 78 kg CO_2e per m^2 respectively, reducing the overall materials CO_2e emissions by 43% and 56%. Adding more biomaterials such as cellulose insulation would further increase the biogenic storage of the building and in turn, reduce the total emissions.

6.0 Conclusion

For a cradle to grave life-cycle (without materials associated with finishes), the masonry building produces 353 kg CO_2e/m^2 against 218 kg CO_2e/m^2 for the timber frame building. This is a saving of 135 kg CO_2e/m^2 or 38%. From *figure 19* it can be seen that there is very little difference in two types of construction in most of the life cycle stages and that stage A1-A3 materials accounts for 125 kg CO_2e/m^2 of the difference.

It is clear that the use of concrete (even with 30% recycled binders), in foundations/floor slabs/intermediate floors/block walls is the reason that the traditional masonry construction has a significantly higher embodied energy than the timber frame construction. Portland cement, a key concrete ingredient, requires a lot of energy to manufacture with an embodied energy of 0.92 kg CO_2e [6] and accounts for approximately 7% of global carbon emissions.

The use of timber joist intermediate floors would reduce the embodied carbon of horizontal structures in the masonry building by 52%. However, this is still insignificant when compared to the carbon savings by converting to timber frame construction. Timber frame construction could be improved upon further by removing the outer leaf of concrete block and replacing with a counter batten, batten, cement board and render system and it is recommended this be assessed further.

Furthermore, if the end of life re-use of the timber was changed from incineration to recycling then the biogenic storage of the wood could be subtracted from the total embodied carbon of new buildings thus progressing towards a net-zero carbon embodied building and creating a circular economy.

The embodied carbon of the substructure in the masonry house, with traditional strip foundations and the ground bearing slab, was 96.3 kg CO_2e /m² compared to the embodied energy of 56.6 kg/m² for the passive raft slab. In the experience of the authors, there is a negligible cost difference between these two types of substructure construction.

One of the difficulties encountered was that not all products had an EPD and substitute similar products with EPDs were used where necessary. EPDs are currently voluntary and if it was mandatory to produce EPDs then there would be greater carbon transparency and it would allow building designers/developers make more informed choices when deciding on what materials and construction types to use. It is also accepted that there are other construction methods in wide use that would be worthy of a similar analysis to determine their overall embodied carbon footprint.

The findings of this report, whilst somewhat narrow, clearly show the large impact that building designers can have reducing upfront emissions of a building by undertaking whole life carbon thinking at an early design stage. The World Green Building Council's publication "Bringing embodied carbon upfront" calls for designers to "adopt a whole life approach to carbon reduction in buildings…, applying our principles in order to identify cost-effective low and, ultimately, net-zero carbon designs while prioritising early emissions savings".

The government too can have a significant impact and leadership role regulating for the use of LCAs for all public projects. Starting with the planned building of 25,000 new homes per annum [9], with an average floor space of 137m2 [10] then based on the calculations of the two different constructions in this report annual saving of up to 460,000 tons of CO_2 equivalent emissions can be made by simply building timber frame buildings instead of the traditional masonry construction. This is equivalent to the amount of carbon that gets stored in 107,000 hectares of Irish forests every year [11], which is 14% of the total area of forestry in Ireland. This is an easy carbon saving to make as both constructions have a similar financial cost per square meter.

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Appendix A
One Click LCA Material Inputs for both Buildings

Jeremy Walsh
Project Management

A.1 Masonry Construction Material Inputs

Construction	Resource	User input	Global warming kg CO_2e	Acidification kg SO2e	Eutrophication kg PO4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ	Comments
Building materials > Foundations and substructure > Foundation, sub-surface, basement and retaining walls									
	Crushed rock (0…100 mm), dry bulk density, 1680 kg/m3 ?	21 ton	135,54	1,2	0,33	0	0,02	1 999,5	Annex E
	Ready-mix concrete, normal-strength, generic, C30/37 (4400/5… ?	21 m3	5 116,01	11,49	1,5	0	0,5	27 974,02	Strip Foundation
	Ready-mix concrete, normal-strength, generic, C30/37 (4400/5… ?	96 m2	2 923,43	6,57	0,86	0	0,28	15 985,16	Ground Floor Slab
	Portland cement - lime mix, for soil stabilisation, generic,… ?	1 000 kg	980,7	1,55	0,19	0	0,12	4 541,7	Cement
	Reinforcement steel (rebar), generic, 97% recycled content (… ?	500 kg	258,89	0,95	0,14	0	0,1	4 632,83	A393 Mesh
	Precast concrete block, 700-2100 kg/m3 (BPCF) ?	5,4 m3	835,21	1,54	0,14	0	0,37	5 000,71	Sub Walls
	EPS insulation, R = 3.2 m2K/W, L = 0.031 W/mK, T: 100 mm, 1… ?	97 m2	1 281,54	4,81	0,56	0	5,54	21 446,08	Underfloor Insulation
	Autoclaved aerated concrete masonry units, 480 kg/m3, SUPER … ?	3,4 m3	874,91	2,06	0,22	0	0,14	5 644,02	Sub Walls
	Radon and moisture membrane for site construction, PP, 1.2 m… ?	120 m2	787,75	3,16	0,42	0	0,17	5 929,2	Radon
	Sand (0…8 mm), loose dry density, 1555 kg/m3 ?	7,3 ton	16,94	0,11	0,03	0	0	427,15	Blinding
		Section total	**13 210,92**	**33,43**	**4,38**	**0**	**7,25**	**93 580,37**	
Building materials > Vertical structures and facade > External walls and facade									
	Portland cement, generic, CEM I ?	7 700 kg	7 703,67	14,56	1,91	0	0,58	33 497,53	Ext & Int Wall
	Lime mortar, 1300 - 1800 kg/m3 (VDPM) ?	130 kg	46,32	0,1	0,01	0	0,01	495,75	Ext & Int Wall
	Precast concrete block, 700-2100 kg/m3 (BPCF) ?	63 m3	9 780,35	18,05	1,62	0	4,37	58 558,5	Ext & Int Wall
	Precast concrete beams, incl. reinforcement, Dimension: 0.20… ?	2,3 m	27,22	0,06	0,01	0	0	192,17	Lintels
	Precast concrete beams, incl. reinforcement, Dimension: 0.20… ?	11 m	136,12	0,31	0,05	0	0,02	960,86	Cills
	EPS insulation, R = 3.2 m2K/W, L = 0.031 W/mK, T: 100 mm, 1… ?	52 m3	3 445,71	12,93	1,51	0	14,88	57 662,69	Cavity insulation beads
	Autoclaved aerated concrete masonry units, 480 kg/m3, SUPER … ?	2,3 m3	578,01	1,36	0,14	0	0,09	3 728,73	Ext & Int Wall
	Sand (0…8 mm), loose dry density, 1555 kg/m3 ?	70 ton	162,4	1,06	0,33	0	0,04	4 095,95	Ext & Int Wall
		Section total	**21 879,81**	**48,42**	**5,57**	**0**	**19,99**	**159 192,18**	
Building materials > Vertical structures and facade > Columns and load-bearing vertical structures									
	Structural steel profiles, generic, 20% recycled content, I… ?	0,26 ton	657,17	2,67	0,47	0	0,39	10 076,5	Steel Column
		Section total	**657,17**	**2,67**	**0,47**	**0**	**0,39**	**10 076,5**	

Building materials > Vertical structures and facade > Internal walls and non-bearing structures									
	Structural sawn timber, kiln dried, planed or machined, 479 ... ?	2,6 m3	319,05	1,8	0,34	0	0,12	9 984	Int Stud Wall
	Plaster, finish, app. th.: 2 mm, Skimcoat, Skimcoat Short Se... ?	2 400 kg	213,4	0,51	0,05	0	0,06	4 340,75	Int Wall
	Fibre cement boards, 1300 kg/m3 (81.16 lbs/ft3) ?	0,035 m3	52,74	0,15	0,02	0	0,01	366,47	Int Wall
	Gypsum plaster board, regular, generic, 6.5-25 mm (0.25-0.98... ?	3 m3	782,56	5,42	0,59	0	0,22	11 741,24	Int Wall
	Plywood, generic, 4-50 mm (0.16-1.97 in), 620 kg/m3 (38.7 lb... ?	0,3 m3	139,29	0,4	0,06	0	0,04	2 566,68	Int Wall
		Section total	**1 507,03**	**8,28**	**1,06**	**0**	**0,45**	**28 999,14**	
Building materials > Horizontal structures: beams, floors and roofs > Floor slabs, ceilings, roofing decks, beams and roof									
	Gypsum plasterboard, 12.5 mm, 8.985 kg/m2 (average product w... ?	3 m3	361,52	1,71	0,41	0	0,17	8 019,78	Ceilings
	Structural sawn timber, kiln dried, planed or machined, 479 ... ?	10 m3	1 262,7	7,13	1,35	0	0,49	39 513,6	Timber
	PIR insulation boards, aluminium foil faced, <= 160 mm, L = ... ?	160 m2	1 592,16	7,22	1,31	0	0,88	27 646,72	Sarking
	Ready-mix concrete, normal-strength, generic, C20/25 (2900/3... ?	90 m2	1 317,09	3,03	0,4	0	0,13	7 496,33	Screed
	Fibre cement boards, 1300 kg/m3 (81.16 lbs/ft3) ?	0,24 m3	364,63	1,04	0,12	0	0,05	2 533,88	Ceilings
	Glass wool insulation panels, unfaced, generic, 25 kg/m3 (1... ?	160 m2	1 247,02	4,07	0,59	0	0,21	17 228,26	Rafter Insulation
	Plywood, generic, 4-50 mm (0.16-1.97 in), 620 kg/m3 (38.7 lb... ?	0,21 m3	99,36	0,29	0,05	0	0,03	1 830,9	Ceilings
	Reinforcement steel (rebar), generic, 97% recycled content (... ?	330 kg	172,42	0,63	0,09	0	0,07	3 085,46	A142 Mesh
	Structural steel profiles, generic, 80% recycled content, I... ?	2 ton	2 771,82	10,34	1,56	0	1,25	48 168,99	Steel Beams
	Coated fibre cement slates, 4mm, 600x300mm, 1.52 kg/unit, 8... ?	250 m2	4 850	9,7	1,57	0	1,56	57 150	Slates
	Waterproof membrane from nonwoven HDPE for roof and wall und... ?	160 m2	83,61	0,19	0,02	0	0,02	2 643,88	Felt
	Precast concrete floor and cover slab, C35/40 (B35 M45) (Ove... ?	120 m2	6 184,14	17,97	2,51	0	1,02	47 909,74	PC Slabs
		Section total	**20 306,46**	**63,31**	**9,96**	**0**	**5,89**	**263 227,53**	
Building materials > Other structures and materials > Windows and doors									
	Roof window (skylight), 978 x 780 mm, 33.1 - 16 - 4 mm, U = ... ?	0,76 m2	72,66	0,36	0,05	0	0,02	1 438,44	Skylight
	Roof window (skylight), 978 x 780 mm, 33.1 - 16 - 4 mm, U = ... ?	3,8 m2	494,46	2,37	0,33	0	0,16	8 825,04	Skylight
	Triple-glazed PVC frame window, size: 1230 x 1480 mm, Uwind ... ?	36 m2	2 750,4	10,91	1,35	0	0,81	0	Windows
	External wood door ?	4 m2	73,63	0,51	0,03	0	0,12	3 485,32	Ext Doors
		Section total	**3 391,15**	**14,15**	**1,75**	**0**	**1,11**	**13 748,8**	

A.2 Timber Frame Construction Material Inputs

Construction	Resource	User input	Global warming kg CO_2e	Acidification kg SO2e	Eutrophication kg PO4e	Ozone depletion potential kg CFC11e	Formation of ozone of lower atmosphere kg Ethenee	Total use of primary energy ex. raw materials MJ	Comments
Building materials > Foundations and substructure > Foundation, sub-surface, basement and retaining walls									
	Crushed rock (0... 100 mm), dry bulk density, 1680 kg/m3?	31 ton	202,99	1,8	0,49	0	0,04	2 994,42	Foundation
	Ready-mix concrete, normal-strength, generic, C30/37 (4400/5...?	18 m3	4 385,15	9,85	1,29	0	0,43	23 977,73	Foundation & Ground Floor
	Reinforcement steel (rebar), generic, 97% recycled content (...?	800 kg	414,22	1,52	0,22	0	0,16	7 412,53	Foundation
	EPS insulation, R = 3.2 m2K/W, L = 0.031 W/mK, T: 100 mm, 2....?	19 m3	1 644,97	6,26	0,71	0	7,26	27 502,88	Foundation Kore
	EPS insulation, R = 3.1 m2K/W, L = 0.03 W/mK, T: 100 mm, 4.2...?	11 m3	1 963,14	7,21	0,81	0	8,83	32 961,2	Foundation Kore
	Radon and moisture membrane for site construction, PP, 1.2 m...?	110 m2	735,23	2,95	0,39	0	0,16	5 533,92	Foundation
	Sand (0...8 mm), loose dry density, 1555 kg/m3?	21 ton	48,72	0,32	0,1	0	0,01	1 228,79	Foundation
		Section total	9 394,42	**29,9**	**4,01**	**0**	**16,88**	**101 611,47**	
Building materials > Vertical structures and facade > External walls and facade									
	Structural sawn timber, kiln dried, planed or machined, 479 ...?	8 m3	981,69	5,54	1,05	0	0,38	30 720	Ext Wall
	PIR insulation boards, aluminium foil faced, <= 160 mm, L = ...?	270 m2	4 299,84	19,5	3,53	0	2,38	74 663,75	Ext Wall
	Plaster, finish, app. th.: 2 mm, Skimcoat, Skimcoat Short Se...?	270 m2	61,37	0,15	0,01	0	0,02	1 248,29	Ext Wall
	Portland cement, generic, CEM I?	2 800 kg	2 769,29	5,23	0,69	0	0,21	12 041,59	Ext Wall
	Glass wool insulation panels, unfaced, generic, 25 kg/m3 (1....?	210 m2	1 262,91	4,12	0,59	0	0,22	17 447,73	Insulation between studs
	Gypsum plaster board, regular, generic, 6.5-25 mm (0.25-0.98...?	270 m2	864,07	5,98	0,65	0	0,25	12 964,28	Ext Wall
	Waterproof membrane from nonwoven HDPE for roof and wall und...?	260 m2	182,17	0,42	0,03	0	0,05	5 813,76	Airtightness Membrane
	Waterproof membrane from nonwoven HDPE for roof and wall und...?	270 m2	188,57	0,43	0,04	0	0,05	6 018,15	Breather Membrane
	Precast concrete block, 700-2100 kg/m3 (BPCF)?	23 m3	3 524,03	6,5	0,58	0	1,57	21 099,65	Ext & Int Wall
	Precast concrete beams, incl. reinforcement, Dimension: 0.20...?	18 m	217,8	0,49	0,08	0	0,02	1 537,38	Sills & Lintels
	OSB panels, 600 kg/m3, OSB3 T&G (MEDITE SMARTPLY)?	270 m2	513,01	2,03	0,32	0	0,39	8 391,28	Ext Wall
	Render mortar, normal render, high-grade render, 1550 kg/m3,...?	270 m2	979,79	1,03	0,29	0	0,01	9 964,8	Ext Wall
		Section total	15 844,54	**51,42**	**7,86**	**0**	**5,54**	**201 910,66**	

Building materials > Vertical structures and facade > Internal walls and non-bearing structures								
Structural sawn timber, kiln dried, planed or machined, 479 ...?	2,6 m3	3,19E2	1,8E0	3,4E−1	5,76E−9	1,23E−1	9,96E3	Int Stud Wall
Plaster, finish, app. th.: 2 mm, Skimcoat, Skimcoat Short Se...?	2 400 kg	2,13E2	5,09E−1	4,85E−2	9,46E−6	5,58E−2	4,34E3	Int Wall
Fibre cement boards, 1300 kg/m3 (81.16 lbs/ft3)?	0,035 m3	5,27E1	1,5E−1	1,73E−2	1,9E−6	7,12E−3	3,66E2	Int Wall
Gypsum plaster board, regular, generic, 6.5-25 mm (0.25-0.98...?	3 m3	7,83E2	5,42E0	5,9E−1	3,56E−5	2,23E−1	1,17E4	Int Wall
Plywood, generic, 4-50 mm (0.16-1.97 in), 620 kg/m3 (38.7 lb...?	0,3 m3	1,39E2	4,05E−1	6,35E−2	1,48E−5	3,88E−2	2,57E3	Int Wall
	Section total	**1,51E3**	**8,28E0**	**1,06E0**	**6,17E−5**	**4,48E−1**	**2,9E4**	
Building materials > Horizontal structures: beams, floors and roofs > Floor slabs, ceilings, roofing decks, beams and roof								
Gypsum plasterboard, 12.5 mm, 8.965 kg/m2 (average product w...?	3 m3	3,62E2	1,71E0	4,11E−1	4,96E−5	1,69E−1	8,02E3	Ceilings
Structural sawn timber, kiln dried, planed or machined, 479 ...?	10 m3	1,26E3	7,13E0	1,35E0	2,28E−8	4,88E−1	3,95E4	Timber
PIR insulation boards, aluminium foil faced, <= 160 mm, L = ...?	160 m2	1,59E3	7,22E0	1,31E0	2,56E−5	8,8E−1	2,76E4	Sarking
Ready-mix concrete, normal-strength, generic, C20/25 (2900/3...?	90 m2	1,32E3	3,03E0	3,98E−1	3,75E−5	1,32E−1	7,5E3	Screed
Fibre cement boards, 1300 kg/m3 (81.16 lbs/ft3)?	0,24 m3	3,65E2	1,04E0	1,19E−1	1,31E−5	4,92E−2	2,53E3	Ceilings
Glass wool insulation panels, unfaced, generic, 25 kg/m3 (1....?	160 m2	1,25E3	4,07E0	5,87E−1	1,07E−4	2,14E−1	1,72E4	Rafter Insulation
Plywood, generic, 4-50 mm (0.16-1.97 in), 620 kg/m3 (38.7 lb...?	0,21 m3	9,94E1	2,89E−1	4,53E−2	1,05E−5	2,77E−2	1,83E3	Ceilings
Reinforcement steel (rebar), generic, 97% recycled content (...?	330 kg	1,72E2	6,33E−1	9,05E−2	1,53E−5	6,51E−2	3,09E3	A142 Mesh
Structural steel profiles, generic, 80% recycled content, I...?	2 ton	2,77E3	1,03E1	1,56E0	2,21E−4	1,25E0	4,82E4	Steel Beams
Coated fibre cement slates, 4mm, 600x300mm, 1.52 kg/unit, 8....?	250 m2	4,85E3	9,7E0	1,57E0	7,13E−8	1,56E0	5,72E4	Slates
Waterproof membrane from nonwoven HDPE for roof and wall und...?	160 m2	8,36E1	1,88E−1	1,56E−2	1,99E−8	2,07E−2	2,64E3	Felt
Precast concrete floor and cover slab, C35/40 (B35 M45) (Ove...?	120 m2	6,18E3	1,8E1	2,51E0	1,92E−4	1,02E0	4,79E4	PC Slabs
	Section total	**2,03E4**	**6,33E1**	**9,96E0**	**6,72E−4**	**5,89E0**	**2,63E5**	
Building materials > Other structures and materials > Windows and doors								
Roof window (skylight), 978 x 780 mm, 33.1 - 16 - 4 mm, U = ...?	0,76 m2	7,27E1	3,61E−1	5,03E−2	6,48E−6	2,25E−2	1,44E3	Skylight
Roof window (skylight), 978 x 780 mm, 33.1 - 16 - 4 mm, U = ...?	3,8 m2	4,94E2	2,37E0	3,27E−1	3,51E−5	1,65E−1	8,83E3	Skylight
Triple-glazed PVC frame window, size: 1230 x 1480 mm, Uwind ...?	36 m2	2,75E3	1,09E1	1,35E0	4,25E−5	8,06E−1	0E0	Windows
External wood door?	4 m2	7,36E1	5,06E−1	2,56E−2	2,57E−6	1,19E−1	3,49E3	Ext Doors
	Section total	**3,39E3**	**1,41E1**	**1,75E0**	**8,66E−5**	**1,11E0**	**1,37E4**	

Appendix B
Material Data Sources

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B.1 Masonry Construction Sources

Sources

Resource name	Technical specification	Product	Manufacturer	EPD program	EPD number	Environment Data Source	Standard	Verification	Year	Country	Upstream database	Density	Product Category Rules (PCR)	Notes about PCR
Autoclaved aerated concrete masonry units	480 kg/m3	SUPER (B3)	Quinn	EPD Ireland	EPDIE-18-10	EPD QUINN-LITE Super (B3), Standard (B5), Seven (B7).	EN15804	Verified	2018	[unitedKingdom]	ecoinvent	480.0	EN15804:2012+A1:2013, EPD Ireland PCR Part A	Only with EN15804
Coated fibre cement slates	4mm, 600x300mm, 1.52 kg/unit, 8.4kg/m2, 1950 kg/m3		Marley Eternit	IBU	EPD-MAR-20140216-CCD1-EN	EPD Coated Fibre Cement Slates Marley Eternit Ltd & Tegral Building Products Ltd	EN15804	Verified	2015	[ireland]	GaBi	1950.0	PCR Fibre cement - Fibre concrete, 07/2014	Only with EN15804
Crushed rock (0....100 mm), dry bulk density	1680 kg/m3			One Click LCA	-	LCA of crushed stone, Bionova 2016	ISO14040	-	2016	[LOCAL]	ecoinvent	1680.0	-	Only with EN15804
EPS insulation	R = 3.2 m2K/W, L = 0.031 W/mK, T: 100 mm, 1.52 kg/m2, 15.2 kg/m3, Lambda=0.031 W/(m.K)	SD EPS 70 Silver	KORE	EPD Ireland	EPDIE-19-14	EPD KORE INSULATION EPS70 White, EPS70 Silver, EPS100 White, EPS100 Silver, EPS150 White, EPS200, EPS300	EN15804	Verified	2018	[ireland]	ecoinvent	15.2	EN15804:2012+A1:2013, EPD Ireland PCR Part A	Only with EN15804
Electricity, Ireland				Bionova		LCA study for country specific electricity mixes based on IEA, Bionova 2019	EN15804			[ireland]	ecoinvent			
External wood door				One Click LCA	-	Bionova	EN15804	-	2011	[LOCAL]	ecoinvent		-	Biogenic CO2 separated
Fibre cement boards	1300 kg/m3 (81.16 lbs/ft3)			One Click LCA	-	One Click LCA	EN15804	-	2019	[LOCAL]	ecoinvent	1300.0	EN15804	-
Glass wool insulation panels, unfaced, generic	25 kg/m3 (1.56 lbs/ft3), (applicable for densities: 0-25 kg/m3 (0-1.56 lbs/ft3)), Lambda=0.031 W/(m.K)			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	25.0	EN15804	-
Gypsum plaster board, regular, generic	6.5-25 mm (0.25-0.98 in), 10.725 kg/m2 (2.20 lbs/ft2) (for 12.5 mm/0.49 in), 858 kg/m3 (53.6 lbs/ft3)			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	858.0280607132333	EN15804	-
Gypsum plasterboard	12.5 mm, 8.985 kg/m2 (average product weight)		Etex Building Performance	BRE	BREG EN EPD 000204	EPD GTEC Plasterboard	EN15804	Verified	2018	[unitedKingdom]	ecoinvent	718.8	EN15804	-
Lime mortar	1300 - 1800 kg/m3		VDPM	IBU	EPD-IWM-20190154-IBG1-DE	EPD Mineralische Werkmörtel: PutzmörtelNormalputz/ Edelputz mit besonderen Eigenschaften Verband für Dämmsysteme, Putz und Mörtel e.V. (VDPM)	EN15804	Verified	2019	[germany]	GaBi		PCR Mineralische Werkmörtel, 07/2014	Only with EN15804
PIR insulation boards, aluminium foil faced	<= 160 mm, L = 0.0215 W/mK, dens. = 32 kg/m3	Various products	Xtratherm	BRE	BREG EN EPD 000226	EPD Xtratherm UK Ltd	EN15804	Verified	2018	[unitedKingdom]	ecoinvent	32.0	EN15804	-
Plaster, finish	app. th.: 2 mm	Skimcoat, Skimcoat Short Set, Carlite, Carlite Ultra	Gyproc	International EPD System	S-P-00584	EPD Gyproc Finish Plaster (Skimcoat, Skimcoat Short Set, Carlite and Carlite Ultra products)	EN15804	Verified	2014	[ireland]	ecoinvent	1315.789	PCR 2012:01 Construction Products and Construction services, ver. 1.2	Only with EN15804
Plywood, generic	4-50 mm (0.16-1.97 in), 620 kg/m3 (38.7 lbs/ft3)			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	620.0	EN15804	-
Portland cement - lime mix, for soil stabilisation, generic	900 kg/m3 (56.2 lbs/ft3) bulk density of 50-50% volumetric mix			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent		EN15804	-

B.1 Masonry Construction Sources

Precast concrete beams, incl. reinforcement	Dimension: 0.20x0.30 m, Béton/Cement: C25/30 XF1, CEM II/A-S.		SNBPE	INIES	INIES_CPOU20171219_104315, 7675	FDES	EN15804	-	2017	[france]	ecoinvent		EN15804	EN15804
Precast concrete block	700-2100 kg/m3		BPCF	IBU	EPD-BPC-20170092-CCD1-EN	EPD UK Manufactured Precast Concrete Blocks Produced by members of the Concrete Block Association (CBA) a product group of British Precast	EN15804	Verified	2017	[unitedKingdom]	GaBi	1425.0	PCR Pre-cast concrete components, 07/2014	Only with EN15804
Precast concrete floor and cover slab	C35/40 (B35 M45)		Overhalla Betongbygg	EPD Norge	NEPD-1907-818-NO	EPD Kompakt slakkarmert dekke	EN15804	Verification	2019	[norway]	ecoinvent	2400.0	EN15804	-
Radon and moisture membrane for site construction, PP	1.2 mm		Icopal	EPD Norge	NEPD00208N	Icopal RMA 1200 radonmembran, NEPD 00208N	EN15804	Verified	2013	[norway]	ecoinvent	916.667	NPCR 022 Roof waterproofing	Only with EN15804
Ready-mix concrete, normal-strength, generic	C30/37 (4400/5400 PSI), 30% recycled binders in cement (300 kg/m3 / 18.72 lbs/ft3)			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	2400.0	EN15804	-
Ready-mix concrete, normal-strength, generic	C20/25 (2900/3600 PSI), 30% recycled binders in cement (240 kg/m3 / 14.98 lbs/ft3)			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	2200.0	EN15804	-
Reinforcement steel (rebar), generic	97% recycled content (typical)			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	7850.0	EN15804	-
Roof window (skylight)	978 x 780 mm, 33.1 - 16 - 4 mm, U = 1.3 W/m2K, 40.38 kg/m2, biogenic CO2 not subtracted (for CML)	Fenêtres de type GGU Fenêtres de type GPU	VELUX FRANCE	INIES	INIES_INOU20190313_105541, 10248	FDES	EN15804	Verified	2019	[france]	ecoinvent		EN15804	EN15804
Roof window (skylight)	978 x 780 mm, 33.1 - 16 - 4 mm, U = 1.3 W/m2K, 35.66 kg/m2, biogenic CO2 not subtracted (for CML)	Fenêtres type GGL Fenêtres type GPL Fenêtres type GFL	VELUX FRANCE	INIES	INIES_IFEN20190313_144317, 10253	FDES	EN15804	Verified	2019	[france]	ecoinvent		EN15804	EN15804
Sand (0…8 mm), loose dry density	1555 kg/m3			One Click LCA	-	LCA inventory for sand quarry operation, Ecoinvent 2016	ISO14040	-	2016	[LOCAL]	ecoinvent	1555.0	-	Only with EN15804
Structural sawn timber, kiln dried, planed or machined	479 kg/m3		Wood for Good	BRE	BREG EN EPD 000124	EPD Kiln dried planed or machined sawn timber	EN15804	Verified	2017	[unitedKingdom]	GaBi	479.0	EN15804	-
Structural steel profiles, generic	20% recycled content, I, H, U, L, and T sections			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	7850.0	EN15804	-
Structural steel profiles, generic	80% recycled content, I, H, U, L, and T sections			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	7850.0	EN15804	-
Triple-glazed PVC frame window	size: 1230 x 1480 mm, Uwind = 0.7 W/m2K, Uglass = 0.7 W	PassiV	Munster Joinery	EPD Ireland	EPDIE-18-08	EPD Passiv PVC Triple Glazed Window	EN15804	Verified	2018	[ireland]	ecoinvent		EN15804	-
Waterproof membrane from nonwoven HDPE for roof and wall underlay	145 g/m2	Tyvek® 2507B	DuPont	IBU	EPD-DUP-20150237-IBE1-EN	Oekobau.dat, EPD DuPontTM Tyvek® 2507B DuPont de Nemours (Luxembourg) s.à r.l.	EN15804	Verified	2016	[germany, luxembourg]	GaBi		PCR False ceiling and underlay sheeting, 07/2014	Only with EN15804

B.2 Timber Frame Construction Sources

Sources

Resource name	Technical specification	Product	Manufacturer	EPD program	EPD number	Environment Data Source	Standard	Verification	Year	Country	Upstream database	Density	Product Category Rules (PCR)	Notes about PCR
Coated fibre cement slates	4mm, 600x300mm, 1.52 kg/unit, 8.4kg/m2, 1950 kg/m3		Marley Eternit	IBU	EPD-MAR-20140216-CCD1-EN	EPD Coated Fibre Cement Slates Marley Eternit Ltd & Tegral Building Products Ltd	EN15804	Verified	2015	[ireland]	GaBi	1950.0	PCR Fibre cement - Fibre concrete, 07/2014	Only with EN15804
Crushed rock (0…100 mm), dry bulk density	1680 kg/m3			One Click LCA	-	LCA of crushed stone, Bionova 2016	ISO14040	-	2016	[LOCAL]	ecoinvent	1680.0	-	Only with EN15804
EPS insulation	R = 3.1 m2K/W, L = 0.03 W/mK, T: 100 mm, 4.27 kg/m2, 42.7 kg/m3, Lambda=0.03 W/(m.K)	UUHD EPS300	KORE	EPD Ireland	EPDIE-19-14	EPD KORE INSULATION EPS70 White, EPS70 Silver, EPS100 White, EPS100 Silver, EPS150 White, EPS200, EPS300	EN15804	Verified	2018	[ireland]	ecoinvent	42.7	EN15804:2012+A1:2013, EPD Ireland PCR Part A	Only with EN15804
EPS insulation	R = 3.2 m2K/W, L = 0.031 W/mK, T: 100 mm, 2.03 kg/m2, 20.3 kg/m3, Lambda=0.031 W/(m.K)	HD EPS 100 Silver	KORE	EPD Ireland	EPDIE-19-14	EPD KORE INSULATION EPS70 White, EPS70 Silver, EPS100 White, EPS100 Silver, EPS150 White, EPS200, EPS300	EN15804	Verified	2018	[ireland]	ecoinvent	20.3	EN15804:2012+A1:2013, EPD Ireland PCR Part A	Only with EN15804
Electricity, Ireland				Bionova		LCA study for country specific electricity mixes based on IEA, Bionova 2019	EN15804			[ireland]	ecoinvent			
External wood door				One Click LCA	-	Bionova	EN15804	-	2011	[LOCAL]	ecoinvent		-	Biogenic CO2 separated
Glass wool insulation panels, unfaced, generic	25 kg/m3 (1.56 lbs/ft3), (applicable for densities: 0-25 kg/m3 (0-1.56 lbs/ft3)), Lambda=0.031 W/(m.K)			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	25.0	EN15804	-
Gypsum plaster board, regular, generic	6.5-25 mm (0.25-0.98 in), 10.725 kg/m2 (2.20 lbs/ft2) (for 12.5 mm/0.49 in), 858 kg/m3 (53.6 lbs/ft3)			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	858.0280607132333	EN15804	-
OSB panels	600 kg/m3	OSB3 T&G	MEDITE SMARTPLY	EPD Ireland	EPDIE-19-17	EPD SMARTPLY Oriented Strand Boards (OSB)	EN15804	Verified	2019	[ireland]	ecoinvent	600.0	EN15804:2012+A1:2013, EPD Ireland PCR Part A	Only with EN15804
PIR insulation boards, aluminium foil faced	<= 160 mm, L = 0.0215 W/mK, dens. = 32 kg/m3	Various products	Xtratherm	BRE	BREG EN EPD 000226	EPD Xtratherm UK Ltd	EN15804	Verified	2018	[unitedKingdom]	ecoinvent	32.0	EN15804	-
Plaster, finish	app. th.: 2 mm	Skimcoat, Skimcoat Short Set, Carlite, Carlite Ultra	Gyproc	International EPD System	S-P-00584	EPD Gyproc Finish Plaster (Skimcoat, Skimcoat Short Set, Carlite and Carlite Ultra products)	EN15804	Verified	2014	[ireland]	ecoinvent	1315.789	PCR 2012:01 Construction Products and Construction services, ver. 1.2	Only with EN15804
Portland cement, generic	CEM I			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	1600.0	EN15804	-
Precast concrete beams, incl. reinforcement	Dimension: 0.20x0.30 m, Béton/Cement: C25/30 XF1, CEM II/A-S.		SNBPE	INIES	INIES_CPOU20171219_104315, 7675	FDES	EN15804	-	2017	[france]	ecoinvent		EN15804	EN15804
Precast concrete block	700-2100 kg/m3		BPCF	IBU	EPD-BPC-20170092-CCD1-EN	EPD UK Manufactured Precast Concrete Blocks Produced by members of the Concrete Block Association (CBA) a product group of British Precast	EN15804	Verified	2017	[unitedKingdom]	GaBi	1425.0	PCR Pre-cast concrete components, 07/2014	Only with EN15804

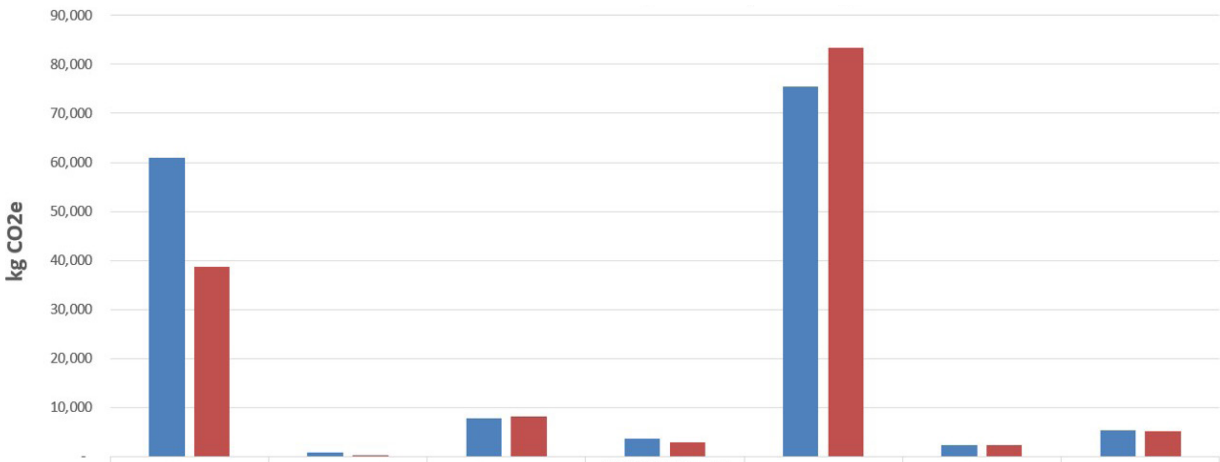
B.2 Timber Frame Construction Sources

Radon and moisture membrane for site construction, PP	1.2 mm		Icopal	EPD Norge	NEPD00208N	Icopal RMA 1200 radonmembran, NEPD 00208N	EN15804	Verified	2013	[norway]	ecoinvent	916.667	NPCR 022 Roof waterproofing	Only with EN15804
Ready-mix concrete, normal-strength, generic	C30/37 (4400/5400 PSI), 30% recycled binders in cement (300 kg/m3 / 18.72 lbs/ft3)			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	2400.0	EN15804	-
Reinforcement steel (rebar), generic	97% recycled content (typical)			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	7850.0	EN15804	-
Render mortar, normal render, high-grade render	1550 kg/m3, EPD coverage: 1300 - 1800 kg/m3		IWM	IBU	EPD-IWM-20130242-IBG1-DE	Oekobau.dat 2017-I, EPD Mineralische Werkmörtel: Putzmörtel-Normalputz/Edelputz Industrieverband WerkMörtel e.V. (IWM)	EN15804	Verified	2014	[germany]	GaBi	1550.0	PCR Mineralische Werkmörtel, 10/2012	Only with EN15804
Roof window (skylight)	978 x 780 mm, 33.1 - 16 - 4 mm, U = 1.3 W/m2K, 40.38 kg/m2, biogenic CO2 not subtracted (for CML)	Fenêtres de type GGU Fenêtres de type GPU	VELUX FRANCE	INIES	INIES_INOU20190313_105541, 10248	FDES	EN15804	Verified	2019	[france]	ecoinvent		EN15804	EN15804
Sand (0...8 mm), loose dry density	1555 kg/m3			One Click LCA	-	LCA inventory for sand quarry operation, Ecoinvent 2016	ISO14040	-	2016	[LOCAL]	ecoinvent	1555.0	-	Only with EN15804
Structural sawn timber, kiln dried, planed or machined	479 kg/m3		Wood for Good	BRE	BREG EN EPD 000124	EPD Kiln dried planed or machined sawn timber	EN15804	Verified	2017	[unitedKingdom]	GaBi	479.0	EN15804	-
Structural steel profiles, generic	90% recycled content (typical), I, H, U, L, and T sections			One Click LCA	-	One Click LCA	EN15804	-	2018	[LOCAL]	ecoinvent	7850.0	EN15804	-
Triple-glazed PVC frame window	size: 1230 x 1480 mm, Uwind = 0.7 W/m2K, Uglass = 0.7 W	PassiV	Munster Joinery	EPD Ireland	EPDIE-18-08	EPD Passiv PVC Triple Glazed Window	EN15804	Verified	2018	[ireland]	ecoinvent		EN15804	-
Waterproof membrane from nonwoven HDPE for roof and wall underlay	195 g/m2	Tyvek® 2524B	DuPont	IBU	EPD-DUP-20150239-IBE1-EN	Oekobau.dat, EPD DuPontTM Tyvek® 2524B DuPont de Nemours (Luxembourg) s.à r.l.	EN15804	Verified	2016	[germany, luxembourg]	GaBi		PCR False ceiling and underlay sheeting, 07/2014	Only with EN15804

Appendix C Results Comparison Graphs (Totals)

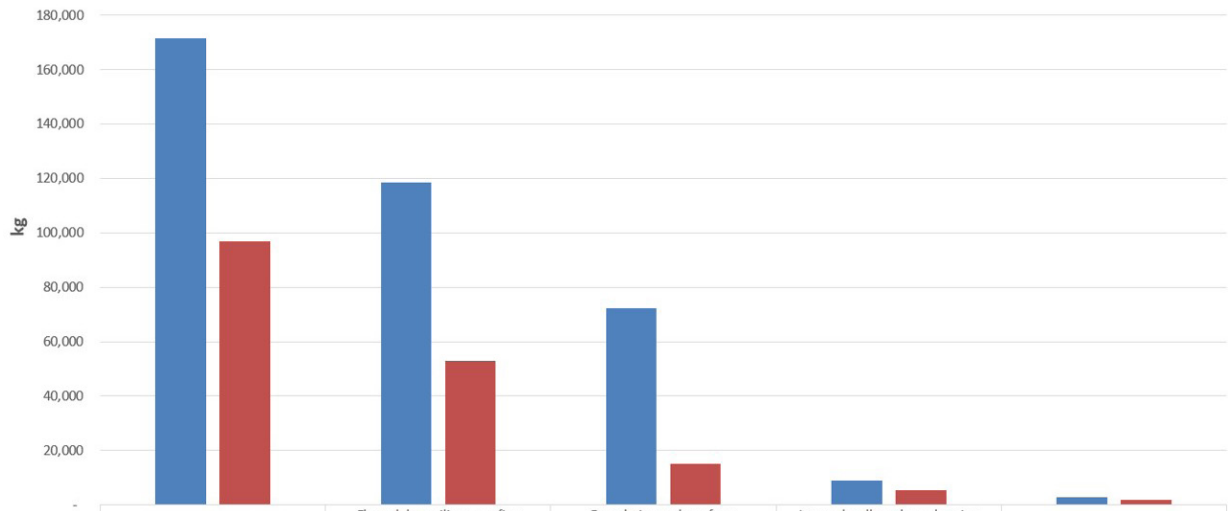
jwpm Jeremy Walsh Project Management

Global Warming - Life-cycle Stages



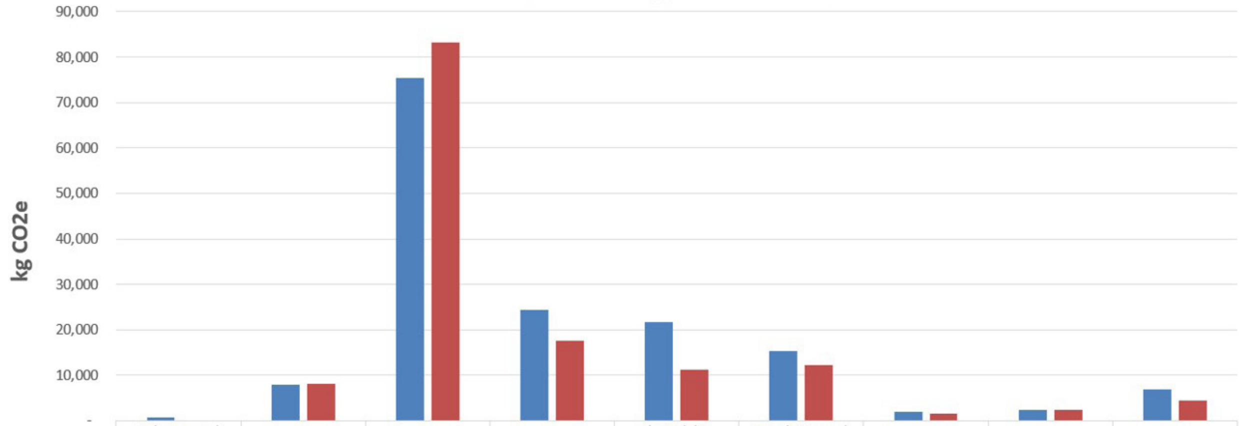
	A1-A3 Materials	A4 Transportation	A5 Construction	B1-B5 Maintenance and replacement	B6 Energy	B7 Water	C1-C4 End of life
Masonry Construction	60,953	852	7,859	3,688	75,498	2,394	5,401
Timber Frame Construction	38,760	362	8,132	2,841	83,312	2,394	5,131

Mass Classifications



	External walls and facade	Floor slabs, ceilings, roofing decks, beams and roof	Foundation, sub-surface, basement and retaining walls	Internal walls and non-bearing structures	Windows and doors
Masonry Construction	171,379	118,442	72,350	8,901	2,698
Timber Frame Construction	96,979	52,980	15,027	5,434	1,876

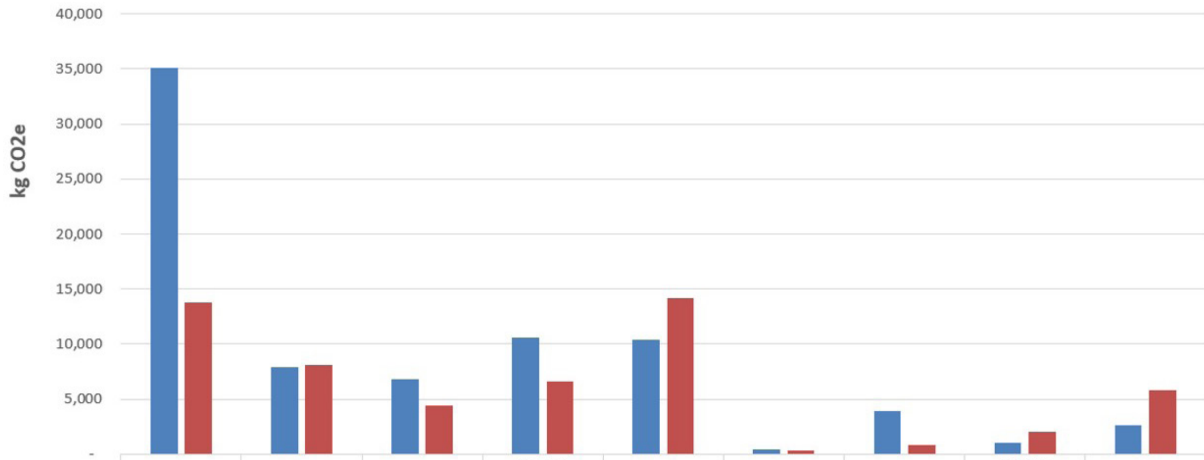
Global Warming - Classifications



	Columns and load-bearing vertical structures	Construction site scenarios	Electricity use	External walls and facade	Floor slabs, ceilings, roofing decks, beams and roof	Foundation, sub-surface, basement and retaining walls	Internal walls and non-bearing structures	Total water consumption	Windows and doors
Masonry Construction	660	7,859	75,498	24,377	21,724	15,308	2,018	2,394	6,807
Timber Frame Construction		8,132	83,312	17,635	11,219	12,203	1,613	2,394	4,424

Masonry Construction Timber Frame Construction

Global Warming - Resource Types



	Concrete	Construction site	Doors & windows	Gypsum, plaster & cement	Insulation	Masses	Metals	Plastics, membranes & roofing	Wood
Masonry Construction	35,123	7,859	6,807	10,615	10,349	453	3,897	1,019	2,631
Timber Frame Construction	13,748	8,132	4,424	6,653	14,145	313	819	2,038	5,768

Masonry Construction Timber Frame Construction

Thank you.

jwpm Jeremy Walsh
Project Management