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The Role of Embodied Carbon Databases in the Accuracy of Life Cycle Assessment (LCA) Calculations for the Embodied Carbon of Buildings

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Abstract: Studies conducted by major national and international scientific bodies have indisputably concluded that the increase in anthropogenic greenhouse gas emissions (GHG) since the mid-20th century has led to irreversible changes in the climate. Data has shown that the contribution of the building sector accounts for 39% of these emissions. Reducing GHG emissions associated with the construction phase of buildings, or embodied carbon (EC), will prevent GHG emissions from entering the atmosphere earlier, reducing the negative impacts. However, to achieve any meaningful reduction, there is a need for consistency and accuracy in the calculations. The accuracy of these calculations is primarily tied to the accuracy of embodied carbon factors (ECF) used in the calculations, values determining the environmental impact of a product or procedure per unit weight. The emissions of any product can be calculated by performing a Life Cycle Assessment (LCA). While the requirements for carrying out an LCA have been standardised in ISO14044, the lack of a definitive national ECF database in the UK means that EC calculations can vary drastically based on the chosen database. An LCA has been carried out on a standard Lidl supermarket design within the A1–A3 boundary. For the calculation, the ECFs were sourced from two different databases, using the GHG conversion factor data published in 2020 by the UK Department of Energy & Climate Change and data published in 2019 by the Inventory of Carbon and Energy (ICE). The latter is currently accepted as the most consistent database for carbon factors in the UK. This study showed that using a more detailed database compared to using a more general database could result in a 35.2% reduction of embodied carbon, while using more detailed data from a single database can reduce it by a further 5.5%. It is necessary to establish the most accurate baseline for embodied carbon so that any carbon reduction attempts can be as effective as possible.

Keywords: embodied carbon; LCA; embodied carbon factor; EC; ECF; BIM

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1. Introduction

The reduction of greenhouse gas (GHG) emissions is a vital task that needs to be taken on a global level to mitigate the negative impacts of climate change. According to a 2019 report from the United Nations Environment Programme (UNEP), the building sector accounts for 39% of the global energy-based GHG emissions, which have increased by 6% in the past decade [1].

The building sector has a high potential for emission reduction [2]. However, the focus on the operational phase in the past [3] has neglected the 6% of all global energy use and the 11% of energy-based GHG emissions that are attributed to the construction industry [1]. The focus on the operational phase has resulted from several factors. The main factor has been the assumption that the operational phase contributes a more significant percentage of a building's lifetime emissions and energy use, up to 90% in a 50-year operational lifespan [4,5]. More recent studies have determined that, given the parameters of a case study, this ratio can expand so that the energy use and subsequent emissions during the operational phase can contribute as low as 32% [6]. This focus on the operational phase has led to the development of various software and methodologies for calculating operational energy use, making the process easier, which, in turn, is another influencing factor. Another result of this focus is a shift in the ratio between the emissions during construction and emissions during the use phase towards the former, causing the construction period emissions to contribute a more significant portion to the lifetime emissions and the consequent negative impact of those emissions. A vital factor to consider is that the operational emissions are produced during a more extended period compared to construction emissions, which are produced during a shorter period and also at the beginning of a building's timeline. Consequently, the GHG emissions will enter the atmosphere earlier, and the negative impacts will be seen across an extended period.

These facts highlight the necessity to focus on the energy used and GHG emissions during the construction period. Regardless of the carbon reduction methodology, the accuracy of the starting carbon amount is vital in determining an accurate and achievable reduction goal. This study has observed how decisions during this step can result in inaccurate data. It has also surmised how inaccuracies in the calculations during this stage can hinder the carbon reduction process.

1.1. Embodied Energy and Embodied Carbon

Embodied energy is all energy used to produce a product, from the extraction of raw material, transport, and the production process. The emissions of a building can be divided into three sections. The first are the emissions produced during the construction up to practical completion. This includes the embodied carbon of the building materials, transport of those materials, and all emissions produced during the on-site construction [7]. The emissions produced on-site include the energy use of construction equipment, temporary on-site structures, material waste, and the emissions associated with on-site waste disposal [8]. Each greenhouse gas is given a global warming potential (GWP), and in order to make a comparison possible, all GHGs emitted are converted to their carbon dioxide equivalent, CO2e. In order to calculate the embodied carbon, all of the energy used during the production process is broken down by energy source and the GHG emissions produced by that type of energy source or fuel [9] which are then converted to the CO2 equivalent. Recurring embodied carbon is all the GHG emissions produced from the refurbishment and repairs to the building's structure [10]. Although these emissions occur further down the building's lifetime, they are still majorly determined by the factors contributing to the initial embodied carbon and need to be included when calculating the embodied carbon of buildings. The scope of the assessments carried out in some studies may or may not include the recurring embodied carbon. The length of the lifespan of buildings directly affects the level of recurring embodied carbon [11]. The second section of a building's emissions are the emissions produced during the use phase of a building. These include the carbon emitted for maintenance, the operational energy and water use, or the operational carbon. The third is all carbon emissions produced during the demolition and disposal of buildings [7]. This study has focused on the first section of the building's emissions or the embodied carbon of the building, not including the recurring embodied carbon.

1.2. Embodied Carbon Calculations

1.2.1. LCA Methodology (A1–A3, A1–A5)

A Life Cycle Assessment (LCA) is a tool that can be used to calculate embodied carbon. An LCA is a process in which the potential environmental impacts for a product throughout its lifecycle is calculated. In 1997, the International Organization for Standards (ISO) published ISO 14,040 to set the standards guideline for performing an LCA, which was later amended in 2006 and 2020 and published in ISO 14,044 [12–14]. A product's lifecycle is typically divided into four main stages: 1—Material manufacturing, 2—Construction, 3—Use and maintenance, and 4—End of life (Figure 1). An LCA could include one or any number of these stages. The process of calculating the embodied carbon of a building can be divided into a cradle-to-gate LCA (A1–A3) and a cradle-to-cradle LCA which covers only one part of the life cycle, e.g., construction process (A4–A5) [15]. The process of performing an LCA is primarily done in four stages. 1. Goal and Scope: Determines which processes of the unit's life cycle will be included in the assessment. 2. Life Cycle Inventory (LCI): Collection of input data needed for the assessment. 3. Life Cycle Impact Assessment (LCIA): Evaluation of the size and significance of the environmental impacts of a product throughout its life cycle. 4. Life Cycle Interpretation: Analysis of the results of the LCI and LCIA within the goal and scope. This analysis can provide recommendations for the reduction of the environmental impact, relative to the goal and scope of the LCA. This stage can also include reviewing, revising, and refining the LCA methodology (Figure 2) [12].

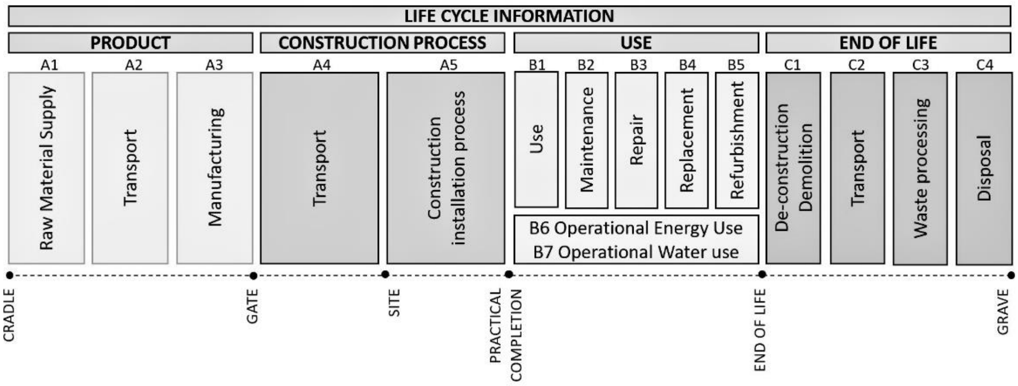


Figure 1. Life cycle stages reproduced from istructe How to calculate embodied carbon [11].

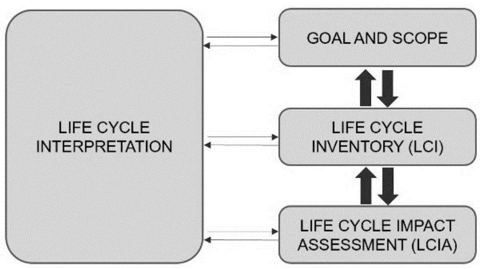


Figure 2. LCA stages reproduced from ISO 14,040 [14].

1.2.2. A1–A3 Calculation

When performing an LCA within the A1–A3 boundary, Equation (1) [8] can be used to calculate the embodied carbon of materials. There are two sets of input data required for this calculation, collected during the LCI stage.

$$\text{Material quantity (Kg)} \times \text{Carbon factor (KgCO2e/Kg)} = \text{Embodied Carbon (KgCO2e)} \quad (1)$$

The material weight can be calculated in one of two ways, dependent on at what stage of the construction the LCA is being performed. If the LCA is being carried out as a case study post-construction, a Process LCA (PLCA) (a process used when the physical flow of all aspects can be identified and traced [16]) approach can be taken to collect all data. If the LCA is performed pre-construction, material weights can be derived from Building Information Modelling (BIM). In the former scenario, the number of unknown elements is significantly reduced, such as material waste. In contrast, in the latter scenario, these elements must be assumed and do not provide adequate guidelines for carbon reduction in industry situations. Most LCAs have been performed as case studies of existing buildings.

While adding valuable information to this area of knowledge, the post hoc nature of these studies does not provide the opportunity for early design intervention [3].

1.2.3. Embodied Carbon Factor (ECF) Databases

The second set of input data required for embodied carbon calculations are carbon factors. Carbon factors provide an estimation of the GWP impact of each product or process. Obtaining correct and accurate values are an essential part of performing an LCA. Carbon factors can be derived from several secondary sources in order to perform an assessment. These will include [17]:

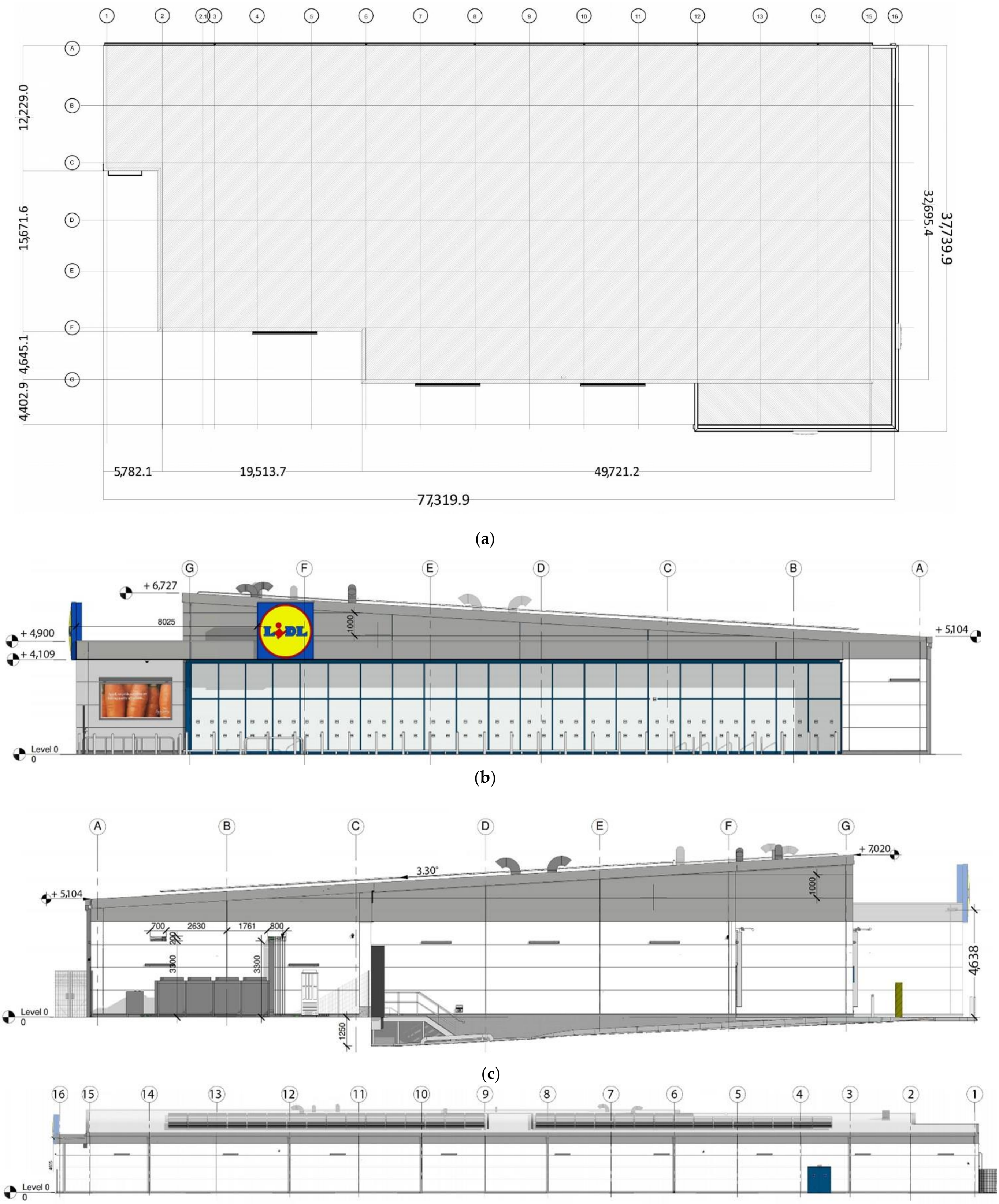
- Environmental Product Declarations (EPD) [11];
- Industry data;
- Government data;
- Factor from commercial LCA database (ICE database);
- PAS 2050 compliant carbon footprint;
- Factor derived/aggregated from literature.

Each data source varies in detail, specificity, and accuracy. The most accurate data can be obtained from EPDs. EPDs are assessments carried out by manufacturers adhering to the requirements of BS EN 15804:2012 and A2:2019. The process in which the EPD is produced must also adhere to the ISO 14,044 standard. Based on EN 15,804 requirements, an EPD is only required to be performed within the A1–A3 boundary, and all other life cycle stages can be performed voluntarily. However, there is no requirement for manufacturers to publish EPDs, even though the number of published EPDs is steadily increasing (3500 globally in 2017 [18]), so the number of available EPDs are limited.

In cases where the other stages are included in the EPD, standard practices of the area or country where the EPD is published must be considered. For instance, a cradle-to-grave EPD published in Germany is more likely to assume energy recovery for the end-of-life procedure of a material. Meanwhile, in the UK, the end-of-life of materials is typically either recycling or landfill disposal [19]. Other sources for carbon data are industry data and national databases. In 1999, later amended in 2009, BRE published the Environmental Profiles Methodology highlighting the embodied carbon of over 200 of the most common building materials using data procured from the UK building industry. One of the most updated and widely used databases in the UK is the Inventory of Carbon and Energy (ICE) databases produced by Hammond and Jones in 2008. This database has been updated regularly, with the most recent update published in 2019 [20]. This database provides the cradle-to-gate carbon factor of over 500 of the most common building materials. This study investigates how the choice of ECF database and the approach taken for assigning an ECF to materials during an LCA can affect the outcome.

2. Methodology

For the purposes of this study, an A1–A3 LCA was carried out for a standard Lidl supermarket. The standard design for these supermarkets is a 2500 m^2 single-story layout (Figure 3a–e). The structure of Lidl supermarkets in the UK is composed of a steel frame and composite external walls. The standard design for Lidl supermarket buildings was simulated using the BIM software Autodesk® Revit® (Figure 4a,b) based on the design plans and data provided by Lidl GB Ltd. to calculate the weight for each of these materials and their composing components. To perform an A1–A3 LCA, the minimum elements that would need to be included are the substructure and the superstructure. The substructure consists of the foundation and the ground-bearing slabs of the building. The superstructure consists of the structural frame, upper floors, roof, stairs and ramps, and external and internal walls and partitions [8]. The details included in the BIM model were floors, structural foundation, roofs, structural columns and framing, walls, windows, and the mechanical duct system. The AHU (air handling units), electrical and plumbing systems were excluded from the model and calculations. The carbon contribution of these building components is not contained within the A1–A3 boundary as the calculation for these components must also include the recurring embodied carbon [11]. All materials used in the Lidl standard design in the UK are presented in Table 1 according to Lidl designs.



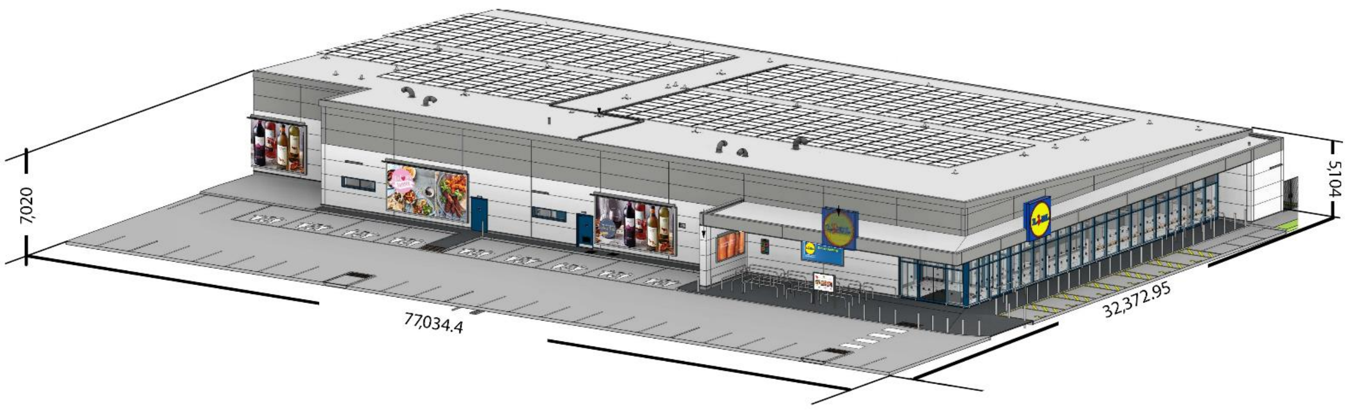
(**a**)

(**b**)

(**c**)

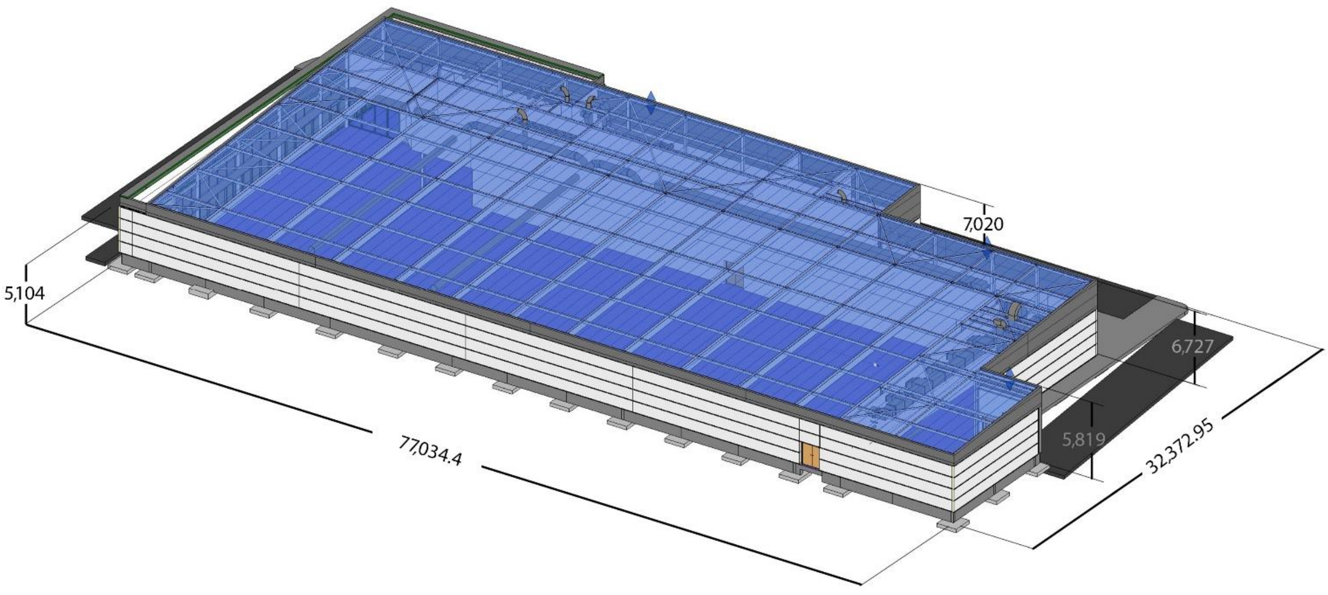
(**d**)

Figure 3. *Cont.*

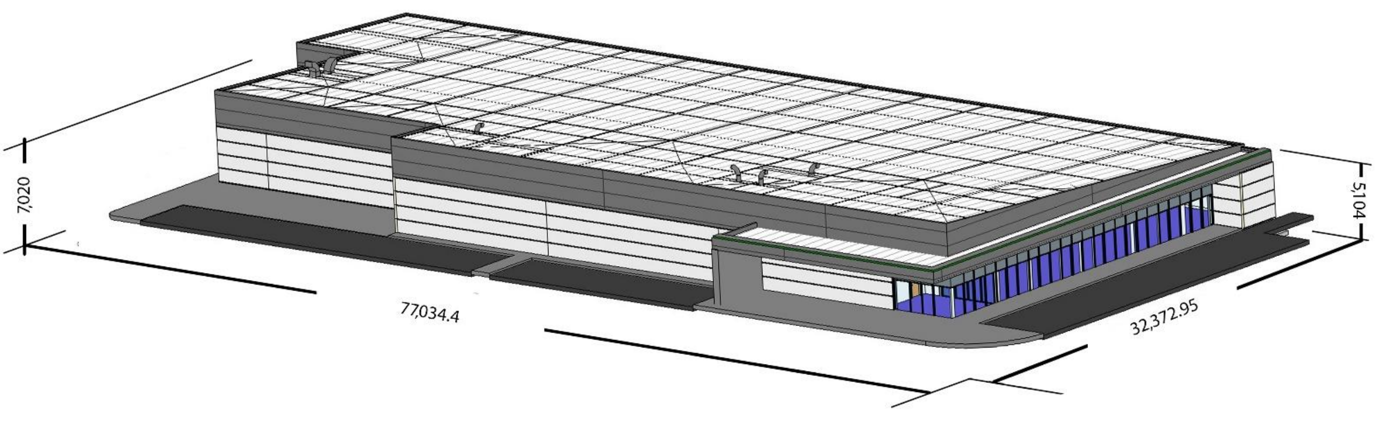


(**e**)

Figure 3. A 3D model and plans of Lidl standard design: (**a**) Building footprint; (**b–d**) Façades; (**e**) 3D model of Lidl standard supermarket design.



(**a**)



(**b**)

Figure 4. Simulated standard design model for Lidl supermarket buildings using Autodesk® Revit® BIM software: (**a**,**b**) Isometric view of the model.

Table 1. Material list of structural material used in Lidl standard design supermarkets in the UK.

Building Element	Structural Element	Component	Component Details
Substructure	Floors	Floor	Floor: Floor-Upper 160 mm Concrete
	Structural Foundations	Foundation Slab	Foundation Slab: Standard with tiles
	Structural Foundations	Pile Cap	Pile Cap: 1500 × 1500 × 500
	Structural Foundations	Wall Foundation	Wall Foundation: Standard
Envelope	Roofs	Basic Roof	Metal roof panels, flat soffit-NBS 20–50–55/150
	Roofs	Basic Roof	Metal single skin, 125 mm insulation
Framing	Structural Columns	Square Hollow Sections-Column	RHS200 × 100 × 6.3 SHS80 × 80 × 8 SHS150 × 150 × 5 SHS200 × 200 × 6.3 SHS250 × 250 × 6.3
	Structural Columns	UC-Universal Columns-Column	UC152 × 152 × 23 UC152 × 152 × 30 UC203 × 203 × 46
	Structural Framing	Circular Hollow Sections	CHS114.3 × 5
	Structural Framing	Light Gauge-Kingspan Multibeam Purlins	M205065180
	Structural Framing	Light Gauge-Kingspan Multibeam Rails	M205065180
	Structural Framing	PFC-Parallel Flange Channels	PFC150 × 75 × 18 PFC200 × 75 × 23
	Structural Framing	Plate	Plate: 10 × 100 PLT
	Structural Framing	Rectangular Hollow Sections	RHS140 × 80 × 6.3 RHS200 × 100 × 6.3
	Structural Framing	Square Hollow Sections	SHS150 × 150 × 5 SHS180 × 180 × 6.3
	Structural Framing	UB-Universal Beams	UB203 × 133 × 25 UB203 × 133 × 25 UB254 × 146 × 31 UB305 × 165 × 54 UB406 × 140 × 39 UB533 × 210 × 122 UB610 × 229 × 101 UB686 × 254 × 125
Envelope	Walls	External wall type 1	Longspan insulated cladding panels (1000 mm) fixed to primary steel columns
	Walls	External wall type 2	365 mm concrete wall (80 mm insulation) faced with 20 mm render to external side, painted white concrete face internally (grey plinth at ground level externally)
	Walls	External wall type 3	Canopy end wall −2 × 60 mm Cladding panels fixed back to Secondary steelwork via top hats. Grey rendered plinth externally at ground level
	Walls	Internal wall type 1A (300mm) Internal wall type 1B (399 mm) Internal wall type 1C (428 mm)	Metal stud twin frame + 15 mm Duraline on each side

Table 1. *Cont.*

Building Element	Structural Element	Component	Component Details
	Walls	Internal wall type 2	146 mm metal stud + 15 mm Duraline on each side
	Walls	Internal wall type 3	70 mm metal stud + 15 mm Duraline on each side
	Walls	Internal wall type 4	70 mm metal stud + 15 mm Duraline on one side
	Walls	Internal wall type 5	92 mm metal stud + 15 mm Duraline on one side
	Walls	Internal wall type 6	140 mm blockwork + 15 mm Plaster on each side
	Walls	Internal wall type 7	140 mm concrete + 15 mm Plaster on each side
Curtain wall	Windows	Curtain wall opening	2100 mm × 4000 mm clear opening
	Windows	Curtain wall type 1	1430 mm × 4000 mm curtain wall
	Windows	Curtain wall type 2	1050 mm–2050 mm × 4000 mm curtain wall

2.1. Revit® Building Information Modelling (BIM)

The modelling of the building was initially carried out without assigning specific materials and using Revit® default materials for each building element. Each building element was then assigned the corresponding material according to Lidl plan specifications. The material assigned for each building element was selected based on the following order of preference:

- Manufacturer-provided BIM building material;
- Manual recreation of BIM building material according to manufacturer details;
- Manual recreation of BIM building material according to plan specifications;
- Generic/Default materials.

According to plan specifications, the material for the model's roof is a metal insulated sandwich panel roofing system. The BIM material published by Kingspan, hosted in the National BIM library, "Kingspan Insulated Panels-Metal Insulating Sandwich Panel Roofing System-Quad Core Trapezoidal Roof Panel-KS1000RW 120 mm", was assigned to the main roof component. For the external wall type 1, a BIM material published by Arcelor Mittal, "Flamstyl S ArcelorMittal-1000 mm Horizontal: 180 mm", was assigned. For the material of the curtain walls, BIM components published by Schueco, hosted in the BIM object library, "Façade UCC 65 SG" for the walls and "Sliding System ASS 77 PD" for the opening were edited to fit plan specifications and assigned. External wall types 2, 3, and the internal walls were recreated in the BIM model according to the plan specifications. This building is designed with a steel framing structure; therefore, a steel material was assigned to each framing component in the BIM model. The square hollow section and universal columns in the model were assigned the "Metal-Steel 50–355" from the Revit material library. The circular hollow sections, multibeam purlins and rails, parallel flange channels (PFC) plan, rectangular and square hollow sections and universal beams were assigned the "Metal-Steel-S275" material. The "Cast-in-Place Concrete" material was assigned to the floor, foundation slab, wall foundation and pile cap components. All of these materials are depicted in Table 2.

Table 2. Material list of structural material used in Lidl standard design supermarkets in the UK with the added material in Revit®.

Component	Assigned Component	Assigned Material in BIM Model	Material Layer Details
Floor	Floor: Floor-Upper 160 mmConc-CorusComFlor51	Concrete 15 MPa	
Foundation Slab	Foundation Slab: Standard with tiles	Cast-in-Place Concrete	
Pile Cap	Pile Cap: 1500 × 1500 × 500	Cast-in-Place Concrete	
Wall Foundation	Wall Foundation: Standard	Cast-in-Place Concrete	
Basic Roof	Kingspan Insulated Panels-Metal Insulating Sandwich Panel Roofing System-Quad Core Trapezoidal Roof Panel-KS1000RW 120 mm	NBS Kingspan Insulated Panels PIR Foam Board PIR Insulation	
		NBS Kingspan Insulated Panels Steel Profiled Sheet Quad-Core Trapezoidal Roof Panel KS1000RW External Weather Sheet	
		NBS Kingspan Insulated Panels Steel Profiled Sheet Quad-Core Trapezoidal Roof Panel KS1000RW Internal Liner Sheet	
Basic Roof	Metal single skin, 125 mm insulation	Default Roof–metal single skin	
		Default Roof–Generic insulation 125 mm	
Square Hollow Sections-Column	RHS200 × 100 × 6.3 SHS80 × 80 × 8 SHS150 × 150 × 5 SHS200 × 200 × 6.3 SHS250 × 250 × 6.3	Metal-Steel 50–355	
UC-Universal Columns-Column	UC152 × 152 × 23 UC152 × 152 × 30 UC203 × 203 × 46	Metal-Steel 50–355	
Circular Hollow Sections	CHS114.3 × 5	Metal-Steel-S275	
Light Gauge-Kingspan Multibeam Purlins	M205065180	Metal-Steel-S275	
Light Gauge-Kingspan Multibeam Rails	M205065180	Metal-Steel-S275	
PFC-Parallel Flange Channels	PFC150 × 75 × 18 PFC200 × 75 × 23	Metal-Steel-S275	
Plate	Plate: 10 × 100 PLT	Metal-Steel-S275	
Rectangular Hollow Sections	RHS140 × 80 × 6.3 RHS200 × 100 × 6.3	Metal-Steel-S275	
Square Hollow Sections	SHS150 × 150 × 5 SHS180 × 180 × 6.3	Metal-Steel-S275	
UB-Universal Beams	UB203 × 133 × 25 UB203 × 133 × 25 UB254 × 146 × 31 UB305 × 165 × 54 UB406 × 140 × 39 UB533 × 210 × 122 UB610 × 229 × 101 UB686 × 254 × 125	Metal-Steel-S275	

Table 2. *Cont.*

Component	Assigned Component	Assigned Material in BIM Model	Material Layer Details
External wall type 1	Flamstyl S ArcelorMittal-1000 mm Horizontal: 180 mm	ArcelorMittal-Mineral Wool	Thermoplastic Resin
		Pre-painted Steel ArcelorMittal Construction HAIRULTRA	Steel, paint finish, ivory, glossy
		Pre-painted Steel ArcelorMittal Construction INTÉRIEUR	Polymethyl Methacrylate
External wall type 2	External wall type 2	Portland Cement Concrete	Concrete
		Insulation/Support Frame	
		Paint-White Lining	
External wall type 3	External wall type 3	Cladding, Vertical Ribbed	
		Insulation/Support Frame	
Internal wall type 1	Internal wall type 1A (300 mm) Internal wall type 1B (399 mm) Internal wall type 1C (428 mm)	Gypsum Wall Board	
		Light gauge steel framing, thermal air layer	Metal Stud Layer
		Rock Wool	
Internal wall type 2	Internal wall type 2	Gypsum Wall Board	
		Light gauge steel framing, thermal air layer	Metal Stud Layer
		Rock Wool	
Internal wall type 3	Internal wall type 3	Gypsum Wall Board	
		Light gauge steel framing, thermal air layer	Metal Stud Layer
		Rock Wool	
Internal wall type 4	Internal wall type 4	Gypsum Wall Board	
		Light gauge steel framing, thermal air layer	Metal Stud Layer
		Rock Wool	
Internal wall type 5	Internal wall type 5	Gypsum Wall Board	
		Light gauge steel framing, thermal air layer	Metal Stud Layer
		Rock Wool	
Internal wall type 6	Internal wall type 6	Common brick	
		Plaster	
Internal wall type 7	Internal wall type 7	Concrete-Precast Concrete-35 MPa	
		Plaster	
Curtain wall opening	Schueco ASS 77 PD-HI Family-2D-1 OF-150 mm: Type 2D	Soda Lime Glass	
		Aluminium	
Curtain wall type 1	Schueco Façade UCC 65 SG Family-03: Type 1	Soda Lime Glass	
		Aluminium	
Curtain wall type 2	Schueco Façade UCC 65 SG Family-13: Type 1	Soda Lime Glass	
		Aluminium	

BIM Delimitations

Based on the plan specifications, 91% of the internal walls in the model were assigned stud wall layers of various thicknesses. The material was initially designed using the internal Revit material "Metal Stud Layer: Light gauge steel framing, thermal air layer". However, this Revit material does not account for the gaps between each individual steel frame. The material and subsequent unit weight attributed to this layer is steel leading to a discrepancy in the material weight for these walls. The internal walls were modelled individually, as depicted in Table 3, in the software to mitigate this discrepancy and take-off the correct material weight (Figure 5). When taking this approach, the total weight of the stud layer was reduced from 1,466,265.9 kg to 169,630.2 kg, signifying an 88.4% reduction. Had the LCA been carried out using the former values, an additional 1,296,635.60 kg of steel would be calculated (Table 4), thus, demonstrating the necessity of this step to ensure an accurate result.

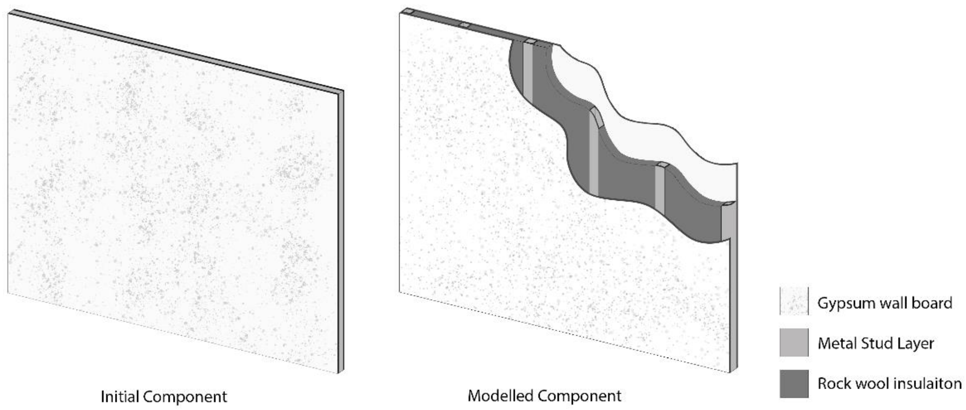


Figure 5. Schematic image of internal wall with internal stud layer modelled in Revit®.

Table 3. Internal wall, layer details in Revit® BIM software.

Wall Type		Layer Details of Modelled Material in Revit®			
		Function	Material	Thickness	Wraps
(A) Internal wall type 1A, layer details in Revit® BIM software	1	Finish 2 [5]	Gypsum Wall	0.0150	☑
	2	**Core Boundar**	**Layers Above**	**0.0000**	
	3	Structure [1]	Rock Wool	0.0818	☐
	4	Structure [1]	Metal Stud La	0.0102	☐
	5	Thermal/Air Lay	<By Category	0.0860	☐
	6	Structure [1]	Metal Stud La	0.0102	☐
	7	Structure [1]	Rock Wool	0.0818	☐
	8	**Core Boundar**	**Layers Below**	**0.0000**	
	9	Finish 2 [5]	Gypsum Wall	0.0150	☑
		Function	Material	Thickness	Wraps
(B) Internal wall type 1B, layer details in Revit® BIM software	1	Finish 2 [5]	Gypsum Wall	0.0150	☑
	2	**Core Boundar**	**Layers Above**	**0.0000**	
	3	Structure [1]	Rock Wool	0.0818	☐
	4	Structure [1]	Metal Stud La	0.0102	☐
	5	Thermal/Air Lay	<By Category	0.1850	☐
	6	Structure [1]	Metal Stud La	0.0102	☐
	7	Structure [1]	Rock Wool	0.0818	☐
	8	**Core Boundar**	**Layers Below**	**0.0000**	
	9	Finish 2 [5]	Gypsum Wall	0.0150	☑

Table 3. *Cont.*

Wall Type	Layer Details of Modelled Material in Revit®

(C) Internal wall type 1C, layer details in Revit® BIM software

	Function	Material	Thickness	Wraps
1	Finish 2 [5]	Gypsum Wall	0.0150	☑
2	**Core Boundar**	**Layers Above**	**0.0000**	
3	Structure [1]	Rock Wool	0.0818	☐
4	Structure [1]	Metal Stud La	0.0102	☐
5	Thermal/Air Lay	<By Category	0.2140	☐
6	Structure [1]	Metal Stud La	0.0102	☐
7	Structure [1]	Rock Wool	0.0818	☐
8	**Core Boundar**	**Layers Below**	**0.0000**	
9	Finish 2 [5]	Gypsum Wall	0.0150	☑

(D) Internal wall type 2, layer details in Revit® BIM software

	Function	Material	Thickness	Wraps
1	Finish 1 [4]	Gypsum Wall	0.0150	☑
2	**Core Boundar**	**Layers Above**	**0.0000**	
3	Structure [1]	Rock Wool	0.1200	☐
4	Structure [1]	Metal Stud La	0.0260	☐
5	**Core Boundar**	**Layers Below**	**0.0000**	
6	Finish 1 [4]	Gypsum Wall	0.0150	☑

(E) Internal wall type 3, layer details in Revit® BIM software

	Function	Material	Thickness	Wraps
1	Finish 1 [4]	Gypsum Wall B	0.0150	☑
2	**Core Boundary**	**Layers Above W**	**0.0000**	
3	Structure [1]	Rock Wool	0.0641	☐
4	Structure [1]	Metal Stud Lay	0.0059	☐
5	**Core Boundary**	**Layers Below W**	**0.0000**	
6	Finish 1 [4]	Gypsum Wall B	0.0150	☑

(F) Internal wall type 4, layer details in Revit® BIM software

	Function	Material	Thickness	Wraps
1	Finish 1 [4]	Gypsum Wall	0.0150	☑
2	**Core Boundar**	**Layers Above**	**0.0000**	
3	Structure [1]	Rock Wool	0.0641	☐
4	Structure [1]	Metal Stud La	0.0059	☐
5	**Core Boundar**	**Layers Below**	**0.0000**	

(G) Internal wall type 5, layer details in Revit® BIM software

	Function	Material	Thickness	Wraps
1	Finish 1 [4]	Gypsum Wall	0.0150	☑
2	**Core Boundar**	**Layers Above**	**0.0000**	
3	Structure [1]	Metal Stud La	0.0102	☐
4	Structure [1]	Rock Wool	0.0818	☐
5	**Core Boundar**	**Layers Below**	**0.0000**	

Table 4. Comparison of stud wall weight when using Revit® material vs. modelled component.

Wall Type	Assigned Material in BIM Model	Unit Weight kg/m^3	Initial Component Weight (kg)	Modelled Component Weight (kg)
Internal wall type 1A	Light gauge steel framing, thermal air layer	7850.0 kg/m^3	583,049.2 kg	64,644.6 kg
Internal wall type 1B	Light gauge steel framing, thermal air layer	7850.0 kg/m^3	6758.8 kg	753.6 kg
Internal wall type 1C	Light gauge steel framing, thermal air layer	7850.0 kg/m^3	420,240.7 kg	46,589.6 kg
Internal wall type 2	Light gauge steel framing, thermal air layer	7850.0 kg/m^3	141,260.3 kg	25,143.5 kg
Internal wall type 3	Light gauge steel framing, thermal air layer	7850.0 kg/m^3	38,849.5 kg	3289.1 kg
Internal wall type 4	Light gauge steel framing, thermal air layer	7850.0 kg/m^3	52,948.1 kg	4458.8 kg
Internal wall type 5	Light gauge steel framing, thermal air layer	7850.0 kg/m^3	223,159.2 kg	24,751.0 kg

2.2. Material Weight

The material weight for each building element was derived from a quantity take-off (QTO) of the BIM model. The categories included in this take-off were Floors, Curtain panels, Roofs, Structural Columns, Structural Foundation, Structural Framing, Walls, and Windows. A material take-off process provides a complete and accurate weight for each composing materials for the elements within these categories (Table 5). The weight for the mechanical ducts cannot be derived by this method. However, the total size of the mechanical elements can be obtained from a mechanical schedule take-off in Revit®. The weight for each component can then be calculated using Equations (2) and (3).

$$\text{Rectangular duct mass} = 2 \times (\text{Height} + \text{Width}) \times \text{length} \times \text{thickness} \times \text{materials density} \quad (2)$$

$$\text{Round duct mass} = \text{length} \times \pi \times \text{diameter} \times \text{thickness} \times \text{material density} \quad (3)$$

In these formulas, the density of the materials is 7800 kg/m^3. Additionally, the minimum thickness is assigned to the ducts. The minimum thickness for each component is determined by size according to DW/144 specifications [21]. This process is repeated for the mechanical duct fittings using the values obtained from a duct fitting schedule take-off in Revit®.

Table 5. Material weight of building components in Lidl supermarket standard design.

Category	Family and Type	Material: Name	Material: Weight (kg)
Floors	Floor: Floor-Upper_160 mmConc-CorusComFlor51	Concrete, Cast-in-Place-C15	14,674.397 kg
Structural Foundations	Foundation Slab: Standard with tiles	Default Mass Floor	1190.908 kg
	Pile Cap: 1500 × 1500 × 500	Concrete-Cast-in-Place Concrete	97,024.061 kg
	Wall Foundation: Standard	Concrete, Cast In Situ	4.813 kg
Mechanical	Rectangular Duct: Standard, Fitting Round Duct: Standard, Fitting	Steel	4528.741 kg

Table 5. *Cont.*

Category	Family and Type		Material: Name	Material: Weight (kg)
Roofs	Kingspan Insulated Panels-Metal Insulating Sandwich Panel Roofing System-Quad Core Trapezoidal Roof Panel-KS1000RW 120 mm		NBS_KingspanInsulatedPanels_ PIRFoamBoard_PIRInsulation	12,965.762 kg
			NBS_KingspanInsulatedPanels_ SteelProfiledSheet_QuadCore TrapezoidalRoofPanel_KS1000RW_ ExternalWeatherSheet	19,720.414 kg
			NBS_KingspanInsulatedPanels_ SteelProfiledSheet_QuadCore TrapezoidalRoofPanel_KS1000RW_ InternalLinerSheet	29,468.400 kg
	Metal single skin, 125 mm insulation		Default Roof–metal single skin	43.790 kg
			Default Roof–Generic insulation 125 mm	178.040 kg
Structural Columns	RHS200 × 100 × 6.3 SHS80 × 80 × 8 SHS150 × 150 × 5 SHS200 × 200 × 6.3 SHS250 × 250 × 6.3	UB203 × 133 × 25 UC152 × 152 × 23 UC152 × 152 × 30 UC203 × 203 × 46	Metal-Steel 50–355	20,982.768 kg
Structural Framing	CHS114.3 × 5 M205065180 M205065180 PFC150 × 75 × 18 PFC200 × 75 × 23 10 × 100 PLT RHS140 × 80 × 6.3 RHS200 × 100 × 6.3 SHS150 × 150 × 5 SHS180 × 180 × 6.3	UB203 × 133 × 25 UB203 × 133 × 25 UB254 × 146 × 31 UB305 × 165 × 54 UB406 × 140 × 39 UB533 × 210 × 122 UB610 × 229 × 101 UB686 × 254 × 125 UC152 × 152 × 23	Metal-Steel-S275	64,730.549 kg
Walls	External wall type 1		ArcelorMittal–Mineral Wool	244,027.357 kg
			Prepainted_Steel- ArcelorMittal_Construction_ HAIRULTRA-35	27,644.390 kg
			Prepainted_Steel- ArcelorMittal_Construction_ INTÉRIEUR	3213.457 kg
			Cladding, Vertical Ribbed	11,376.568 kg
	External wall type 2		Concrete	9764.194 kg
			Insulation/Support Frame	8.912 kg
			Paint-White Lining	0.557 kg
	External wall type 3		Cladding, Vertical Ribbed	6747.893 kg
			Insulation/Support Frame	19.551 kg
	Internal wall type 1A (300 mm) Internal wall type 1B (399 mm) Internal wall type 1C (428 mm)		Default Wall	768.253 kg

Table 5. *Cont.*

Category	Family and Type		Material: Name	Material: Weight (kg)
	Internal wall type 1A (300 mm) Internal wall type 1B (399 mm) Internal wall type 1C (428 mm) Internal wall type 2	Internal wall type 3 Internal wall type 4 Internal wall type 5	Gypsum Wall Board	36,163.635 kg
	Internal wall type 1A (300 mm) Internal wall type 1B (399 mm) Internal wall type 1C (428 mm) Internal wall type 2	Internal wall type 3 Internal wall type 4 Internal wall type 5	Metal Stud Layer	169,630.170 kg
	Internal wall type 1A (300 mm) Internal wall type 1B (399 mm) Internal wall type 1C (428 mm) Internal wall type 2	Internal wall type 3 Internal wall type 4 Internal wall type 5	Rock Wool	33,027.235 kg
	Internal wall type 6		Brick, Common	25,933.089 kg
	Internal wall type 6 Internal wall type 7		Plaster	4467.497 kg
	Internal wall type 7		Concrete-Precast Concrete-35 MPa	12,790.706 kg
Curtain wall	Schueco ASS 77 PD-HI Family-2D-1 OF-150 mm: Type 2D Schueco Façade UCC 65 SG Family-03: Type 1 Schueco Façade UCC 65 SG Family-13: Type 1		Alu	2678.138 kg
	Schueco ASS 77 PD-HI Family-2D-1 OF-150 mm: Type 2D Schueco Façade UCC 65 SG Family-03: Type 1 Schueco Façade UCC 65 SG Family-13: Type 1		Glass	8094.866 kg
Windows	AWS60BD 2 Vents: AWS60BD 2 Vents		Glass	191.179 kg
	Total			862,078.845 kg

2.3. Embodied Carbon Calculations

In this study, the method of assigning embodied carbon factors was defined by choice of ECF database or source and the choice of appropriate data within those databases or sources.

The carbon factors in this study were derived from two primary databases. The first database used was the GHG conversion factors dataset published by the UK Department of Energy & Climate Change [9]. In this dataset, the ECFs are broken down into 40 different categories, with construction materials broken down into the following fourteen categories: Aggregates, Average construction, Asbestos, Asphalt, Bricks, Concrete, Insulation, Metals, Soils, Mineral oil, Plasterboard, Tyres, and Wood. The second database used was the Embodied Carbon–ICE Database published by the Institute of Civil Engineering [19]. Furthermore, ECFs were also sourced from published data and data derived from literature.

In this effect, two approaches were taken in the assignment of appropriate embodied carbon factors. The first approach was to assign ECFs to materials based on the general category of the material. The second approach was to assign ECFs to each material to be the closest to materials details.

The first set of calculations were carried out using the UK Department of Energy & Climate Change database. Given the limited nature of this database, the first approach in assigning ECFs was taken. The second set of calculations also used the first approach of ECF assignment using the ICE database, which provides more vast data. The detailed or second approach was taken for the third set of calculations. In this approach, the ECF assigned to each material was chosen to be the closest to materials details. In this approach, the majority of the ECFs were taken from the ICE database. However, for some materials, published data and data derived from literature was used for a more accurate ECF value (Figure 6).

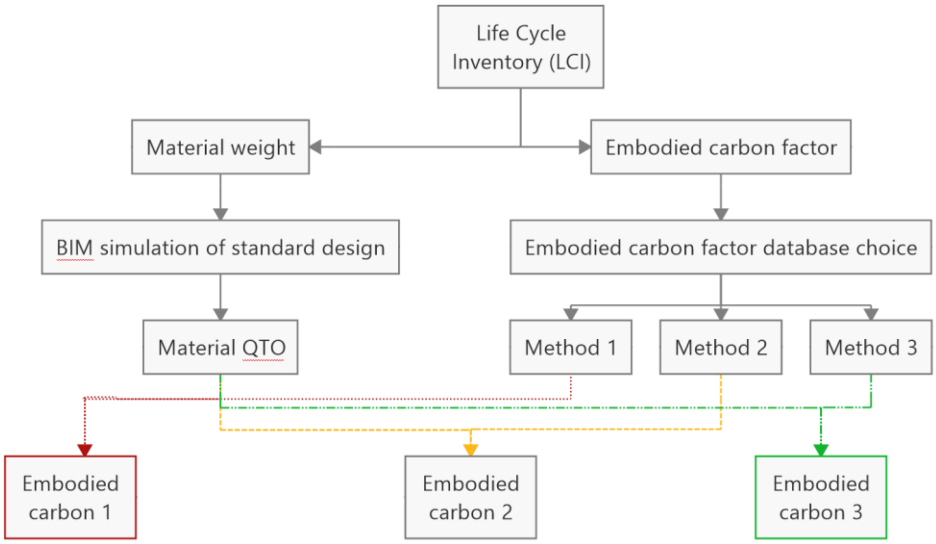


Figure 6. Flowchart depicting the methodology.

In method one, the fourteen ECF values in the construction category of the database were assigned. The "Concrete" ECF was assigned to all concrete materials of the building components, including materials in the floor, structural foundation, and internal wall elements. The ECF value attributed to concrete in this database is 0.135 kgCO2e/kg. In methods 2 and 3, "ICE-Concrete, General" was assigned to the materials in the structural foundation and floor elements. In this database the ECF value for this material is 0.103 kgCO2e/kg, while ECF assigned to the concrete material for internal wall element in method two was "ICE-precast ACC block" and in method three "ICE-Concrete 35/45", their values respectively 0.28 kgCO2e/kg and 0.1609 kgCO2e/kg.

The "Metals" ECF was assigned to all metal materials assigned to the building components, including steel, aluminium, cladding, and sheet metals in the roof, walls, curtain wall, windows, mechanical ducts, and structural framing elements. The carbon factor for all metals in this database is 4.769 kgCO2e/kg. In methods two and three, "ICE-Steel", with a value of 2.970 kgCO2e/kg, was assigned to the internal wall metal materials. This value was also assigned to the roof and external wall metal materials in method two. While "ICE-Steel, organic coated sheet" with a value of 3.060 kgCO2e/kg was assigned to these elements in method three. "ICE-Steel pipe" with a value of 3.02 CO2e/kg was assigned to the mechanical duct material. "ICE-aluminium sheet general EU including imports" with a value of 3.291 kgCO2e/kg were assigned to the external wall and roof metal materials in methods two and three. "ICE-Steel section" with a value of 1.55kgCO2e/kg was assigned to the structural framing material in method two, and "ICE-steel section UK open section" ECF with a value of 2.45 kgCO2e/kg was assigned in method three. For aluminium framing of the curtain walls and windows, "ICE-aluminium general EU including transport" was assigned in method two with "ICE-aluminium extruded profile EU including transport" assigned in method three, with their values respectively being 6.669 kgCO2e/kg and 1.706 kgCO2e/kg. The "Insulation" ECF with a value of 1.865 kgCO2e/kg was assigned to all insulation layers of materials, including the internal layers of the roof and wall elements in method one. In methods two and three, "ICE-insulation" ECF with a value of 1.44 kgCO2e/kg was assigned to the insulation's layers in the roof and internal walls. This ECF is also assigned to the insulation materials for the external walls in method two. While in method three, the ECF value for "Glass wool" derived from a publication by EU UTS in 2012 [22] equal to 0.74 kgCO2e/kg was assigned. For the Polymethyl Methacrylate (PMMA) material layer in the external walls, "Plastics: average plastics" ECF was assigned in method one, and in method two, "ICE-Rubber" was assigned. In method three, the ECF for PMMA was derived from a dataset published by the University of Melbourne in 2019 [23] equal to 15.4 kgCO2e/kg. For plasterboard elements, the ECF for "Plasterboard" was assigned in method one, and "ICE-plasterboard" was assigned in methods two and three, with their values respectively being 0.12 kgCO2e/kg and 0.39 kgCO2e/kg. For brick wall elements, the ECF for "Brick" was assigned in method one and "ICE-generic brick" was assigned in methods two and three. With their values respectively being 0.245 kgCO2e/kg and 0.213 kgCO2e/kg. For glass elements, the ECF for "Glass" was assigned in method one, "ICE-glass general" was assigned in method two, and "ICE-glass toughened 3mm" was assigned in method three, with their values respectively being 0.895 kgCO2e/kg, 1.437 kgCO2e/kg, and 1.667 kgCO2e/kg (Table 6).

Table 6. Assigned embodied carbon factor for each material of the standard supermarket design.

Material Name	Method One ECF Source	Method Two ECF Source	Method Three ECF Source
Concrete, Cast-in-Place-C15 Default Mass Floor Concrete-Cast-in-Place Concrete Concrete, Cast In Situ Concrete	Concrete	ICE-Concrete, General	ICE-Concrete, General
Concrete-Precast Concrete-35 MPa	Concrete	ICE-precast AAC block	ICE-Concrete 35/45
Steel	Metals	ICE-steel pipe	ICE-steel pipe
QuadCoreTrapezoidalRoofPanel_KS1000RW_ExternalWeatherSheet	Metals	ICE-Aluminium sheet EU	ICE-Aluminium sheet EU inc transport
QuadCoreTrapezoidalRoofPanel_KS1000RW_Internal Liner Sheet	Metals	ICE-Steel	ICE-Steel, organic coated sheet
Default Roof–metal single skin	Metals	ICE-Steel	ICE-Steel, organic coated sheet
Metal-Steel 50-355	Metals	ICE-Steel section	ICE-steel section UK open sections
Metal-Steel-S275	Metals	ICE-Steel section	ICE-steel section UK open sections
Prepainted_Steel-ArcelorMittal_Construction_HAIRULTRA-35-CORAL-4309-[RAL_3000]	Metals	ICE-Steel	ICE-Steel, organic coated sheet
Cladding, Vertical Ribbed	Metals	ICE-aluminium sheet general EU including imports	ICE-aluminium sheet general EU including imports
Metal Stud Layer	Metals	ICE-Steel	ICE-Steel
Aluminium	Metals	ICE-aluminium general EU including transport	ICE-aluminium extruded profile EU including transport
PIRFoamBoard_PIRInsulation	Insulation	ICE-Insulation	ICE-Insulation
Default Roof–Generic insulation 125 mm	Insulation	ICE-Insulation	ICE-Insulation
ArcelorMittal–Mineral Wool	Insulation	ICE-Insulation	ec.europa.eu-glass wool
Insulation/Support Frame	Insulation	ICE-Insulation	ec.europa.eu-glass wool
Rock Wool	Insulation	ICE-Insulation	ICE-Insulation
Default Wall	Plasterboard	ICE-plasterboard	ICE-plasterboard
Gypsum Wall Board	Plasterboard	ICE-plasterboard	ICE-plasterboard

Table 6. *Cont.*

Material Name	Method One ECF Source	Method Two ECF Source	Method Three ECF Source
Plaster	Plasterboard	ICE-plasterboard	ICE-plasterboard
Brick, Common	Bricks	ICE-generic brick	ICE-generic brick
Prepainted_Steel-ArcelorMittalConstruction INTÉRIEUR 12 WHITE 912	Plastics: average plastics	ICE-Rubber	PMMA.pdf
Paint-White Lining	Average construction	ICE-paint	ICE-paint

3. Results and Discussion

The results presented in Table 7 and Figure 7 show the significant effect the choice of ECF database can have on an LCA. While this study was conducted within the A1–A3 boundary, some ECFs such as the ECFs for aluminium sheets within the ICE database were defined by production location, either EU or international. If the material used by a project is produced within the same country, the use of this ECF could result in over calculation of the embodied carbon. In this scenario, the existence of an EPD published by the manufacturer would provide more accurate data. The transport emissions could then be calculated based on the projects site location.

For materials such as concrete used in foundations, the difference between using different databases is not as significant as the choice within one database. It can be assumed that this is due to the common use of concrete and the high volume of data available regarding this material [24]. The mitigation strategy for reduction of the embodied carbon in concrete is the replacement of cement with material with lower embodied carbon such as Pulverised Fuel Ash (PFA) while maintaining the desired strength. As presented by Gibbons and Orr in the 2020 istructe manual [8], this is an attainable undertaking. The ICE database provides several ECF for different concrete mixtures, which provides the data necessary for an EC reduction strategy. The most noticeable difference can be seen in the metal materials. When a project such as the model observed in this study is composed of a steel structure, this difference can be immense. Table 8 shows that this caused a 200-tonne CO2e difference between the first and third methods. The first ECF database assigned a value of 4.769 kgCO2e/kg to all metal materials, while the second database showed that the ECF for different metals could range between 1.706 kgCO2e/kg and 6.669 kgCO2e/kg.

Furthermore, these values are only for virgin metal materials. As with cement, the first mitigation strategy for reducing embodied carbon in metal is the partial or total use of recycled metal. Additionally, it does not take into account the material production method with materials produced using a basic oxygen furnace (BOF) have a much higher embodied carbon, compared to the materials produced using an electric arc furnace (EAF) [8]. Another ECF that caused a noticeable difference is the ECF choice for the PMMA material. For this material, the necessity for detail originated from manufacturer-provided BIM building material in the model. Therefore, a more general approach was taken in the ECF assignment in methods one and two. For this building element which is the main element used in the building envelope, manufacturer provided EPD would be preferable.

The total embodied carbons presented in Table 8 shows that the use of more general ECF for embodied carbon calculations result in overcalculation. These results show that using the more detailed ECF compared to the more general database resulted in a 35.2% reduction of embodied carbon. The lack of a primary or nationalised database resulted in additional labour in performing an LCA. This point is a significant deterrent for the undertaking of an LCA as part of the design and construction process. Additionally, when embodied carbon calculations are carried during the design and construction process, it provides a baseline for the carbon reduction of that project or future projects. The overcalculation of embodied carbon resulting from a generalised approach could hinder reduction efforts by presenting the perception that a higher carbon reduction is possible.

Furthermore, a detailed approach would require the sourcing of ECFs from several sources, reducing the reliability in the comparison stage of the EC reduction effort.

Table 7. The calculated embodied carbon for each material of the standard supermarket design.

	Method One EC (kgCO2e)	Method Two EC (kgCO2e)	Method Three EC (kgCO2e)
Concrete, Cast-in-Place-C15 Default Mass Floor Concrete-Cast-in-Place Concrete Concrete, Cast In Situ Concrete	16,534.20 kgCO2e	12,682.80 kgCO2e	12,682.80 kgCO2e
Concrete, Cast-in-Place-C15	1978.1 kgCO2e	3581.4 kgCO2e	2058.0 kgCO2e
Default Mass Floor	160.5 kgCO2e	123.1 kgCO2e	123.1 kgCO2e
Concrete-Cast-in-Place Concrete	13,078.8 kgCO2e	10,032.3 kgCO2e	10,032.3 kgCO2e
Concrete, Cast In Situ	0.6 kgCO2e	0.5 kgCO2e	0.5 kgCO2e
Concrete	1316.2 kgCO2e	1009.6 kgCO2e	1009.6 kgCO2e
Concrete-Precast Concrete-35 MPa	1724.2 kgCO2e	2276.7 kgCO2e	3581.4 kgCO2e
Steel	21,597.1 kgCO2e	13,676.8 kgCO2e	13,676.8 kgCO2e
QuadCore_Trapezoidal_Roof_Panel_ KS1000RW_ExternalWeatherSheet	94,044.7 kgCO2e	129,760.3 kgCO2e	64,892.0 kgCO2e
QuadCore_Trapezoidal_Roof_Panel_ KS1000RW_Internal_LinerSheet	140,531.9 kgCO2e	87,521.1 kgCO2e	90,173.3 kgCO2e
Default Roof–metal single skin	208.8 kgCO2e	130.1 kgCO2e	134.0 kgCO2e
Metal-Steel 50-355	100,064.7302 kgCO2e	32,523.3 kgCO2e	51,599.0 kgCO2e
Metal-Steel-S275	301,353.4338 kgCO2e	98,961.3 kgCO2e	153,575.3 kgCO2e
PrepaintedSteel_ArcelorMittal_ Construction_HAIRULTRA-35- CORAL	131,833.3 kgCO2e	82,103.8 kgCO2e	84,591.8 kgCO2e
Cladding, Vertical Ribbed	86,433.70 kgCO2e	41,616.40 kgCO2e	41,616.40 kgCO2e
Metal Stud Layer	808,949.3 kgCO2e	503,801.6 kgCO2e	503,801.6 kgCO2e
Aluminium	12,771.8 kgCO2e	17,859.7 kgCO2e	4569.7 kgCO2e
PIRFoamBoard_PIRInsulation	24,178.6 kgCO2e	18,670.7 kgCO2e	18,670.7 kgCO2e
Default Roof–Generic insulation 125mm	13.2 kgCO2e	678.3 kgCO2e	678.3 kgCO2e
ArcelorMittal–Mineral Wool	455,062.215 kgCO2e	351,399.4 kgCO2e	180,580.2 kgCO2e
Insulation/Support Frame	53.10 kgCO2e	41.00 kgCO2e	21.10 kgCO2e
Rock Wool	61,589.2 kgCO2e	47,559.2 kgCO2e	47,559.2 kgCO2e
Default Wall	92.3 kgCO2e	299.6 kgCO2e	299.6 kgCO2e
Gypsum Wall Board	4343.3 kgCO2e	14,103.8 kgCO2e	14,103.8 kgCO2e
Plaster	536.5 kgCO2e	1742.3 kgCO2e	1742.3 kgCO2e
Brick, Common	6348.4 kgCO2e	5523.7 kgCO2e	5523.7 kgCO2e
PrepaintedSteel_ArcelorMittal_ Construction_INTÉRIEUR-12- WHITE	10,739.4 kgCO2e	9158.4 kgCO2e	49,487.2 kgCO2e
Paint-White Lining	0.0 kgCO2e	1.3 kgCO2e	1.3 kgCO2e
Total	2293.84 tonneCO2e	1487.76 tonneCO2e	1359.70 tonneCO2e

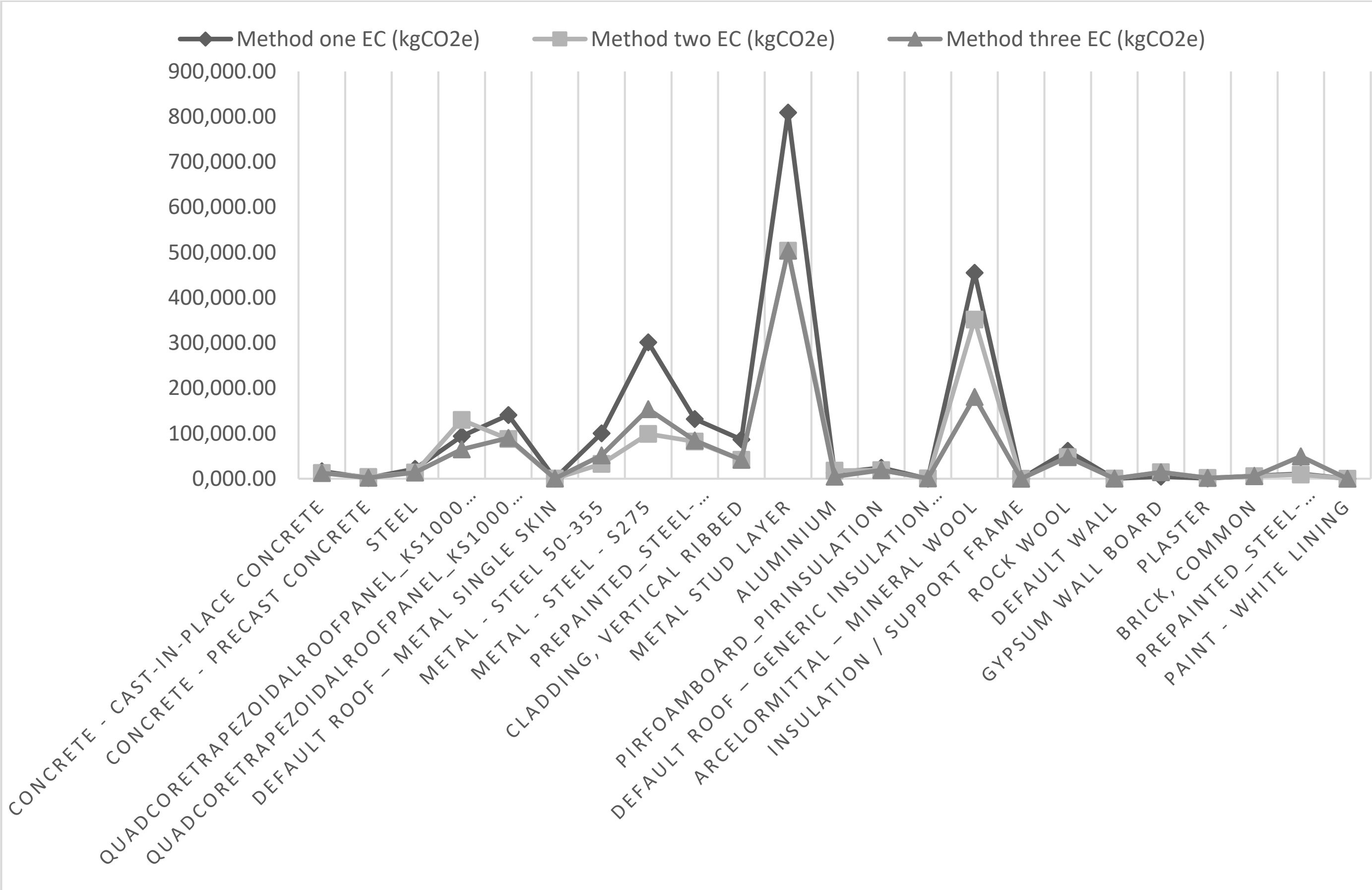


Figure 7. Calculated embodied carbon for each material of the standard supermarket design.

Table 8. The total embodied carbon for each structural element of the standard supermarket design.

Category	Material: Weight (tonne)	Method One EC (tonneCO2e)	Method Two EC (tonneCO2e)	Method Three EC (tonneCO2e)
Curtain Panels	169.11	331.94	252.72	148.34
Floors	14.67	1.98	1.52	1.52
Roofs	62.37	258.98	236.76	174.55
Structural Columns	20.98	100.06	32.52	51.60
Structural Foundations	98.22	13.24	10.16	10.16
Structural Framing	64.73	308.69	101.35	157.35
Walls	416.48	1237.08	807.92	785.58
Windows	10.96	20.18	29.77	18.38
Mechanical	4.53	21.60	13.68	13.68
TOTAL	862.079	2293.84	1487.76	1359.70

4. Conclusions and Future Work

Reducing the embodied carbon of buildings as a significant contributor to GHG emissions is a vital task that must be undertaken to reduce anthropogenic emissions and mitigate climate change. Performing Life Cycle Assessments is a vital step in the goal to reduce GHG emissions. The lack of a concrete approach in performing an LCA deters the undertaking of an LCA as part of the design and construction process. This study was conducted to observe the role of embodied carbon factor databases in the accuracy of an LCA and the adverse outcomes of the lack of an official national ECF database.

This study calculated the embodied carbon of a standard Lidl supermarket using a general database and a more detailed database, as well as choosing ECFs to be the closest to materials details. This study showed that using a more detailed database compared to using a more general database could result in a 35.2% reduction of calculated embodied carbon. Meanwhile, assigning ECFs to be the most accurate to materials details reduces it by a further 5.5%. The accuracy of this assessment is directly connected to the accuracy of the embodied carbon factors used in the process. If an LCA is carried out to reduce the embodied carbon of a design, the overcalculation that can occur as a result of a general approach or database can create an inflated starting point for reduction. It is necessary to establish the most accurate baseline for embodied carbon so that any carbon reduction attempts can be as effective as possible. The limit of specific databases also impedes further calculations for GHG reduction. If an LCA is carried out as part of the early design process, the ECF database would need to provide multiple alternatives. The consistent collection method within an ECF database would guarantee that the comparison of different designs would be viable. This study showed that while reliable databases for embodied carbon factors are available, the lack of an official national database can confuse the LCA process. This confusion results in additional necessary labour in performing an LCA, acting as a disincentive for carrying out an EC calculation.

The ICE database is currently the most reliable in the UK, most recently updated in 2019. However, the 7-year period between this update and the previous update in 2012 created the necessity to produce other databases. If manufacturer data is used to calculate and model a design, then the ECF must be sourced separately. A manufacturer-provided EPD would be preferable. However, as currently there are no regulations for manufacturers to produce EPDs, this method would be unlikely. These additional steps to perform an LCA create another obstacle preventing more action in this area. Requiring EPD publication by manufacturers and expanding and officialising ECF databases are necessary future steps in this field.

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