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Life Cycle Carbon Analysis of Extensions and Subterranean Development in RBK&C

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Life Cycle Carbon Analysis

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1. Executive Summary

Life Cycle Carbon Analysis

Eight Associates have been appointed to provide an evidence base for the Royal Borough of Kensington & Chelsea (RBKC) policy related to meeting environmental standards and carbon emission reductions for subterranean development in the Borough.

Brief and Findings

1. To consider the impact in terms of embodied carbon emissions for two types of development – extensions and subterranean developments, to inform the Council on the required environmental standards.

   This is detailed in section 4 and concludes that there is a significant impact in terms of embodied carbon emissions of subterranean development in comparison to that of extensions.

2. The methodology employed is a desktop life cycle analysis of two case studies to demonstrate the carbon intensity of extensions and subterranean development.

   A particular focus is placed on a life cycle analysis (LCA), which encompasses several stages of the development process as well as the occupation, including the sourcing and production of the materials, the activity during construction works and the subsequent operations of the building.

3. Provide recommendations on the relative impact of extensions compared to subterranean development.

   It is concluded that subterranean developments have a significantly higher carbon emissions impact over the life cycle when compared with developments classed as extensions. The embodied carbon in the robust materials used to construct underground is the key influence in terms of carbon.

Summary of the Key Findings

- The carbon emissions of the subterranean development are greater than those of the extension over the buildings' life cycle.
- The embodied carbon in a subterranean development is 828 kgCO_2 per m^2 floor area compared with 279 kgCO_2 per m^2 for extensions. This equates to 3 times the amount of embodied carbon per m^2 floor area provided.
- The life cycle analysis shows that there is high level of embodied CO_2 in the building materials relative to the operational CO_2 emissions of subterranean developments, when looked at over a 30-year life.
- The structural elements used in subterranean development accounts for nearly half of the embodied carbon in the developments materials.
- The pre-construction excavation process in subterranean developments increases carbon emissions throughout the works process

2. Introduction

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2.1 Aim of the Report

Life Cycle Carbon Analysis

Introduction	RBKC is currently experiencing an unprecedented number of planning applications for Subterranean Development. In response to this, the feasibility of such development has come under increased scrutiny. The environmental credentials of such development are being reviewed. The current policy is detailed below. *" The Council will require an assessment to demonstrate that subterranean development achieve the following relevant BREEAM standards: i. Residential Development: EcoHomes Very Good (at Design and Post Construction) with 40% of credits achieved under the Energy, Water and Materials sections, or comparable when BREEAM for Refurbishments is published."* RBKC has provided a brief to determine the significance of embodied carbon in subterranean developments. This significance will be demonstrated and analysed through a comparison with a standard new build extension.
Aim	This document aims to: • To consider the impact in terms of life-cycle carbon emissions for two types of development – extensions and subterranean developments • Establish and analyse the impact of the two case studies to determine the relative impact of subterranean developments in comparison to standard extensions.
Caveats	The methodology used in this report has been clearly defined and the data used has been attributed to the source. There are several ways to undertake Life Cycle Analysis, one being the methodology we have chosen. There is no national calculation methodology that could be adhered to. This report compares two very different buildings in terms of materials used, construction method and size, however the functional purpose of the buildings is not taken into account. Where we have made assumptions we have assumed the worst-case value. An example is the level of recycled content of materials.

3. Methodology

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3.1 Step by Step Description

Life Cycle Carbon Analysis

Methodology	The below section provides a step-by-step description of the project methodology. The final column indicates the relevant section of the report covering each step.	Section
Brief	The brief is to analyse and then compare the carbon intensity of two types of development – extensions and subterranean development. A particular focus is to be placed on a whole life cycle analysis, which encompasses all stages of development from the sourcing of the materials, the activity during construction works and the operations of the building.	ii
1 – Case Studies	RBKC have provided two case studies, which serve as a typical subterranean development (Case Study 1) and a typical single storey extension (Case Study 2). The case studies have information relating to the development such as drawings and other consultant reports. The drawings are provided in the appendices.	Appendix 1
2 – Life-Cycle Modelling	Eight Associates modelled Case Study 1 and Case Study 2 taking into account the construction type, volume of materials, activity during construction works and the likely operational usage. A detailed breakdown of the data input for each case study is provided, as well as a further breakdown of the carbon factors relating to materials and fuel is provided in Appendix 1.	iv
3 – Analysis of Carbon Emissions	Eight Associates have broken down the whole life carbon emissions and provided the embodied carbon, carbon relating to construction works and the operational carbon using the same methodology for both case studies. The embodied carbon and site works calculations are based on the drawings and construction method statements together with recognised data from the Environment Agency and Bath University. The operational carbon is based on SAP modelling using the methodology set out in Part L1B and a life cycle of 30 years.	iv
4 – Comparative Analysis of Carbon Intensity	A comparison of life cycle emissions of Case Study 1 and Case Study 2 is made to indicate the respective carbon intensity of developments classed as extensions and those as subterranean development.	iv

4. Life Cycle Analysis

4.1 Overview and modelling Life Cycle Carbon Analysis

Background

Life Cycle Analysis (LCA) is a methodology for assessing the environmental performance of a product (i.e. building) over its life cycle, often referred to as cradle-to-grave analysis. The term cradle in this project refers to the extraction of raw materials. For the purpose of this report the Life Cycle will be from 'cradle' to 30 years of building operation, as the focus of the report is on the embodied carbon in the finished building and a defined time of operation. Building operation beyond 30 years and decommissioning/demolition has not been taken into account.

LCA can be measured in terms of energy or carbon emissions. All data in this report refers to carbon emissions throughout all processes.

Building summary – Case Study 1

Case study 1 is the subterranean development at 44 Markham Square. The existing building is a five-storey Georgian house that plans to incorporate a proposed subterranean basement of around 75m^2 internal floor area.

The basement development will require the following works:

- Excavation of around 1200m^3 soil;
- Installation of steel piles and cementitous grout around the perimeter of the excavated void;
- Insulated concrete slab flooring;
- Insulated concrete block-work and concrete upper floor.

Building summary – Case Study 2

Case study 2 is a small extension to 4 Deagarno Gardens. The existing building is two-storey three-bed terrace that plans to build a single storey 10.35m^2 extension to the rear of the building.

The extension will require the flowing works:

- Insulated ground Floor Concrete Slab;
- 13.6m of Brick/Insulation/Block wall making up three sides of the extension;
- Insulated Slate roof to match existing building.

Modelling

Building data input

- Construction plans, drawings, elevations and measurements
- Construction Method Statements

Benchmark data

- Environmental agency – All material volume to weight factors
- Bath University Inventory of Carbon and Energy (ICE) V1.6 – All Carbon Factors
- Greenspec and DEFRA – Where noted in Appendices

Model

- Combined building data and benchmark data (See Appendices)

Information in appendix

- All model data and calculations

4. Lifecycle Analysis

4.2 Case Study 1 Embodied Carbon

Introduction

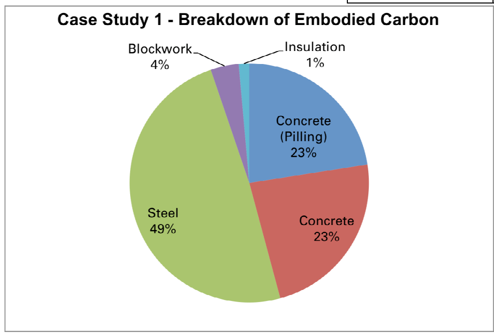
The following section analyses the vital characteristics of the modelling and gives a breakdown of the embodied carbon in each element, including the key calculations that give the total embodied carbon for Case study 1 – Subterranean development.

Vital Characteristics

The chart and graph below shows that the steel contains almost half of the development's overall embodied carbon; despite being the second least used material in terms of weight. This is due to the high carbon factor of steel – 1.77kgCO_2/kg, which can be attributed to the energy intensive production of steel from molten iron. Rockwool insulation, like most insulation, has a high embodied carbon factor, although it weighs just 40kg/m3, hence its low carbon impact.

The high levels of concrete needed in subterranean development make the overall carbon impact of the development high.

Element	Description	Volume	Weight (KGs)	Carbon Factor (kgCO2/kg)	Embodied Carbon
Concrete (Pilling)	Cementittous Grout - (RC25 data)	43.2m3	103,809 kg	0.14	14,118 kg
Concrete	Concrete floor and upper floor	37.8m3	90,720 kg	0.16	14,606 kg
Steel	Ischebeck Titan 127/111 Steel Pilling	N/A	17,340 kg	1.77	30,692 kg
Blockwork	Standard 10MPa Concrete Blocks	13.44m3	32,256 kg	0.07	2,387 kg
Insulation	Rockwool Insulation	21.01m3	840 kg	1.05	882 kg
				Total Embodied Carbon	62,685 kg



4. Lifecycle Analysis

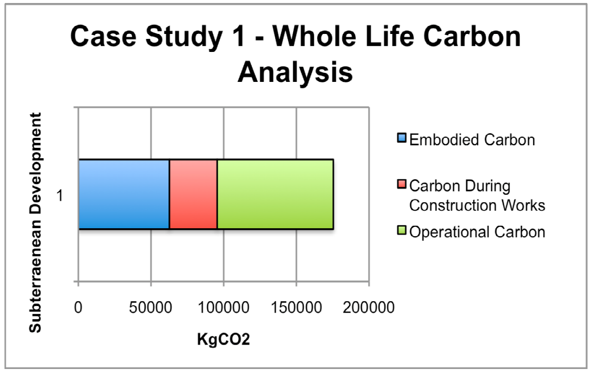
4.2 Case Study 1 Life Cycle Carbon Analysis

Introduction	The following section looks at the carbon emissions throughout the life cycle of the building. This is broken into three figures – Embodied carbon in the physical structure, carbon associated with construction works and the actual occupation and operation of the building.
Description of Stages	Embodied carbon – The previous page of this report (p8) showed the embodied carbon associated with the physical structure of the development. Construction works – The carbon emissions of construction works takes into account the energy from site plant, material and staff transportation and construction waste disposal, based on benchmark data. Operations - The operational carbon has been calculated using SAP to determine the yearly Dwelling emission rate of the building if built to part L1B building regulations.
Observations	The embodied carbon of the basement is almost as much as the operational emissions, which is very high. A rule of thumb is around 30% embodied carbon over an operational period of 30 years.

Summary table

Life Cycle Stage	Carbon emissions	Carbon emissions per m2 of floor area (Net Internal Floor Area)
Embodied Carbon	62,685 $kgCO_2$	828 $kgCO_2/m^2$
Carbon During Construction Works	34,068$kgCO_2$	450 $kgCO_2/m^2$
Operational Carbon	79,875 $kgCO_2$	1065 $kgCO_2/m^2$

Summary graph

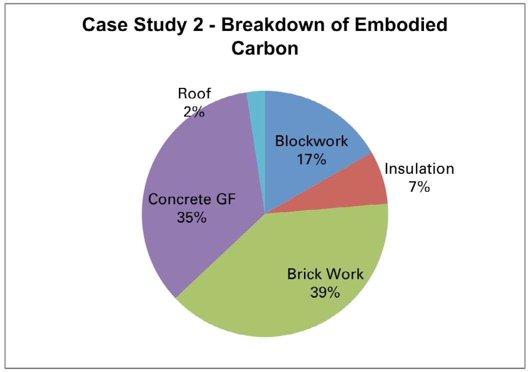


4. Lifecycle Analysis

4.3 Case Study 2 Embodied Carbon

Introduction	The following section analyses the vital characteristics of the modelling and gives a breakdown of the embodied carbon in each element, including the key calculations that give the total embodied carbon for Case study 2 – Extension.
Vital Characteristics	The graph below shows that the majority of embodied carbon in the extension is from the concrete ground floor and the brickwork. Despite the lower overall weight (KG) of bricks compared to concrete blocks the embodied energy in bricks is more than twice as high. This is due to the high energy associated with firing bricks. The roof has a very low embodied energy due to the low carbon factor of the slate.

Element	Description	Volume	Weight (KGs)	Carbon Factor (kgCO2/kg)	Embodied Carbon
Blockwork	Standard 10MPa Concrete Blocks	2.72m3	6528 kg	0.07	483 kg
Insulation	Rockwool Insulation	4.79m3	192 kg	1.05	201 kg
Brickwork	Clay Brick	2.72m3	5168 kg	0.22	1137 kg
Concrete GF	Ground Floor Slab	2.59m3	6216 kg	0.16	1001 kg
Roof	Slate	0.52m3	1248 kg	0.06	70 kg
				Total Embodied Carbon	2,891.88 kg



4. Lifecycle Analysis

4.3 Case Study 2

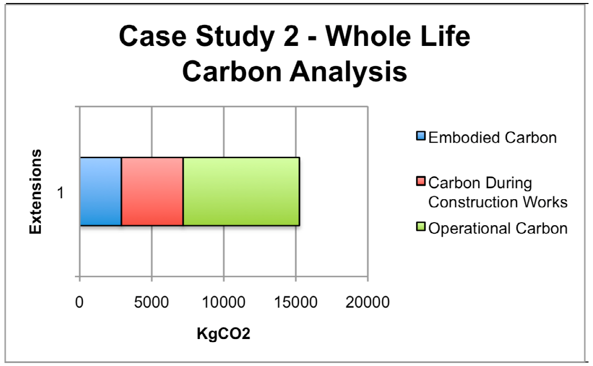
Life Cycle Carbon Analysis

Introduction	The following section looks at the carbon emissions throughout the life cycle of the building. This is broken into three figures – Embodied carbon in the physical structure, carbon associated with construction works and the actual occupation and operation of the building.
Description of Stages	Embodied carbon – The previous page of this report (p10) showed the embodied carbon associated with the physical structure of the extension. Construction works – The carbon emissions of construction works takes into account the energy from site plant, material and staff transportation and construction waste disposal based on benchmark data. Operations - The operational carbon has been calculated using SAP to determine the yearly Dwelling emission rate of the building if built to part L1B building regulations.

Summary table

Life Cycle Stage	Carbon emissions	Carbon emissions per m2 of floor area (Net Internal Floor Area)
Embodied Carbon	2,892 kgCO2	279 $kgCO_2/m^2$
Carbon During Construction Works	4,451 kgCO2	430 $kgCO_2/m^2$
Operational Carbon	8,073 kgCO2	780$kgCO_2/m^2$

Summary graph



4. Lifecycle Analysis

4.4 Comparison

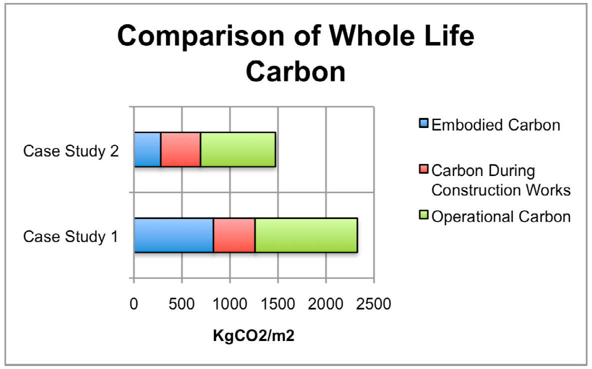
Life Cycle Carbon Analysis

Introduction	The following section analyses the differing results of the two case studies.
Comparative analysis	In order to directly compare the two case studies, the carbon emission figures have been divided by the floor area of each development. This gives comparable CO2 emissions per m^2 of floor area. The results of the modelling below show that the embodied carbon in the materials used for the subterranean development are three times that of the conventional ground level extension. The carbon used in construction works is higher in subterranean developments, which can be attributed to the energy intensive excavation and associated transport.

Summary table

Comparison	Case Study 1	Case Study 2
Embodied Carbon	828 $kgCO_2/m^2$	279 $kgCO_2/m^2$
Carbon During Construction Works	450 $kgCO_2/m^2$	430 $kgCO_2/m^2$
Operational Carbon	1065 $kgCO_2/m^2$	780 $kgCO_2/m^2$

Summary Graph



5. Conclusion
Life Cycle Carbon Analysis

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Key Findings	
	- The carbon emissions of the subterranean development are greater than those of the extension over the buildings' life cycle. - The embodied carbon in a subterranean development is 828 $kgCO_2$ per m^2 floor area compared with 279 $kgCO_2$ per m^2 for extensions. This equates to 3 times the amount of embodied carbon per m^2 floor area provided. - The life cycle analysis shows that there is high level of embodied CO_2 in the building materials relative to the operational CO_2 emissions of subterranean developments, when looked at over a 30-year life. - The structural elements used in subterranean development accounts for nearly half of the embodied carbon in the developments materials. - The pre-construction excavation process in subterranean developments increases carbon emissions throughout the works process

Appendix 1 Case Study 1
Data Input, Benchmark Data & Calculations
Life Cycle Carbon Analysis

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Measurements

Length – 20.20m
Width – 3.75m
Height – 2.8m
Floor and Ceiling area – 75.75m2
Perimeter – 48m

Embodied Calculations

Steel Piling
Diameter – approx 48m
Piles every 400mm = 48/0.4 = Approx 120 steel piles
Piles 5000mm long and have 111mm diameter
Total Steel piling 120 units x 5 metres
Weight factor – 28.9kg/per metre
Total Weight - 28.9 x 5m x 120 = 17,340kg
CARBON FACTOR – General Steel – 1.77 $kgCO_2$/kg (uk typical)

17, 340kg x 1.77 = 30,691.8 $kgCO_2$

Piling Concrete
Cementous Grout – 48m x 300m x 3000mm high = 43.2m^3 Grout (RC25)
Weight factor – 2403kg/m^3
Total Weight - 2403 x 43.2 = 103,809.6kg
CARBON FACTOR (RC25) – 0.136 $kgCO_2$/kg

103,809.6kg x 0.136 = 14,118$kgCO_2$

Floors
Ground Slab – 75.75m2 x 250mm = 18.9m^3
Upper Slab – 75.75m2 x 250mm = 18.9m^3
Total Concrete – 37.8m^3
Weight factor – 2400kg/m^3
Total Weight - 37.8 x 2400 = 90,720kg
CARBON FACTOR – 0.161 $kgCO_2$/kg (RC35)

90,720 x 0.161 = 14,605$kgCO_2$

Walls
100mm Blockwork x 48m x 2.8m = 13.44m^3
Weight factor – 2400kg/m^3
CARBON FACTOR – 0.074$kgCO_2$/kg
Total Weight - 13.44 x 2400 = 32,256kg

32,256 x 0.074 = 2,386$kgCO_2$

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Appendix 1
Case Study 1
Data Input, Benchmark Data & Calculations
Life Cycle Carbon Analysis

Insulation
Wall - 100mm Insulation x 48m x 2.8m = 13.44m^3
Ground - 75.75m2 x 100mm = 7.57m^3
Volume – 21.01m^3
Weight factor – 40kg/m^3 (Greenspec.co.uk)
Total Weight – 21.01 x 40 = 840.4kg
CARBON FACTOR – 1.05 kgCO_2/kg (Rockwool)

840.4 x 1.05 = 882.4kgCO_2

Construction Phase Calculations

Works Time-frame
Underpinning, excavation, pilling, concrete casting – 6 months
Fit out works - 9 months
Total time on site – 15 months
CARBON FACTOR 2000kg/month

15 x 2000 = 30,000kg

Construction Materials
Assume Average 8 yard 6m^3 skip
125.67m^3 materials + one additional trip for steel piles
Assume 50km by road for materials
3.5 Tonne Skip van emissions – 400gCO_2 per Km (DEFRA)
125.67/6 = 21 trips (42 there and back) @ 50Km = 2100Km

2100 x 0.4kg CO2 = 560kg/CO_2

Staff Travel
Assume Average travel distance 15km by Van
4 staff in 2 vans
Van emissions – 224.4gCO_2 per Km
22 days per month on site
15 months = 330 days on site
330x15 x 2 = 9900Km

9900 x 0.2444 = 2420kgCO_2

Waste
1200m^3 excavated earth
Assume 10% construction material (126 m^3) is waste = 12.6m^3
Assume 5Km by Road to Landfill
Assume Average 8 yard 6m^3 skip
3.5 Tonne Skip van emissions – 400gCO_2 per Km (DEFRA)
1212.6m^3/6 = 202trips (404 there and back) @ 5Km by Road to Landfill = 2020Km

2020 x 0.4kg CO2 = 808kg/CO_2

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Appendix 2
Case Study 2
Data Input, Benchmark Data & Calculations
Life Cycle Carbon Analysis

Mesurements

Total Extension Wall Length – 13.6m
Height – 2m
Floor and Roof area – 10.35m^2

Embodied Calculations

Brick
100mm x 13.6m x 2m – 2.72m^3
Weight factor – 1900kg/m^3
Total Weight - 1900 x 2.72 = 5,168kg
CARBON FACTOR – 0.22kgCO_2/kg

5,168kg x 0.22 = 1,137kgCO_2

Block
100mm x 13.6m x 2m – 2.72m^3
Weight factor – 2400kg/m^3
Total Weight – 2400 x 2.72 = 6,528kg
CARBON FACTOR – 0.074kgCO_2/kg

6,528 x 0.074 = 483.07 kgCO_2/kg

Insulation
Floor - 10.35m2 x 100mm Insulation = 1.035m^3
Roof - 10.35m2 x 100mm Insulation = 1.035m^3
Walls - 13.6m x 100mm x 2m = 2.72m^3
Total m^3 = 4.79m^3
Weight Factor = 40kg/m^3
Total Weight = 40 x 4.79 = 191.6kg
CARBON FACTOR - 1.05 kgCO_2/kg

191.6 x 1.05 = 201.18 kgCO_2

Roof
10.35m2 x 50mm Concrete Tiles = 0.52m^3
Weight Factor = 2400kg/m^3
Total Weight = 2400 x 0.52 = 1248kg
CARBON FACTOR – 0.13 kgCO_2/kg

1248 x 0.13 = 162.24kgCO_2

Appendix 2
Case Study 2
Data Input, Benchmark Data & Calculations
Life Cycle Carbon Analysis

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Construction Phase Calculations

Works Time-Frame
Estimated time frame for build – 2 months
CARBON FACTOR 2000kg/month

2000 x 2 = 4000kgCO_2

Construction Materials transport
Assume Average 8 yard 6m^3 skip
13.34m^3 materials
Assume 50km by road for materials
3.5 Tonne Skip van emissions – 400gCO_2 per Km (DEFRA)
13.34/6 = 3 trips (6 there and back) @ 50Km = 300Km

300 x 0.4kg CO2 = 120kg/CO_2

Staff Travel
Assume Average travel distance 15km by Van
4 staff in 2 vans
Van emissions – 224.4gCO_2 per Km
22 days per month on site
2 months = 44 days on site
44x15x2 = 1320Km

1320 x 0.2444 = **323kgCO_2**

Waste
Assume 10% construction material (13.3m^3) is waste = 1.3m^3
Assume 5Km by Road to Landfill
Assume Average 8 yard 6m^3 skip
3.5 Tonne Skip van emissions – 400gCO_2 per Km (DEFRA)
1 trips @ 5Km by Road to Landfill = 10Km

10 x 0.4kg CO2 = 4kg/CO_2