Investigate the design of an office building and explore the impact of the ISTRUCTE carbon tool on the design

Content page :

Table of Contents

1. Introduction 2

2. Makeup of the building: 3

2.1 Slabs: 3

2.2 Shear core and walls: 4

2.3 Columns: 5

2.4 Foundations: 6

3. Load paths 7

4. What is slab spanning? 7

5. Loading for the office: 8

5.1.1 Data for calculating the maximum internal loads: 8

5.1.2 Calculations for total internal loads: 9

5.1.3 Calculations for the maximum perimeter loads: 9

5.2.1 Calculations for the area of tension steel required at the base of pile-cap for perimeter columns: 10

5.2.2 Calculations for the area of tension steel required at the base of pile-cap for perimeter columns: 11

6.Carbon footprint during constructing: 12

6.1 Calculations for the building's SCORS rating 12

6.2 Analysis of the results 13

7. Conclusions: 15

8. References: 16

9. Acknowledgement: 18

1. Introduction

This research project aims to investigate the structural design of a building and explores the influence of the carbon tool on the design. The project's structure is a 10-story office skyscraper designed by Sheppard Robson, a British architecture firm. The building's structure is primarily made up of concrete columns and concrete slabs, and it is designed to withstand specific axial forces that can be calculated based on the loads required. The carbon tool for ISTRUCT used is able to calculate the carbon emission level for the construction of the building, and further improvement could be done by engineer.

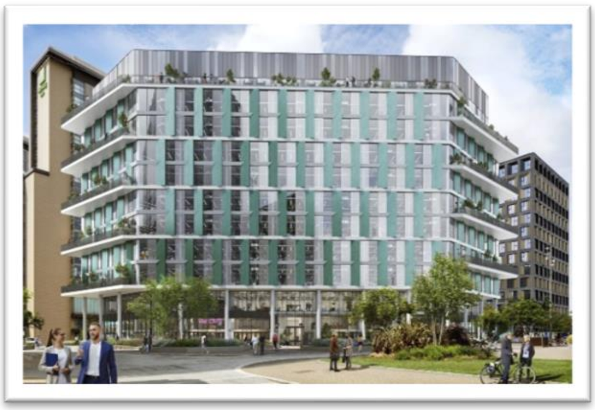


Figure 1- Front view of the building (Robson, 2022)

Figure 2- Structure of the ground floor

Disclaimer: Since the corporation has not yet disclosed the data, the computations in this project did not utilize the real figure. All calculations are performed with the assumption that the building has a simple regular prism structure, with reasonable measurements provided by my supervisor Sean.

2. Makeup of the building:

To construct a building that is safe to stay in, many components are required, and all with their unique unreplaceable functions. Several examples of the building's parts are provided below:

2.1 Slabs:

Slabs are the building's floors. The slabs for the office in this project are built of reinforced concrete, which is a brittle yet tough material, with steel as reinforcement, a ductile metal. The concrete usually takes 28 days to reach full strength (90% of its strength).

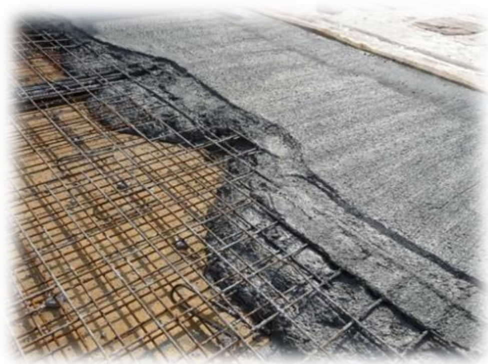


Figure 3- Concrete with steels inside (Patterson, 2021)

The slabs in the building are constructed as simply supported beam structures, as shown in ***Figure 4***, with supports at both ends. The beams in this case are statically determinate, where their unknown reaction forces can be calculated only using the equilibrium equation. The arrows demonstrate the direction of the force exerted on the floor, which creates a bending moment within the beams.

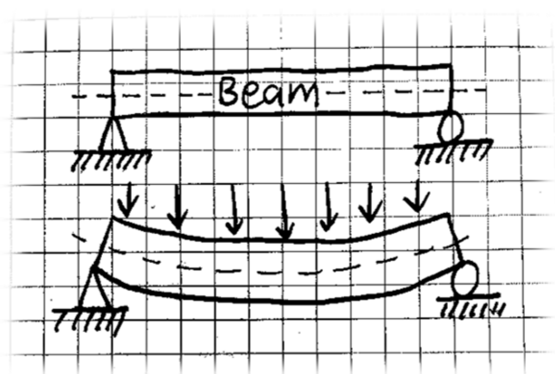


Figure 4- Hand sketch of s statically determinate beam, bending (sagging) under a uniformly distributed load.

In Figure 4, the tringle under the beam represents a pin, which is associated with two reaction forces- force in the x-direction and the y-direction; the circle under the beam represents a roller, which is associated with one reaction force only- the force that is perpendicular to the support surface. To find out the unknown reaction forces with the equilibrium equation, three rules are applied.

$$1. The\ sum\ of\ forces\ in\ the\ x-direction\ =\ 0$$

$$2. The\ sum\ of\ forces\ in\ the\ y-direction\ =\ 0,$$

$$3. The\ sum\ of\ the\ moment\ about\ the\ z-axis\ at\ the\ point\ of\ the\ pin\ =\ 0$$

According to ***table 1,*** the ratio of the span to depth is 30, with the span of the bay being, 7.5m, the depth of the concrete of the slab for the building is calculated as follows:

$$7.5m/30\ =\ 0.25\ m\ =\ 250mm$$

2. Thickness of Slab

The following table gives the maximum values of the ratio of span to depth.

Type of slab	Ratio of span to depth
Simply supported and spanning in one direction	30
Continuous and spanning in one direction	35
Simply supported and spanning in two directions	35
Continuous and spanning in two directions	40
Cantilever slabs	12

Table 1- The ratio of span to depth (Mishra, 2018)

The roof is made of the same material as the slabs on the other levels of the building, but it has a smaller area and a different load value due to its different functions. For example, most buildings have air conditioning units which are not in the other layers of the building and will normally have fewer people on the roof.

2.2 Shear core and walls:

Shear structural walls are designed to withstand lateral stresses such as earthquakes and winds. It is crucial in maintaining the building's stability. In the building, the shear walls are 300mm thick. The shear core of the project's building incorporates services such as a lift and stairs that allow people to navigate between levels.

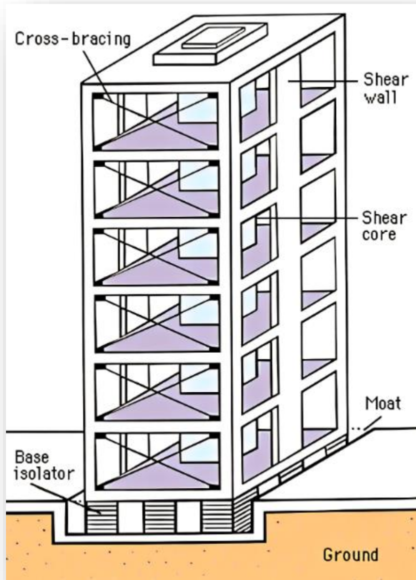


Figure 5- the structure of shear walls and the shear core (William, no date)

2.3 Columns:

Columns are all the pillars in a building. Columns come in a variety of sizes and materials, and they can be located either inside or outside of the building. The most seen columns for the construction of buildings are square and rectangular columns, because they are the easiest to shutter and to stay still while the concrete is still in flowable condition.

Figure 6- Columns of a building(Simply Paving, no date)

The loads transmitted by columns in various places varies; perimeter columns transfer smaller loads than internal columns due to less area of the slab that they are supporting. In the building, the reinforcement bars are in circle shape with diameter 25mm. More detailed calculations related to the columns are under the 'Loading of the office' section.

2.4 Foundations:

The foundation for the structure is pile caps and piles. In the building's foundation, four piles are below each pile caps. The piles have diameter 400mm. The capacity of all the piles depends on the loads of the building, which will be calculated under section 5.

The foundation is made with substantial concrete that is driven deeply into the ground. It prevents the building from falling. There are different methods to construct piles. Driven pile means driving the piles into the soil and pushing the soil sideways and compressing the solid around the pile; broad pile means digging a hole in the soil and pouring concrete inside the holes. (Riyaz, 2023)

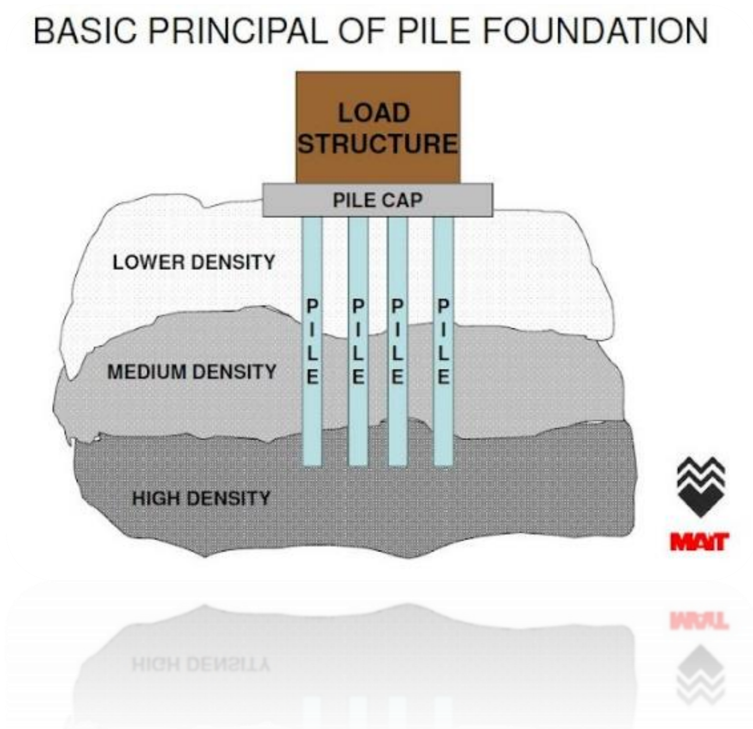


Figure 7- A foundation for the building, with piles inserted into the soil, and pile cap on top of the piles (MAIT, 2013)

3. Load paths

Load paths are routes that forces take to travel from the building's top to the base. The force may include the weight of the slab, the people inside the building, etc. Below is a picture demonstrating how load paths work:

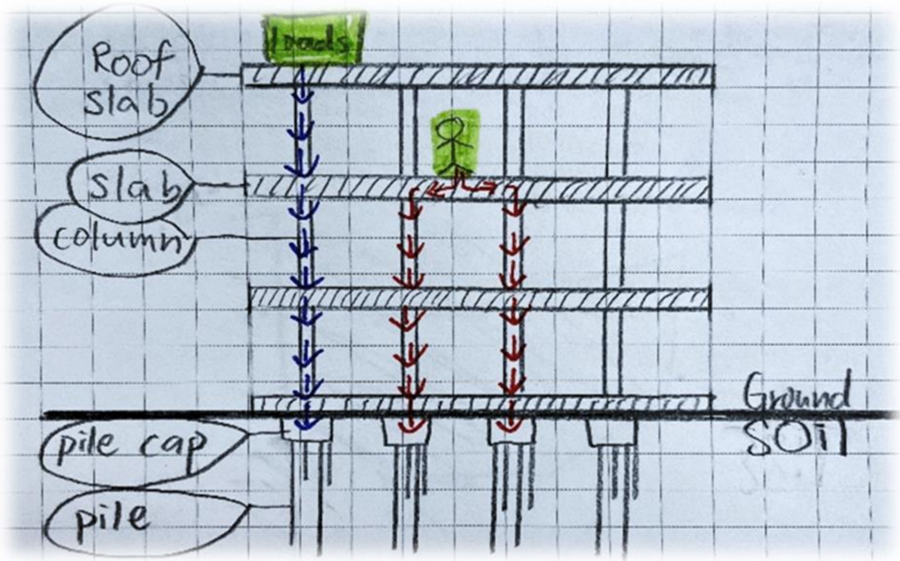


Figure 8- Hand draw examples of the load path in the building

4. What is slab spanning?

Slab spanning determines the direction of the load distribution on the ground. Traditional floor systems are either designed to span at one or two ways. In a one-way span, the slabs span in one direction only (figure 9), while two-way slabs span in both directions (Paul, 2017). In the building, the slabs are spanning in two directions (figure 10).

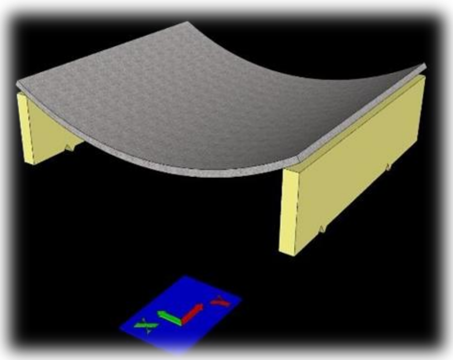


Figure 9- A one-way span, slab bends in one direction (Pratap, 2016)

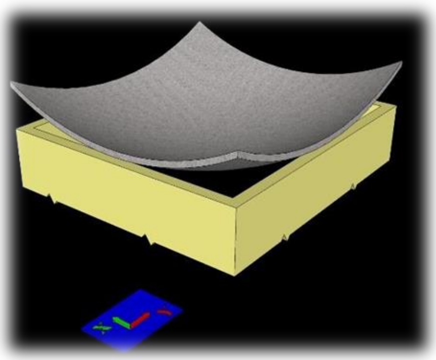
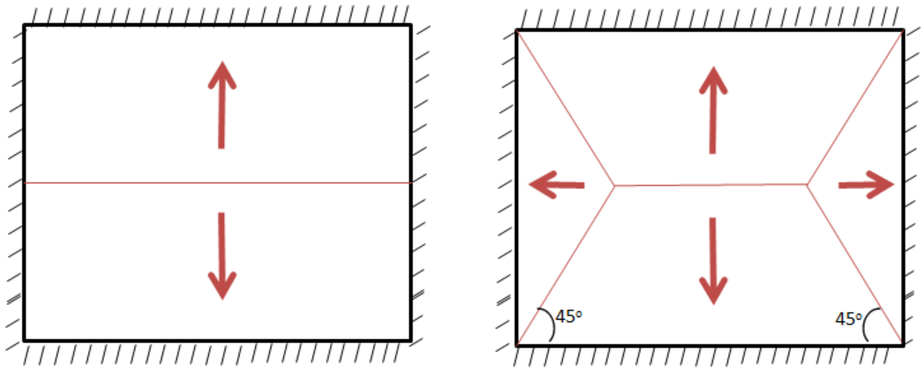


Figure 10- A two-way span, slab bends in two directions (Pratap, 2016)

The load on one-way slab is only supported by 2 supportive walls, and the loads on 2-way slabs are supported by 4 supportive walls.



One way spanning slab　　Two way spanning slab

Figure 11- Direction of spanning shown with arrows (Prasad, 2023)

5. Loading for the office:

Loads are different for every building, depending on their functions as different uses of building create different number of vibrations.

5.1.1 Data for calculating the maximum internal loads:

Subjects	**Explanation**	**Values for project's building**	
Live load (LL)	The loads that are movable (People, internal walls etc.)	**One floor** Variable load: 1.5 KN/m^2 Partitions : 1.0 KN/m^2 **Total : 1.5 + 1.0 = 2.5 KN/m^2**	**Roof** Maintenance: 0.6 KN/m^2 Plant loading (MEP): 7.5 KN/m^2 **Total: 0.6 + 7.5 = 8.1 KN/m^2**
Dead load (DL)	The loads that are fixed in position (ceilings, slabs etc.)	**One floor** Self-weight of concrete: 6.25 KN/m^2 Ceiling + surfaces: 0.5 KN/m^2 **Total: 6.25 + 0.5 = 6.75 KN/m^2**	**Roof** Same as one floor
TYPICAL Bay (B)	Differences between 2 frames	One floor　Roof 7.5 m　7.5m	
Factors of safety (F)	It is applied to the loads value for safety purpose.	Live load: 1.5	Dead load: 1.35

5.1.2 Calculations for total internal loads:

One floor Applied safety factor to Dead Load:
6.75 X 1.35 = 9.1125 kN/m^2

Applied safety factor to Live Load:
2.5 x 1.5 = 3.75 kN/m^2

Bay area:
7.5 x 7.5 = 56.25 m2

Total load:
(9.1125 + 3.75) x 56.23 = 723.5 KN (4 s.f)

Roof Applied safety factor to Dead Load:
6.75 x 1.35 = 9.1125

Applied safety factor to Live Load:
8.1 x 1.5 = 12.12

Bay area:
7.5 x 7.5 = 56.25

Total load:
(9.1125 + 12.12) x 56.25 = 1196 KN (4 s.f)

Ground Total of 10 floors + roof:
1196 + 723.5 x 10 = 8431 KN (4 s.f)

5.1.3 Calculations for the maximum perimeter loads:

9 floors Applied safety factor to Dead Load:
6.75 X 1.35 = 9.1125 kN/m^2

Applied safety factor to Live Load:
2.5 x 1.5 = 3.75 kN/m^2

Bay area:
7.5 x 7.5/2 = 28.125 m2

Total load:
(9.1125 + 3.75) x 28.125 x 9 = 3256 KN (4 s.f)

1 roof Applied safety factor to Dead Load:
6.75 x 1.35 = 9.1125 kN/m

Applied safety factor to Live Load:
8.1 x 1.5 = 12.2 kN/m

Bay area:
7.5m x 7.5/2 = 28.125 m

Total load:
(9.1125 + 12.2) x 28.125 /2 = 300 KN

Ground Total of 9 floors + roof:
3256 + 300 = 3555 KN (4 s.f)

5.2.1 Calculations for the area of tension steel required at the base of pile-cap for perimeter columns:

By inputting the loads of internal columns as the axial force, and using an ISTRUCTE Technical Guidance, the calculation made is as followed:

Table 2 – Designing pile cap for internal columns

Determine the are of thnsion steel requited at base of pile-cap		
Subject	value	unit
Axiel force (N)	8431	kN
half the distance between centroid of the pile grooup and the centre of vertical eleme	600	mm
distance between the top of the pile-cap and top of the pile (d)	700	mm
Tension =	1605904.76	N
Tension strength of reinforcement	500	N/mm^2
Area of tension steel required =	3691.73508	mm^2
Area of tension steel required for 2 bars =	7383.47017	mm^2
provide	3015	mm^2
average width of the tension area above the piles	700	mm
effective depth of the pile-cap	700	mm
axial tensile strength of concrete	2.9	N/mm^2
Minimum area required =	738.92	mm^2
	< 3015	mm^2
Node stress check		
Subject	value	unit
factor applied to node compressive strength where a tension force is present (k2	0.85	
concree cylinder compressive strength (fck	30	N/mm^2
strength reduction factor for concrete cracked in shear(v =	0.88	N/mm^2
factor that takes into acc the long term effects on compressive strength (acc	0.85	
partial safety factor (γ	1.5	
design value of the concrete's compressive strength (fcd =	17	N/mm^2
max node strength =	12.716	N/mm^2
diameter of piles	400	mm
total compressive strength =	1598.58286	kN
applied force =	2810.33333	kN
	< 2000	kN

Table 3

5.2.2 Calculations for the area of tension steel required at the base of pile-cap for perimeter columns:

By inputting the loads of perimeter columns as the axial force, and using an ISTRUCTE Technical Guidance, the calculation made is as followed:

Table 3- designing pile cap for perimeter columns

Determine the are of thnsion steel requited at base of pile-cap		
Subject	value	unit
Axiel force (N)	3555	kN
half the distance between centroid of the pile groour and the centre of vertical eleme	600	mm
distance between the top of the pile-cap and top of the pile (d)	700	mm
Tension =	677142.857	N
Tension strength of reinforcement	500	N/mm^2
Area of tension steel required =	1556.65025	mm^2
Area of tension steel required for 2 bars =	3113.30049	mm^2
provide	3015	mm^2
average width of the tension area above the piles	700	mm
effective depth of the pile-cap	700	mm
axial tensile strength of concrete	2.9	N/mm^2
Minimum area required =	738.92	mm^2
	< 3015	mm^2
Node stress check		
Subject	value	unit
factor applied to node compressive strength where a tension force is present (k2	0.85	
concree cylinder compressive strength (fck	30	N/mm^2
strength reduction factor for concrete cracked in shear(v =	0.88	N/mm^2
factor that takes into acc the long term effects on compressive strength (acc	0.85	
partial safety factor (γ	1.5	
design value of the concrete's compressive strength (fcd =	17	N/mm^2
max node strength =	12.716	N/mm^2
diameter of piles	400	mm
total compressive strength =	1598.58286	kN
applied force =	1185	kN
	< 2000	kN

6.Carbon footprint during constructing:

CO_2 emissions causes global warming. To reduce pollution, a carbon rating scheme 'SCORS' is used to evaluate the embodied carbon, and a grade is assigned based on the emission level. 'SCORS' is encouraged to use by ISTRUCT, and a target is set based on the grading system.

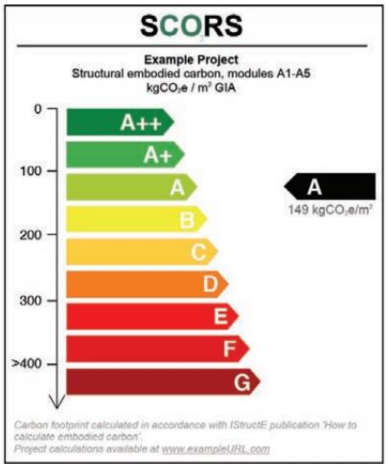


Figure 12- SCORS rating scheme (Will, 2020)

6.1 Calculations for the building's SCORS rating

To find out the building's SCORS rating, we will first find out the capacity of materials for tits structure. Then, we sill input the calculated data into a carbon calculating spreadsheet. Finally, the SCORS grade will be achieved.

Total volumes of slabs between floor 1-10	Area = 3825 m^2 Thickness = 0.25 m Number = 11 **Volumes = 3825 x 0.25 x 11 = 10516 m^3**
Total volumes of roof slabs	Area = 3443 m^2 Thickness = 0.25 m Number = 1 **Volumes = 3443 x 0.25 x 1 = 861 m^3**
Total volumes of internal columns between floor 1-10	diameter = 0.5 m height = 3 m Number = 32 **Volumes = 32 x 3 x $\pi(0.5/2)^2$ = 19 m^3**
Total volumes of roof internal columns	diameter = 0.5 m height = 3 m Number = 620 **Volumes = 620 x 3 x $\pi(0.5/2)^2$ = 365 m^3**
Total volumes of perimeter columns between floor 1-10	diameter = 0.5 m height = 3 m Number = 620 **Volumes = 30 x 3 x $\pi(0.5/2)^2$ = 18 m^3**
Total volumes of roof perimeter columns	diameter = 0.5 m height = 3 m

	Number = 620 **Volumes = 300 x 3 x π(0.5/2)^2 = 177 m^3**
Total volumes of foundations	Pile: Diameter = 0.6 m Height = 1.8m Number = 368 **Volume of piles = 368 x 1.8 x π (0.6/2)^2 = 187m^3** Pile caps: Height = 0.7m Width = 3m Number = 92 **Volume of pile caps = 0.7 x 3 x 3 x 92 = 580 m^3** **Sum of volumes = 187 + 580 = 767**

Material	Material Type	Material Specification	Structural Element	Description	Component Lifespan [years]	Temporary Works	% of Temp Works Wasted	Volume [m^3] or Mass [kg]?
Concrete	Insitu	UK C32/40 (25% GGBS)	1.1 Lowest floor/slab	GF Slab and upper floors	50	No		Volume [m3]
Concrete	Insitu	UK C32/40 (25% GGBS)	Other	roof slab	50	No		Volume [m3]
Concrete	Insitu	UK C32/40 (25% GGBS)	2.2 Upper floors/slabs	general slab x 11	50	No		Volume [m3]
Concrete	Insitu	UK C32/40 (25% GGBS)	2.5 Structural ext. walls	roof internal columns	50	No		Volume [m3]
Concrete	Insitu	UK C32/40 (25% GGBS)	2.5 Structural ext. walls	general internal columns	50	No		Volume [m3]
Concrete	Insitu	UK C32/40 (25% GGBS)	1.1 Foundations (incl. pile caps)	pile caps + piles	50	No		Volume [m3]
Concrete	Insitu	UK C32/40 (25% GGBS)	2.5 Structural ext. walls	roof perimeter columns	50	No		Volume [m3]
Concrete	Insitu	UK C32/40 (25% GGBS)	2.5 Structural ext. walls	general perimeter columns	50	No		Volume [m3]

Table 4- Calculation for embodied carbon

The SCORS grade achieved is D, with total embodied carbon of 268 kgCO_2e/m^2.

6.2 Analysis of the results

The embodied carbon is equivalent to 11,038 one-way flights from London to New York; 5,519 people's consumption of meat, dairy and beer for 1 year; 3,036 average family cars running for 1 year. In which the CO2 emissions from the upper floors and slabs account for up to 46% of the building's overall emissions. The grade D attained falls short of the grade C target for structural embodied carbon for the year 2023.

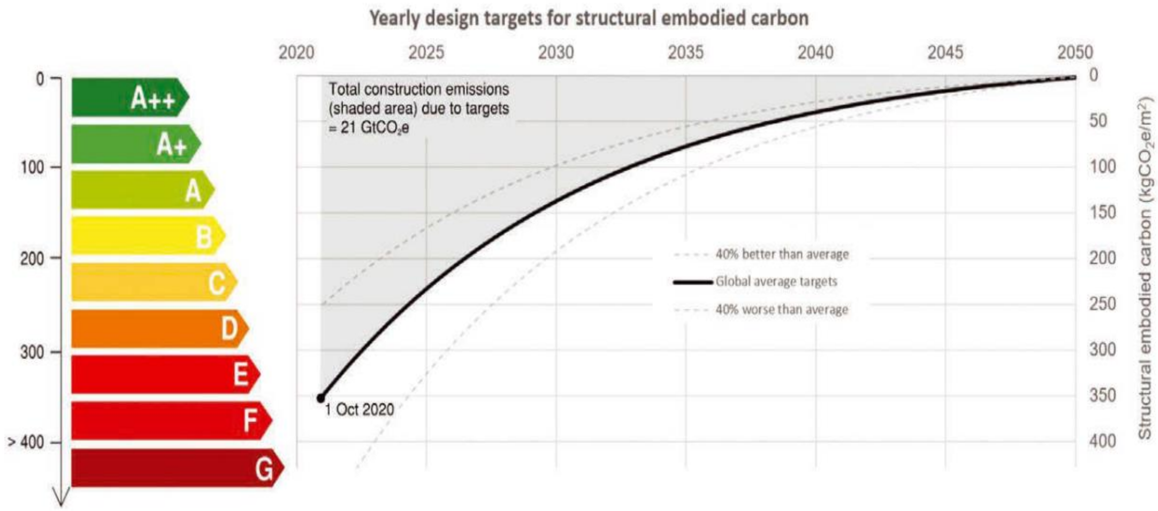


Figure 13- Target set by ISTRUCT for embodied carbon (Will, 2020)

To achieve a better 'SCORS' rating, improvement on the selection and utilization of materials could be done. Selection-wise, adding ground granulated blast-furnace slag into the concrete mixture to enhance its stability and durability, so less concrete is used during construction. Additionally, replacing concrete with timber, which absorbs carbon dioxide while growing, reduces the embodied carbon. In other words, it has a negative carbon footprint. Utilization-wise, the more effectively a material is used, the less waste and pollution there will be. Using materials that are designed for re-use can also save energy during production, reducing the need to burn fossil fuels and lowering carbon emissions.

7. Conclusions:

The project has given examples of the structure of the building, along with demonstrations on the calculation of the building's loads. At the end, we've find out that the building does not meet the SCORS rating target set by ISTRUCT, and improvement based on the material used is suggested.

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9. Acknowledgement:

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