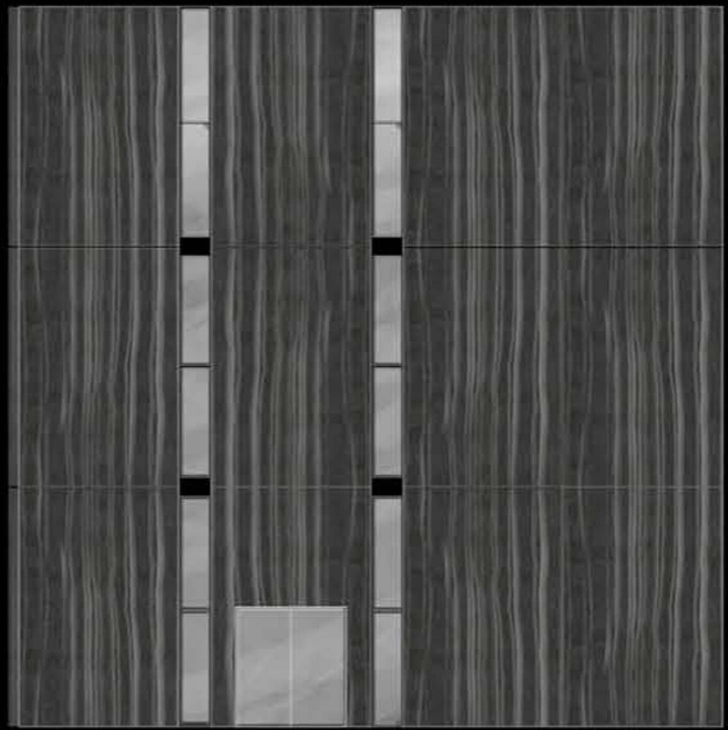
# FORMWORKS CO$_2$ CAPTURE CONCRETE FACADE PANEL

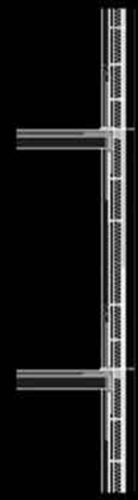
DUE TO THE RELEASE OF CO$_2$ TO THE ATMOSPHERE THAT OCCURS DURING THE PRODUCTION PROCESS OF CONVENTIONAL PORTLAND CEMENT. CONCRETE IS WIDELY CONSIDERED TO BE AN NON-ENVIRONMENTALLY FRIENDLY BUILDING MATERIAL. THE OBJECTIVES OF THIS STUDY IS TO EXPLORE HOW THE NATURAL CARBONATION OF CONCRETE CAN BE CAPITALISED TO SHIFT THE NATURE OF CONCRETE FROM A CARBON EMITTER TO A MORE POSITIVE. CO$_2$ ABSORBING BUILDING MATERIAL. IN ORDER TO MAXIMISE CO$_2$ SEQUESTRATION THE NATURE IN WHICH CONCRETE IS UTILISED AS A BUILDING MATERIAL MUST ADAPT. CONCENTRATING ON CONCRETE FACADE PANELS. THE OBJECTIVE OF THIS STUDY AIMS TO ENHANCE THE MATERIALS PERFORMANCE IN RELATION TO ITS ENVIRONMENTAL IMPACT.

THE FOCUS IS ON DESIGNING A SUSTAINABLE CONCRETE FACADE PANEL. WITH MAXIMUM SURFACE AREA AND MINIMUM VOLUME. THIS AIMS TO ACHIEVE MAXIMUM CARBONATION AND MINIMUM EMBODIED CARBON TO REDUCE ENVIRONMENTAL IMPACT.

BARK TEXTURE OF A PINE TREE
DESIRED TEXTURE OF CONCRETE FACADE PANEL



ELEVATION
SCALE 1:50



SECTION
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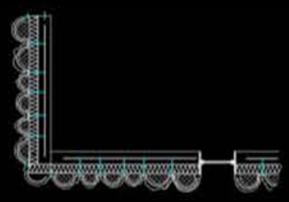


PLAN
SCALE 1:50

THE CONCEPT FOR MY FACADE PANEL DESIGN DEVELOPED FROM AN INITIAL OBJECTIVE TO USE THE FORMS AND UNDULATING SHAPES OF NATURE TO CREATE A PANEL WITH MAXIMUM SURFACE AREA. AFTER RESEARCHING VARIOUS NATURAL MATERIALS. SUCH AS STONES AND SAND. I CAME TO THE CONCLUSION TO USE TREES TO CREATE THE FORM. THE TRUNKS OF PINE FORESTRY THINNINGS ARE USED TO CREATE THE FORMWORK MOULD WHICH THE CONCRETE IS CAST IN. VERTICALITY AND PROTRUDING VOLUMES CHARACTERISE THE FACADE SYSTEM DESIGN. PANELS ARE MIRRORED TO CREATE VERTICAL CONTINUITY. THE FACADE SYSTEM AS A WHOLE REQUIRES ONE PANEL PATTERN. WHICH IS MIRRORED. AND THEREFORE REQUIRES TWO FORMWORK MOULDS TO CREATE. PANELS HAVE ALSO BEEN ROTATED 180 DEGREES TO CREATE VARIETY IN THE FACADE.

THE STRUCTURE IS PRECAST CONCRETE. SANDWICH PANELS WITH A PRECAST FLOOR INTERFACE. THE CONCRETE FACADE PANEL HAS A MINIMUM THICKNESS OF 75MM. 35MM EITHER SIDE OF A STEEL MESH REINFORCEMENT. WHICH IS TIED BACK TO THE STRUCTURAL CONCRETE PANEL. MESH REINFORCEMENT IN THE FACADE PANEL ALLOWS THE PANEL TO BE TIED TO THE STRUCTURAL PANEL AT THE MOST INWARD POINTS. 150MM OF RIGID BOARD INSULATION SITS BETWEEN THE INTERNAL AND EXTERNAL CONCRETE PANELS AND MINERAL WOOL INSULATION FILLS THE HOLLOW SPACES WHERE THE 'TREE TRUNKS' EXTRUDE.

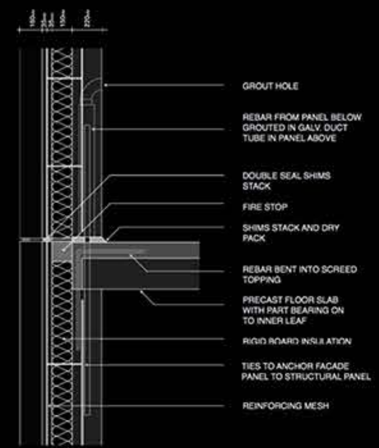
ELEVATION OF A TYPICAL FACADE

PLAN OF A TYPICAL FACADE





SANDWICH PANEL
PRECAST FLOOR INTERFACE SECTION
DETAIL
SCALE 1:20




CORNER AND WINDOW JUNCTION
AXONOMETRIC CORNER DETAIL
SCALE 1:50

FORMWORK CONSTRUCTION

THE FORMWORK WOULD BE CREATED USING TREE TRUNKS FROM THE THINNINGS OF A FORESTRY. THE USE OF THINNINGS MEANS NO TREES ARE BEING FELLED SPECIFICALLY FOR THE CONSTRUCTION OF THE FORMWORK. THE USE OF TREE TRUNKS TO CREATE THE FORMWORK FOR THE FACADE PANEL CAME FROM THE INITIAL CONCEPT TO TAKE THE SHAPES AND TEXTURES FROM NATURAL MATERIALS AND APPLY THEM TO THE PANEL.

IN ORDER FOR MINIMUM CONCRETE USE IN THE FACADE PANEL. THE PANEL NEEDS TO BE HOLLOWED AT THE 'TRUNK' POINTS CREATING A PANEL THAT IS 75MM THINK AT ALL POINTS. STEEL MESH REINFORCEMENT WOULD BE BENT INTO SHAPE WITH 35MM OF CONCRETE EITHER SIDE. THE MESH REINFORCEMENT WOULD ALSO BE USED TO TIE THE FACADE PANEL TO THE STRUCTURAL PANEL ON THE INTERIOR AND CREATE THE SANDWICH PANEL. THE CONCRETE FACADE PANEL WOULD BE CREATED USING AN ENCLOSED FORMWORK IN ORDER TO CREATE THE FIGURE ON BOTH SIDES OF THE PANEL. TREE TRUNKS WOULD BE USED TO MOULD THE FORMWORK FOR THE SURFACE WITH SILICONE IN ORDER TO MOULD THE TEXTURE, SHAPE AND FORM OF THE TRUNKS. THE CONCRETE WOULD THEN BE POURED FROM THE TOP OF THE ENCLOSED FORMWORK. 150MM OF INSULATION BOARD SITS BETWEEN THE STRUCTURAL PANEL AND THE FACADE PANEL TO CREATE THE SANDWICH PANEL. GAPS IN THE HOLLOWS OF THE FACADE PANEL ARE FILLED WITH MINERAL WOOL.

<u>PANEL EXTERNAL SURFACE AREA</u> :

24.8m$^2$

<u>PANEL VOLUME</u>:

1.3m$^3$

(Both calculated using sketch-up model)

WORKSHOP PROTOTYPE OF FACADE PANEL AT SCALE 1:10. USING BRANCHES. SAND AND FABRIC TO CREATE FORMWORK.

ICE EMBODIED CARBON CALCULATOR

FOR THE ICE CALCULATOR. I DECIDED TO TRIAL AND COMPARE THREE MIXES THAT I ASSUMED WOULD HAVE VERY DIFFERENT EMBODIED CARBON OUTCOMES. I CHOSE TO USE CEM I AS I ASSUMED THAT DUE TO THE HIGH CEMENT CONTENT. CEM1 WOULD HAVE A HIGH EMBODIED CARBON. I TRIALLED THIS MIX TO CALCULATE IF A HIGH CARBONATION RATE BALANCES OUT THE HIGH EMBODIED CARBON. I COMAPRED THIS WITH MIX TWO. CEM III WITH 73%GGBS. THIS MIX HAD A LOW EMBODIED CARBON DUE TO THE HIGH AMOUNT OF CEMENT REPLACEMENT. I COMPARED THESE TWO MIXES WITH CEMII WITH 28% NATURAL POZZOLANIC ASH. THIS MIX BALANCED BETWEEN THE TWO OTHER MIXES AS IT HAS BOTH HIGH CEMENT CONTENT TO INCREASE CARBONATION. AND HIGH ADDED MATERIAL TO REDUCE EMBODIED CARBON.

| Mix 1 | Mix 2 | Mix 3 |
|---|---|---|
| CEM I | CEM III/73% GGBS | CEM II/ 28% N.P.Ash |
| Cement CEM I - Portland cement | Cement CEM III/B - 73% GGBS - Blast furnace cement | Cement CEM II/B-P 28% natural pozzolanic ash - Portland pozzolana cement |

<u>FIGURES ENTERED INTO THE CALCULATOR FOR EACH MIX TYPE.</u>
CEMENT QUANTITY: 290 KG PER M3
WATER TO CEMENT RATIO: 0.5
WATER QUANTITY: 145KG PER M3
AGGREGATES QUANTITY: 1825 KG PER M3
TOTAL MATERIAL QUANTITY: 2260KG PER M3
PRECAST CONCRETE
STEEL REINFORCEMENT: 100KG PER M3
EMBODIED CARBON FACTOR: EUROPE RECYCLED
DELIVERY DISTANCE: 32KM

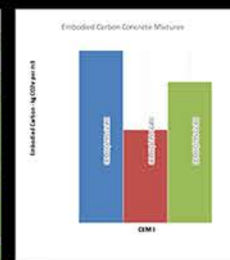
3. RESULTS - Summary Calculations

Embodied carbon factor for cement

| | Mix 1 | Mix 2 | Mix 3 |
|---|---|---|---|
| Embodied carbon factor - CEMENT - kg CO2e/kg | 0.91 | 0.28 | 0.66 |

Concrete calculations - Embodied Carbon Contribution - kg CO2e / m3 concrete

| Material | Embodied Carbon Factor - kg CO2e / kg | Mix 1 CEM I | Mix 2 CEM III/73% GGBS | Mix 3 CEM II/ 28% N.P.Ash |
|---|---|---|---|---|
| Cement | See above | 264.5 | 80.6 | 192.0 |
| GGBS | 0.04 | - | - | - |
| Fly ash | 0.00 | - | - | - |
| Limestone fines | 0.02 | - | - | - |
| Water | 0.00 | 0.0 | 0.0 | 0.0 |
| Admixture | See Below | - | - | - |
| Aggregates | 0.007 | 13.6 | 13.6 | 13.6 |
| Transport of constituents | 0.004091322 | 11.28 | 11.28 | 11.28 |
| Concrete batching plant operations | 0.0007 | - | - | - |
| W/R mixing waste | 1.0% | 2.89 | 1.06 | 2.17 |
| Precasting | 0.0142 | 32.08 | 32.08 | 32.08 |
| Steel reinforcement | See below | 73.00 | 73.00 | 73.00 |
| Transport to site | [illegible] | 6.99 | 6.99 | 6.99 |
| RESULTS - kg CO2e / m3 concrete | | 406 | 219 | 331 |
| RESULTS - kg CO2e / kg concrete | | 0.179 | 0.097 | 0.147 |




CARBONATION CALCULATOR

USING THE SAME 3 MIXES. I USED THE CARBONATION CALCULATOR TO DERIVE THE CARBON ABSORPTION CAPACITY OF THE MIXES. THE THREE CONTRASTING MIXES RESULTED IN VARYING CARBONATION RATES. WHICH I CALCULATED BASED ON A TIME SPAN OF 50 YEARS. GIVEN THE HIGH EMBODIED ENERGY OF CEMI. I CALCULATED THE CARBONATION POTENTIAL OF THE FACADE PANEL USING CEMI TO ASSESS IF THE CARBONATION RATE IS HIGH ENOUGH TO JUSTIFY ITS USE. CEM III WITH 73% GGBS HAD THE LOWEST EMBODIED CARBON AND I CALCULATED ITS CO2 ABSORPTION CAPACITY TO DETERMINE IF IT HAS A HIGH CARBONATION RATE. WHICH WOULD MAKE THIS THE MOST ENVIRONMENTAL CHOICE OF MIX. MIX 3. CEMII WITH NATURAL POZZOLANIC ASH IS THE MEDIAN BETWEEN THESE TWO MIXES AND I CALCULATED THE CARBONATION OF THIS MIX TO DETERMINE IF AN IDEAL BALANCE BETWEEN EMBODIED ENERGY AND CARBON ABSORPTION CAN BE ACHIEVED WITH THIS MIX. FROM THE ICE EMBODIED CARBON CALCULATOR AND CARBON CALCULATOR I WILL DETERMINE THE MOST SUSTAINABLE MIX.

| Element | Cement Type (influences correction factor depending on cement additives) | Strength Class (based on use - see Tab 2) | Mass of cement clinker per m3 concrete based on strength class (See Tab 2) | Percentage of alternative cementitious material based on cement type (See Tab 1) | Mass of Portland Cement Clinker (assuming CEM I = 95% Portland Cement) Cc = C - (C x (AC/100)) | Mass fraction of CaO in clinker | Exposure (see Tab 3) | Carbonation rate (CEM1) based on strength and exposure mm/year (see Tab 3) | Correction Factor to CEM1 rate based on cement additives (see Tab 4) | Corrected carbonation rate | Degree of Carbonation (from Tab 3) | Maximum Theoretical CO2 Uptake (in EN 16757) gCO2/kg (Portland cement in CEM I = 0.95) Utcc = (0.95 (AC/100)) x CaO x (Mco2/MCaO) | Time (in years) | Depth of Carbonation mm d = Kc x √T | Estimated CO2 uptake kg/m2 during T years CO2/m2 = ((d/1000) x Utcc x C x Dc) | Surface area (m2) | CO2 sequestered CO2kg/element = a x CO2kg/m2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | C | AC | Cc | CaO | | k | f | Kc = k(f) | Dc | Utcc | T | d | CO2kg/m2 | a | CO2 kg / element |
| Façade Panel Opt1 | CEM I. Ordinary Portland Cement (OPC) | C28/35 | 290 | 0 | 290 | 0.65 | Outdoor Exposed | 1.1 | 1 | 1.1 | 0.85 | 0.48 | 50 | 7.8 | 0.93 | 24.8 | 23.04 |
| Façade Panel Opt 2 | CEM III/B - 73% GGBS | C28/35 | 290 | 73 | 78 | 0.65 | Outdoor Exposed | 1.1 | 1.3 | 1.43 | 0.85 | 0.11 | 50 | 10.1 | 0.28 | 24.8 | 6.94 |
| Façade Panel 3 | CEM II/B-P 28% natural pozzolanic ash | C28/35 | 290 | 28 | 209 | 0.65 | Outdoor Exposed | 1.1 | 1.05 | 1.155 | 0.85 | 0.34 | 50 | 8.2 | 0.69 | 24.8 | 17.04 |

THE AMBITIONS OF THIS STUDY WAS TO EXPLORE HOW THE NATURAL CARBONATION OF CONCRETE CAN BE CAPITALISED TO SHIFT THE NATURE OF CONCRETE FROM A CARBON EMITTER TO A MORE POSITIVE. CO$_2$ ABSORBING BUILDING MATERIAL. I FOCUSED ON DESIGNING A SUSTAINABLE CONCRETE FACADE PANEL. WITH THE AIM OF REACHING MAXIMUM CARBONATION AND MINIMUM EMBODIED CARBON TO REDUCE ENVIRONMENTAL IMPACT. VARIOUS METHODS WERE USED THROUGH THE PROCESS TO EXPLORE THE OBJECTIVES AND ACHIEVE THE END DESIGN OF THE FACADE PANEL. THE STUDY OF PREVIOUS RESEARCH PAPERS. A FORMWORK AND CASTING WORKSHOP. CONTINUOUSLY IMPROVING CARBONATION AND EMBODIED CARBON CALCULATORS. RESEARCH INTO CONCRETE MIXES. 3D MODELLING. TECHRETE SITE VISIT AND VARIOUS OTHER MODES OF EXPLORATION WERE USED WITH TRIAL AND ERROR TO ACHIEVE AN OPTIMUM BALANCE FOR A CONCRETE FACADE PANEL.

THE FINAL FACADE PANEL ACHIEVES AN OPTIMUM SURFACE AREA OF 24.8M$^2$. AN 82.2% INCREASE ON THE SURFACE AREA. A MINIMUM VOLUME OF 1.3M$^3$ WAS ALSO ACHIEVED BY USING AN ENCLOSED FORMWORK AND A PANEL THICKNESS OF 75MM WITH STEEL MESH REINFORCEMENT. WITH THIS MAXIMISED SURFACE AREA AND MINIMUM VOLUME. VARIOUS CEMENT MIXES WERE TRIALLED IN ORDER TO ACHIEVE LOWEST POSSIBLE EMBODIED ENERGY. AN EMBODIED ENERGY OF 277.76CO$_2$KG OVER A 50 YEAR LIFE SPAN WAS ACHIEVED USING CEM III WITH 73% GGBS. ALTHOUGH THE CARBONATION RATE OF THIS CONCRETE MIX WAS LOWER THAN OTHER MIXES. IT WAS EXPLOITED TO ITS POTENTIAL WITH THE LARGE SURFACE AREA OF THE PANEL AND HELPED IN REDUCING THE EMBODIED CARBON OF THE FACADE PANEL. ALTHOUGH OTHER MIXES HAD HIGHER CARBON ABSORPTION ABILITIES. THE CARBONATION RATE WOULDN'T ABSORB ENOUGH CO2 OVER THE LIFE SPAN OF THE BUILDING TO JUSTIFY USING THESE MIXES.