N3XTCON

3D PRINT DEMO PROJECT

04 JAN 2024

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CRH

NCC

Henning Larsen

BIG

CONTENT

01

INTRODUCTION

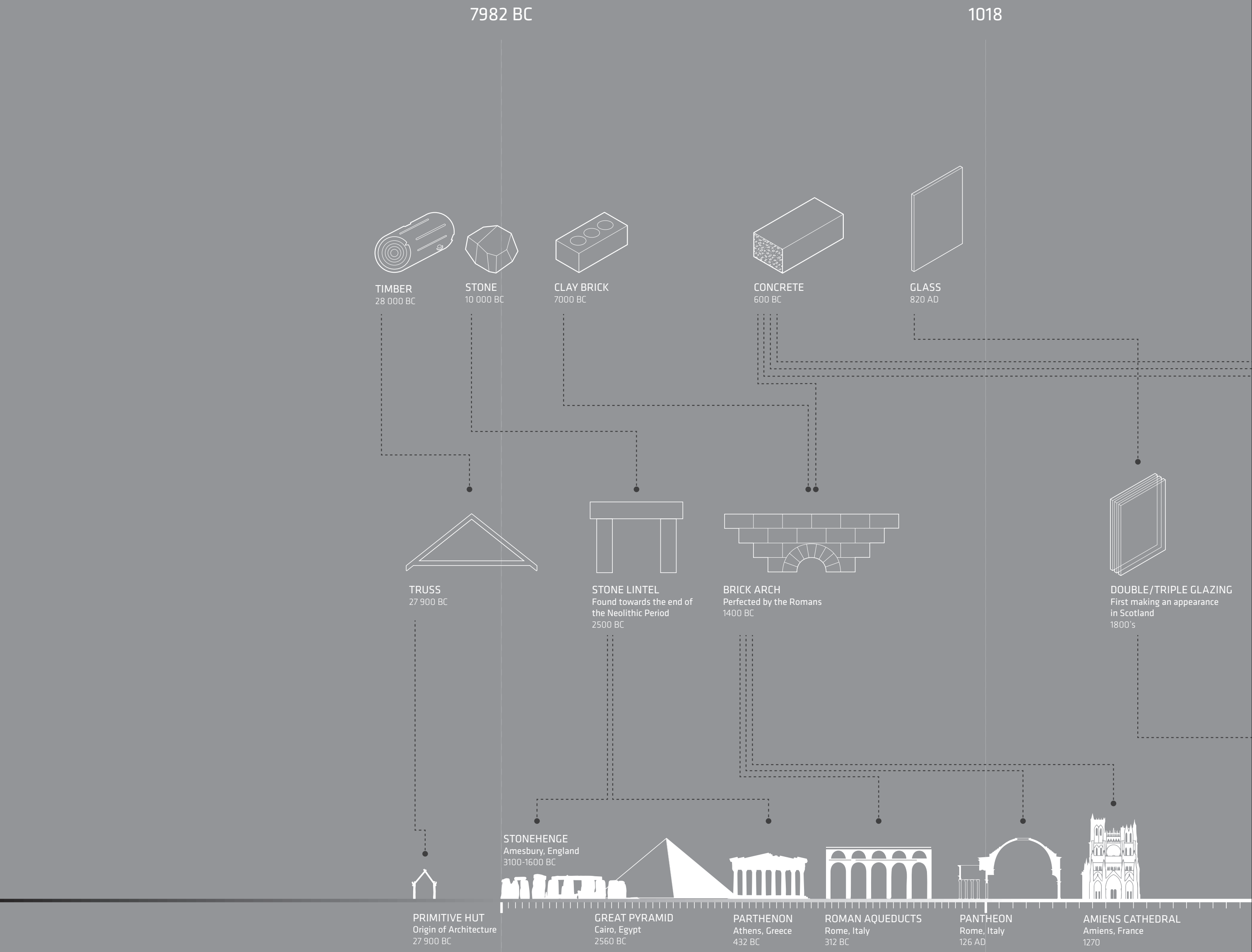
N3XTCON - NEXT GENERATION 3D-PRINTED CONCRETE STRUCTURES

N3XTCON is a project funded by Innovation Fund Denmark to develop a solution that brings 3D Concrete Printing to an industrial scale. As such, we move from the current experimental / exploration phase (i.e. small-scale demo projects without reinforcement) to a real productivity-increasing solution based on reinforced concrete.

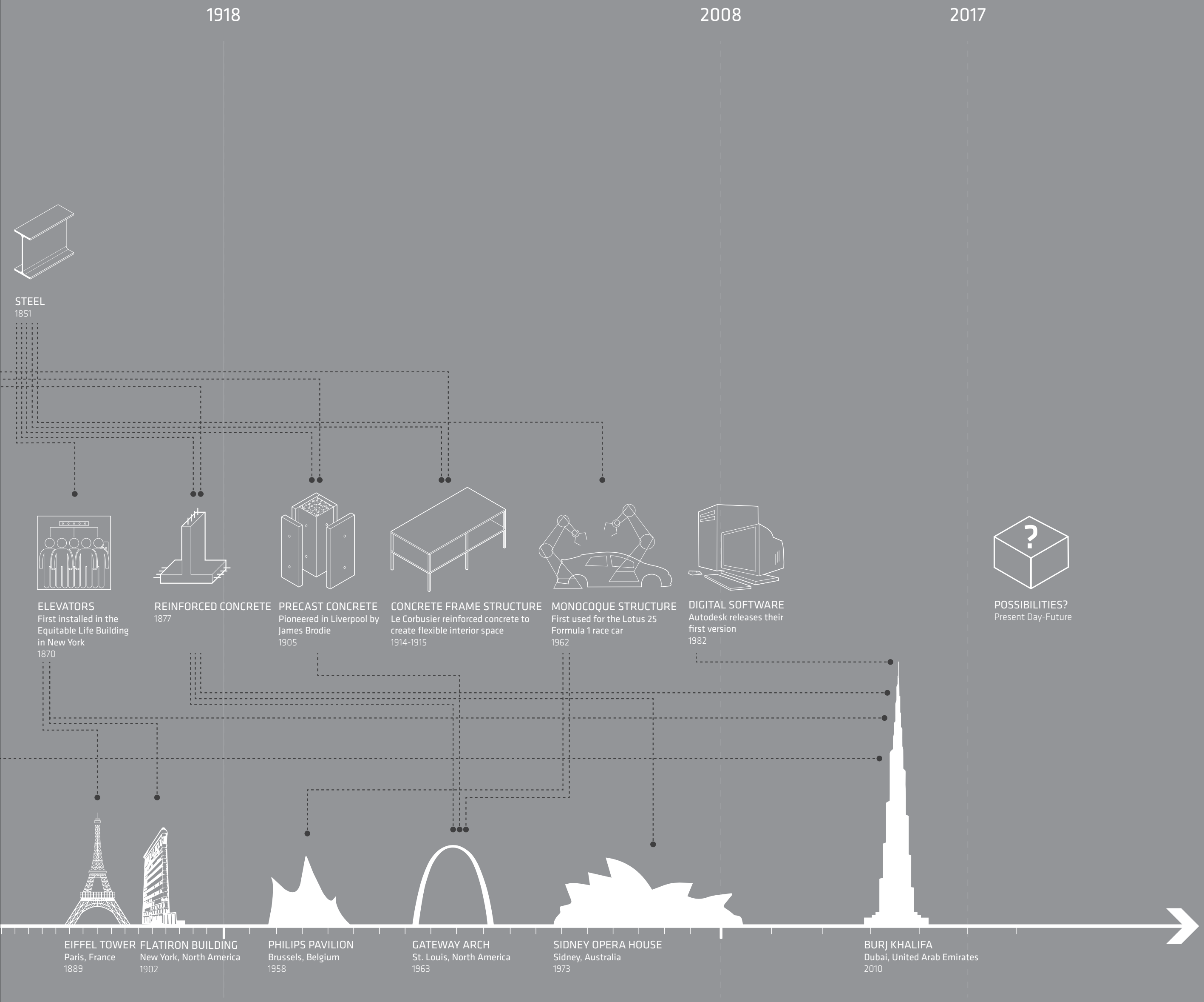
The N3XTCON industrial solution paves the way for digital fabrication of the next generation of custom-made concrete structures that offers significant material savings and new architectural opportunities – all of it at lower costs when compared to traditional construction. Our development relies on current state-of-the-art knowledge on 3DCP and creates new knowledge on, 3DCP simulation based on material and print parameters, upscaling of materials from mortar to concrete and novel reinforcement strategies for 3DCP.

**WITH EVERY TECHNOLOGY COMES A REVOLUTION,
OFTEN WHERE APPLICATION LAGS BEHIND POTENTIAL**

3D PRINTING IN CONSTRUCTION WAS FIRST EXPLORED IN THE 2000S, AND IT IS NOW THAT WE'RE SEEING FEASIBLE APPLICATIONS



7982 BC
1018
TIMBER
28 000 BC
STONE
10 000 BC
CLAY BRICK
7000 BC
CONCRETE
600 BC
GLASS
820 AD
TRUSS
27 900 BC
STONE LINTEL
Found towards the end of the Neolithic Period
2500 BC
BRICK ARCH
Perfected by the Romans
1400 BC
DOUBLE/TRIPLE GLAZING
First making an appearance in Scotland
1800's
STONEHENGE
Amesbury, England
3100-1600 BC
PRIMITIVE HUT
Origin of Architecture
27 900 BC
GREAT PYRAMID
Cairo, Egypt
2560 BC
PARTHENON
Athens, Greece
432 BC
ROMAN AQUEDUCTS
Rome, Italy
312 BC
PANTHEON
Rome, Italy
126 AD
AMIENS CATHEDRAL
Amiens, France
1270


1918
2008
2017
STEEL
1851
ELEVATORS
First installed in the Equitable Life Building in New York
1870
REINFORCED CONCRETE
1877
PRECAST CONCRETE
Pioneered in Liverpool by James Brodie
1905
CONCRETE FRAME STRUCTURE
Le Corbusier reinforced concrete to create flexible interior space
1914-1915
MONOCOQUE STRUCTURE
First used for the Lotus 25 Formula 1 race car
1962
DIGITAL SOFTWARE
Autodesk releases their first version
1982
?
POSSIBILITIES?
Present Day-Future
EIFFEL TOWER
Paris, France
1889
FLATIRON BUILDING
New York, North America
1902
PHILIPS PAVILION
Brussels, Belgium
1958
GATEWAY ARCH
St. Louis, North America
1963
SIDNEY OPERA HOUSE
Sidney, Australia
1973
BURJ KHALIFA
Dubai, United Arab Emirates
2010


COBOD
SPEC OPS

ITS ADVANTAGES LIE IN REDUCING HUMAN LABOR WHILE INCREASING PRECISION AND SPECIFICITY

IN A MARKET DRIVEN BY ECONOMIES OF SCALE, WHERE PROFIT IS ONLY FOUND IN BULK...

**...WE ARE EXPLORING A NEW MODULARITY,
A BESPOKE KIT OF PARTS WITH THE FLEXIBILTY
TO ADAPT TO ANY CONDITION**

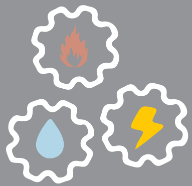
02 ADVANTAGES

Concrete, surpassing steel and wood in versatility, offers a globally available and cost-effective material. Its thermal mass behaviour curtails long-term energy costs and diminishes transportation expenses and associated CO_2 emissions.
Combining concrete with 3D printing technology, exemplified by 3DCP, amplifies its inherent advantages. This construction approach enhances efficiency and minimizes physical labour, formwork, and waste, ultimately offering intensified design flexibility.
Concrete and 3D printing synergy showcases a sustainable and innovative solution with far-reaching implications for diverse applications. As a locally accessible resource worldwide, concrete, when harnessed through 3D printing, emerges as a powerful catalyst for efficient, eco-friendly construction practices, redefining the landscape of contemporary building methodologies.

CONCRETE AS A MATERIAL

Concrete stands out for its strength, durability, resilience, and safety. It adapts easily to various geometries through its fluidity and form works, fulfilling desired shapes. On average, the longevity of concrete buildings falls between 50 to 80 years.

Concrete production is more energy-efficient than steel, and although initial construction costs might exceed those of wood or steel, concrete structures offer long-term energy savings.



DURABILITY,
RESILIENCE, SAFETY

FORM VERSATILITY

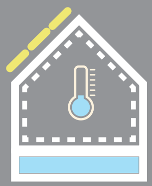
50-80 YEAR
LIFESPAN

LONG-TERM ENERGY
SAVINGS COMPARED TO
WOOD/STEEL

LOWER ENERGY
COMPARED TO STEEL

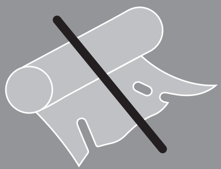
CONCRETE PROPERTIES

When taking the performance of a building over its whole life cycle into account, concrete offers significant sustainability benefits over other building materials thanks to its innate properties, such as its durability, resilience, thermal mass, recyclability, carbon uptake and local availability. These attributes translate into tangible benefits: reduced energy consumption, significant carbon savings during transportation, minimized use of raw materials such as steel leading to decreased waste, and lowered construction costs; all collectively underscore concrete's environmentally conscious and economically viable character.



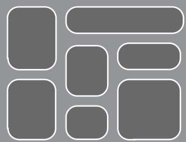
THERMAL MASSING

LOCAL AVAILABILITY



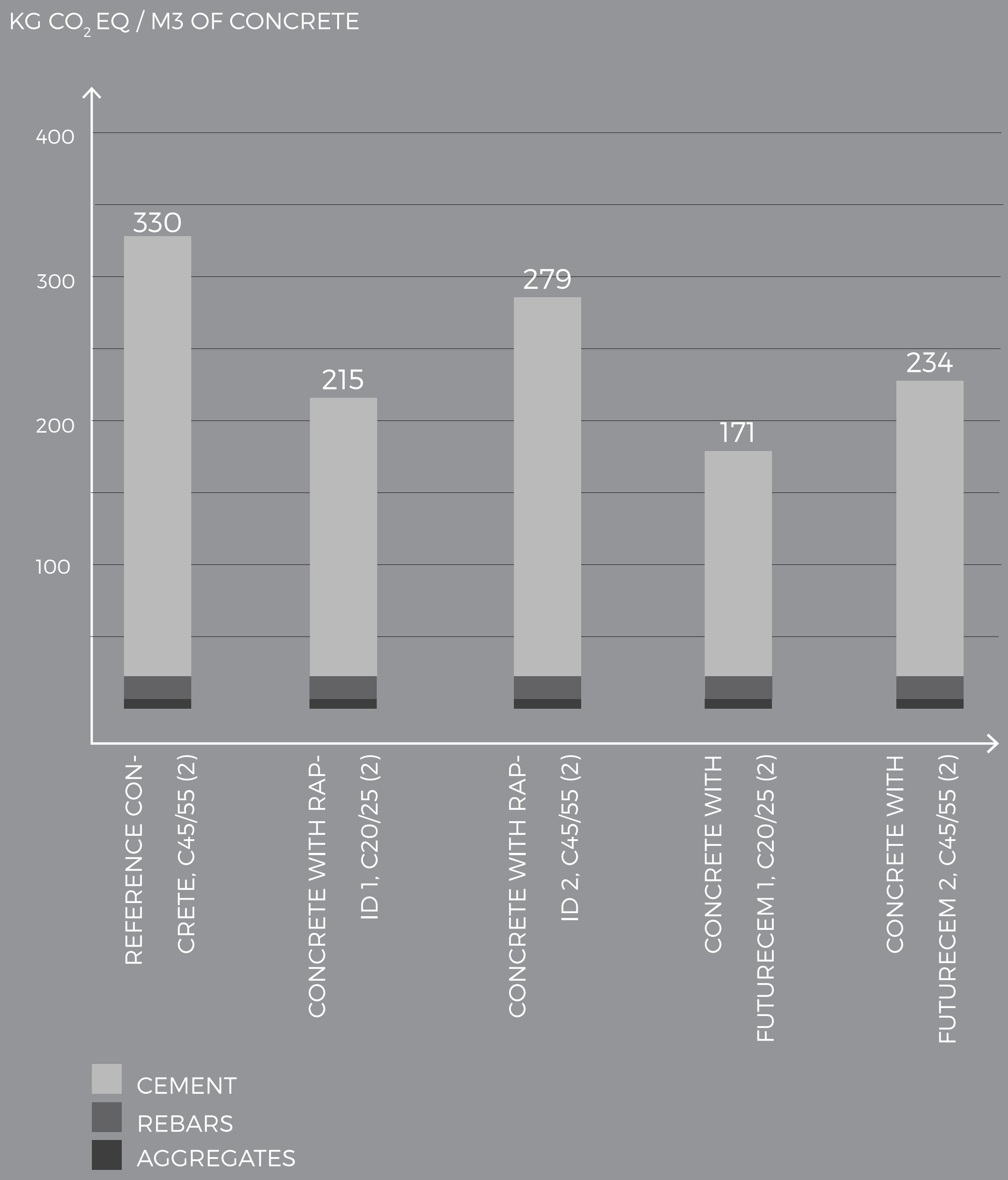
INNER ENVIRONMENT
NO USE OF PLASTIC

RECYCLING
AND RESUSING



STEEL REDUCTION

CONCRETE SUSTAINABILITY

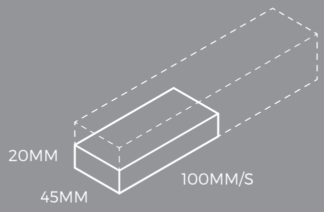


KG CO_2 EQ / M3 OF CONCRETE
400
300
200
100
330
215
279
171
234
REFERENCE CON-
CRETE, C45/55 (2)
CONCRETE WITH RAP-
ID 1, C20/25 (2)
CONCRETE WITH RAP-
ID 2, C45/55 (2)
CONCRETE WITH
FUTURECEM 1, C20/25 (2)
CONCRETE WITH
FUTURECEM 2, C45/55 (2)
CEMENT
REBARS
AGGREGATES

When comparing the global warming potential (GWP) of FutureCem to more typical types of concrete, we can see a noticeable reduction in GWP due to the difference in cement.

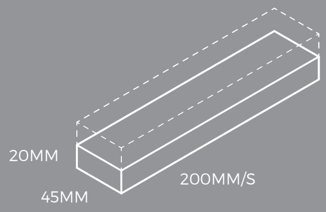
GLOBAL WARMING POTENTIAL

1M3 CONCRETE
/ 185 MIN



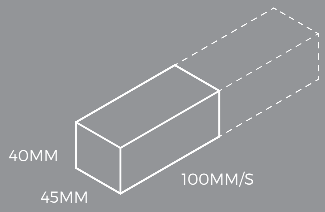
13 KG CO2 EQ /
M3 CONCRETE

1M3 CONCRETE
/ 93 MIN



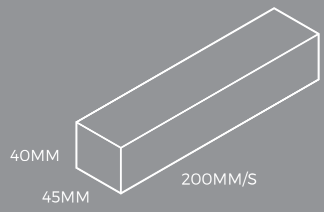
7 KG CO2 EQ /
M3 CONCRETE

1M3 CONCRETE
/ 93 MIN



7 KG CO2 EQ /
M3 CONCRETE

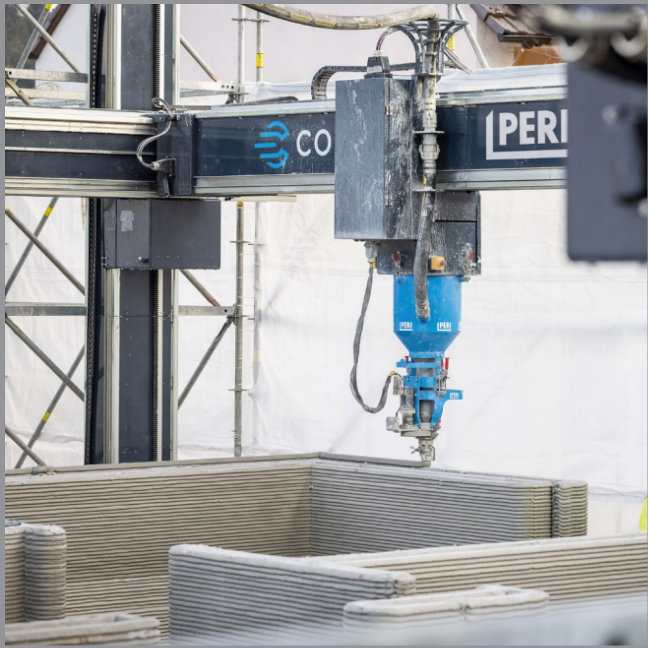
1M3 CONCRETE
/ 46 MIN



3 KG CO2 EQ /
M3 CONCRETE

Although printing fast might use more energy, it does mean that the gantry printer would run for a shorter period of time. This leads to lower carbon emissions.

PRE-CAST VS PRINTED CONCRETE



PRECAST CONCRETE
GWP

291 KG CO2 EQ / M3 CONCRETE

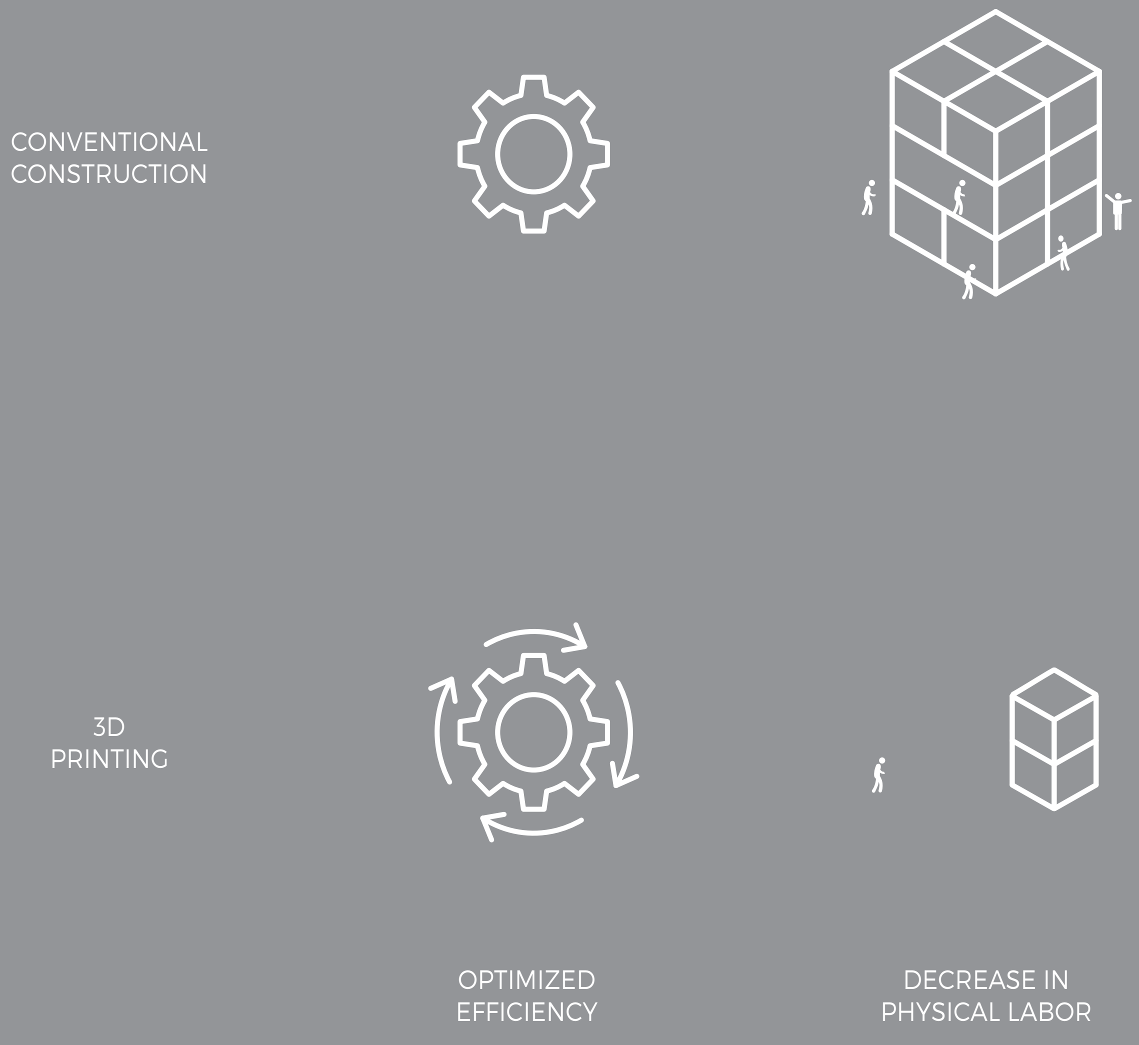
GANTRY PRINTED CONCRETE
GWP

264 KG CO2 EQ / M3 CONCRETE*

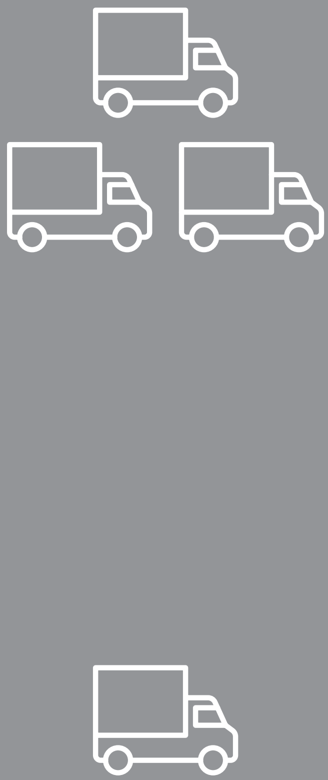
* Numbers to be reduced further

Given the same amount of reinforcement, the Global Warming Potential of precast concrete is compared to that of 3D printed concrete using a gantry robotic printer. The concrete type used for our study is Generic, C20/25, precast concrete representative for Europe (1).

PRE-CAST VS PRINTED CONCRETE


CONVENTIONAL CONSTRUCTION
3D PRINTING
OPTIMIZED EFFICIENCY
DECREASE IN PHYSICAL LABOR

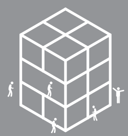
REDUCED WASTE
FROM FORMWORK



REDUCED
TRANSPORTATION

MORE DESIGN
FLEXIBILITY

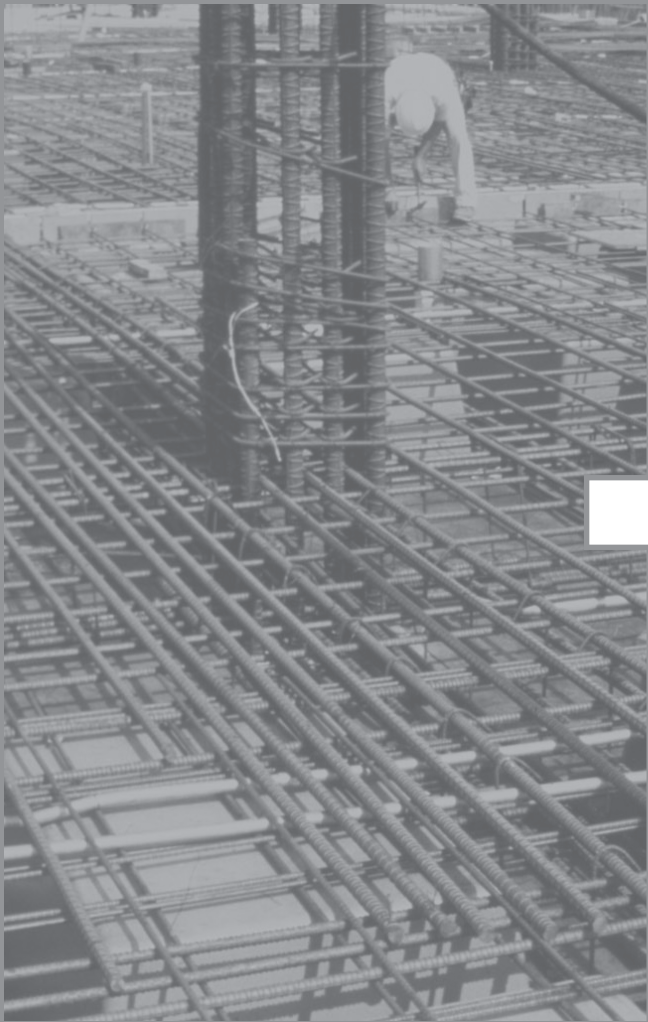
OPTIMIZED EFFICIENCY



DECREASE IN PHYSICAL LABOR

REDUCED WASTE FROM FORMWORK

REDUCING TRANSPORTATION



DESIGN FLEXIBILITY

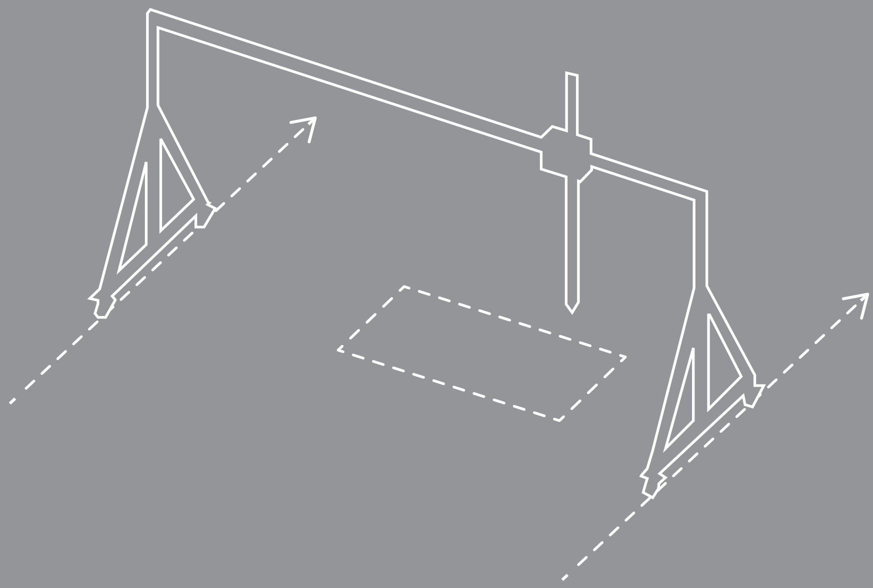
03

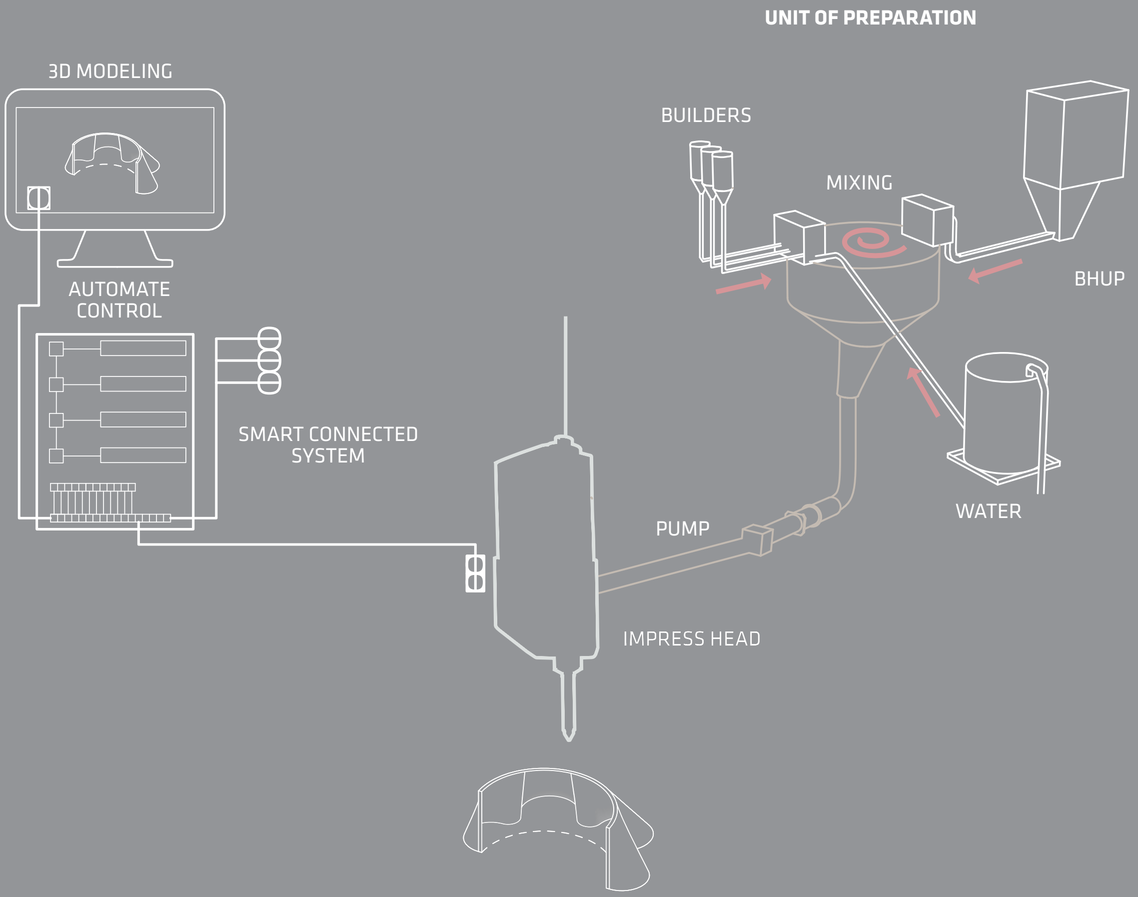
PROCESS AND GUIDELINES

To print concrete structures using a gantry crane robotic printer, we first derive the g-code from our 3D models. This is done through an intelligent connected system that automates the process. While this is happening, the concrete is prepared and the mixture is pumped from the concrete mixer to the print head. At the print head, a screw controls the amount of concrete extruded for a precise and uniform finish as the tool head moves along the three axes.

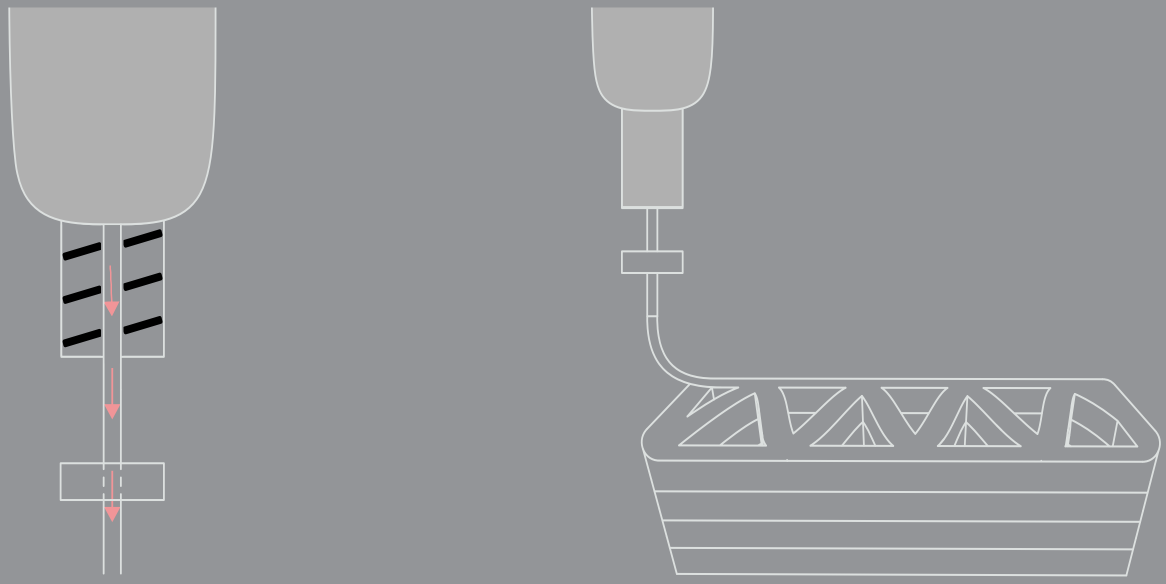
The gantry printing process results in a set of design guidelines and recommendations for an optimal print. While this process offers many new design opportunities, we must adapt our geometries to the principles and constraints that come with it.

GANTRY CRANE ROBOTIC PRINTER



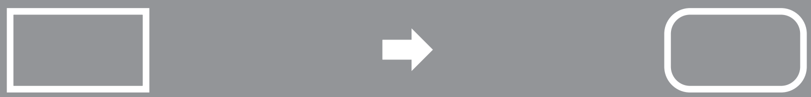


PRINTING PROCESS



PRINTING PROCESS

Due to the nozzle geometry and printing motion, it is recommended to avoid sharp corners and use a minimum radius equal to the printhead diameter.



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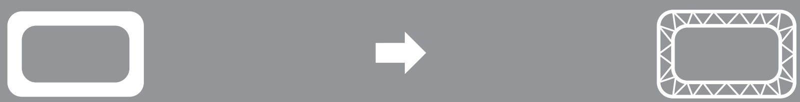
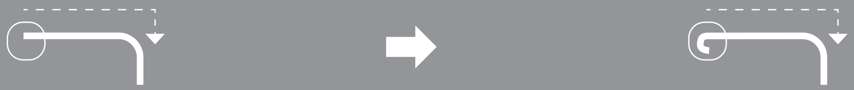
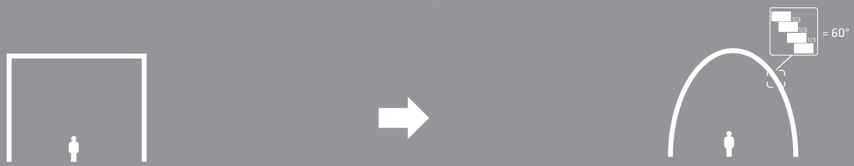


For more efficient structures, 3D printing enables designers to replace solid infills with more optimized, lightweight ones.

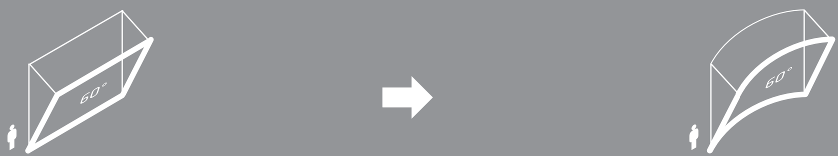
DESIGN GUIDELINES



It is advised to locate the layer start and end points on the inner (hidden) sides of the walls since these locations are prone to over and under extrusion.



Achieving a closed top is only possible if we follow a curved section that would ideally be sloped less than 60˚.



To structurally optimize geometries with slanted sections, curving them in plan could provide reinforcement.

DESIGN GUIDELINES

EXPRESSION 04

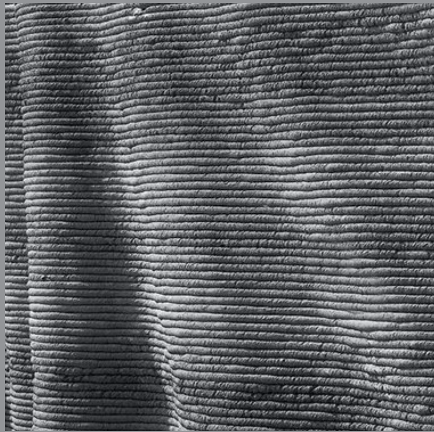
The expression of the prints can vary based on the material and the process of printing. Not only can we change the colors and intensities of the concrete, but 3D printing also offers the advantage of creating gradients in the concrete based on the order that the mixtures are poured in.

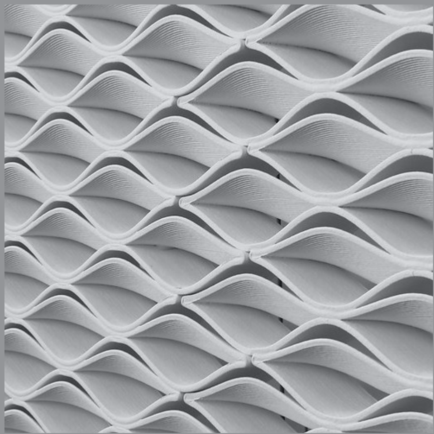
The surface texture and geometry could also be customized by editing some printing parameters. By varying parameters such as speed and toolpath, we can achieve variations of the regular layering that 3D printing offers.

COLOR + GRADIENT

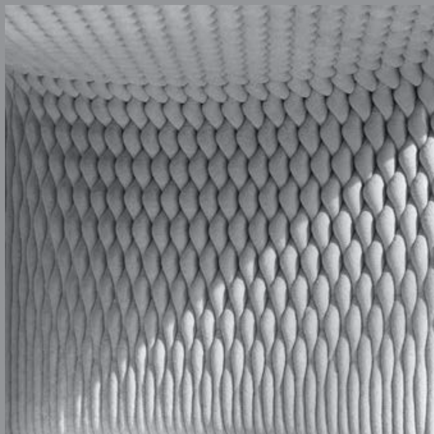
TEXTURES + PATTERNS











05

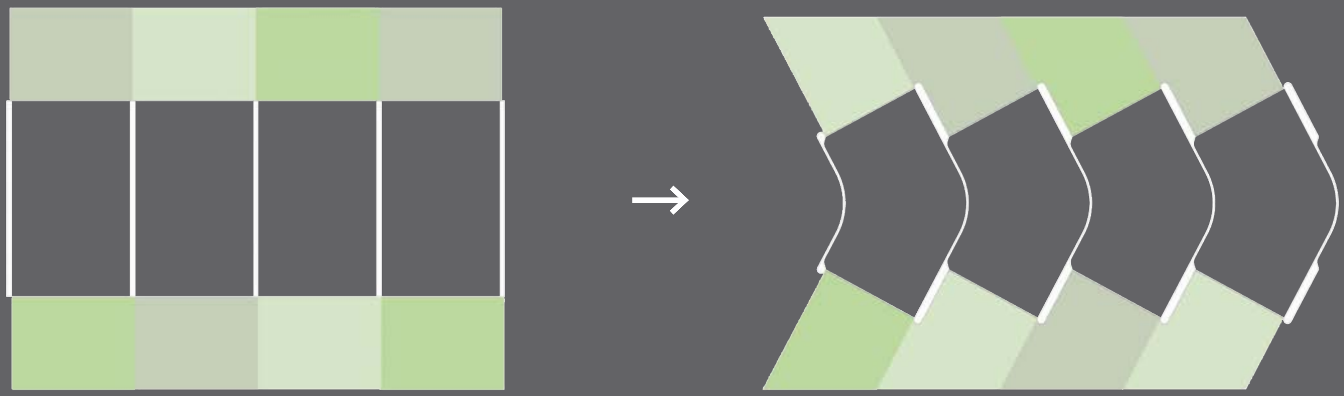
ON-SITE PRINT

HENNING LARSEN

The proposal for an on-site 3D-printed concrete rowhouse, part of the N3XTCON innovation project, explores the fusion of aesthetics and sustainability.
The design uses simple curved wall elements to create a continuous, self-supporting structure, enhancing privacy between neighbours. The layout features an open-plan ground floor for kitchen and living functions, with bedrooms on the upper floor.
A 3D-printed curved staircase connects the floors, allowing circulation between 3D-printed services and spaces. Printing on-site allows the outer perimeter of slabs to be 3D-printed, minimizing concrete usage compared to traditional cast slabs.

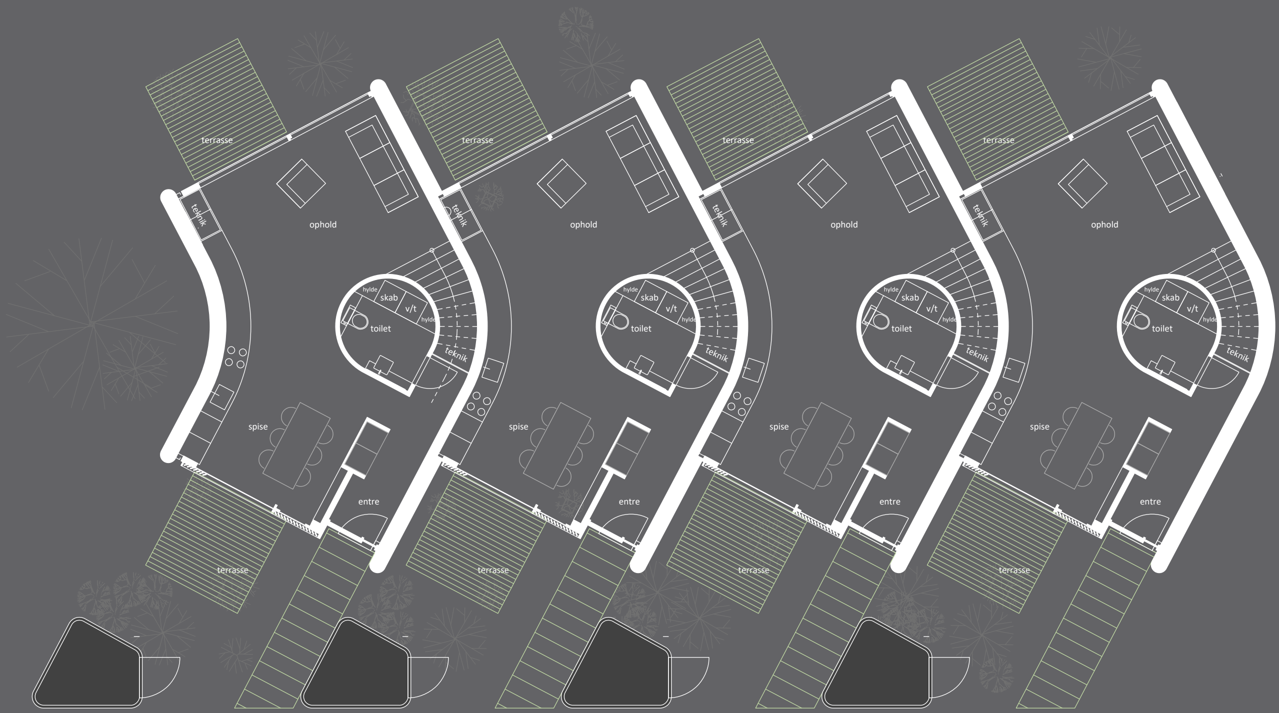
This proposal exemplifies the aesthetic potential of on-site 3D-printed concrete and underscores sustainable construction practices.

The concept revolves around showcasing the aesthetics of 3D-printed concrete with sustainable design principles. A series of simple curved wall elements form the basis of the design, creating a continuous and self-supporting structure that simultaneously creates a private sphere between neighbours.



CONCEPT


36

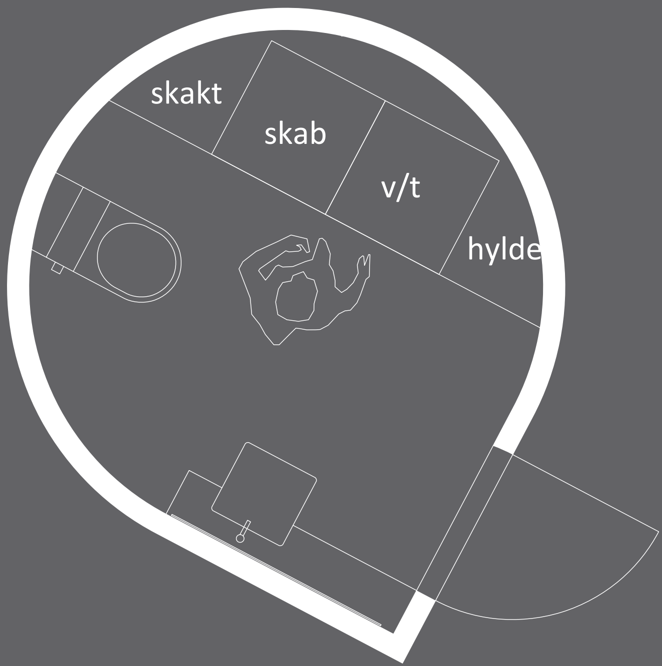


The layout of the rowhouse consists of an open plan for kitchen and living room functions on the ground floor and bedrooms on the upper floor.

PLAN

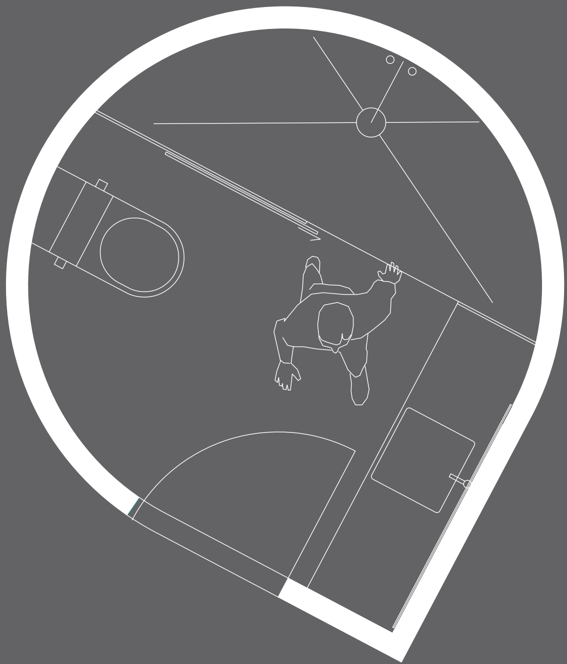
A curved staircase between the wall and toilet core makes a sculptural connection between the floors and is imagined to be 3D printed.

LIVING



Both floors have a toilet/bath core that with 3D printed layout will offer a more considerable degree of freedom in using the print to form the interior of these zones.

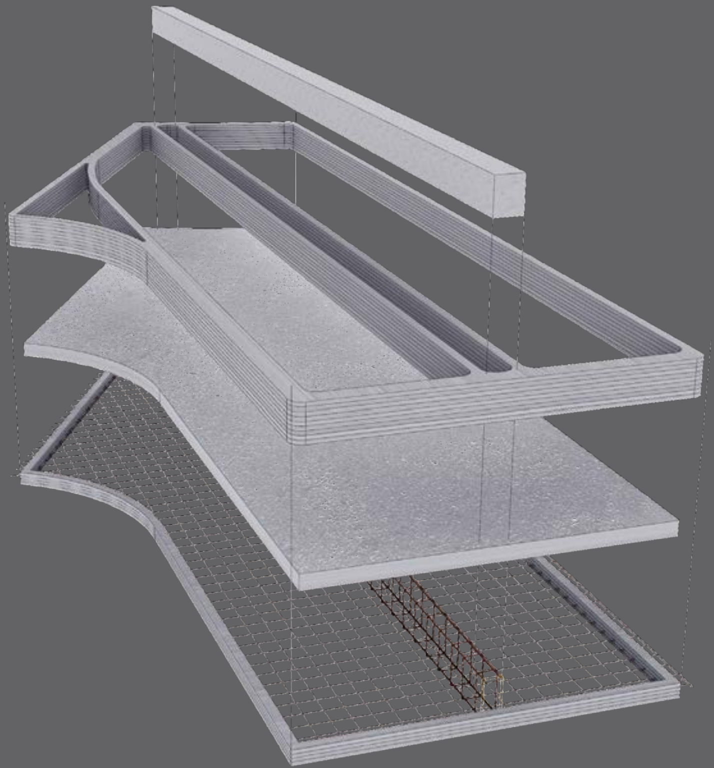
BATHROOM



Both floors have a toilet/bath core that with 3D printed layout will offer a more considerable degree of freedom in using the print to form the interior of these zones.

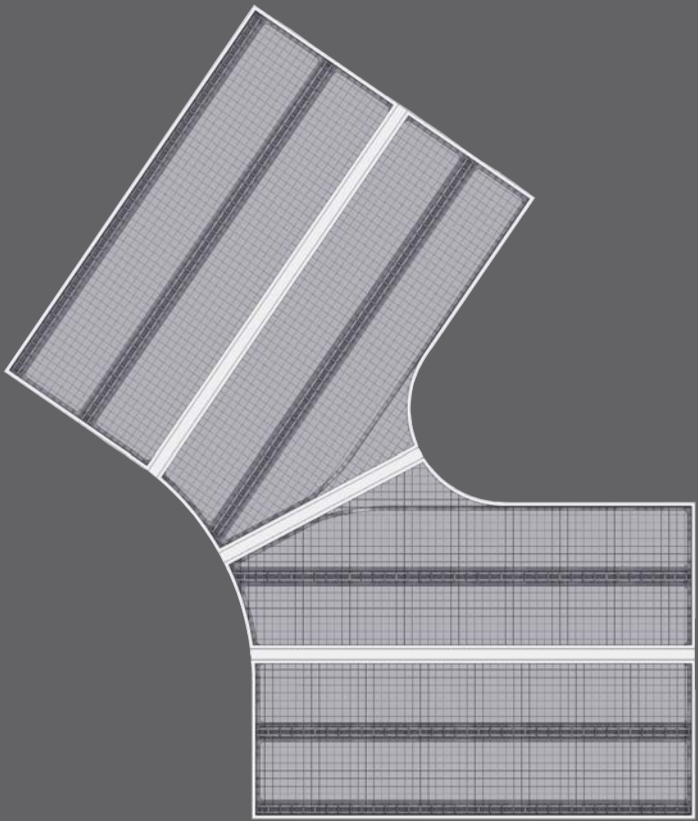
BATHROOM

The façade contains two layers of 80mm concrete with stringers for support.
Between the ground floor and the first floor, a console is placed to carry the load of the wall above and transfer it to the inner wall below.



The slabs are suggested to be built on-site near the 3D-printed house. The construction consists of a 3D-printed outer perimeter cast with concrete after setting. Therefore, the 3D prints act as formwork to minimize the concrete used compared to a traditional cast slab.

SLAB PRINCIPLE



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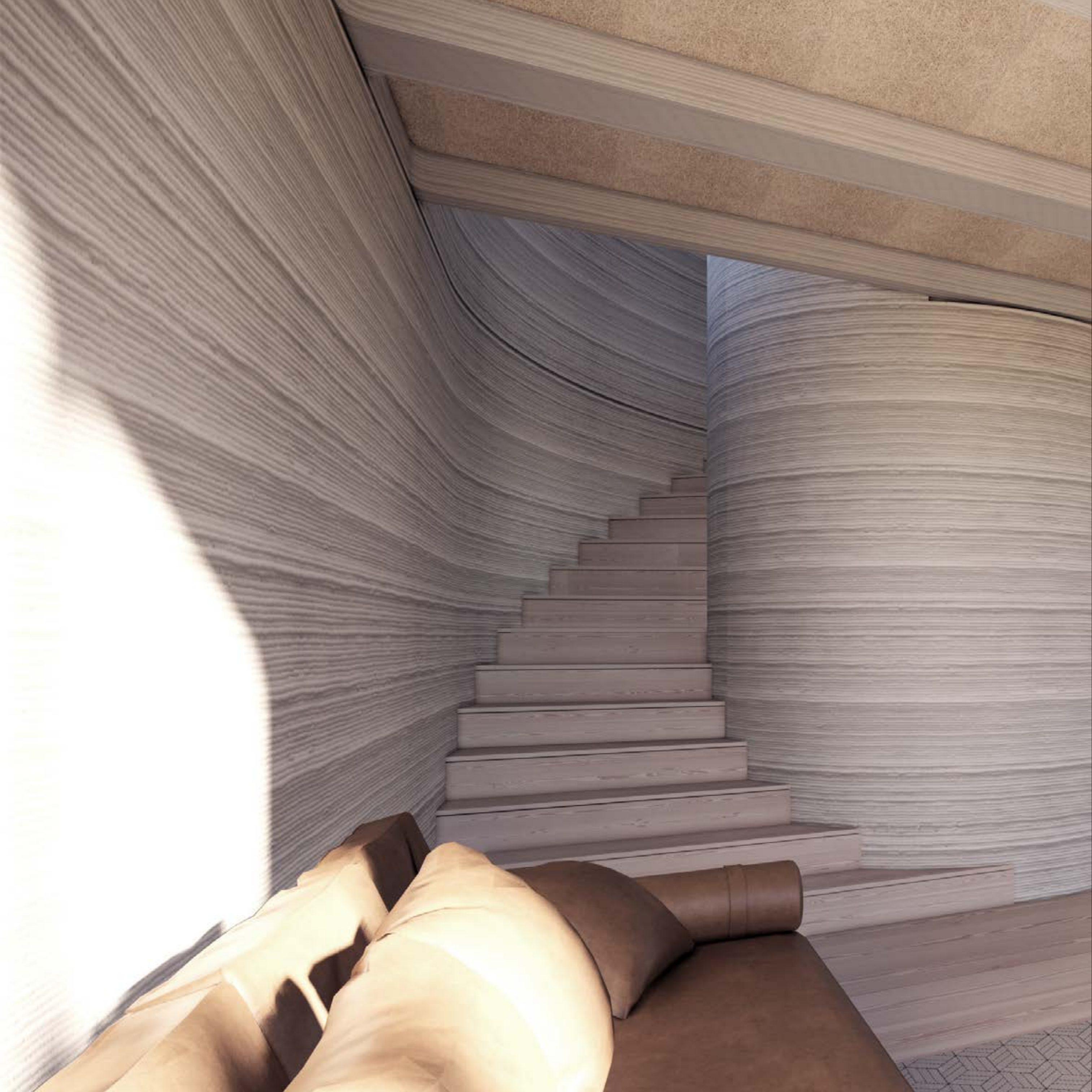


06

OFF-SITE PRINT

BJARKE INGELS GROUP

Prefabricated and modular 3D printed structures offer the combined advantages of both technologies. Due to many factors, off-site printing paves the way for faster progress during construction. While it offers some transportation constraints, we have developed a module that optimizes transportation space and weight. This innovative module not only streamlines logistics but also presents many geometric opportunities in the way it can be assembled.

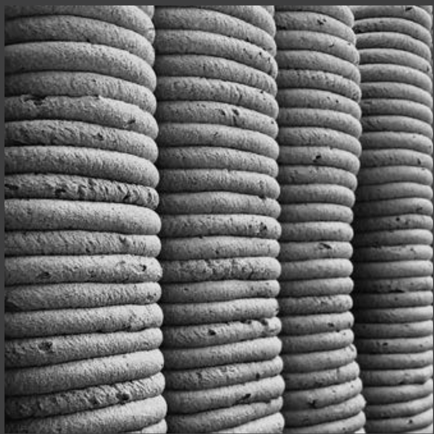
The module is designed to stack shafts and structures while integrating the columns as formwork, reducing waste. The N3XTCON pineapple complex demonstrates the project and research on off-site printing and employs these advanced units as housing modules, envisioning a sustainable and interconnected community within a 3D-printed structure.

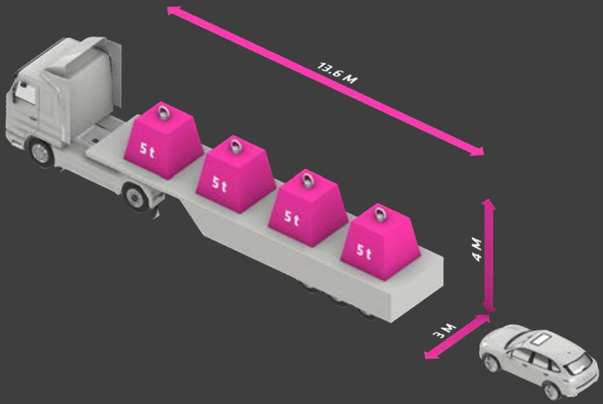
Simultaneously, completing modules and site work streamlines the construction process and minimises formwork, reducing waste production. The controlled factory environment enhances construction quality by averting weather-related delays. The swift assembly and disassembly also contribute to the ease and efficiency of construction. Moreover, off-site construction significantly curtails greenhouse gas emissions by approximately 30%. 3D printing for modules further accelerates construction, yielding substantial time and cost savings while offering more design flexibility. Incorporating eco-friendly insulation materials also has more potential for environmentally responsible design.

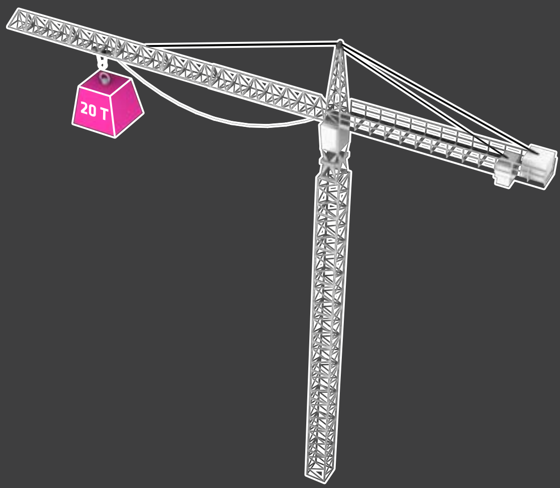






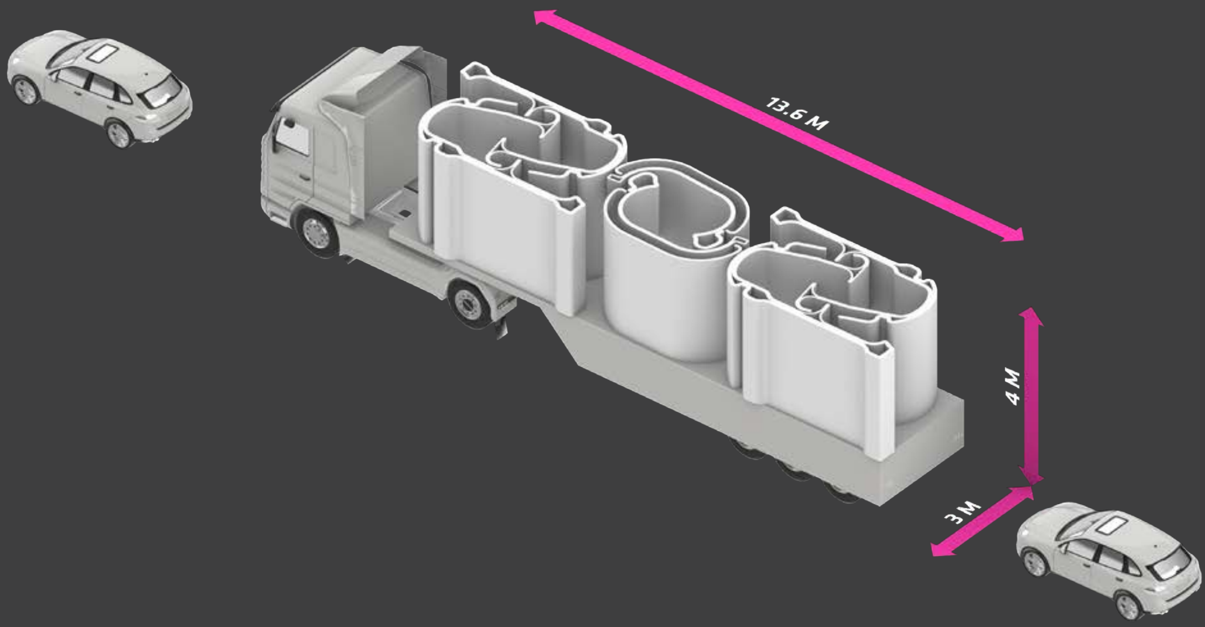





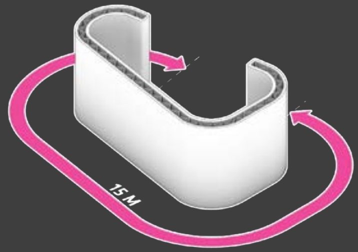
Designing with off-site printing in mind comes with some restrictions that must be considered. The units must fit within the dimensions of the vehicles. It must also respect the weight limitations of the vehicle and the crane that will be installed onsite.

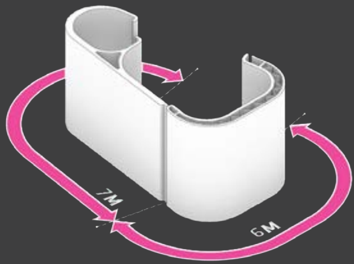
OFF-SITE CONSTRAINTS



The module outlined in the following pages is designed not only to respect transportation but also to optimize it. The module is designed in parts to fit two complete units and two halves per journey per truck.

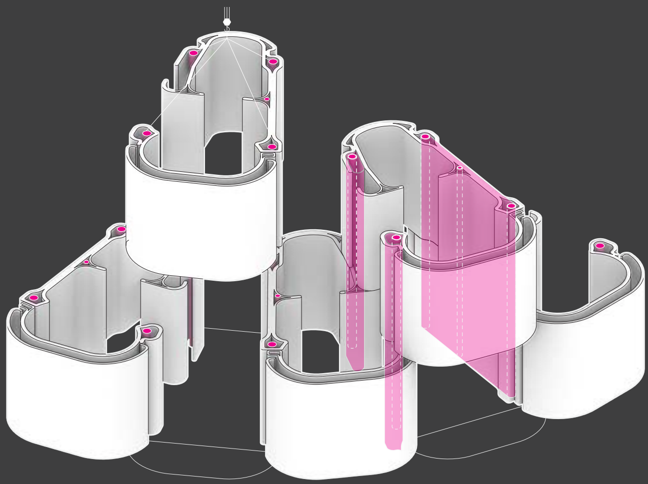
MODULE PACKING

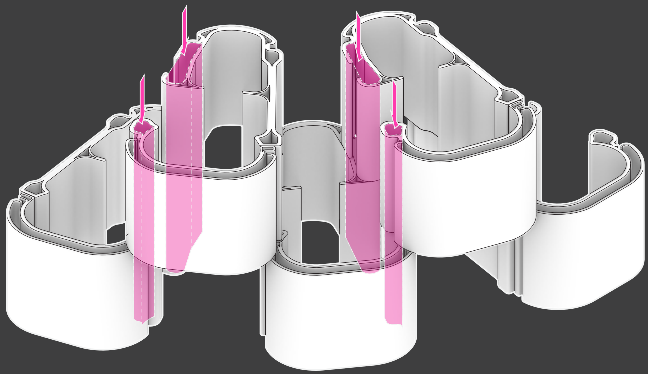




The maximum weight and print are first estimated as a straight wall. It is then curved to form an enclosed unit. The unit is then optimized, detailed and split into parts to facilitate printing and reduce transportation.

MODULE





The module is designed to stack shafts and structures. The stacking of the module also integrates the columns by acting as their formwork, further reducing waste by minimizing formwork.

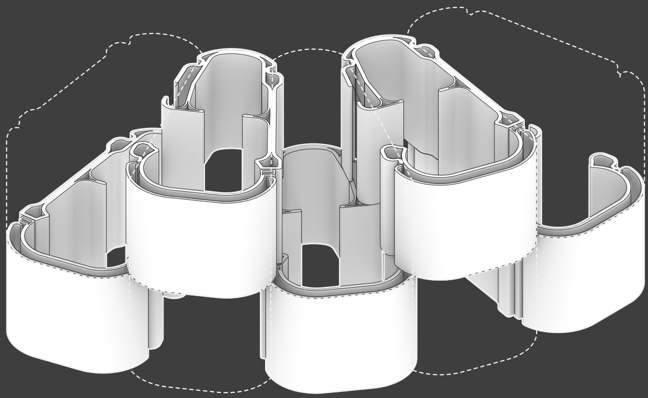
CONTINUOUS STRUCTURE

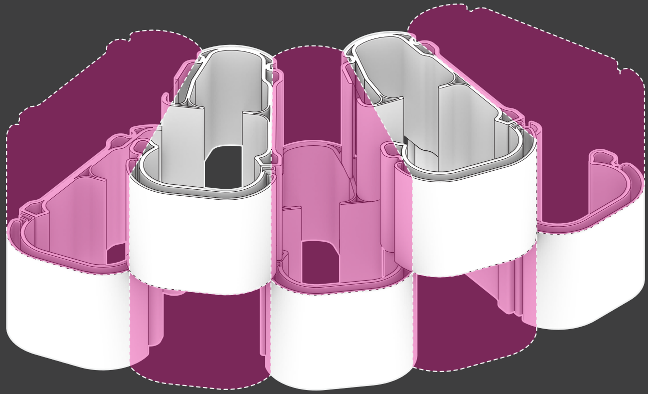
RESIDENCES

OFFICES

The spaces generated by the module offer program flexibility and can be adapted to multiple uses. We have explored the potential of these units in the examples above, both as residential units and office spaces.

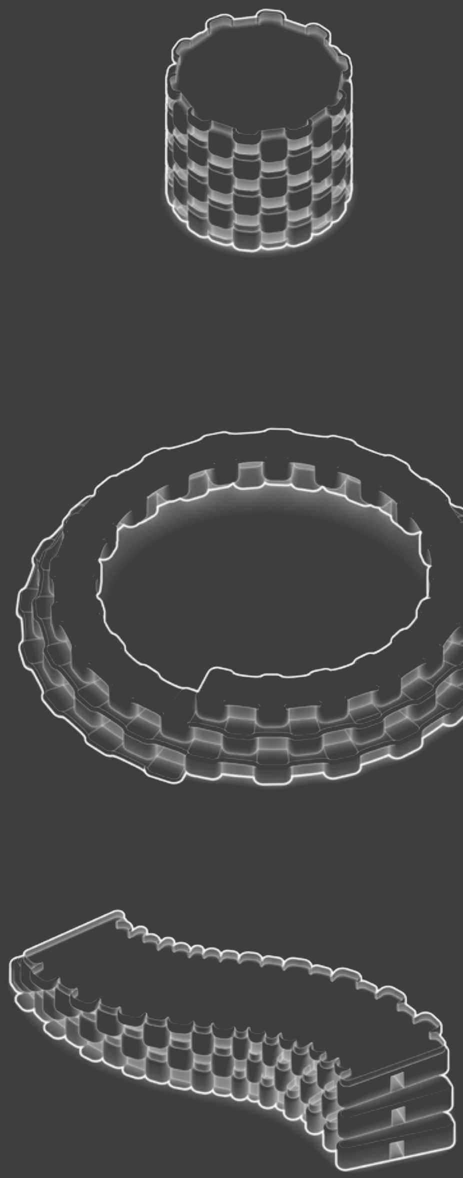
PROGRAM FLEXIBILITY





By stacking the modules in a checkerboard pattern, we can utilize the printed module and the spaces in between.We can print only half of the desired units, saving 50% of material and print time.

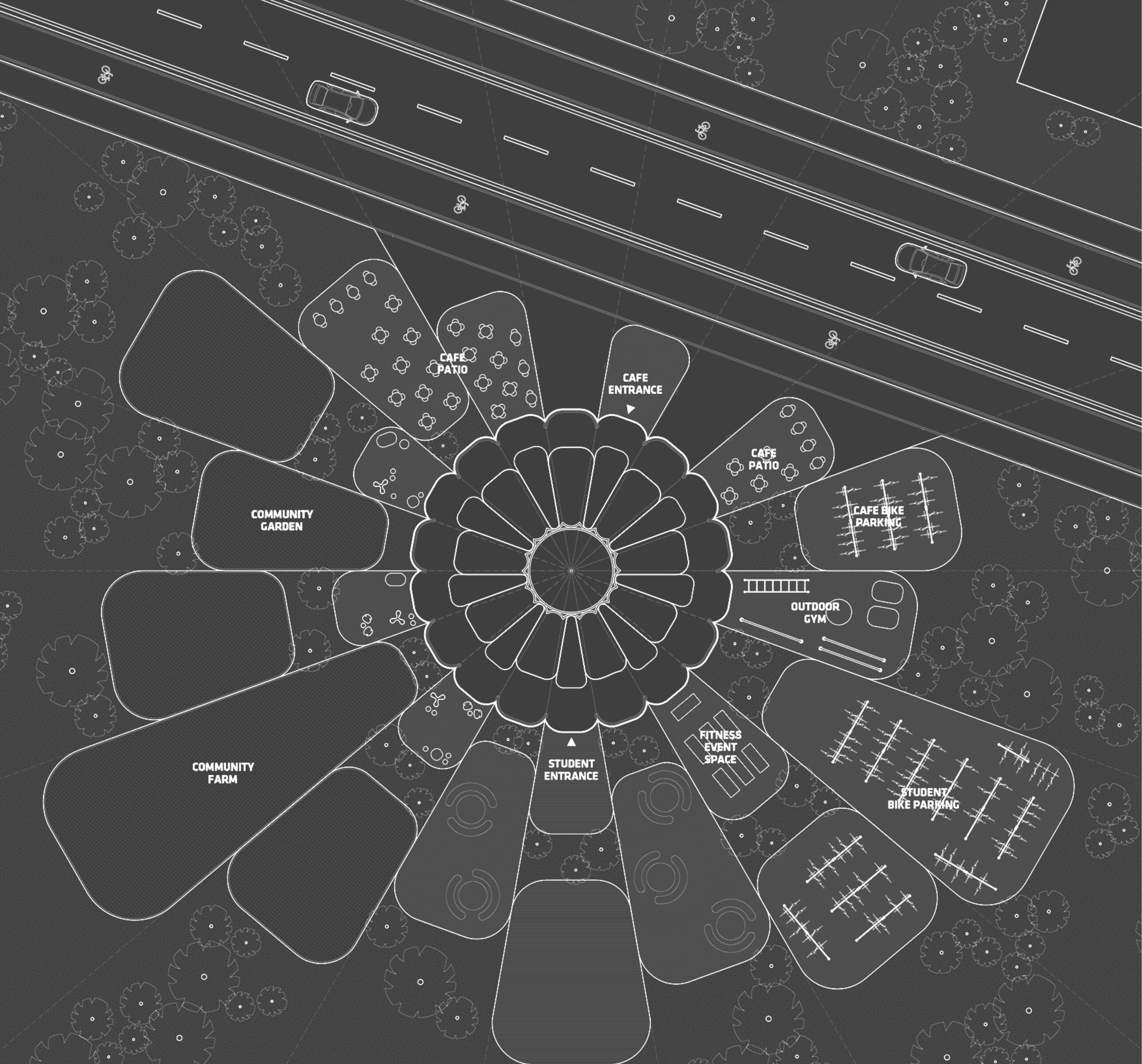
REDUCTION OF MATERIAL



DESIGN FLEXIBILITY

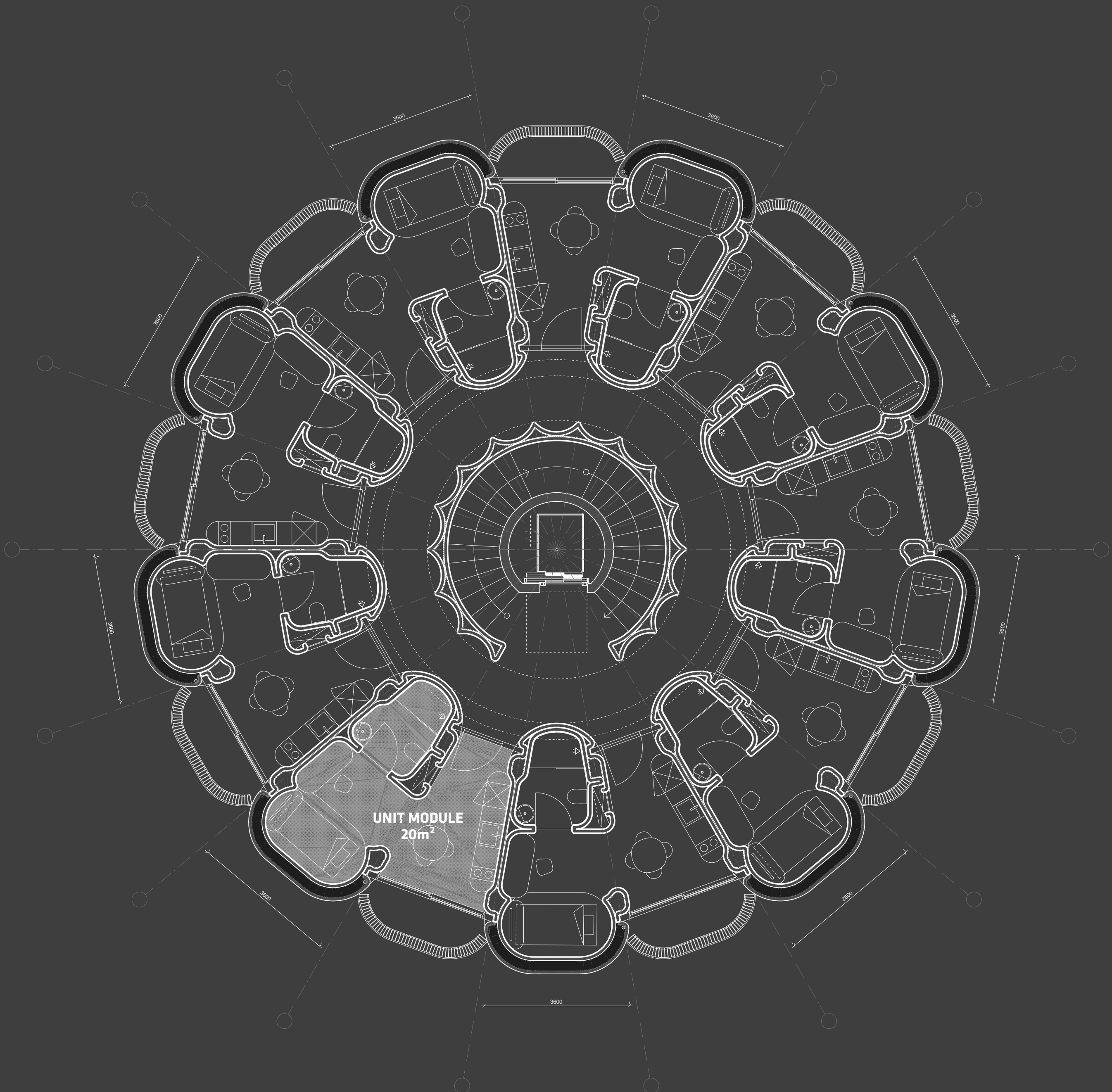
We have elaborated and explored the pineapple assembly further. The units are stacked and laid out in a radial format, and the modularity allows for various heights in the total massing. The pineapple can be prototyped at a smaller scale before its expansion into a more vertical structure.

PINEAPPLE



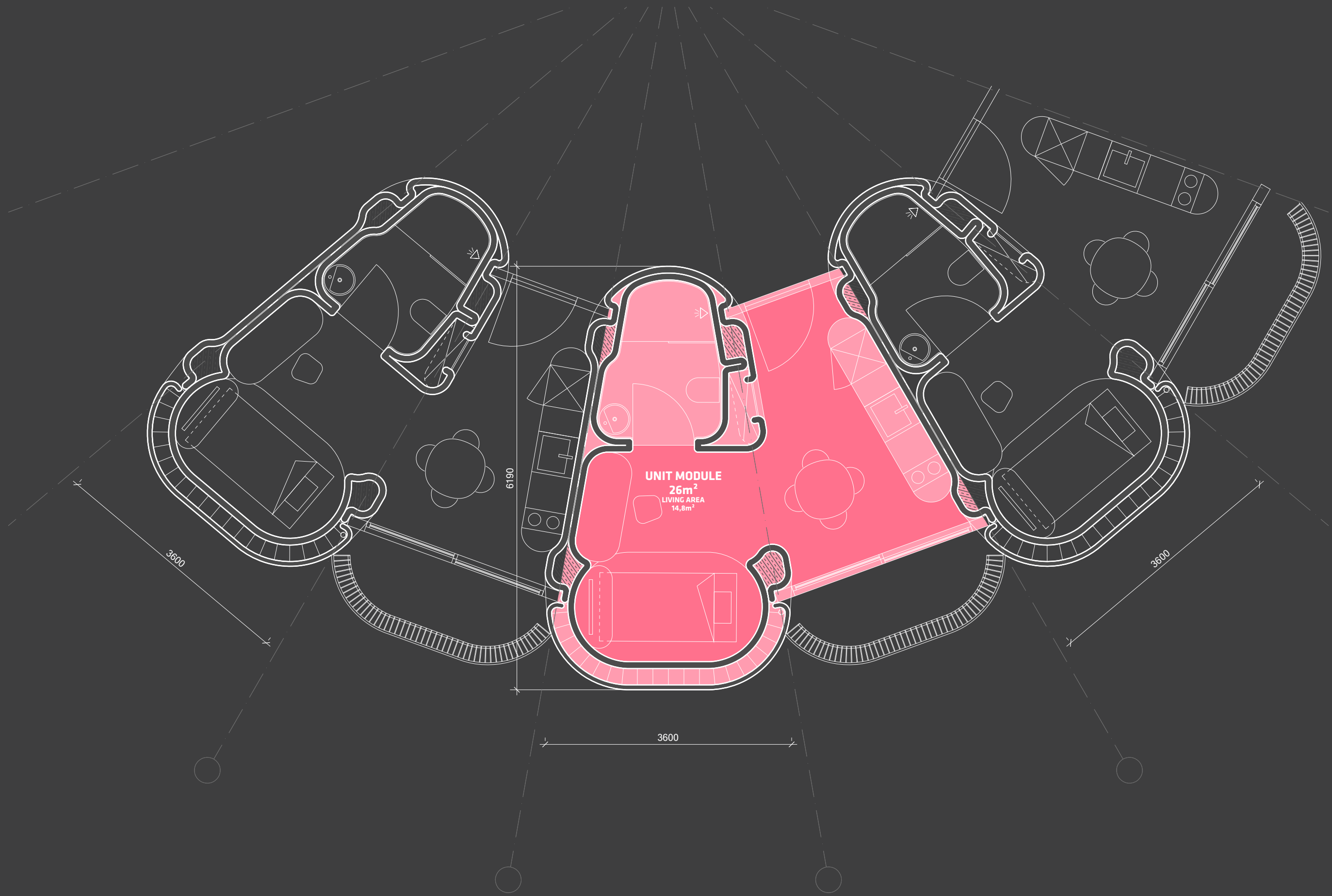
PINEAPPLE - SITE PLAN

PINEAPPLE - GROUND FLOOR PLAN

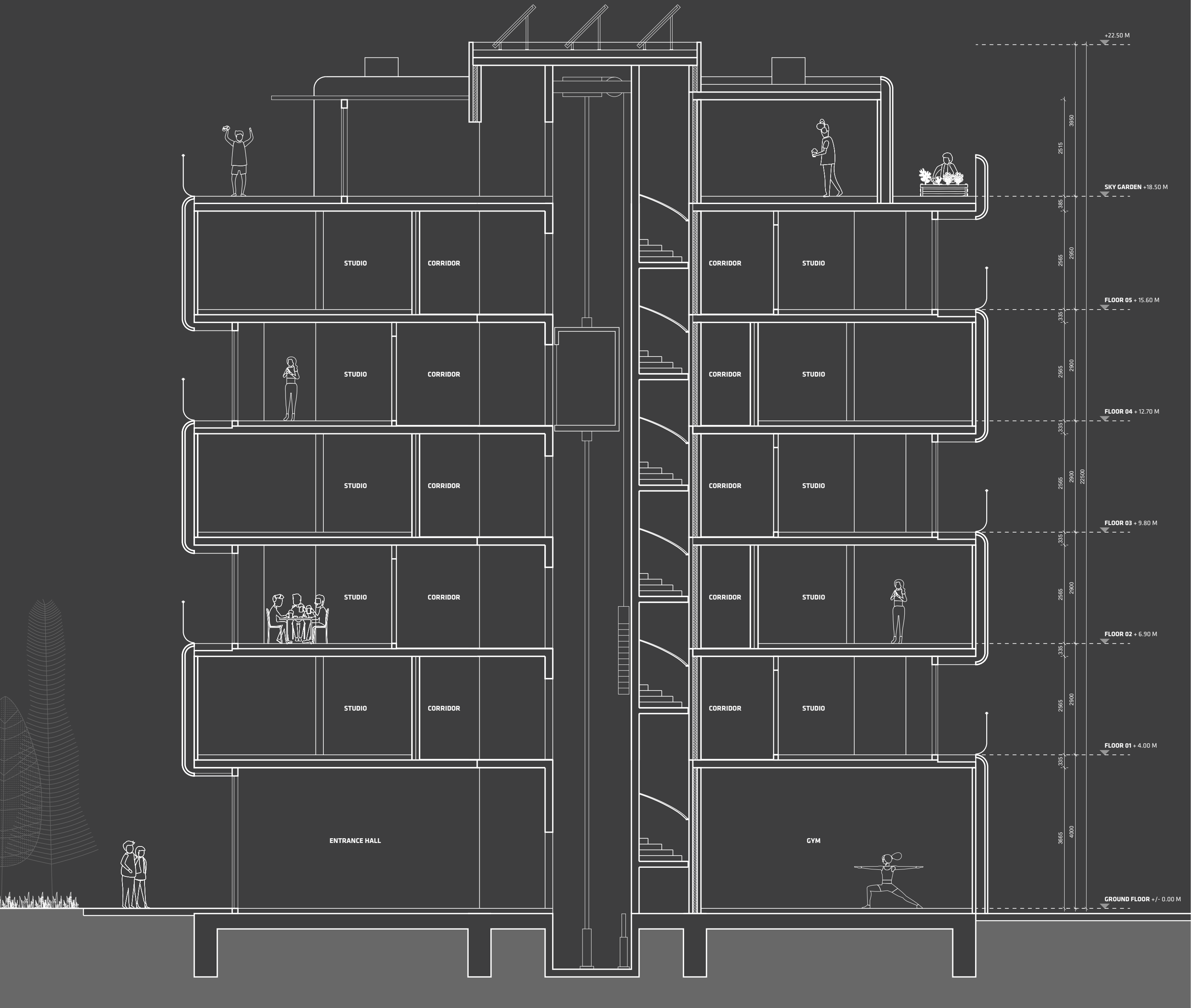


PINEAPPLE - TYPICAL FLOOR PLAN

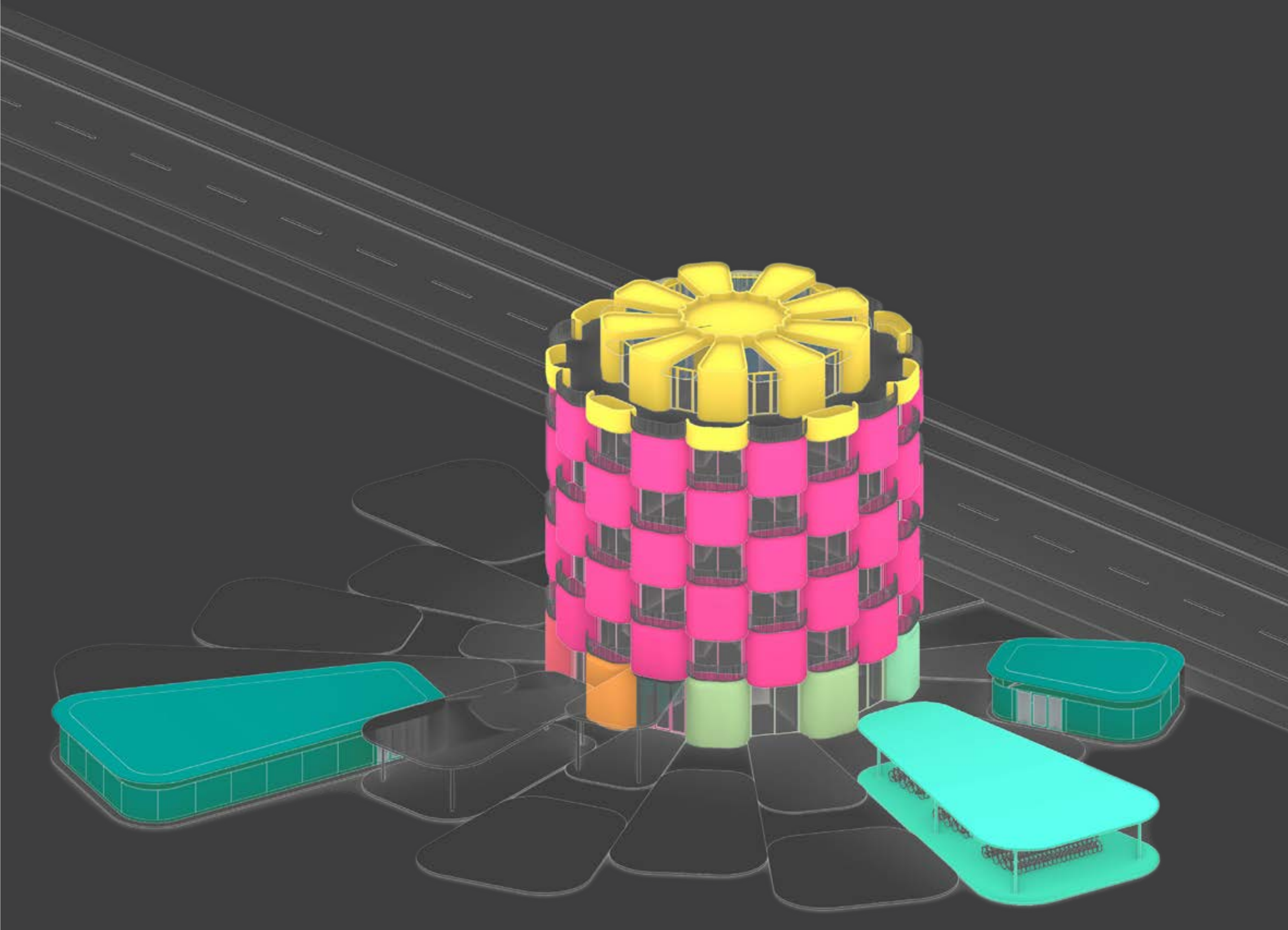
PINEAPPLE - ROOF PLAN



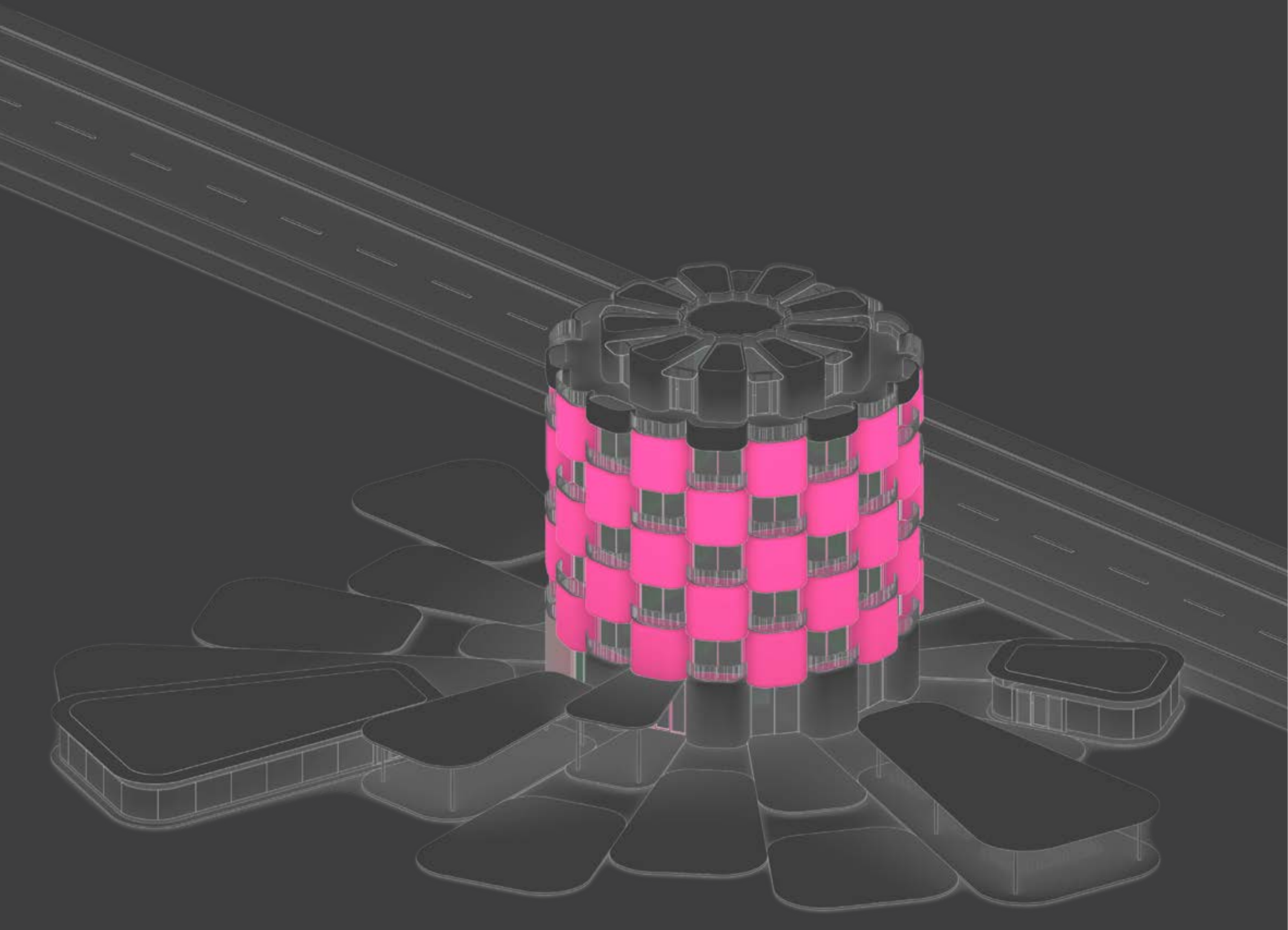
PINEAPPLE - ZOOM IN PLAN



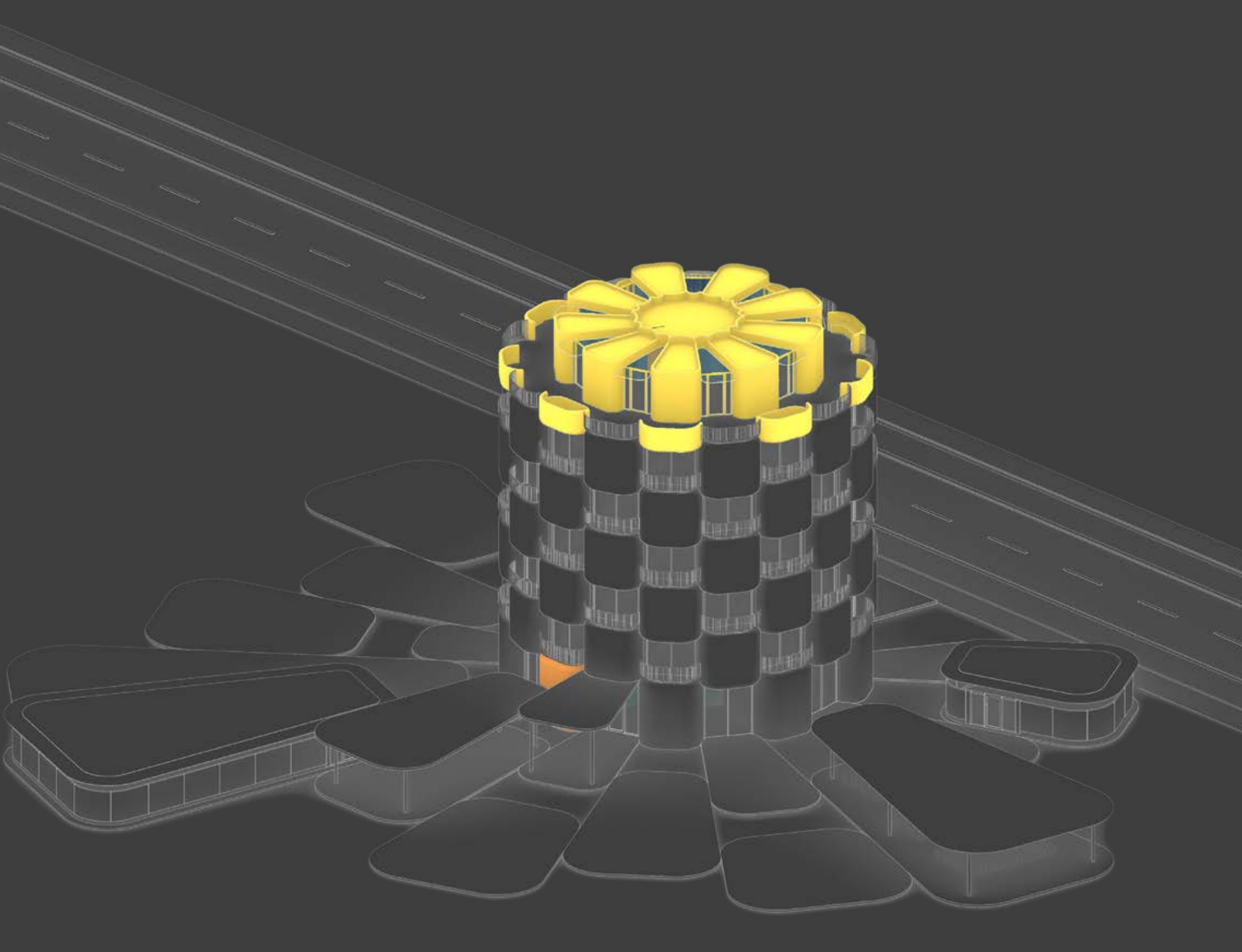
BALCONY SECTION



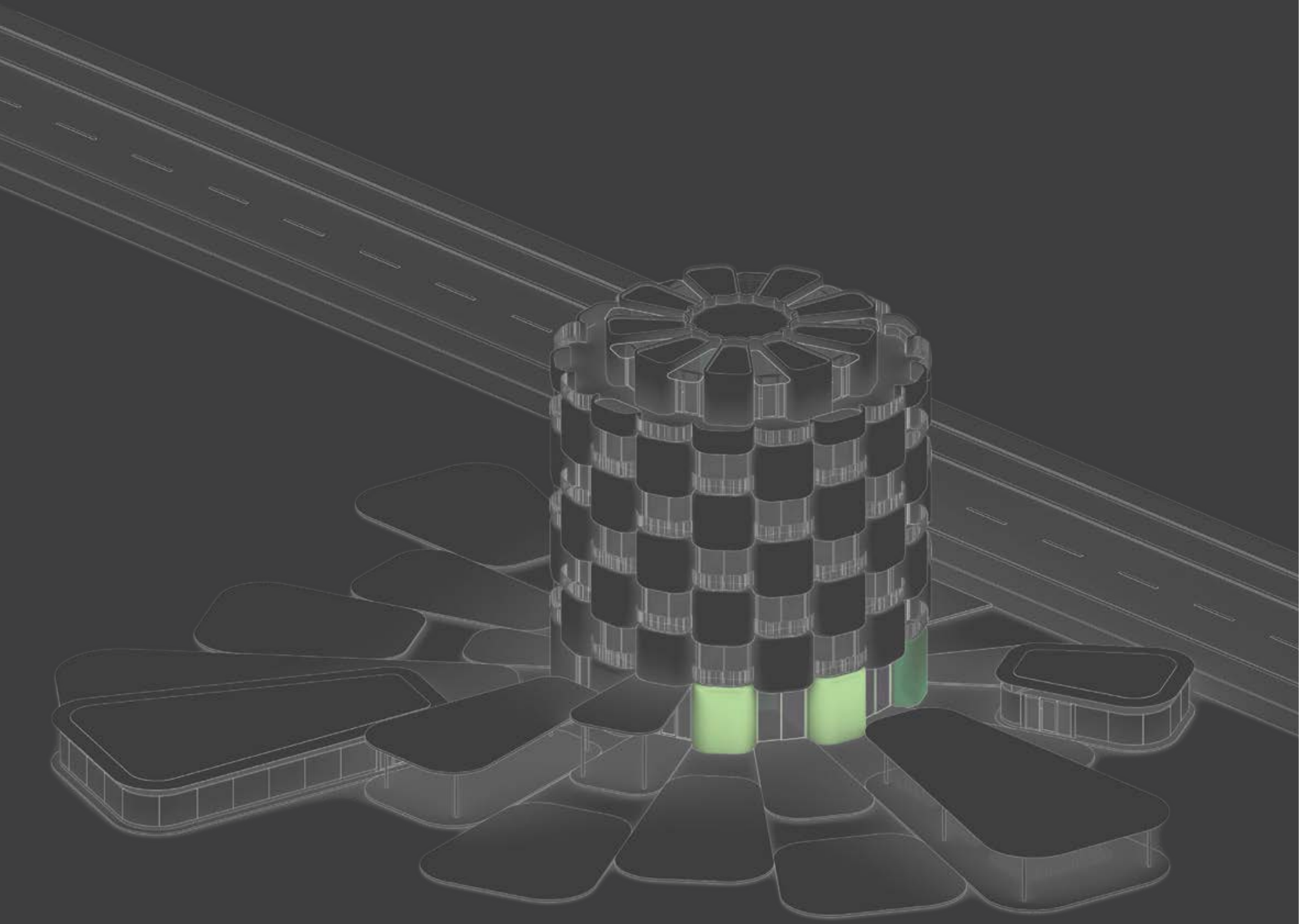
PROGRAM



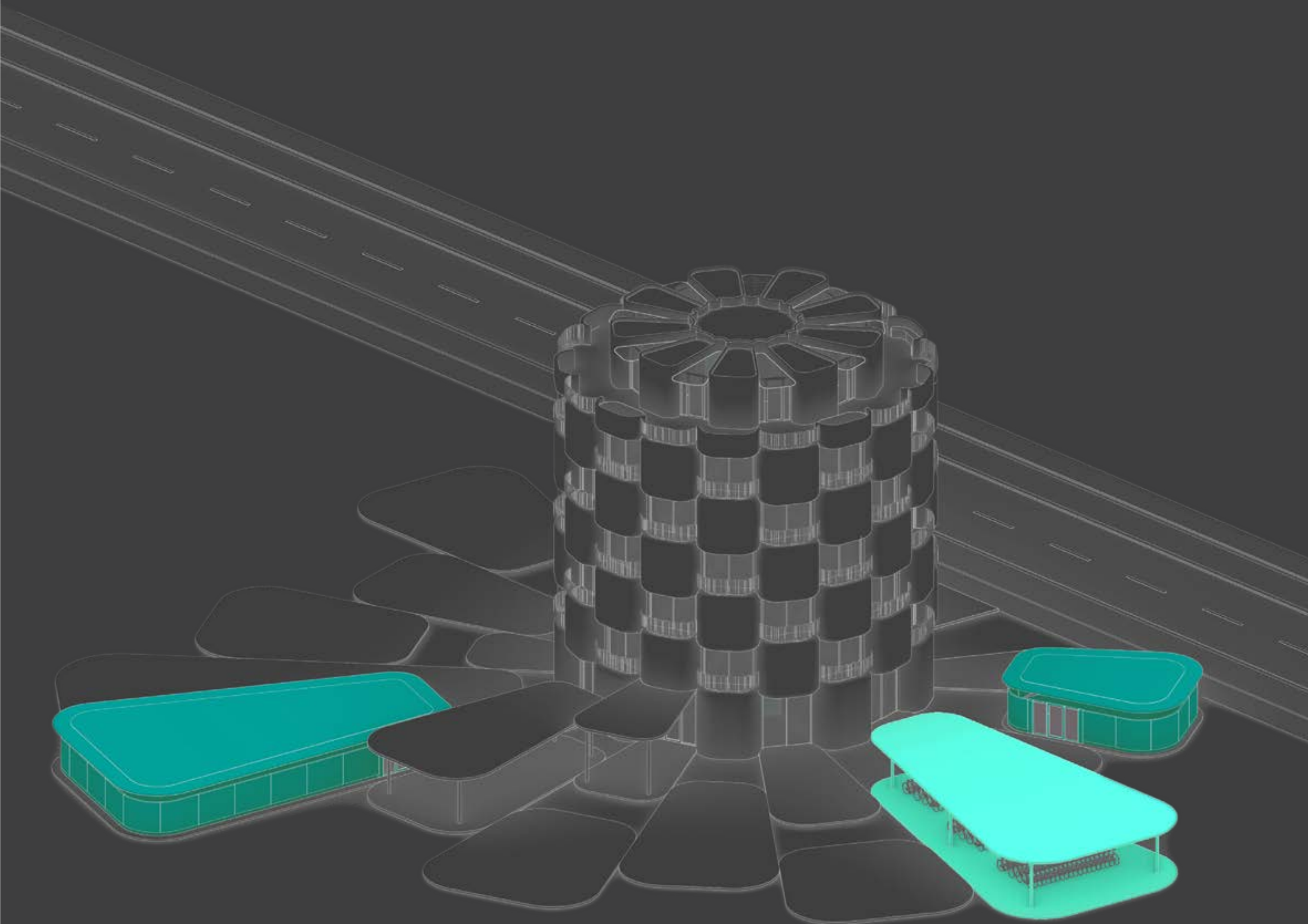
RESIDENTIAL



SHARED SPACES



AMENITIES

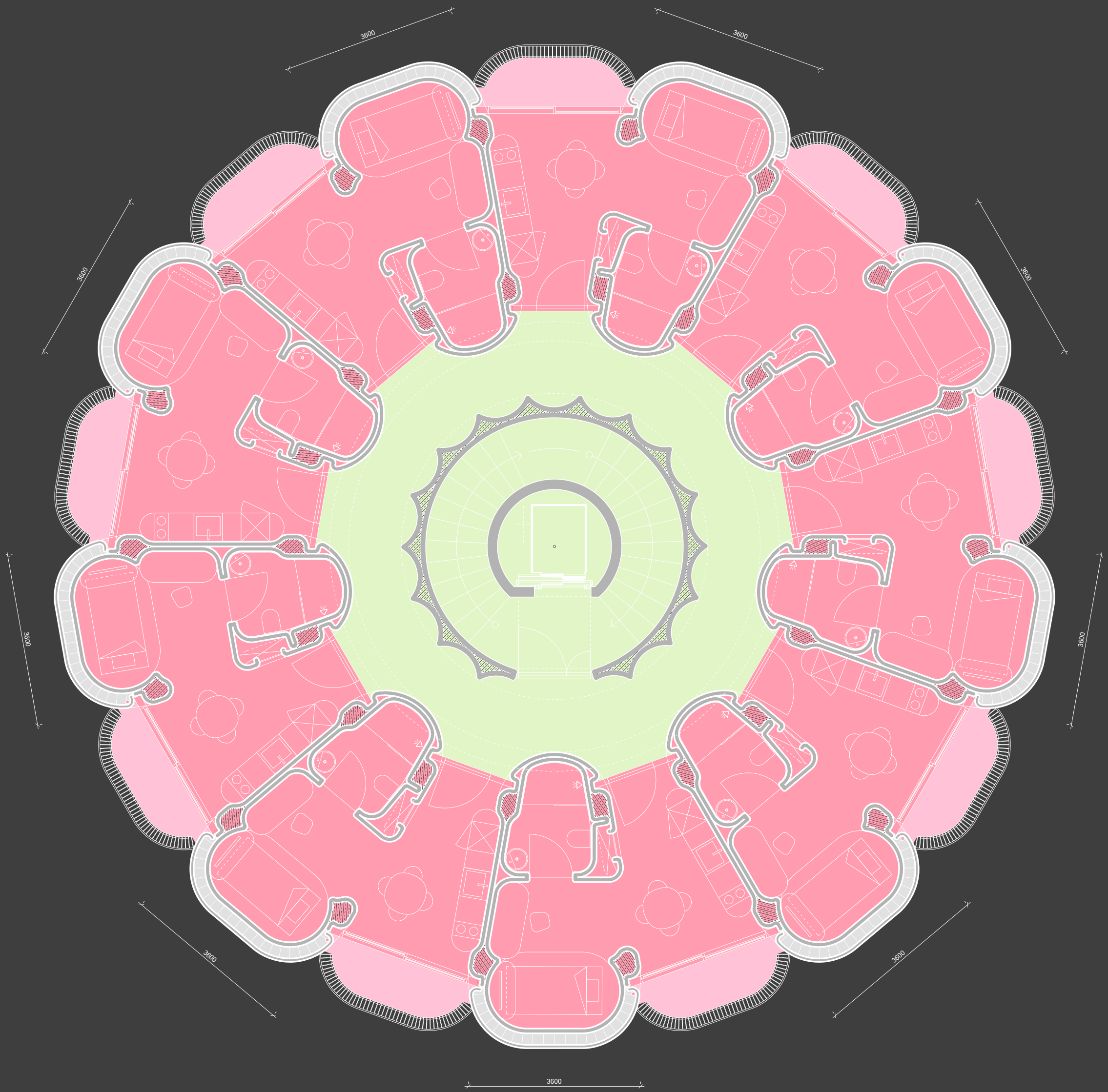


PARKING/SERVICES

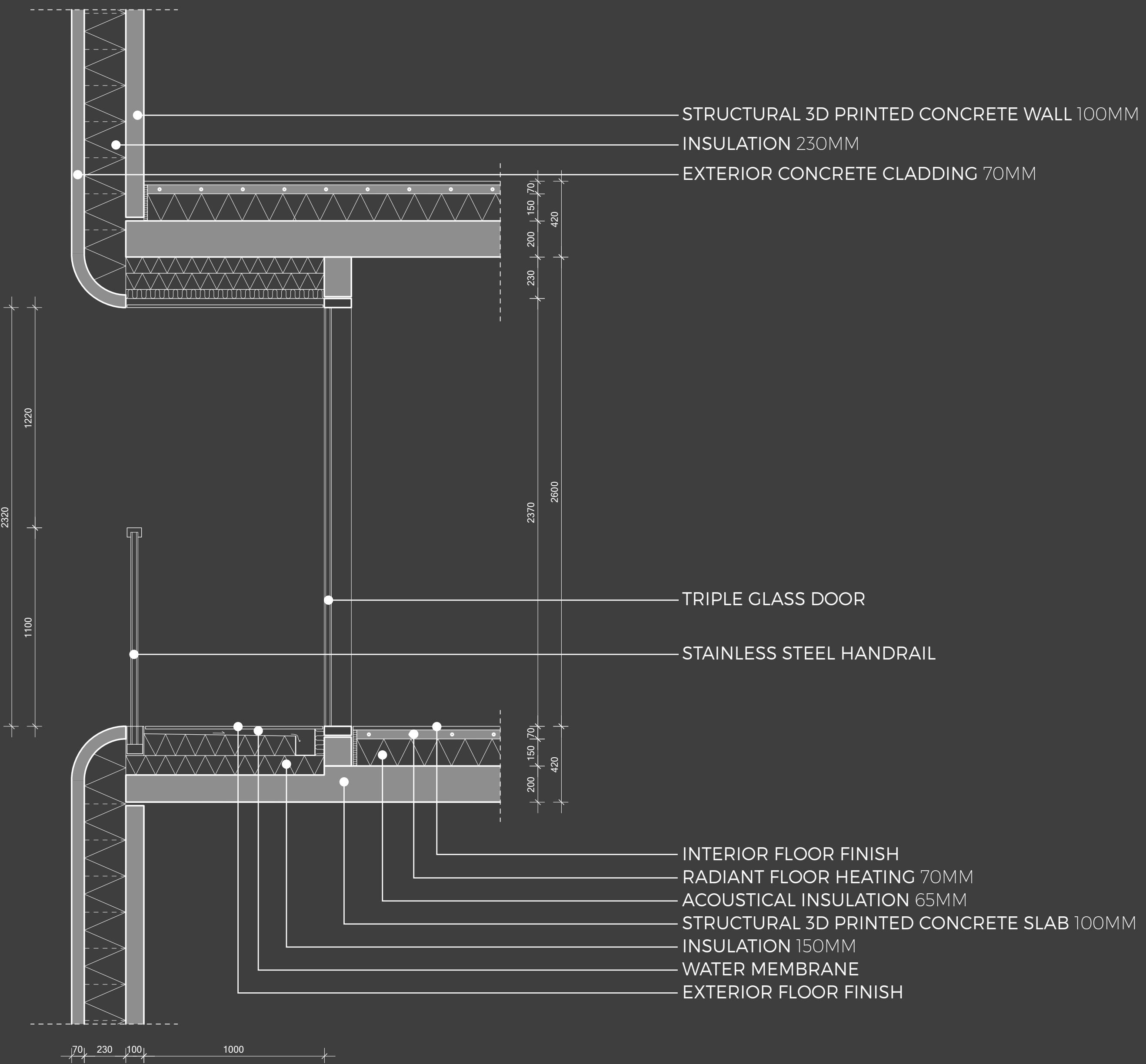
AREA m²							UNIT COUNT	EFFICIENCY
FLOOR	UNIT	OUTDOOR	CIRCULATION	COMMON	COMMERCIAL	GFA		
GF	82,94		52,79	15,28	153,09	304,1	3	17,36%
F01	233,48	24,78	70,71			328,97	9	23,25%
F02	233,48	24,78	70,71			328,97	9	23,25%
F03	233,48	24,78	70,71			328,97	9	23,25%
F04	233,48	24,78	70,71			328,97	9	23,25%
F05	233,48	24,78	70,71			328,97	9	23,25%
F06	233,48	24,78	70,71			328,97	9	23,25%
F07		167,74	24,62	136,6		328,96	0	15,27%
TOTAL	1483,82	316,42	501,67	151,88	153,09	2606,88	57	21,90%

BIKE PARKING	177,4	m²
DEPOT	211,5	m²
GARBAGE ROOM	70	m²
Total	458,9	m²

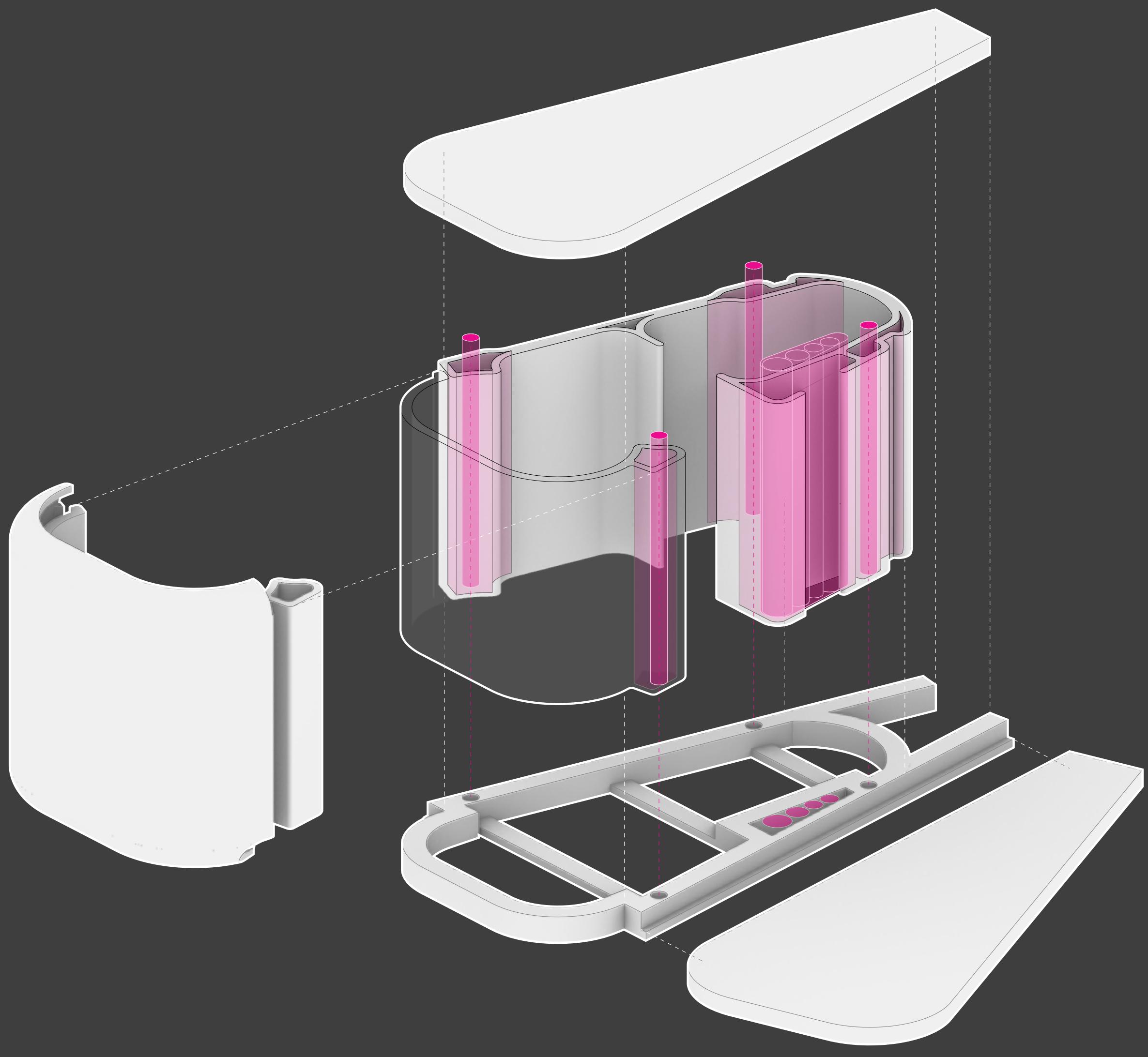
AREAS CALCULATION



CLOSED CORE FORMAT



BALCONY SECTION



EXPLODED AXO

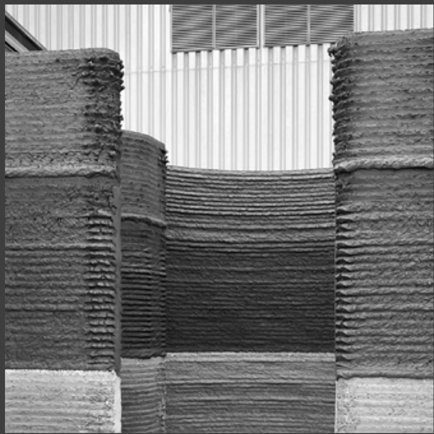
THE MOCK UP

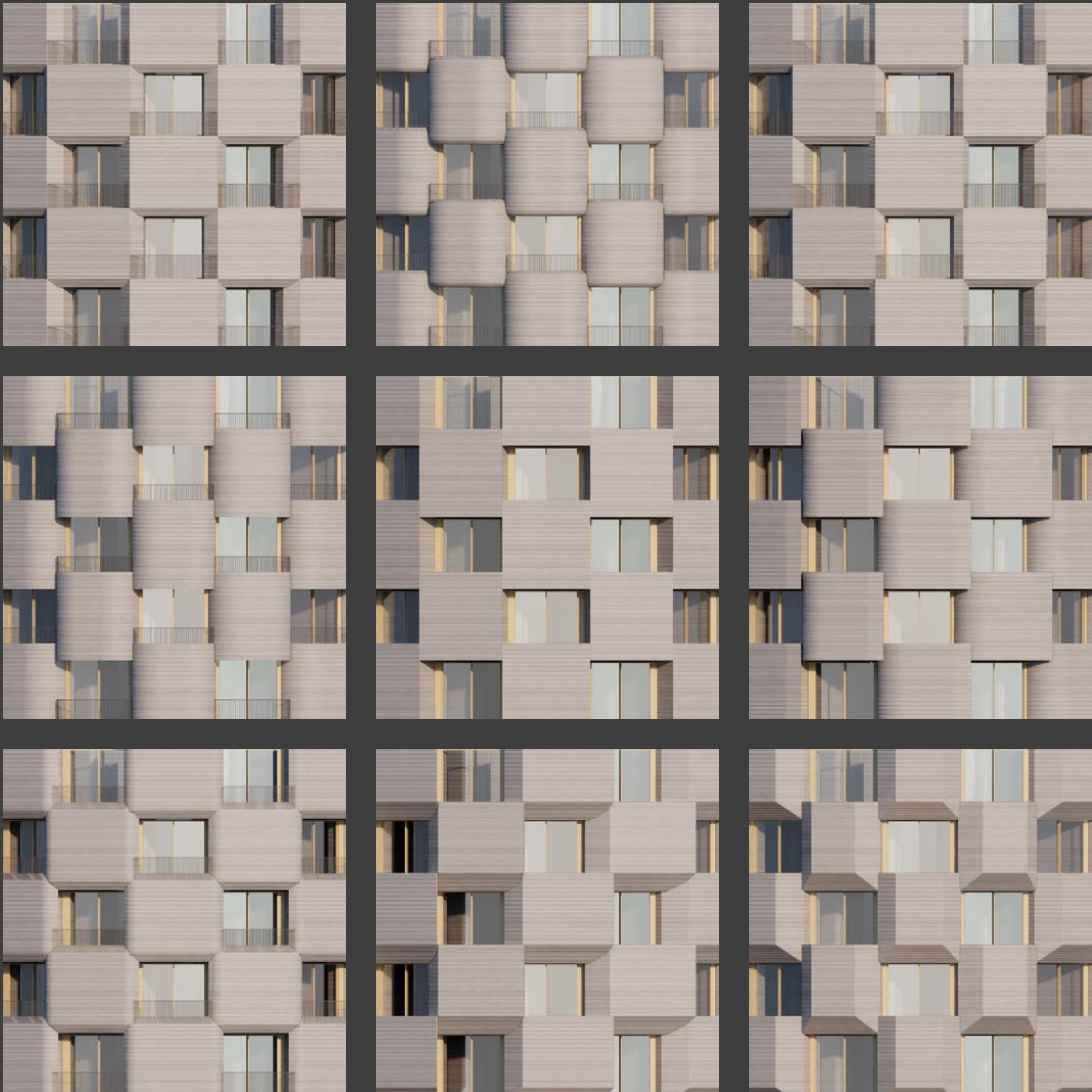
The module is 3D printed off-site, unit by unit, to maximize efficiency and meet transportation needs.





COBOD
COBOD



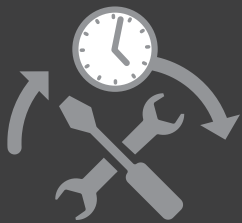
SUSTAINABILITY

EMBEDDED CO2

UNIT VOLUME

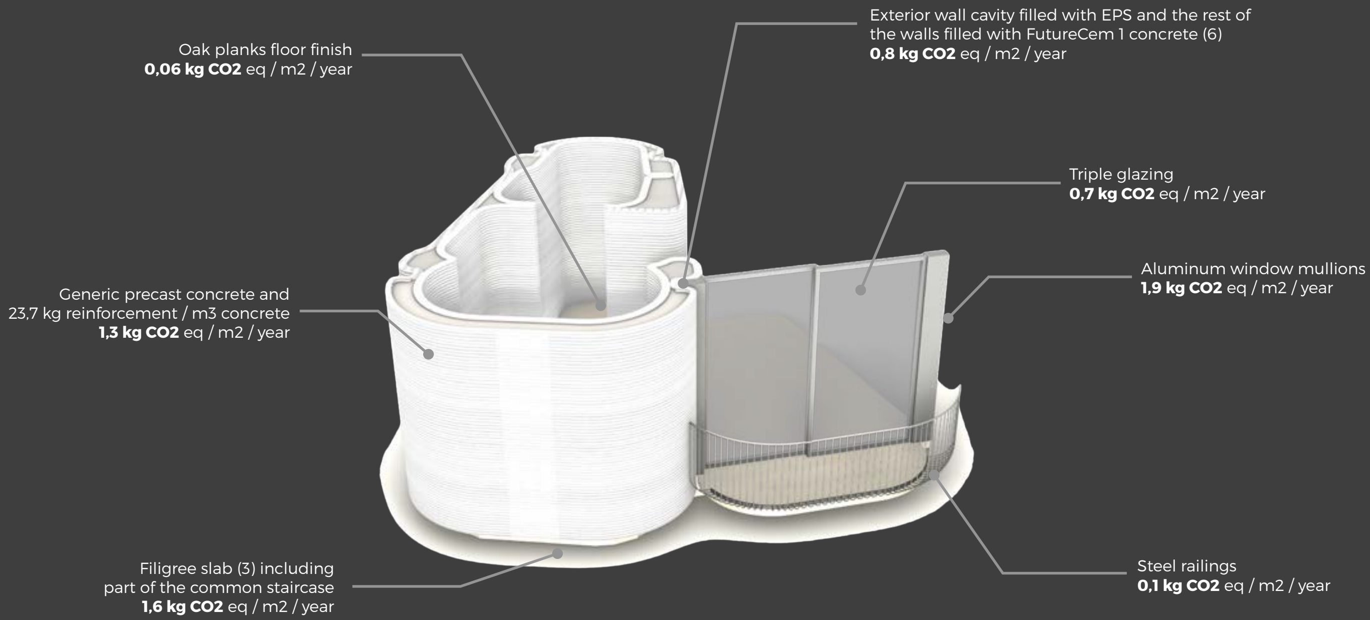
X

TOTAL VOLUME



DURABILITY

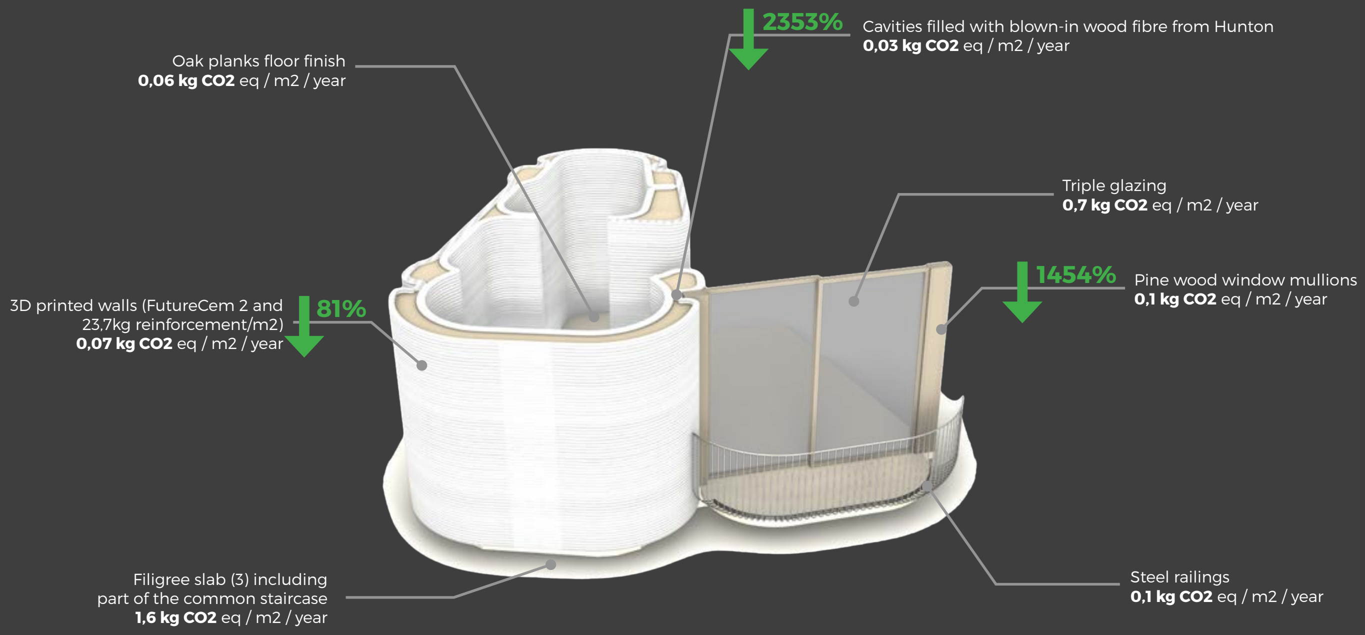
GLOBAL WARMING POTENTIAL (GWP)



6,5 kg CO2 eq / m2 / year*

* This study is only considering the embodied energy of the N3XTCON precast project in concept stage.The analysis uses a reference life span of 50 years and and the floor area is 31,8 m2 taking part of the shared hall way and stair case into account.

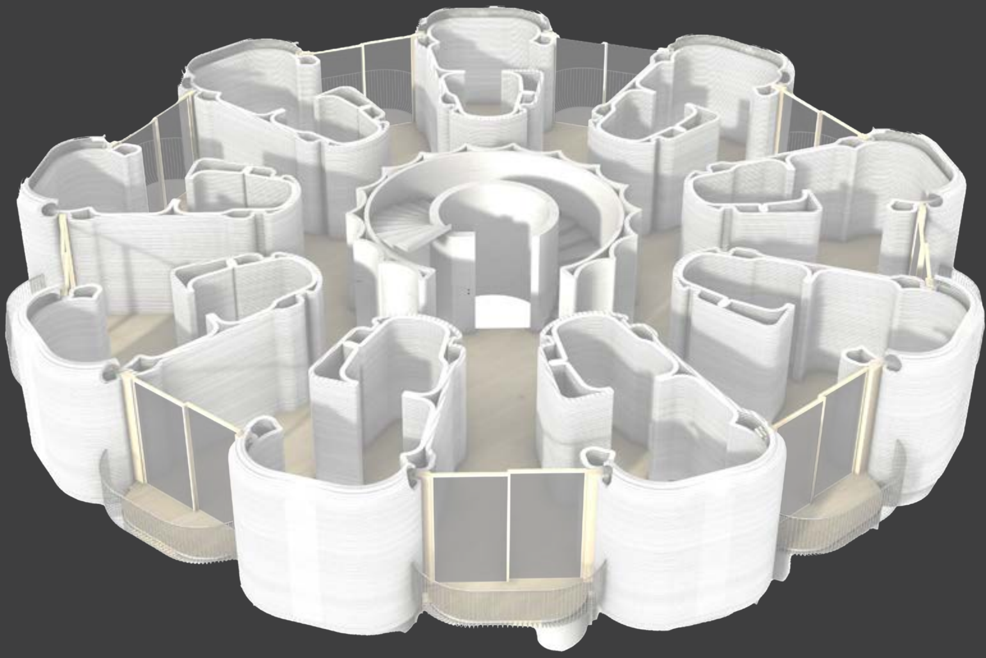
UNIT GWP - MATERIALS WITH **HIGHEST** C FOOTPRINT



3,4 kg CO2 eq / m2 / year* 90%

* This study is only considering the embodied energy of the N3XTCON precast project in concept stage.The analysis uses a reference life span of 50 years and and the floor area is 31,8 m2 taking part of the shared hall way and stair case into account.

UNIT GWP - MATERIALS WITH **LOWEST** C FOOTPRINT



GWP OF 1 FLOOR PLATE - MATERIALS WITH **LOWEST** C FOOTPRINT

3,4 kg CO_2 eq / m² / year
48510 kg CO_2 eq / floor plate / year*

far less than the Danish Building Regulations maximum of
12 kg CO2 eq / m2 / year

* This study is only considering the embodied energy of the N3XTCON precast project in concept stage. The analysis uses a reference life span of 50 years and and the floor area is 287 m2.

GWP OF 1 FLOOR PLATE - MATERIALS WITH **LOWEST** C FOOTPRINT

MATERIAL SPECIFICATIONS FOR LCA

CONCRETE WALLS

Quantities for one unit
4,9 m3 concrete with FutureCem 2

Quantities for one floor plate
44 m3 concrete with FutureCem 2

Assumptions
This study uses concrete with FutureCem 2 for the 3D printed walls. The ingredients ratio and specified aggregates are provided by the Danish Technological Institute (1).
The footprint of one unit is 1,83 m2 and the height is 2,67 m. The concrete "pockets" around the reinforcement is assumed to be 200 mm x 300 mm.

Life cycle stages included
A1-A3, A4, C3 and D

Reference life span
60 years

REINFORCEMENT IN WALLS

Quantities for one unit
116 kg of steel

Quantities for one floor plate
1043 kg of steel

Assumptions
The amount of reinforcement is based on the assumption of 2 rebars of 12 mm diameter C-C 1000 mm. Additional 8 mm horisontal rebar every 300 mm. 23,7 kg reinforcement / m3 concrete.

Life cycle stages included
A1-A3, C4 and D

Reference life span
80 years

INSULATION

Quantities for one unit
8,9 m3 of insulation

Quantities for one floor plate
79 m3 of insulation

Assumptions
4 materials are being assessed for insulating the 3D printed walls: Concrete with FutureCem 1 (1), EPS (2), blown-in cellulose fibre insulation from recycled paper (3) and blown-in wood fibre insulation (4). Fire retarandts EPS: hydrogen bromide, Cellulose: boric acid and borax, Wood fibre: nitrogen and phosphor and ammonium sulfate. Fire resistance class for EPS, Cellulose and Wood fibre: Euroclass E.

Life cycle stages included
A1-A3, C4 and D

Reference life span
80 (EPS), 60 (concrete), 50 (cellulose fibre),
60 (wood fibre)

WINDOW

Quantities for one unit
9 m2 of glass and 16,2 m mullions

Quantities for one floor plate
81 m2 of glass and 146 m mullions

Assumptions
The windows are triple glazing and two different materials are being compared for the mullions: pine and aluminium.
The mullions are assumed to have a linear weight of 2,14 kg/m for the pine wood and 3 kg /m for the aluminium mullions.
The glazing consists of 3 glass panes each 4 mm thick and with a 16 mm distance.

Life cycle stages included
A1-A3, C3, C4 and D

Reference life span
20 (wood), 25 (glass)

SLAB

Quantities for one unit
31,8 m2 of concrete

Quantities for one floor plate
287 m2 of concrete

Assumptions
The slab is a precast concrete filigree slab and the reinforcement is assumed to be 150 kg steel / m3 of concrete (1). The slab is 80 mm thick.

Life cycle stages included
A1-A3, C3 and D

Reference life span
75 years

TOP FLOOR

Quantities for one unit
20 m2 of wood

Quantities for one floor plate
180 m2 of wood

Assumptions
The entire floor inside each unit is assumed to be covered with 20 mm planks of oak.

Life cycle stages included
A1-A3, C3 and D

Reference life span
60 years

PRECAST STAIRS AND ELEVATOR SHAFT

Quantities for one unit
2,8 m3 of concrete, C45/55

Quantities for one floor plate
25,4 m3 of concrete, C45/55

Assumptions
The central staircase and surrounding walls are included and the reinforcement is assumed to be 150 kg steel / m3 concrete for both stairs and elevator shaft.

Life cycle stages included
A1-A3, C4 and D

Reference life span
60 years

RAILINGS FOR THE BALCONY

Quantities for one unit
0,008 m3 of steel

Quantities for one floor plate
0,07 m3 of steel

Assumptions
The railings are made of steel and weigh 62 kg pr balcony.

Life cycle stages included
A1-A3, C4 and D

Reference life span
80 years

MATERIAL SPECIFICATIONS FOR LCA

N3XTCON