P4 - PRESENTATION

T T E

TALL TIMBER EXTENSION

Design study for a new construction method

in the city of Rotterdam

Student

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Mentors

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External supervisor | IMd Raadgevende Ingenieurs

Structural extensions on existing buildings

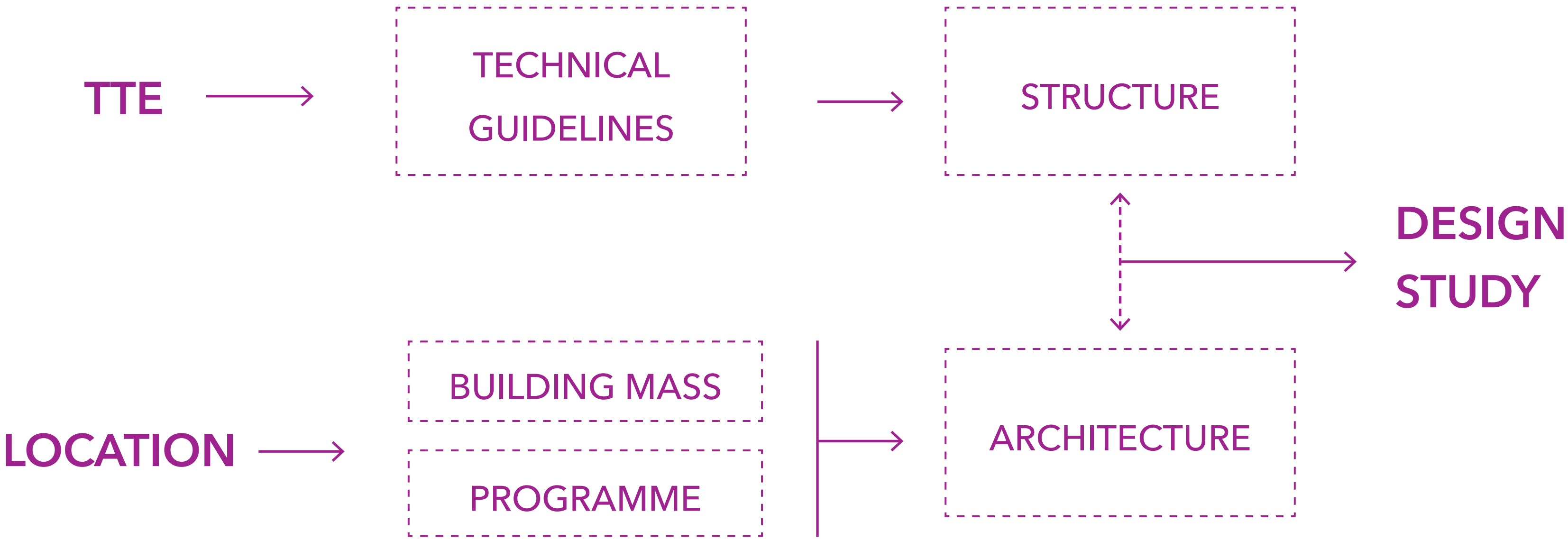
Lateral stability systems for tall structures

Engineered timber products

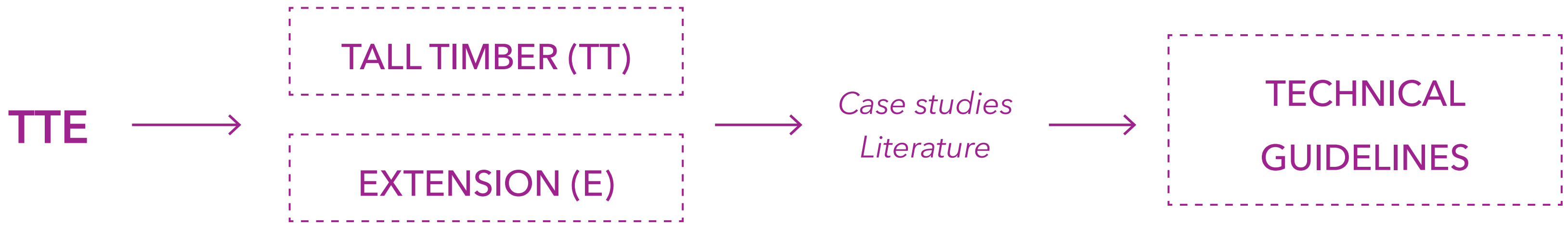
Sustainable structures

HOW CAN WE DESIGN AN INTEGRATED TALL TIMBER EXTENSION (TTE) IN THE INTENDED LOCATION?

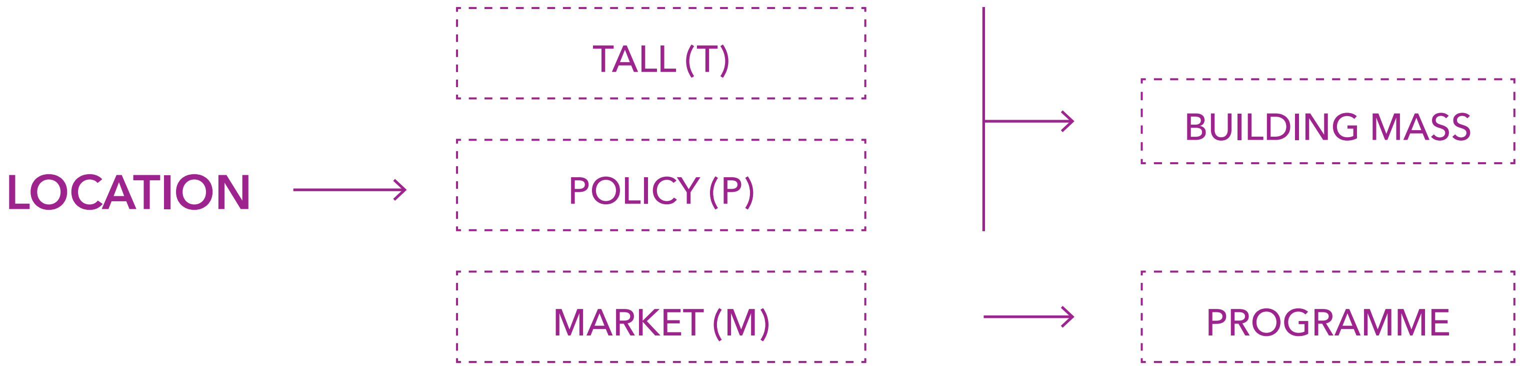
PART 0 - RESEARCH FRAMEWORK



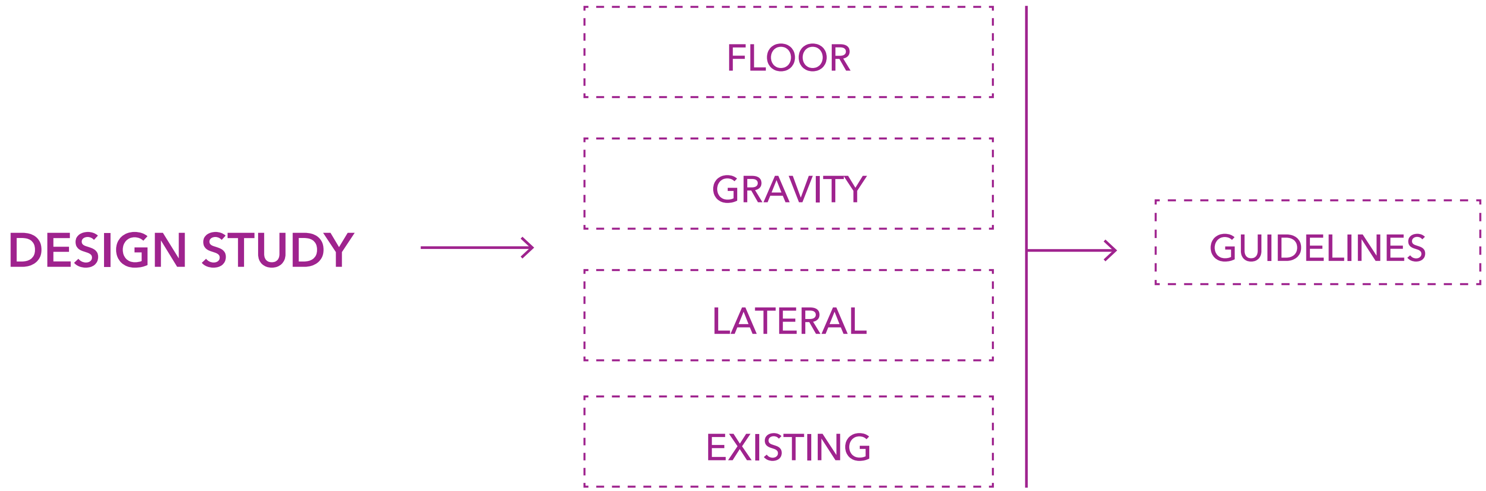
PART 1


TTE
TALL TIMBER (TT)
EXTENSION (E)
Case studies
Literature
TECHNICAL
GUIDELINES

PART 2

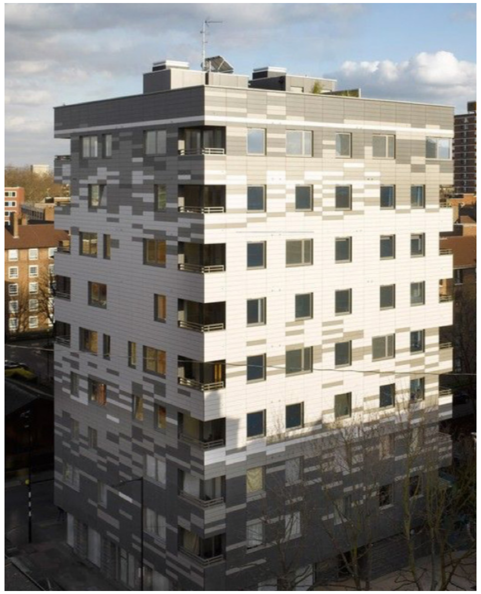


PART 3

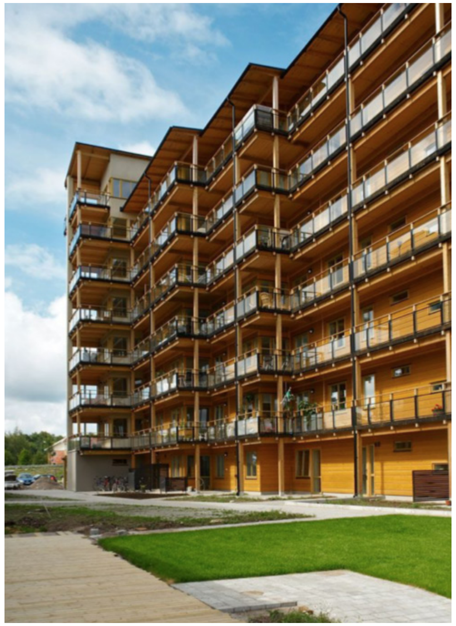
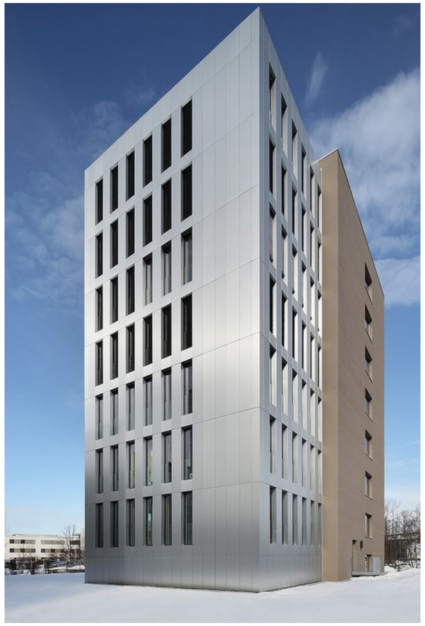


TECHNICAL GUIDELINES

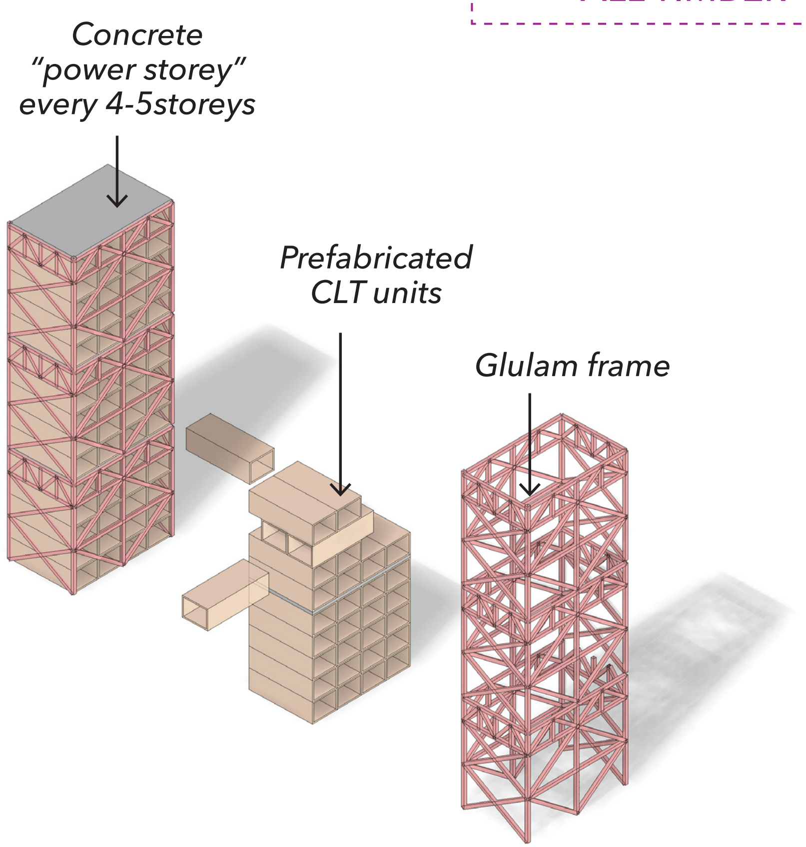
TO WHAT EXTENT IS A TALL TIMBER BUILDING (TT) TECHNICALLY FEASIBLE?

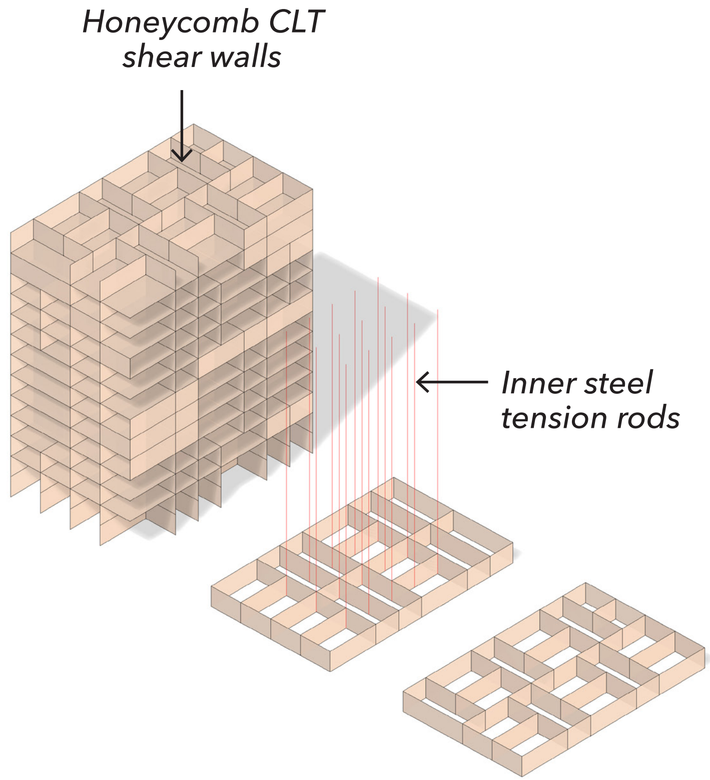






ALL-TIMBER

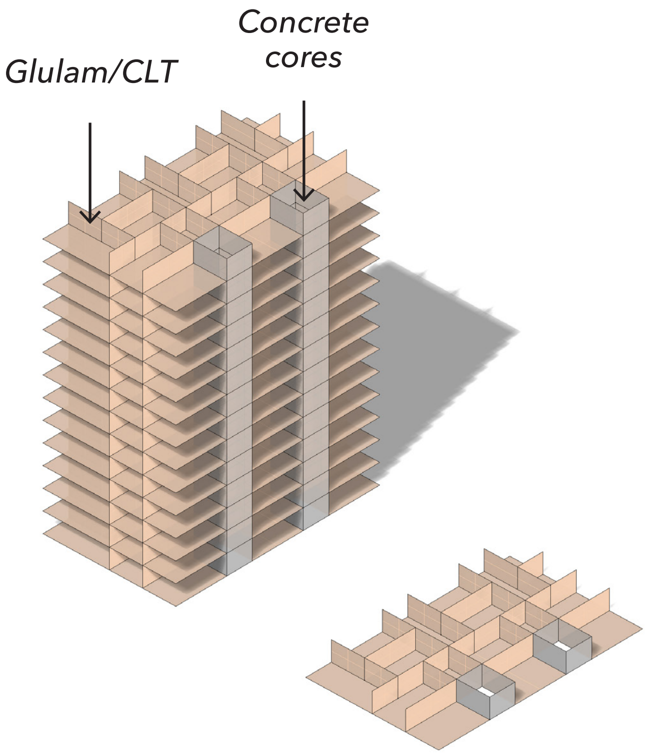


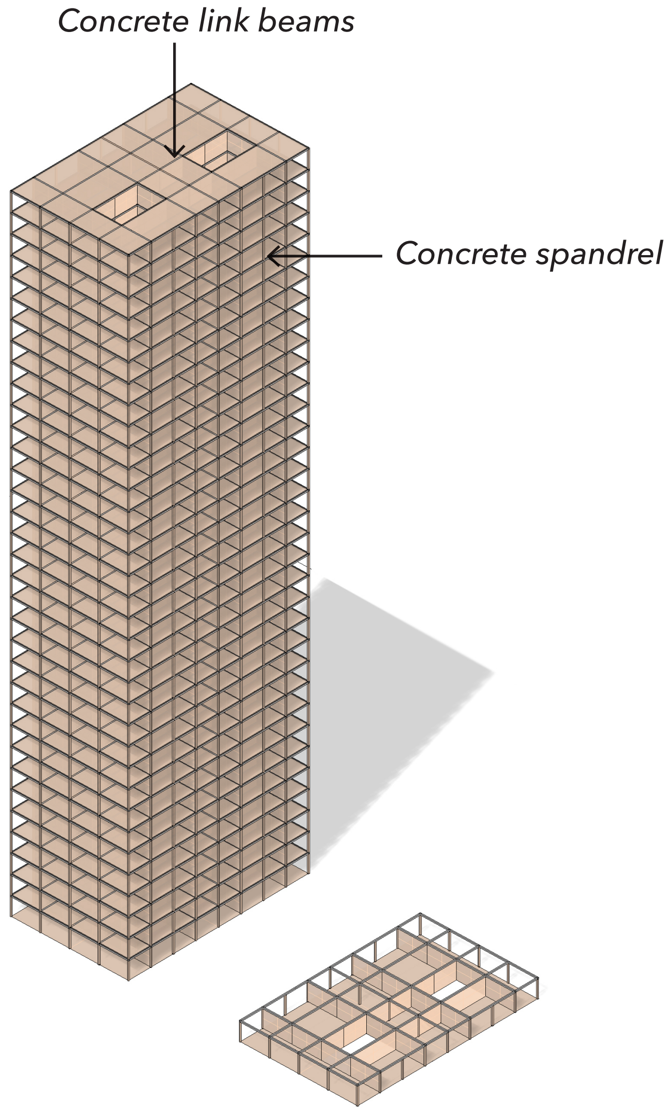


Precedent height: 53 meters
Lateral stability: Braced glulam frame
Vertical loading: CLT modules
Reinforcement: Concrete power storey
Example: The Treet (Norway)

Precedent height: 32.2 meters
Lateral stability: CLT shear walls
Vertical loading: CLT walls
Reinforcement: Steel vertical tension rods or shear plates
Examples: Forte (Australia), Murray Groove (UK)

TIMBER-CONCRETE





Precedent height: 52.8 meters
Lateral stability: Concrete cores
Vertical loading: CLT walls/columns
Example: UBC Brock Common (Canada)

Precedent height: 120 meters
Lateral stability: CLT shear walls and outrigger glulam columns
Vertical loading: CLT walls/columns
Reinforcement: Concrete spandrel and link beams
Example: Concept study by SOM (unbuilt)

MARKETING

TALLEST - 53 M

MOST SUSTAINABLE

CONSERVATIVE DESIGNS → **STRUCTURAL CONSIDERATIONS**

STRUCTURE NOT EXPOSED → **FIRE SAFETY**

ADVANCED DETAILING → **SOUND PROOFING**

STRUCTURAL CONSIDERATIONS

↓

LATERAL RESISTING SYSTEM

DETAILING

↓

GUIDELINES

UPLIFT

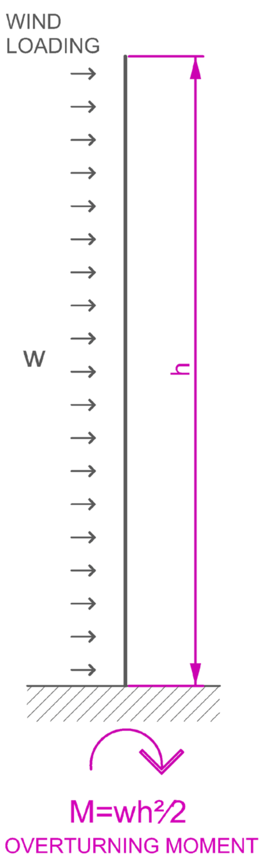
LIGHTWEIGHT BUILDING

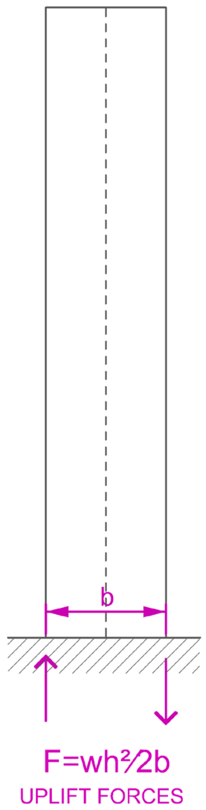
TIMBER	STEEL	CONCRETE
140KG/m3	160KG/m3	300KG/m3
THE TREET (MALO ET AL. 2016)	(CHO ET AL. 2004, YANG ET AL. 2004, HUANG ET AL. 2007)	

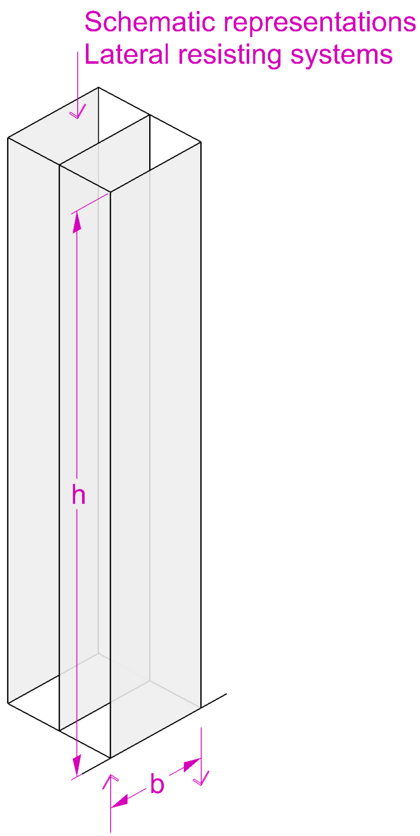
Estimated bulk density for a typical tall building
(dead load by divided by gross volume)

UPLIFT

HOWEVER, WIND LOADING REMAINS THE SAME



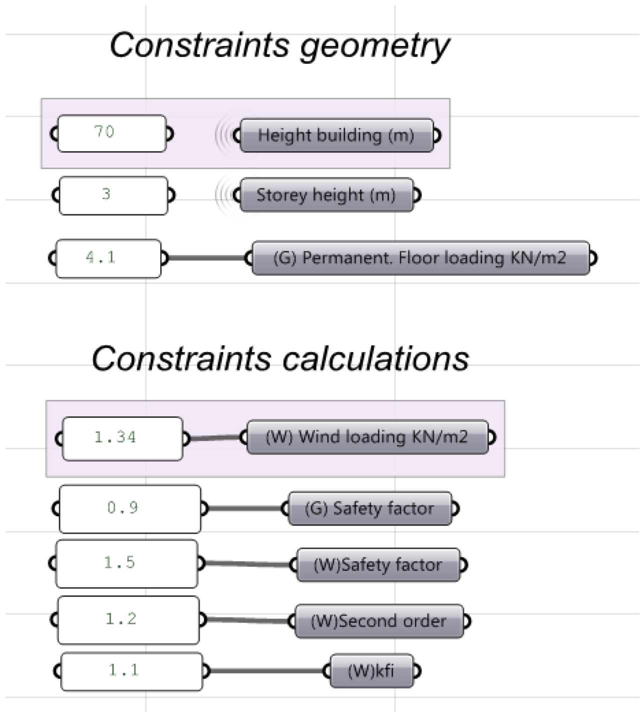


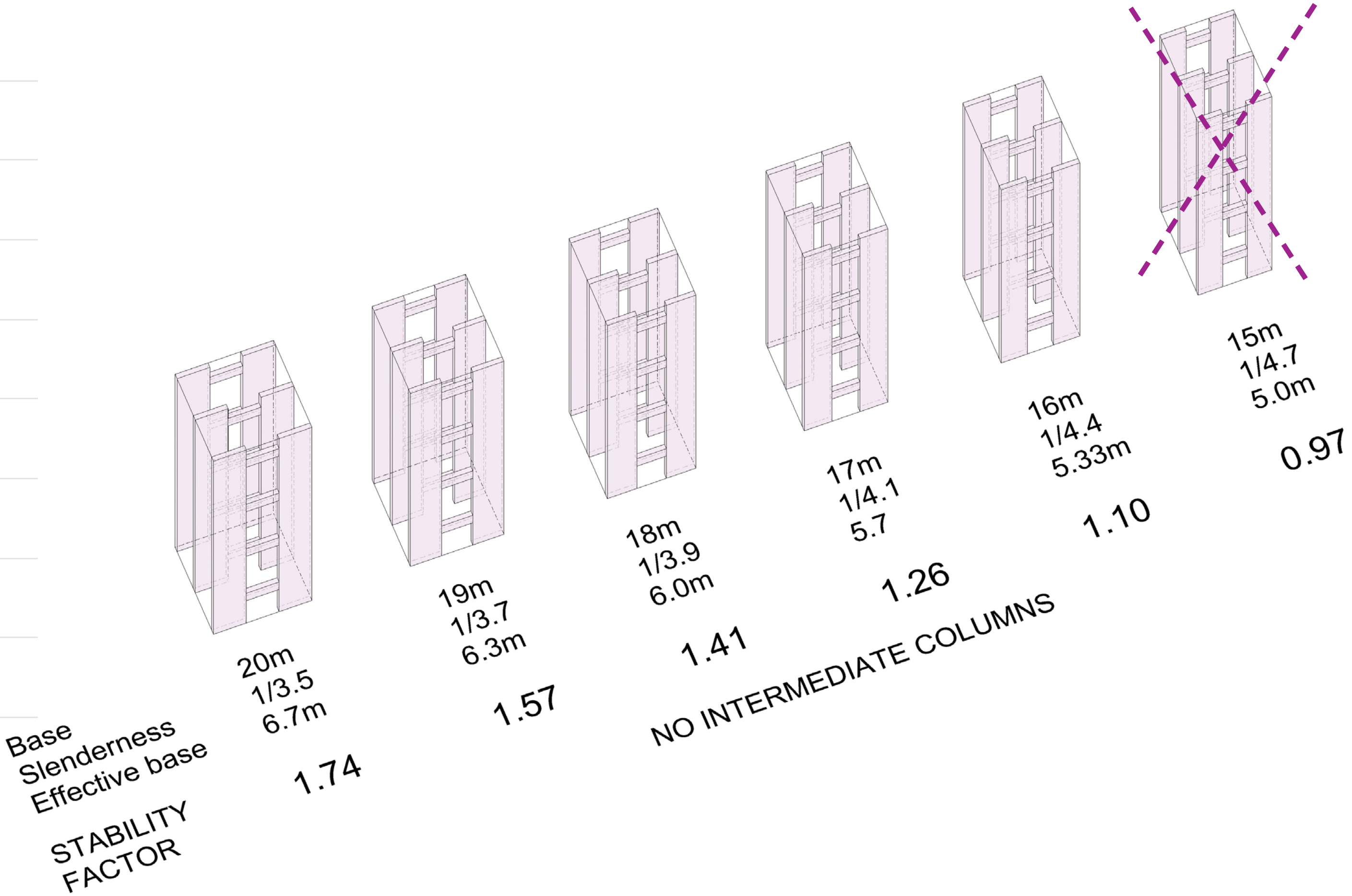


AVOID UPLIFT

BASE DEPTH > 16 M

SLENDER RATIO < 1/4.4

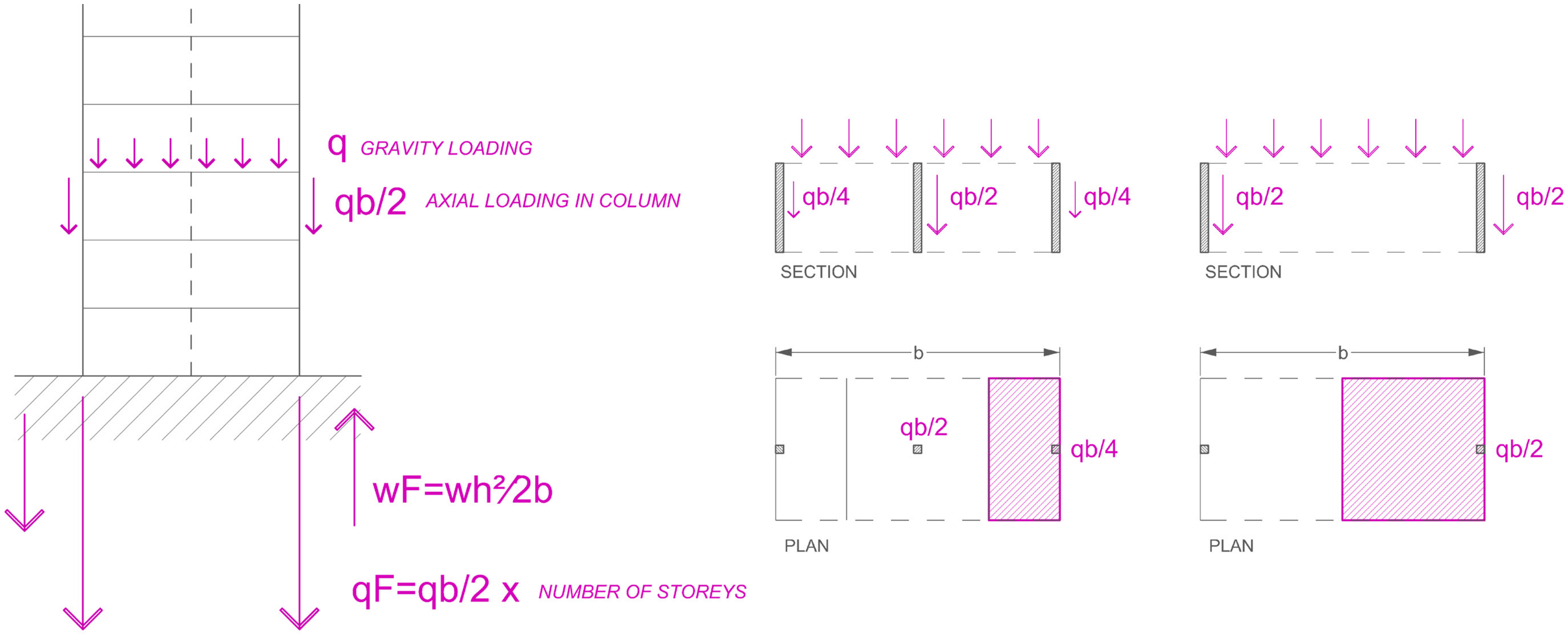




UPLIFT

MAXIMISE GRAVITY LOADING ON LATERAL RESISTING SYSTEM

NO INNER GRAVITY SYSTEM



CLT FLOOR SYSTEM <6m

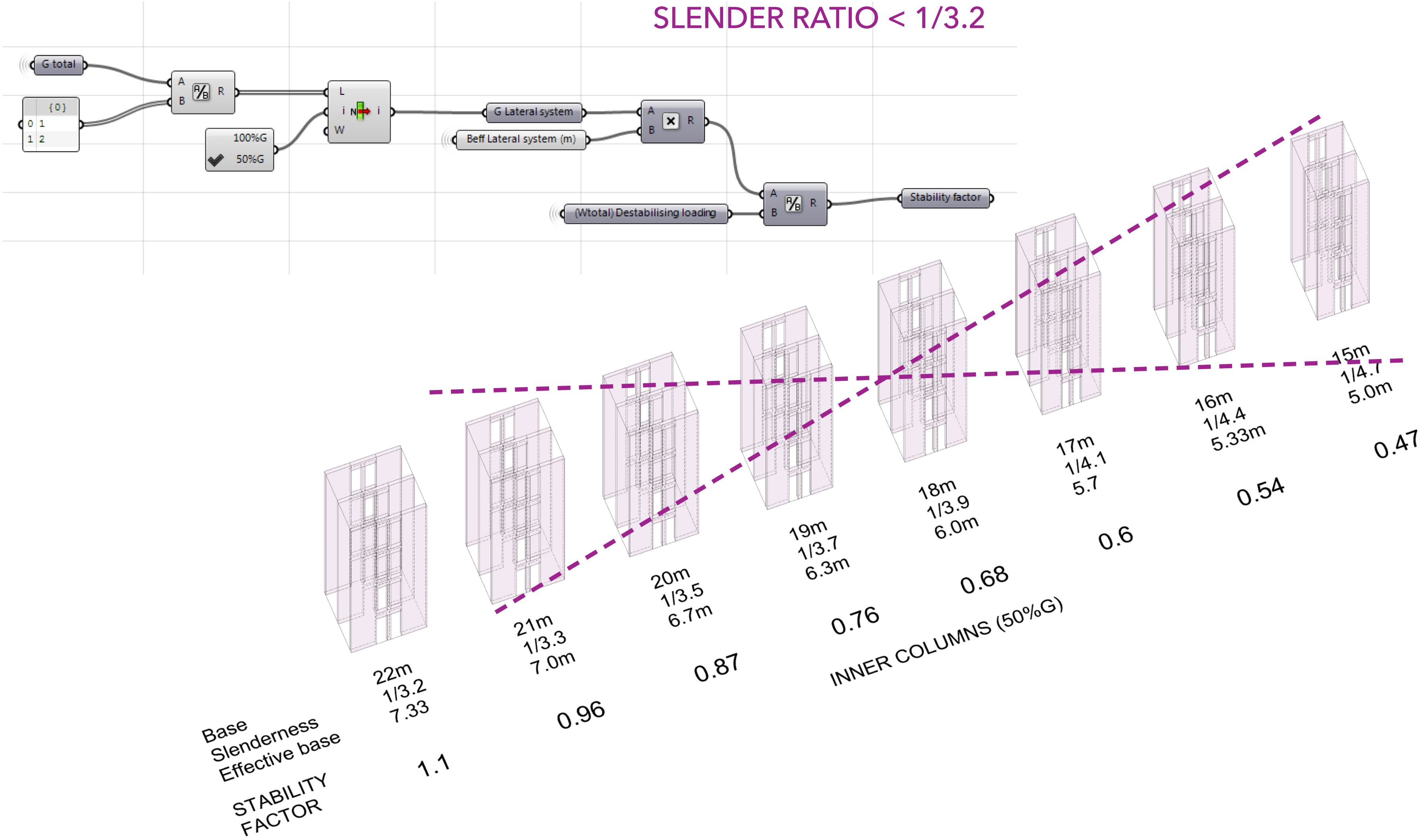
(vibration controlled)

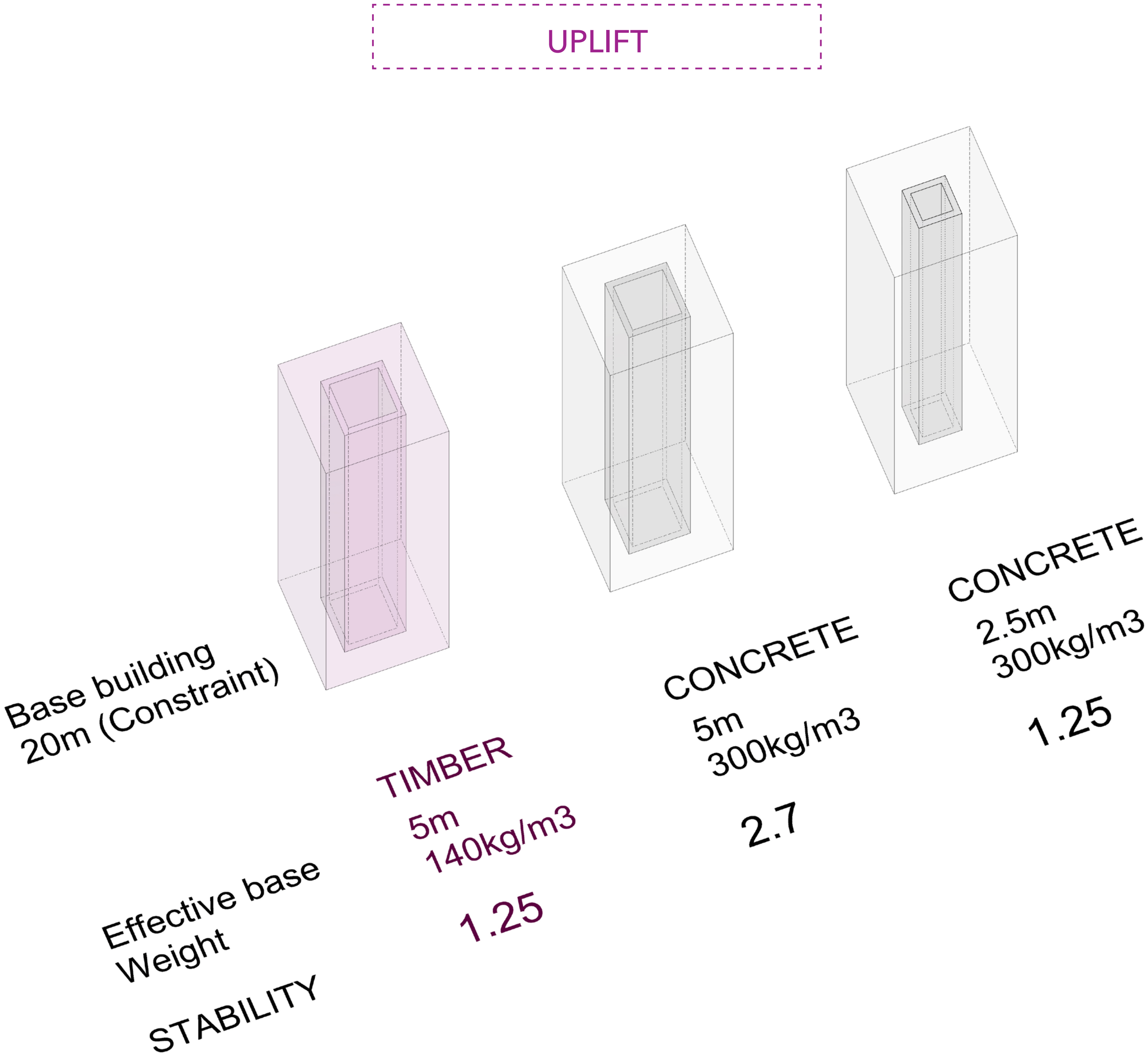
UPLIFT

INNER GRAVITY SYSTEM (50%G)

BASE DEPTH > 22 M

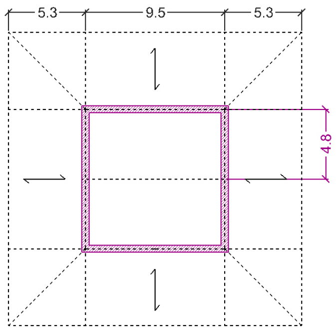
SLENDER RATIO < 1/3.2




UPLIFT
Base building
20m (Constraint)
TIMBER
5m
140kg/m3
1.25
CONCRETE
5m
300kg/m3
2.7
CONCRETE
2.5m
300kg/m3
1.25
Effective base
Weight
STABILITY

UPLIFT

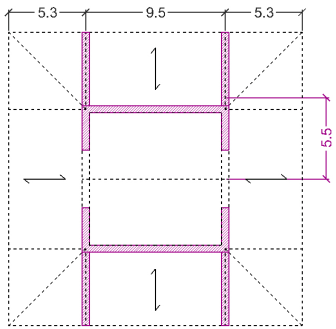
Up to 90% MORE EFFICIENT, engaging perimeter with wing shear walls



Beff = 4.8 m

1.25

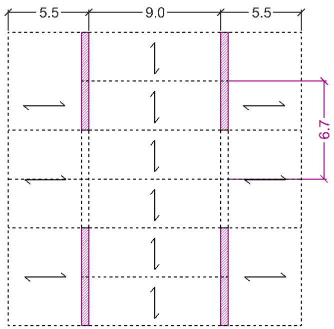
Core



Beff = 5.5 m

1.44

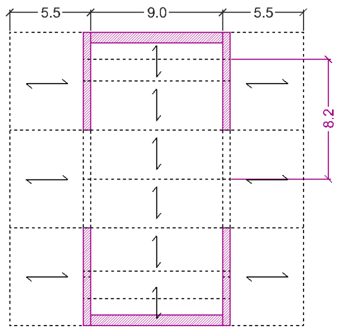
Double H



Beff = 6.7 m

1.74

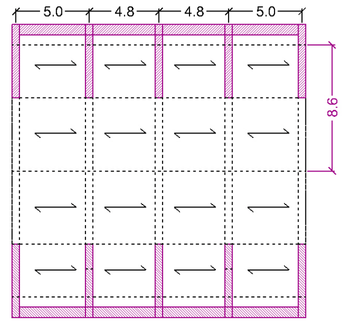
Coupled shear walls



Beff = 8.2 m

2.14

Double C



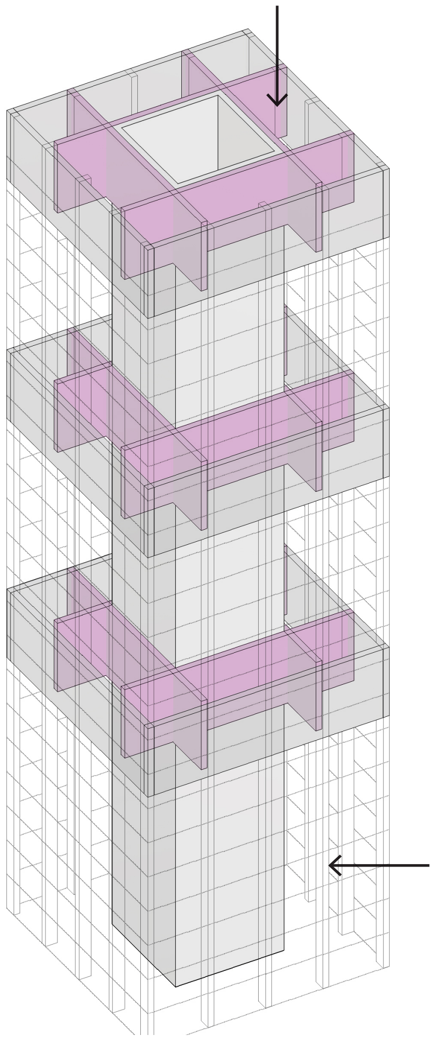
Beff = 8.6 m

2.24

Double spine

UPLIFT

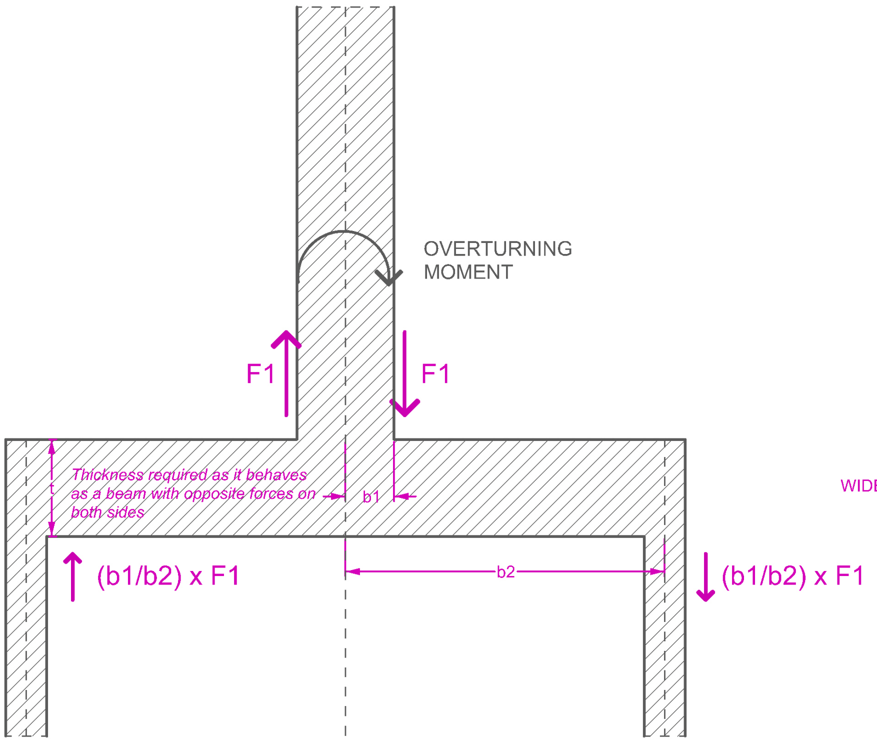
OUTRIGGERS



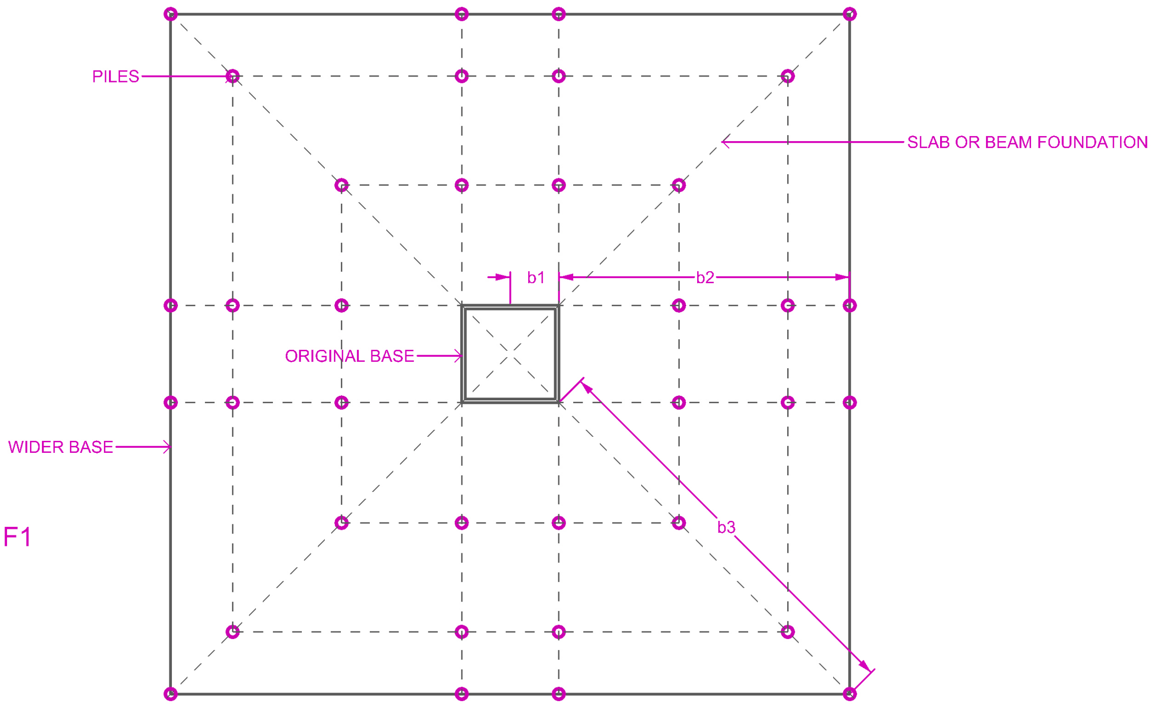
UPLIFT IN FOUNDATION

INCREASE FOUNDATION BASE

Grade beams or foundation slab



FOUNDATION SECTION



FOUNDATION PLAN

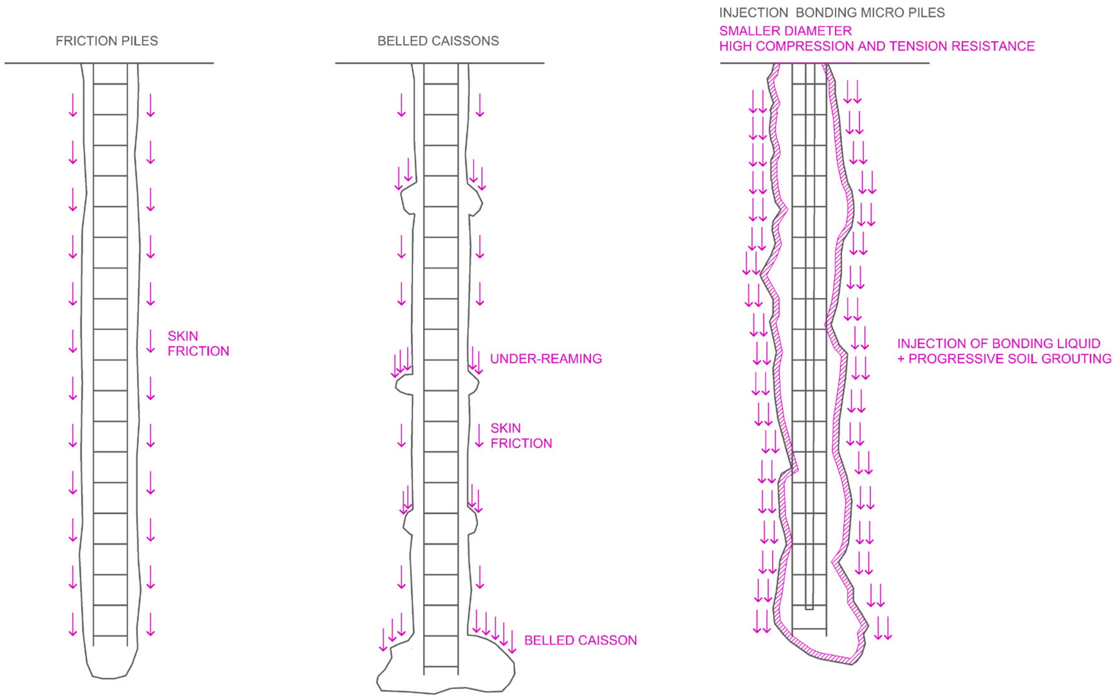
UPLIFT IN FOUNDATION

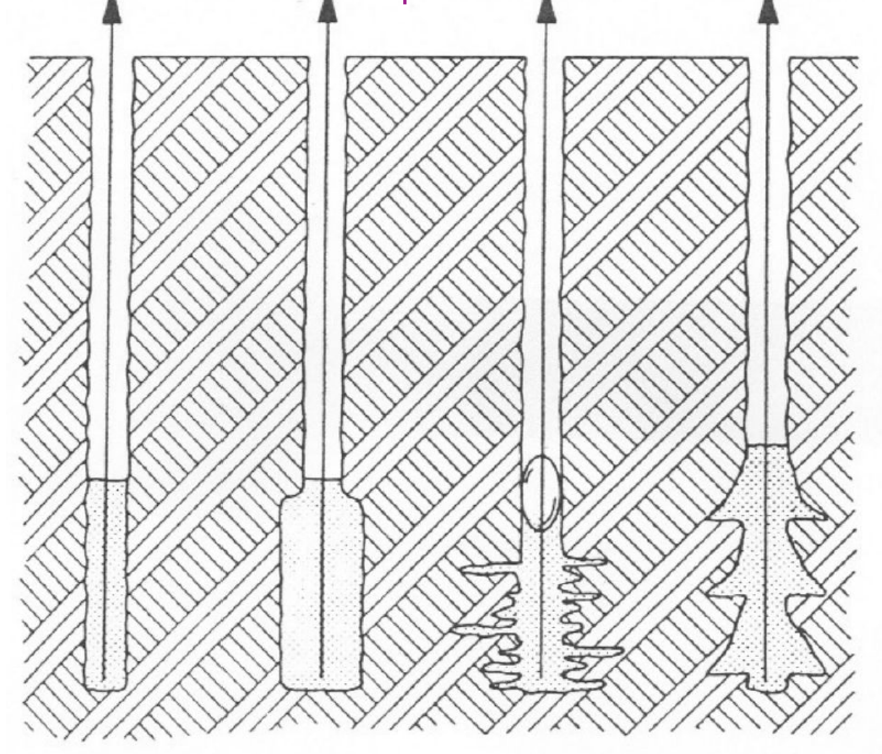
FRICTION PILES

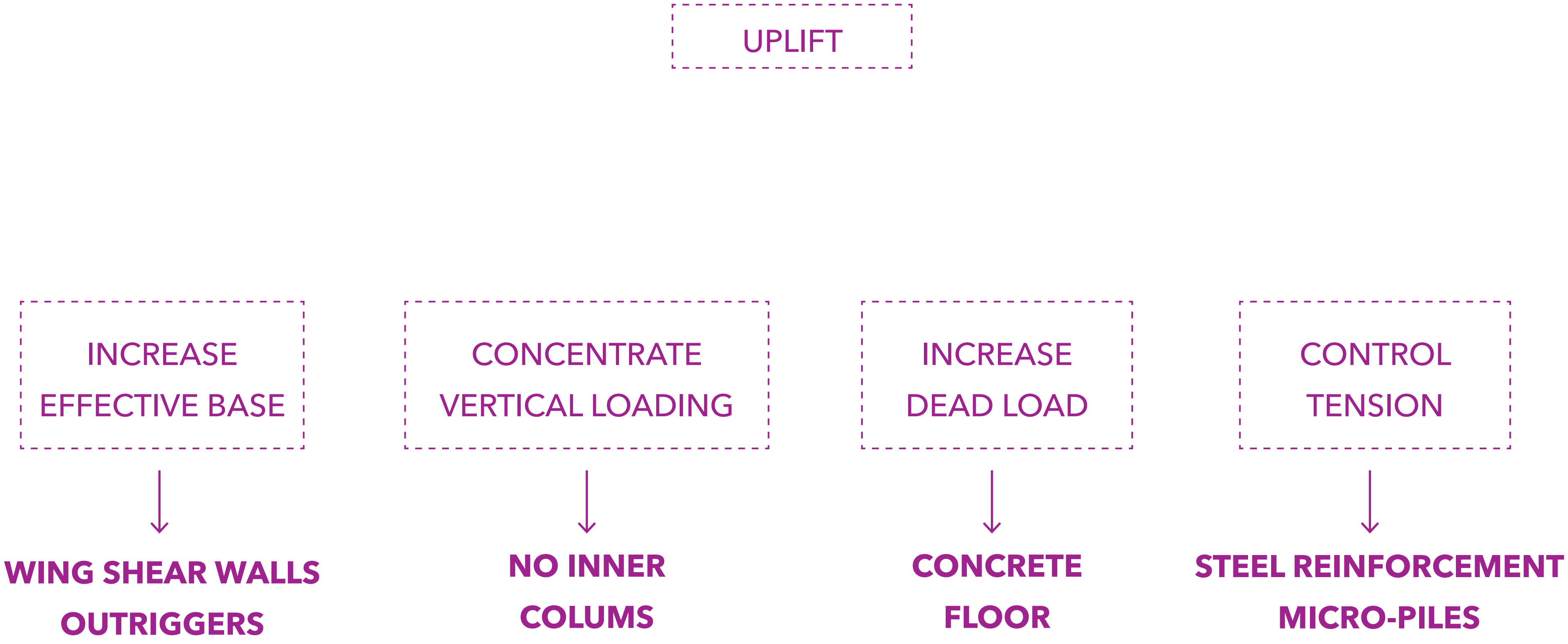
- Limited tension capacity (depending on the soil)
- Noise and vibrations
- Cheap

MICRO PILES

- High tension capacity
- Low disturbances
- Expensive







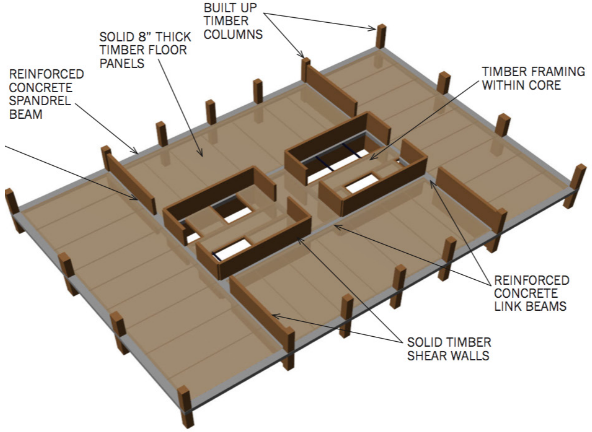
UPLIFT
INCREASE EFFECTIVE BASE
WING SHEAR WALLS
OUTRIGGERS
CONCENTRATE VERTICAL LOADING
NO INNER COLUMS
INCREASE DEAD LOAD
CONCRETE FLOOR
CONTROL TENSION
STEEL REINFORCEMENT
MICRO-PILES

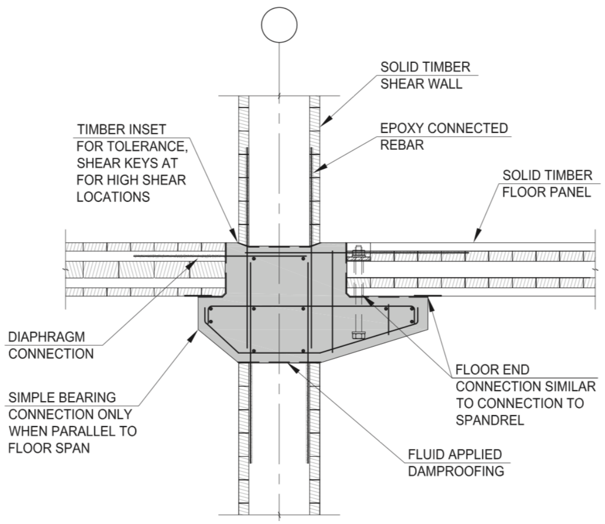
COUPLING ELEMENTS

FURTHER RESEARCH

CONCRETE BEAM

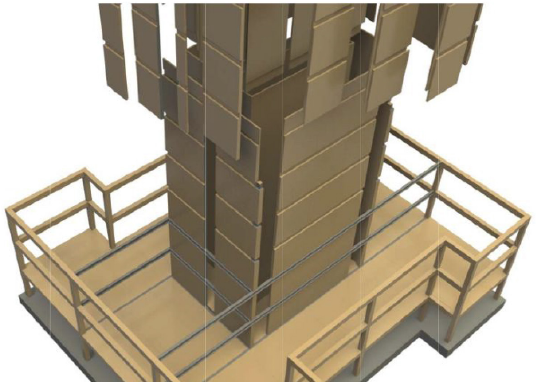
(SOM, 2013)

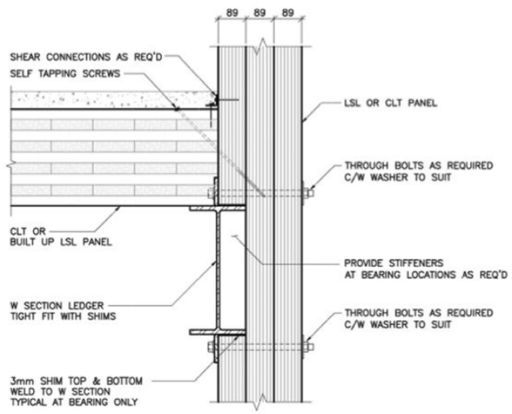




STEEL BEAM

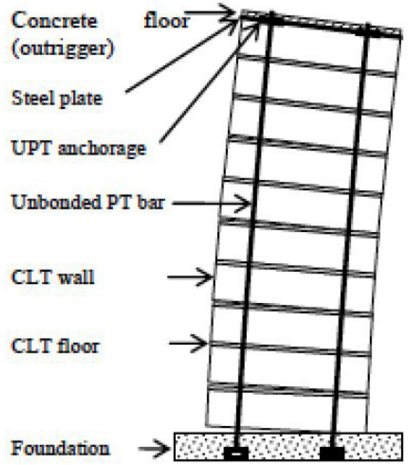
(MICHAEL GREEN, 2013)

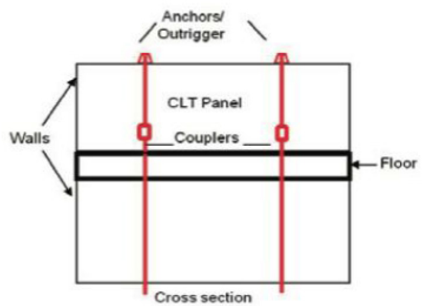




POST-TENSIONED CABLE INSIDE CLT

(VAN DE KUILLEN, 2010)

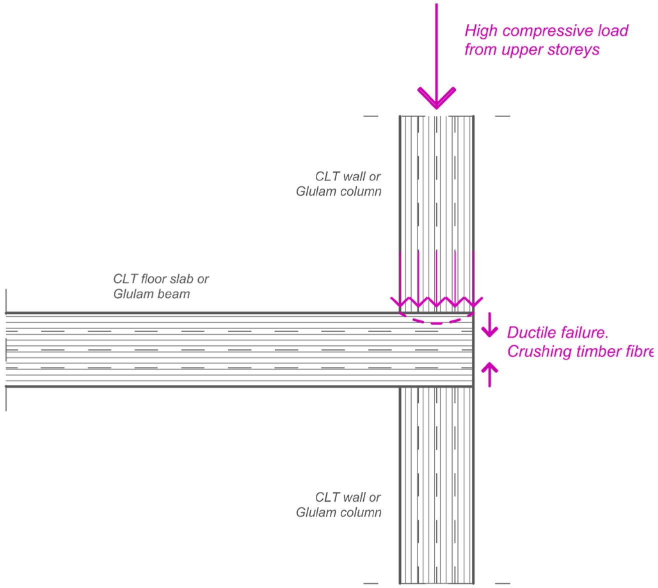




DETAILING

WEAK PERPENDICULAR TO FIBRE

PLATFORM METHOD

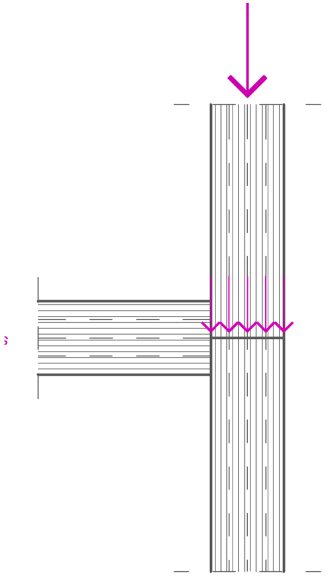


COMPRESSION PERPENDICULAR TO GRAIN

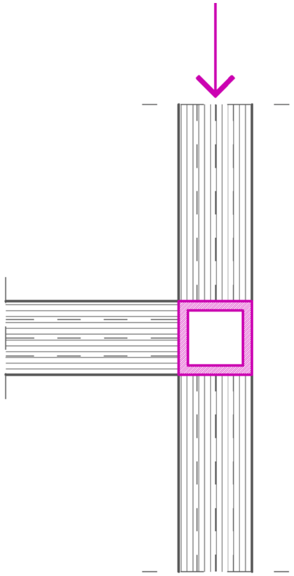
LIMITED TO 10 STOREYS

DETAILING

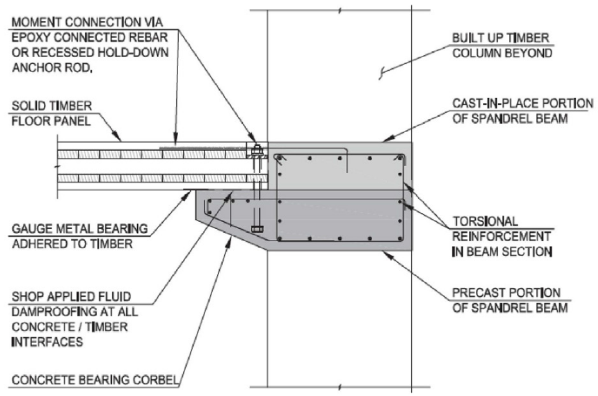
VERTICAL CONTINUITY

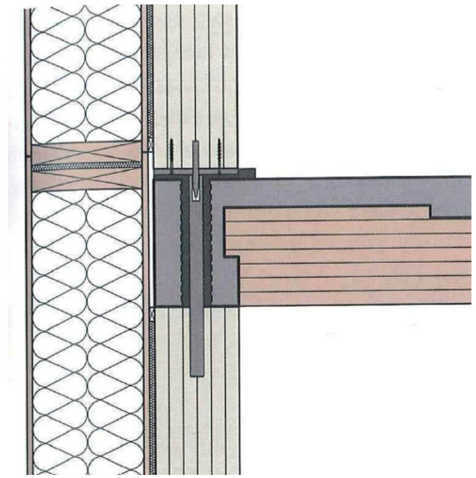


STEEL



CONCRETE

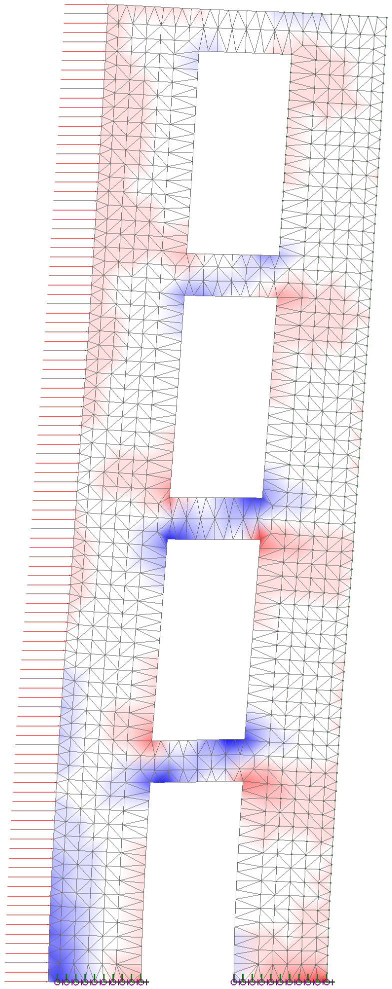


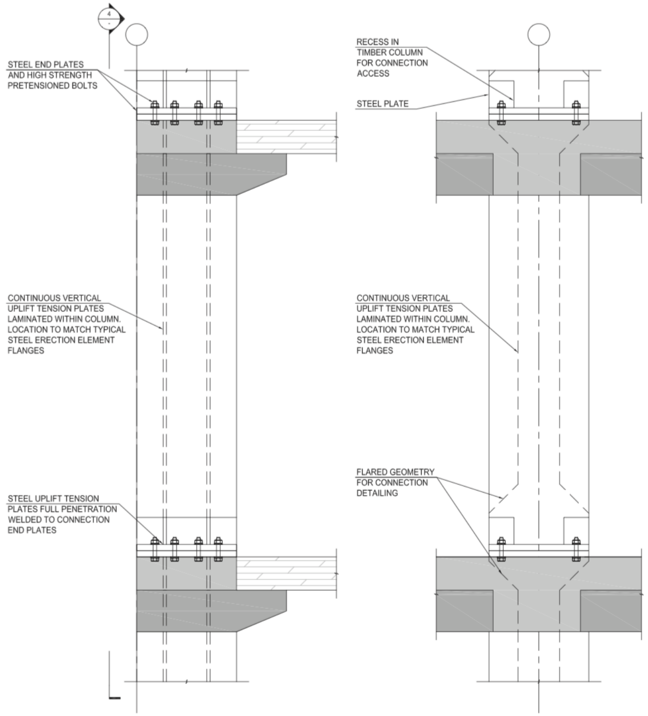


TENSION AT THE BOTTOM

Timber has a fragile failure in tension

Reinforcement with Steel plates/rods inside timber elements





Steel tension rods inside CLT panels

The use of steel tension rods inside CLT shear walls connecting the elements vertically from foundation to top can help in resisting wind-loading and uplift forces and anchoring the building to the concrete base, by absorbing tension forces. In addition, the use of these vertical rods eliminates the need of more complex load-transferring connectors between wall elements.

FURTHER RESEARCH

WIND-INDUCED VIBRATIONS

DIFFERENTIAL SHORTENING

→

FULL-SCALE MOCK UP TESTS

(Above 10 storeys)

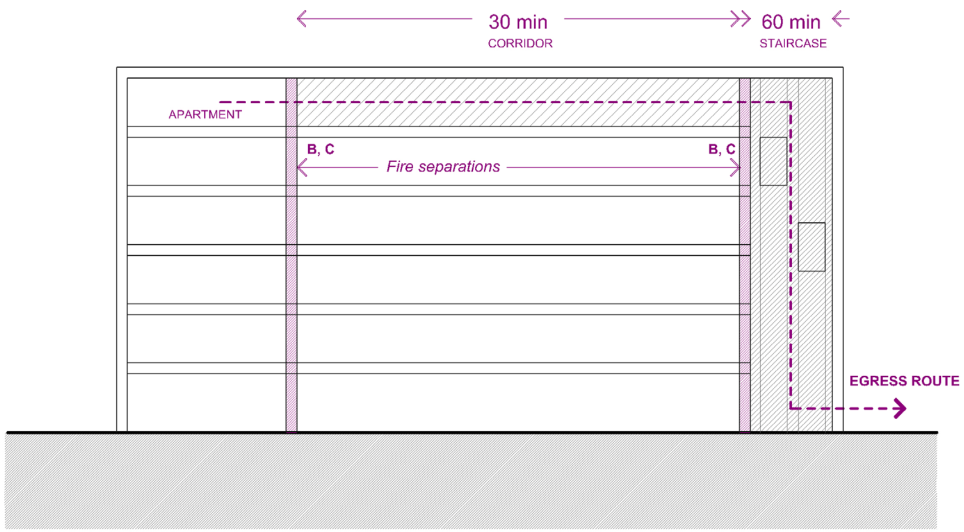
FIRE RESISTANCE

(For buidings higher than 13m in The Netherlands)

STRUCTURE SHOULD PROVIDE 120M (structural capacity)*

VERTICAL CIRCULATIONS > 60MIN (fire and smoke free)

HORIZONTAL CIRCULATIONS > 30MIN (smoke free)



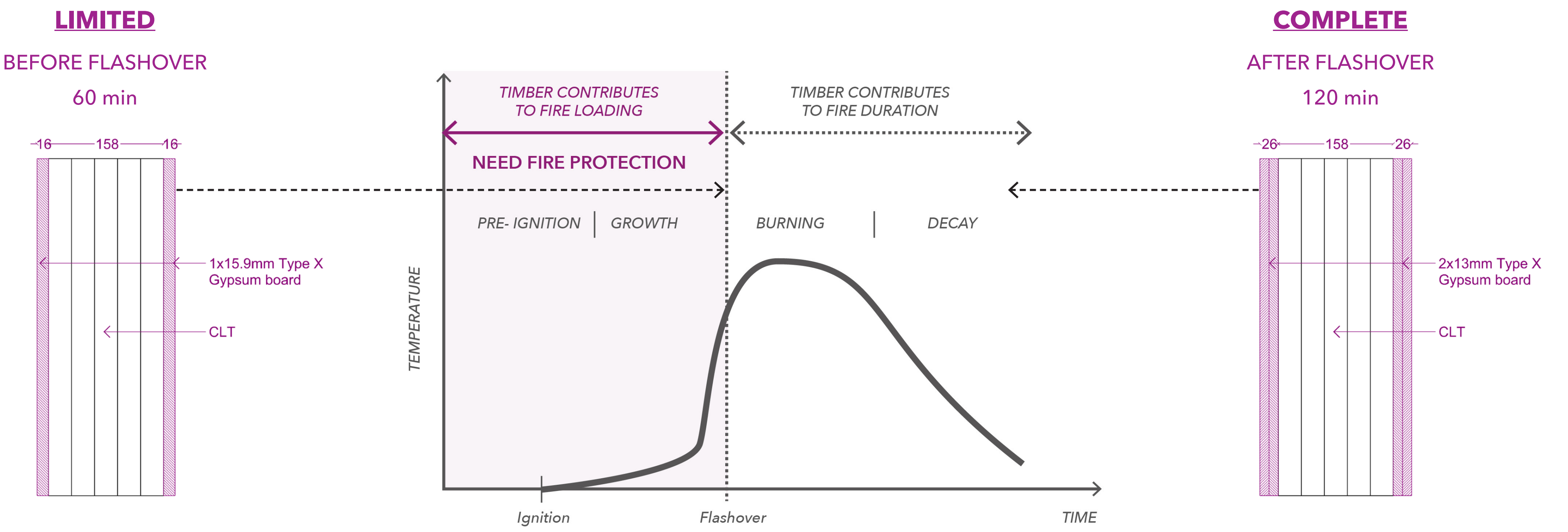
*can be reduced 30-60 minutes if automatic sprinklers

FIRE CONTRIBUTION

CLT

CONTRIBUTION TO FIRE	**D**	Cannot be used in fire separation compartments without additional protection
SMOKE PRODUCTION	**S1/S2**	
FLAME DROPLET CLASS	**D0**	

ENCAPSULATION



EXPOSED

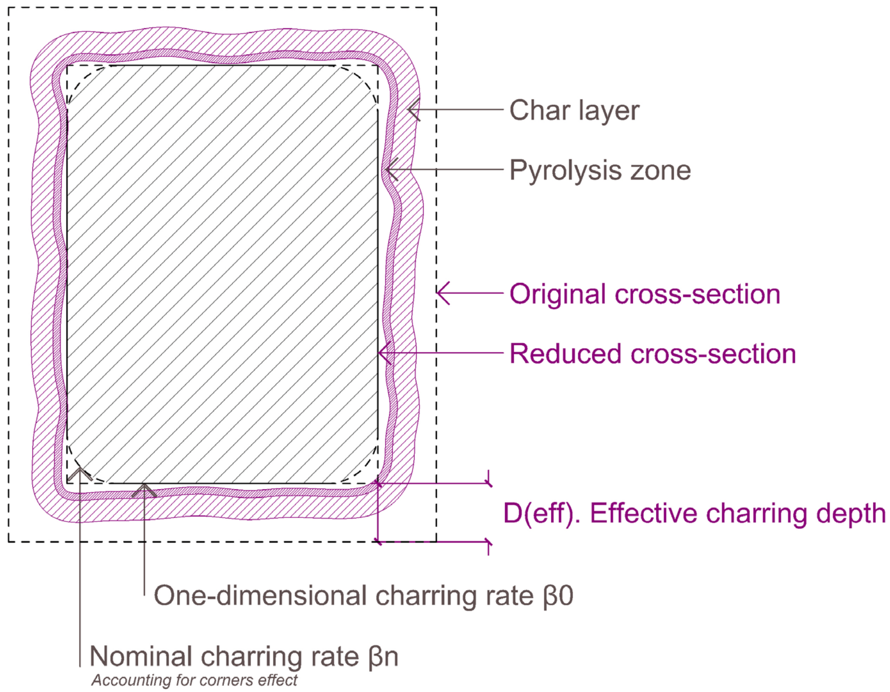
Only within fire compartments

Research + approval with fire authorities

CHARRING DEPTH

Type of timber

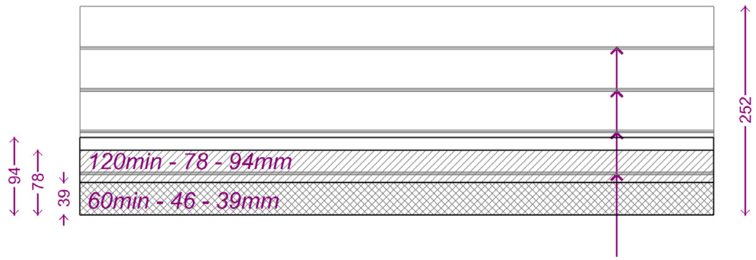
One or more side exposed



DE-LAMINATION CLT

Thickness of laminations

Adhesive type



Phenol-resorcinol-formaldehyde

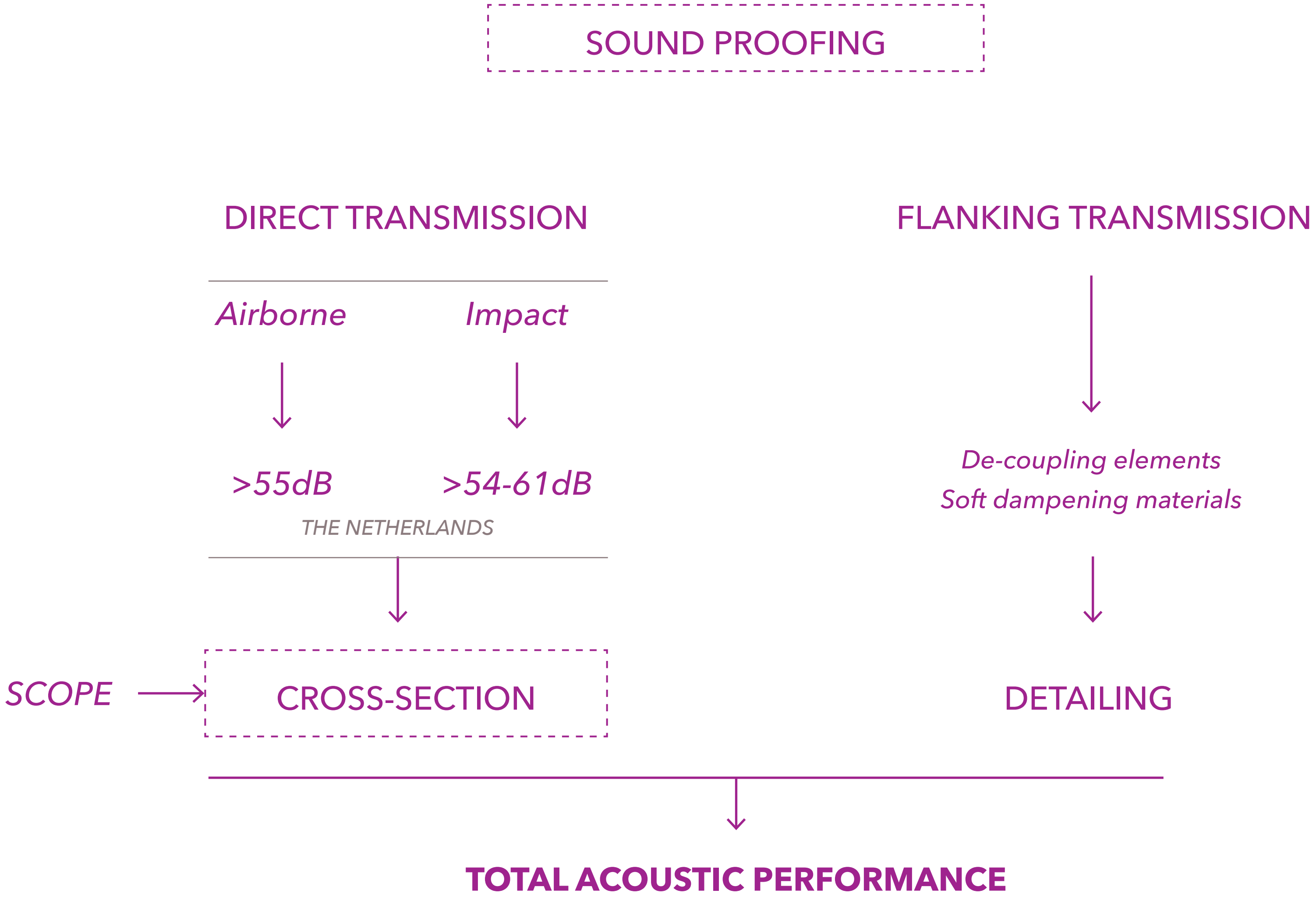
NO DELAMINATION

0.65mm/min

Polyurethane (PUR)

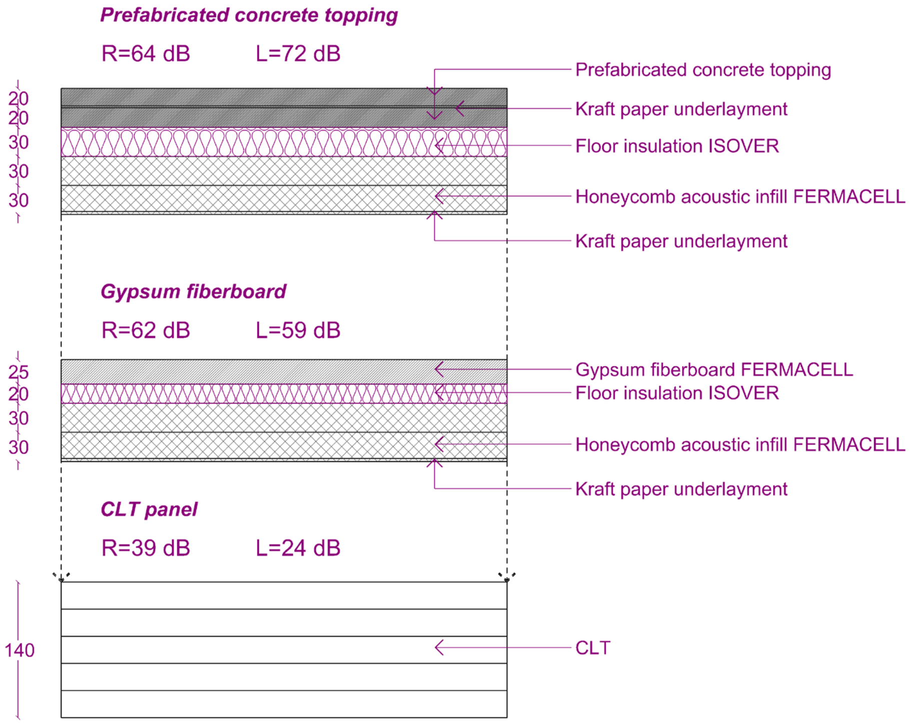
DELAMINATION

35mm - 0.65mm/min
30mm - 0.69mm/min
25mm - 0.73mm/min
20mm - 0.78mm/min

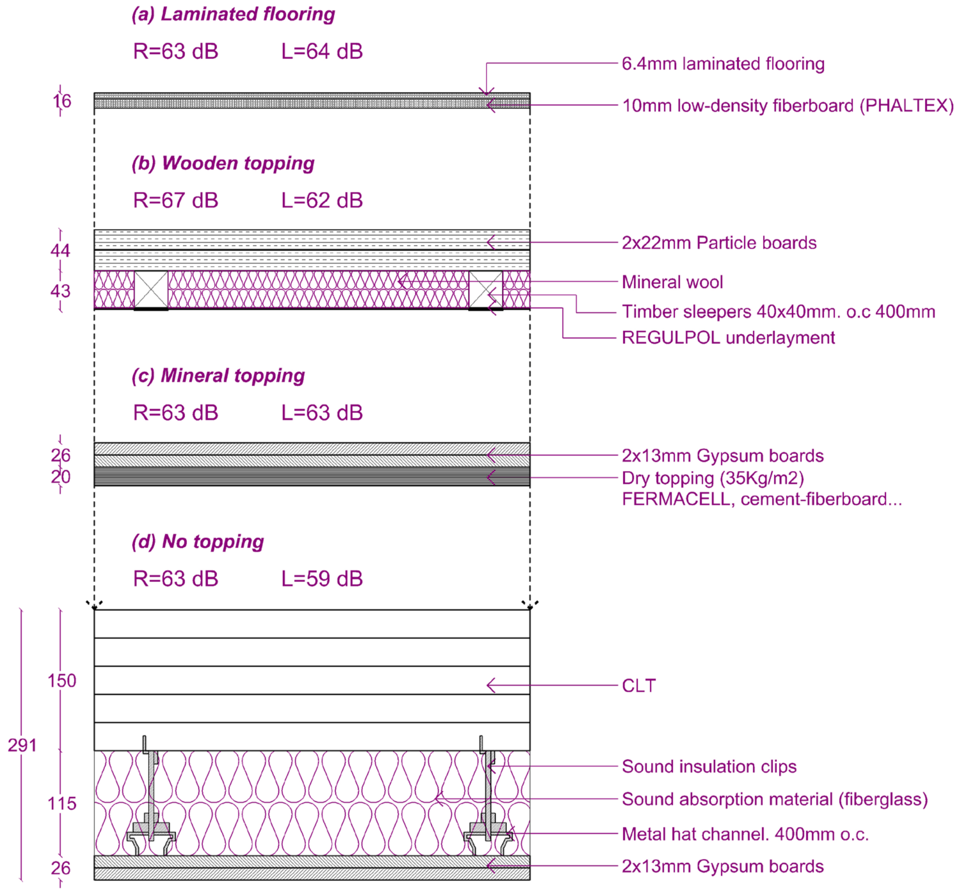

SOUND PROOFING
DIRECT TRANSMISSION
FLANKING TRANSMISSION
Airborne
Impact
>55dB
>54-61dB
THE NETHERLANDS
De-coupling elements
Soft dampening materials
SCOPE
CROSS-SECTION
DETAILING
TOTAL ACOUSTIC PERFORMANCE

SOUND PROOFING

CLT FLOOR



CLT FLOOR + CEILING

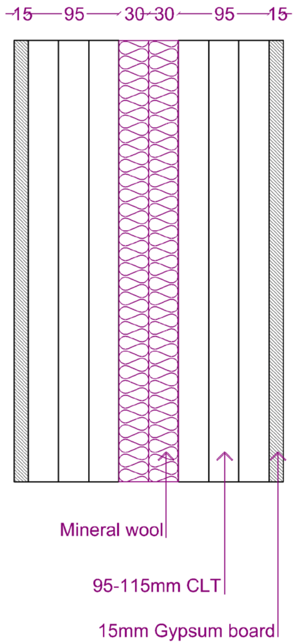


SOUND PROOFING

CLT WALL

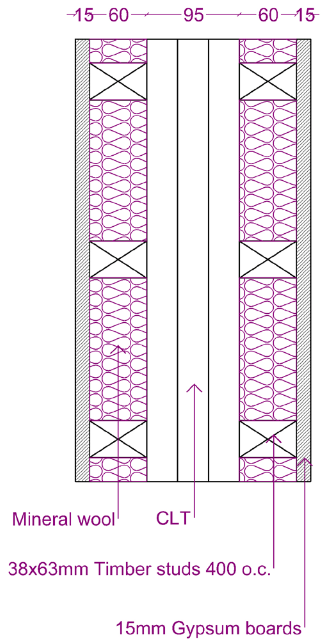
Double CLT panel

30mm Mineral wool
R=55 dB
60mm Mineral wool
R=60 dB



CLT panel + studs

120mm Mineral wool
R=58 dB



EXTENSION (TE)

TO WHAT EXTENT IS A TALL EXTENSION (TE) TECHNICALLY FEASIBLE?




ROYAL
FEST





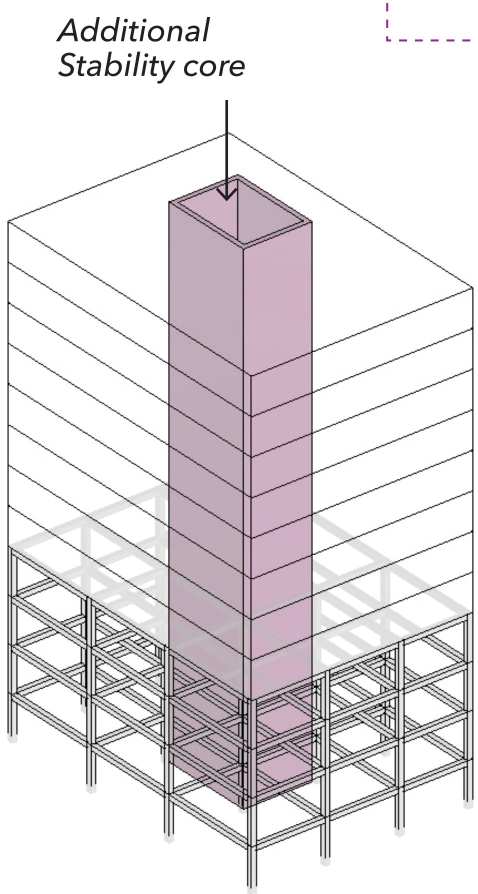




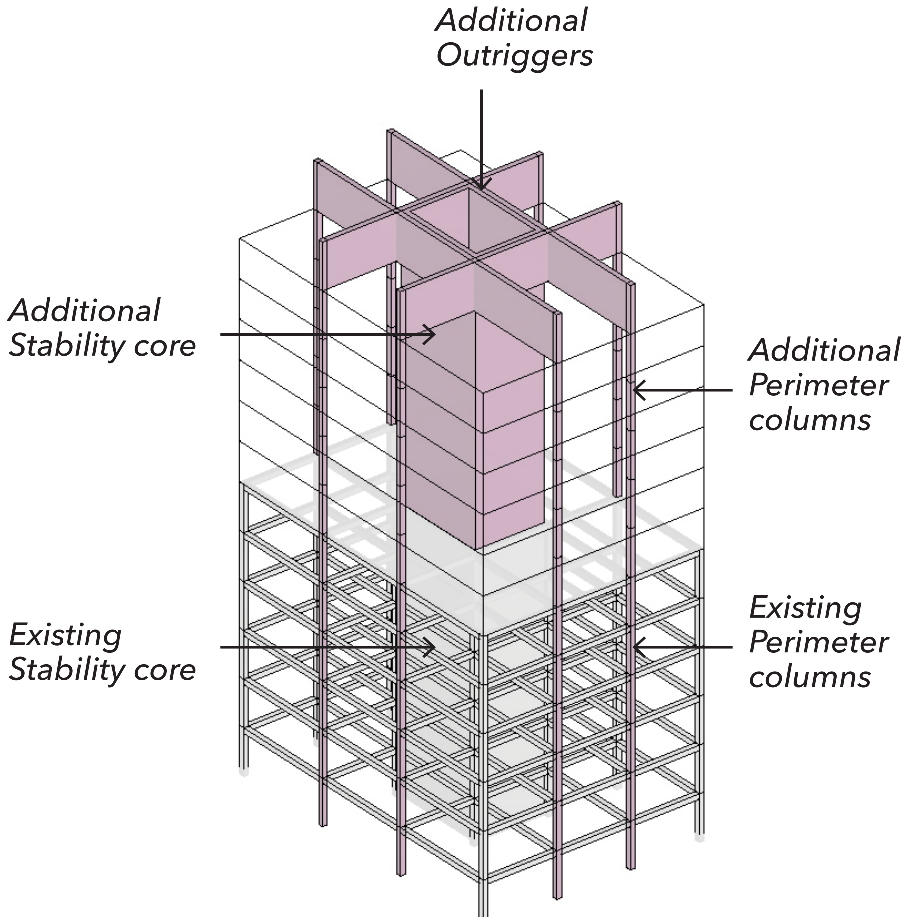

ZARA


© Hearst Corporation via CTBUH

"TALL" EXTENSION

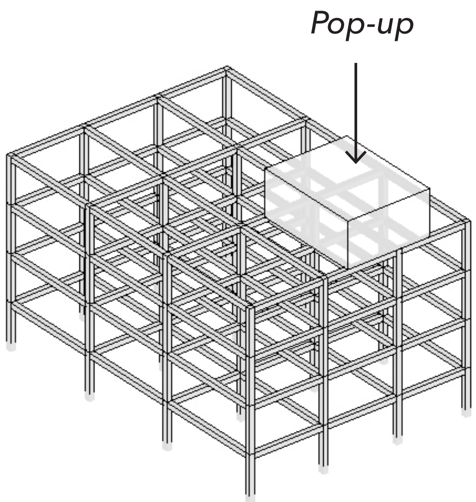


Lateral stability:
- Additional stability core
- Composite action with existing
Vertical loading:
- Existing structure
- Additional stability core
Demolition required
Medium/Large-scale

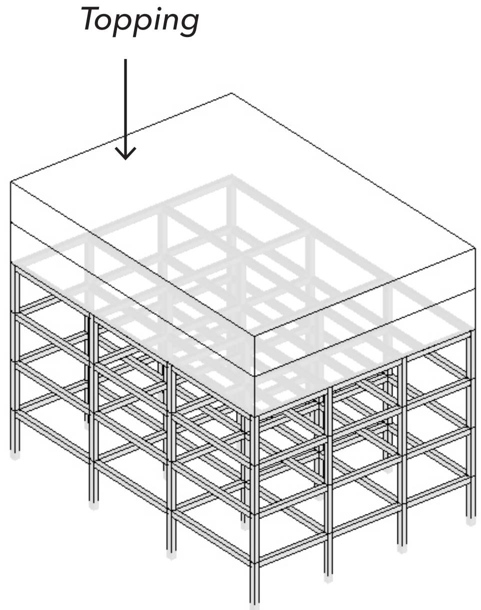


Lateral stability
- Composite action with existing
Vertical loading:
- Existing structure
Demolition required
Medium/Large-scale

“SMALL” EXTENSION



Lateral stability:
- Existing structure
Vertical loading:
- Existing structure
No demolition
Small scale



Lateral stability:
- Existing structure
Vertical loading:
- Existing structure
Reduced demolition
Small/medium scale

EXTENSIONS

Type of extension	Extra storeys	Use of existing structure	Demolition	Tall building
Pop-up	1-2	+	-	-
Topping	2-4	+	-	-
Stability cores	4-16	+/-	+/-	+/-
Outriggers	2-4	+/-	+/-	+/-
Table structure	2-4	-	-	-

+ Likely; +/- Partially; - Unlikely

EXTENSIONS

"TALL" EXTENSION

> 4 extra storeys

New stability system

Strengthen existing structure

Demolition

Complex

"SMALL" EXTENSION

< 4 extra storeys

Existing stability system

No demolition

RESPECT EXISTING STRUCTURAL GRID

EVEN DISTRIBUTION OF VERTICAL LOADING

Avoid extra complexity, transfer structures, differential settlements

WHAT IS A TALL BUILDING?

TALLNESS AND HEIGHT

HEIGHT is objective (number of meters)

TALL is subjective (in relation to references)

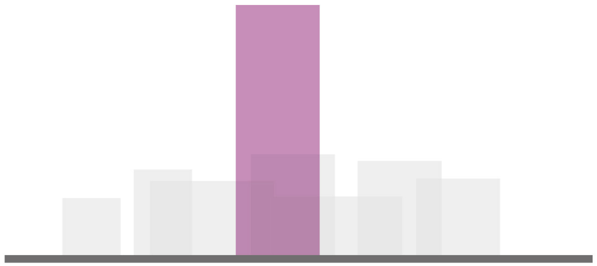
OBJECTIVE HEIGHT

According to CTBUH, tall building is above 50 meters

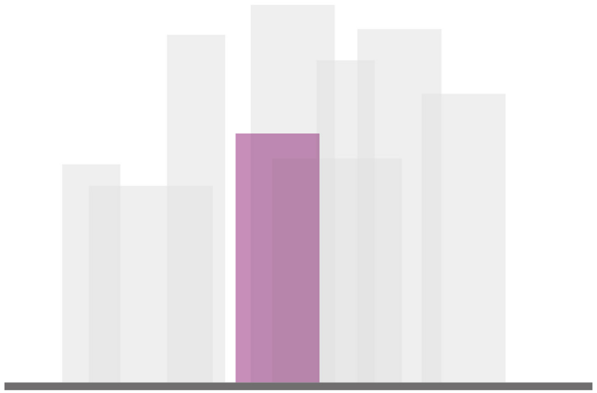
According to National Convenant Hoogbouw, tall building is above 70 meters

SUBJECTIVE TALLNESS

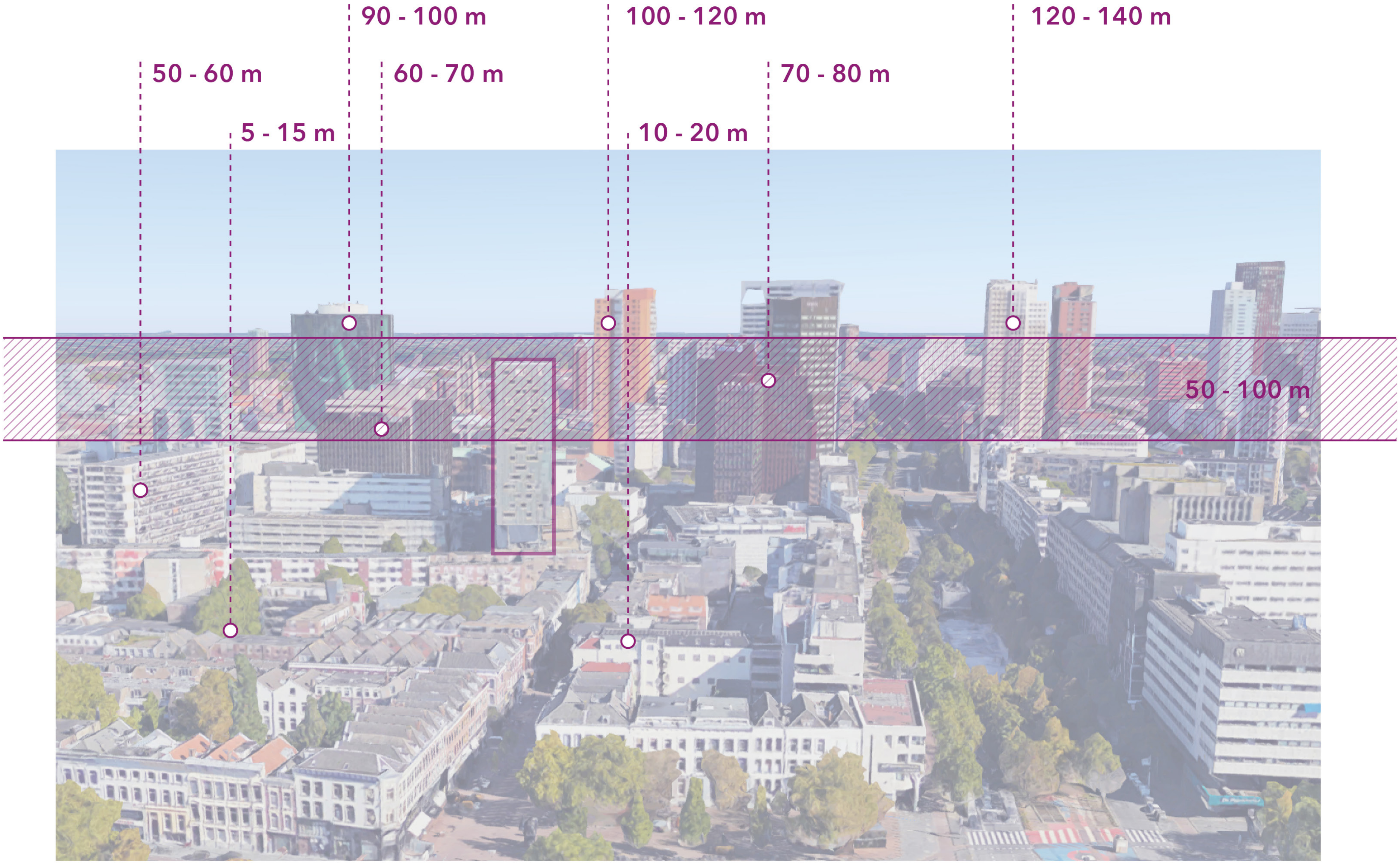
According to context (CTBUH)



PERCEIVED AS "TALL BUILDING"

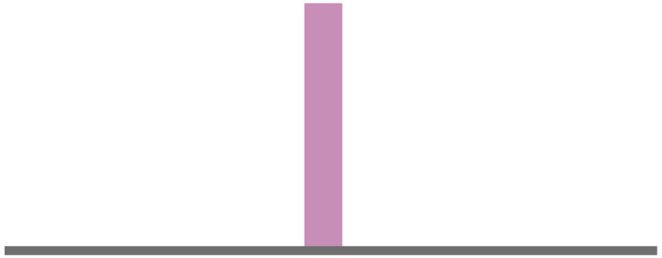


PERCEIVED AS "LESS TALL BUILDING"


90 - 100 m
100 - 120 m
120 - 140 m
50 - 60 m
60 - 70 m
70 - 80 m
5 - 15 m
10 - 20 m
50 - 100 m


6,0 tot 7,0
7,0 tot 8,0
8,0 tot 9,0
9,0 tot 10,0
10,0 tot 12,0
12,0 tot 14,0
14,0 tot 16,0
16,0 tot 18,0
18,0 tot 20,0
20,0 tot 25,0
25,0 tot 30,0
30,0 tot 35,0
35,0 tot 40,0
40,0 tot 45,0
45,0 tot 50,0
50,0 tot 60,0
60,0 tot 70,0
70,0 tot 80,0
80,0 tot 90,0
90,0 tot 100,0
100,0 tot 125,0
125,0 tot 150,0
150,0 tot 175,0
175,0 tot 200,0
SCHOUWBURGPLEIN
DIERGAARDESINGEL
LIJNBAAN
AERT VAN NESSTRAAT
HOOGSTRAAT
BEURSPLEIN
VAN OLDENBARNEVELTPLAATS
KAREL DOORMANSTRAAT
BINNENWEGPLEIN
COOLSINGEL
BLAAK
WIJNSTRAAT
WIJNHAVEN
WESTBLAAK
OUDE BINNENWEG
NIEUWE BINNENWEG
WESTERSINGEL
GOUVERNESTRAAT
MAURITSSTRAAT
JACOBUSSTRAAT
WITTE DE WITHSTRAAT
ROCHUSSENSTRAAT
BREITNERSTRAAT
MUSEUMPARK
SCHIEDAMSEDIJK
KORTE HOOGSTRAAT
STEIGER
KEIZERSTRAAT
GLASHAVEN
WIJNKADE
GROTEKERKPLEIN
RODEZAND

According to proportion (CTBUH)



PERCEIVED AS “TALL BUILDING”

PERCEIVED AS “LESS TALL BUILDING”

According to CTBUH a building can be considered tall if it uses tall-building technologies:

- Lateral resisting system
- Damping for wind-induced accelerations
- Fire design
- Vertical transportation

According to Foster et al. 2013, tall building can be defined as any height that exceeds current precedents

Tall Timber (TT)

The Treet" and UBC Brock Commons

↓

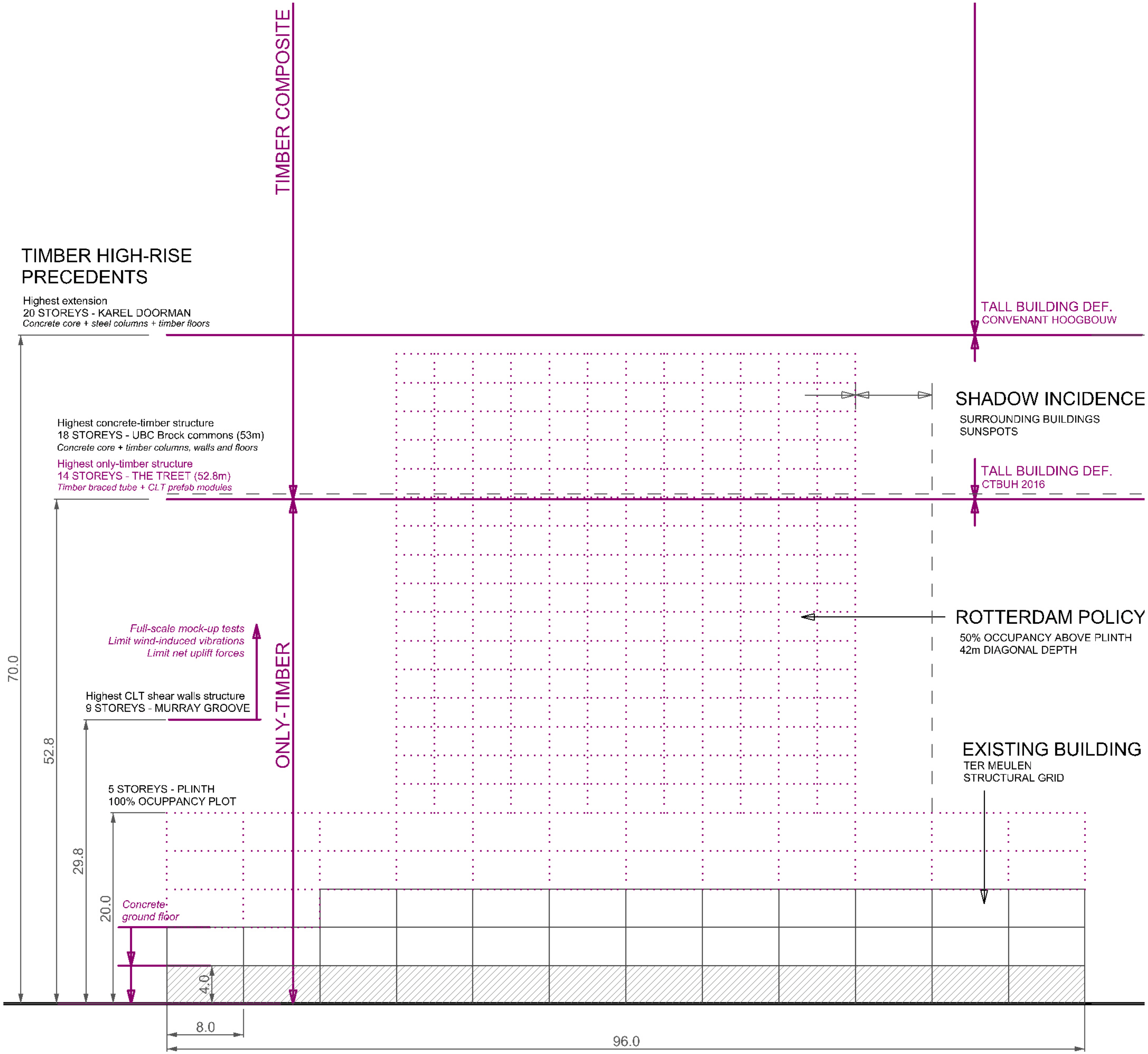
53 M

Tall Extension (TE)

Karel Doorman

↓

70 M



TIMBER COMPOSITE
TIMBER HIGH-RISE PRECEDENTS
Highest extension
20 STOREYS - KAREL DOORMAN
Concrete core + steel columns + timber floors
TALL BUILDING DEF.
CONVENANT HOOGBOUW
SHADOW INCIDENCE
SURROUNDING BUILDINGS
SUNSPOTS
Highest concrete-timber structure
18 STOREYS - UBC Brock commons (53m)
Concrete core + timber columns, walls and floors
Highest only-timber structure
14 STOREYS - THE TREET (52.8m)
Timber braced tube + CLT prefab modules
TALL BUILDING DEF.
CTBUH 2016
ROTTERDAM POLICY
50% OCCUPANCY ABOVE PLINTH
42m DIAGONAL DEPTH
Full-scale mock-up tests
Limit wind-induced vibrations
Limit net uplift forces
ONLY-TIMBER
70.0
52.8
Highest CLT shear walls structure
9 STOREYS - MURRAY GROOVE
EXISTING BUILDING
TER MEULEN
STRUCTURAL GRID
5 STOREYS - PLINTH
100% OCUPPANCY PLOT
29.8
20.0
Concrete ground floor
4.0
8.0
96.0

DESIGN STUDY

WHAT IS THE CITY POLICY REGARDING TALL BUILDINGS IN THE INTENDED LOCATION?

LOCATION

Important commercial location

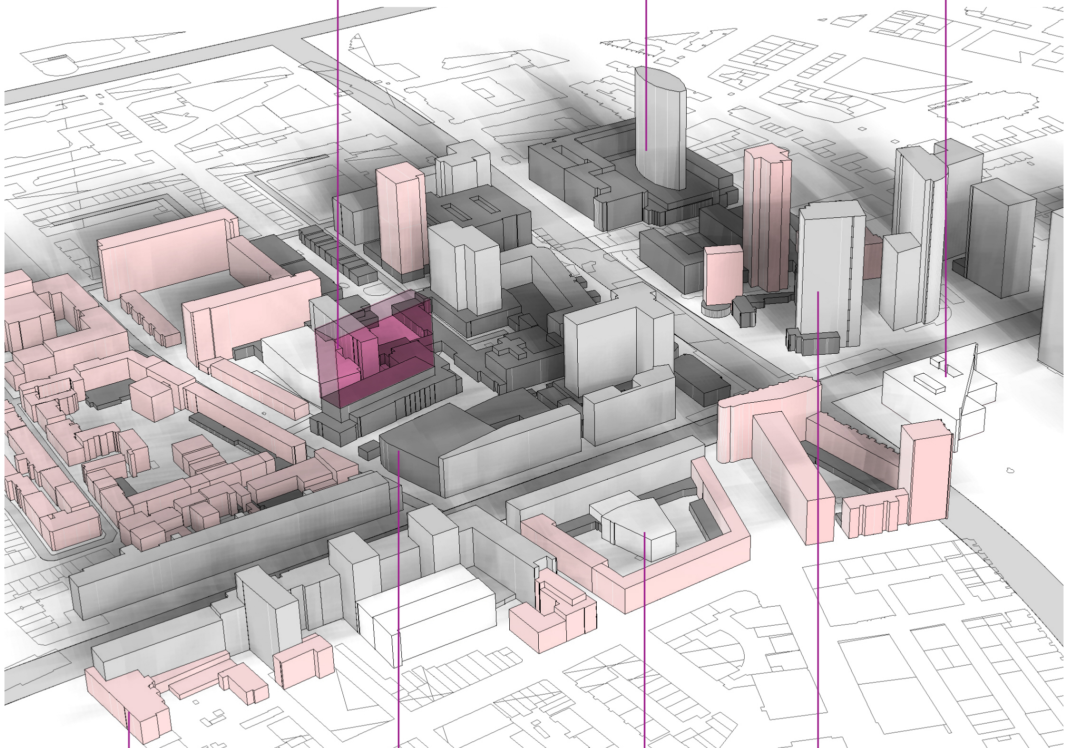
Pedestrian active area

COOL DISTRICT - ROTTERDAM CENTER

KAREL DOORMAN + TER MEULEN

WORLD TRADE CENTER

MARITIME MUSEUM



HOUSING

COMMERCIAL

PARKING

OFFICE

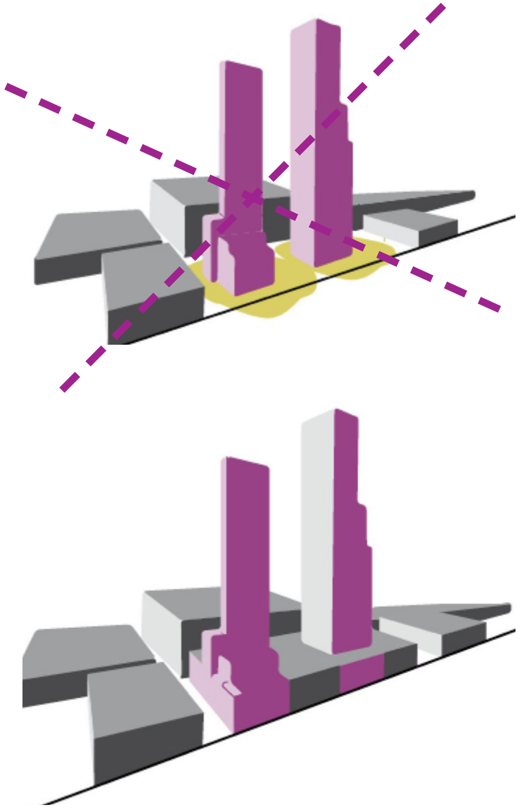
HIGH-RISE ZONING

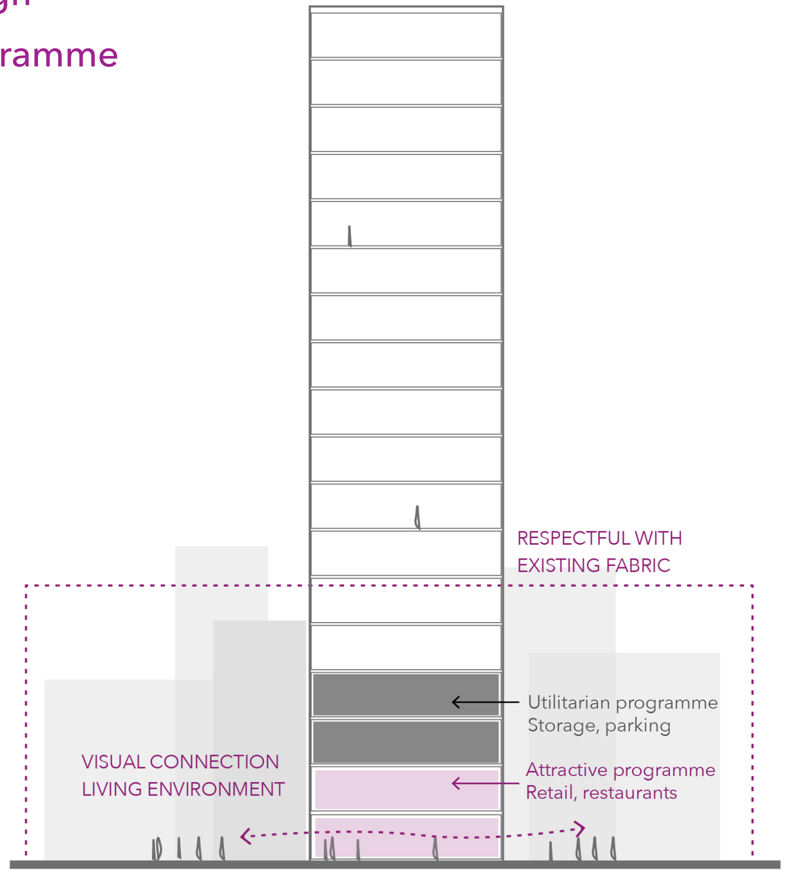
URBAN PLINTH

Urban fabric continuity

20-25 meters high

Urban-attractive programme





SHADOW IMPACT

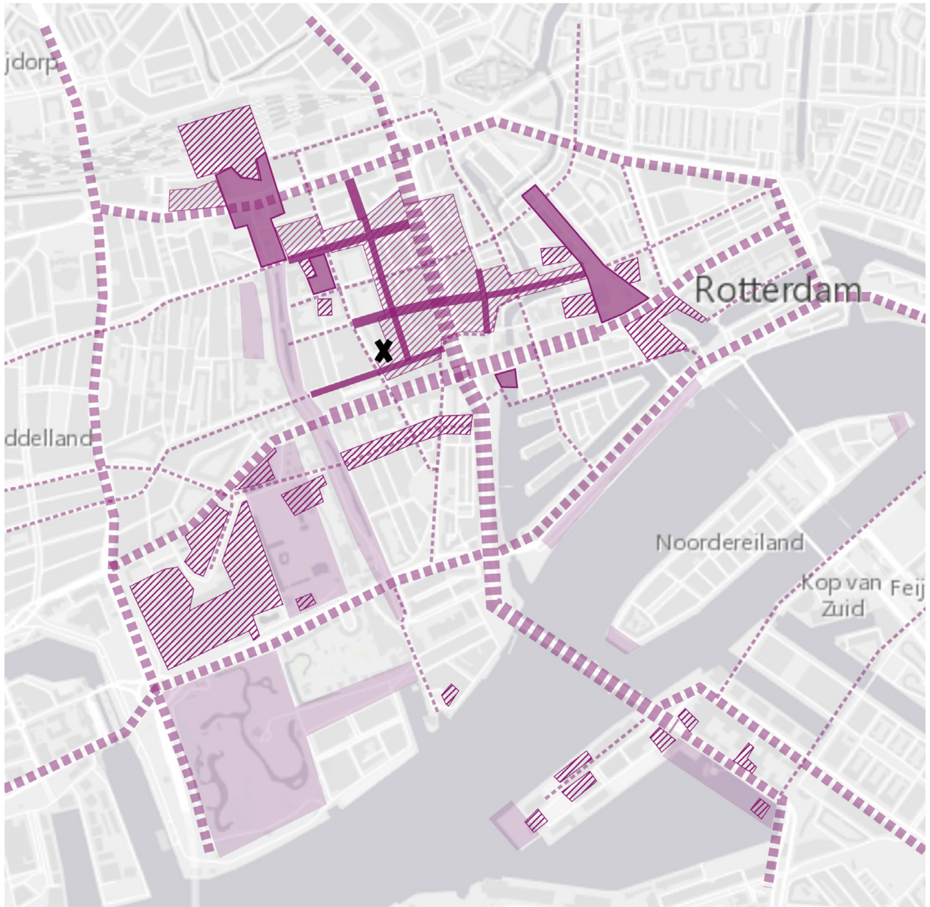
CLIMATE COMFORT ZONE

Comfort zone

Super high-rise areas

Climate buffer zone

ACTIVE CITY CENTRE



Main avenues and boulevards

Secondary streets

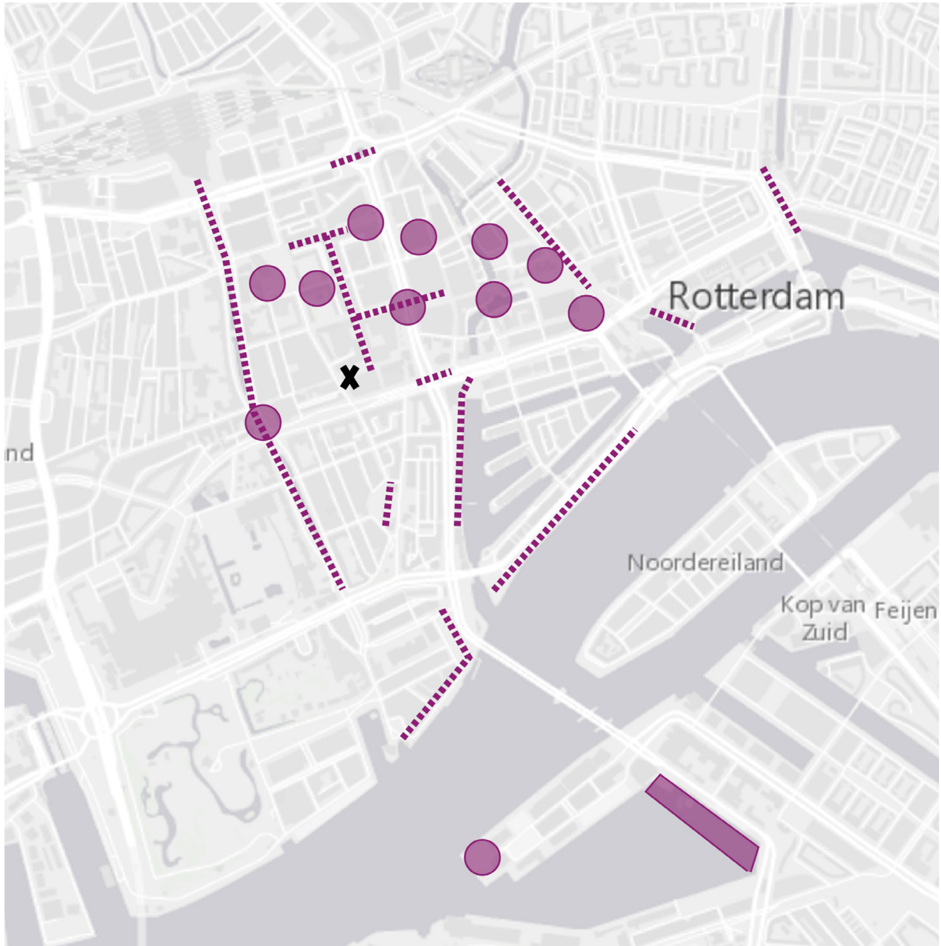
Squares

(Semi) public ground floor

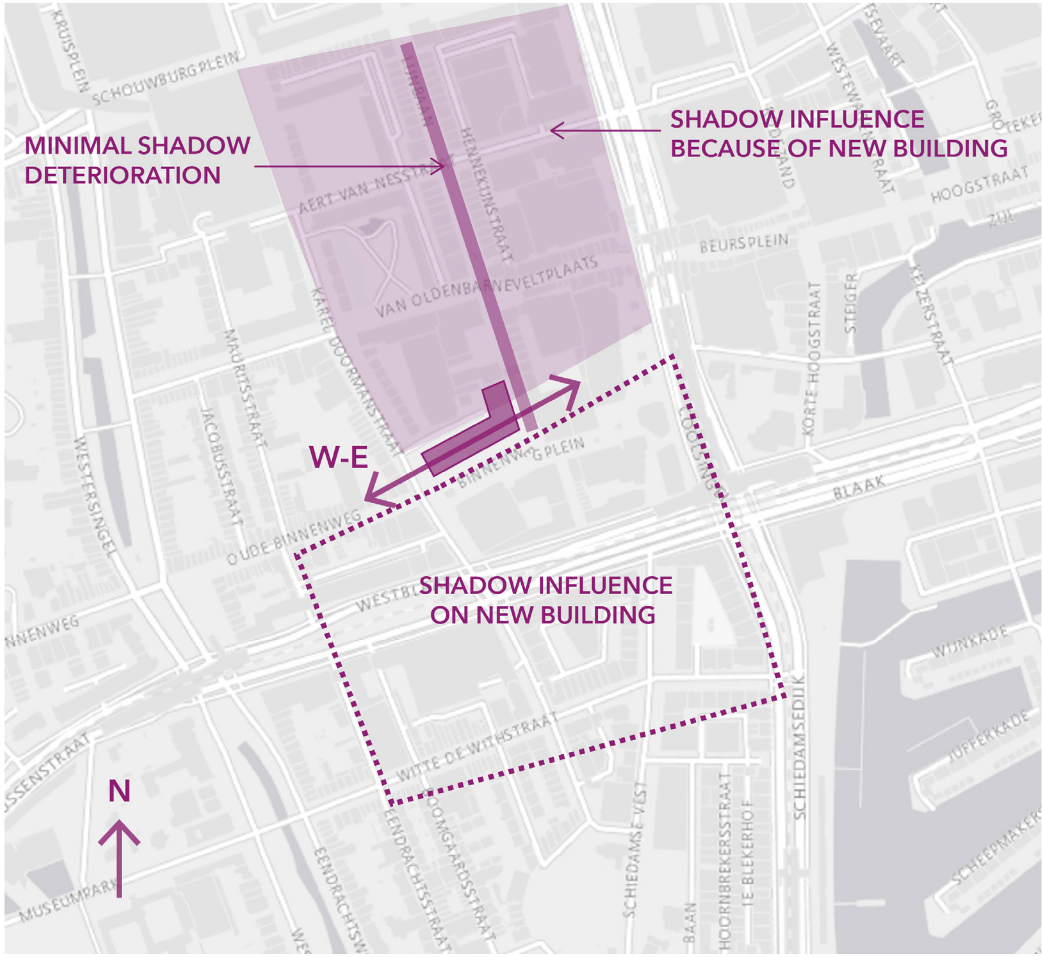
Parks

SHADOW IMPACT

PROTECTED ZONES



LOCATION

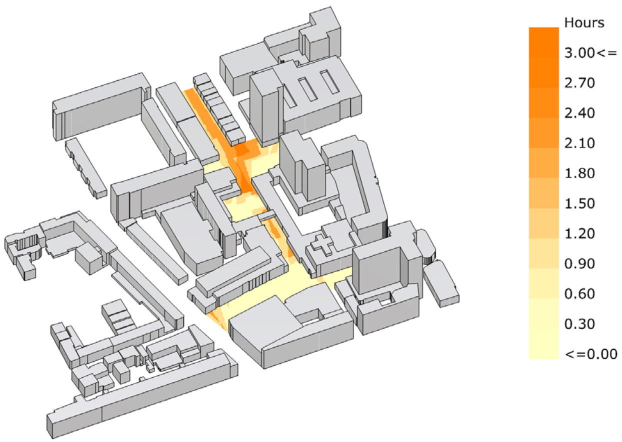


Sunpots. No deterioration allowed during time of use.

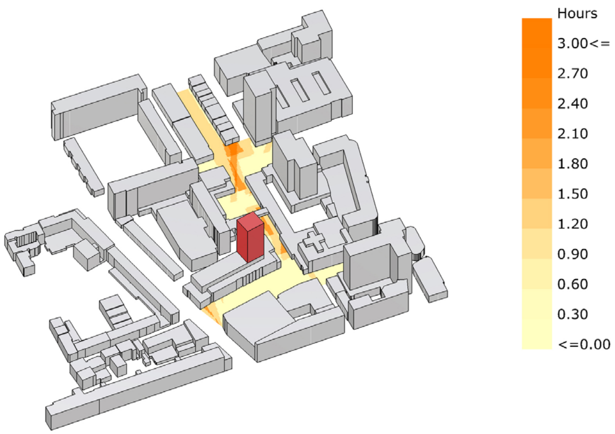
Sites with special quality (Slight shadow deterioration is allowed)

SHADOW ANALYSIS

21 DEC



CONTEXT >1h sunlight : 34%
>2h sunlight: 16%

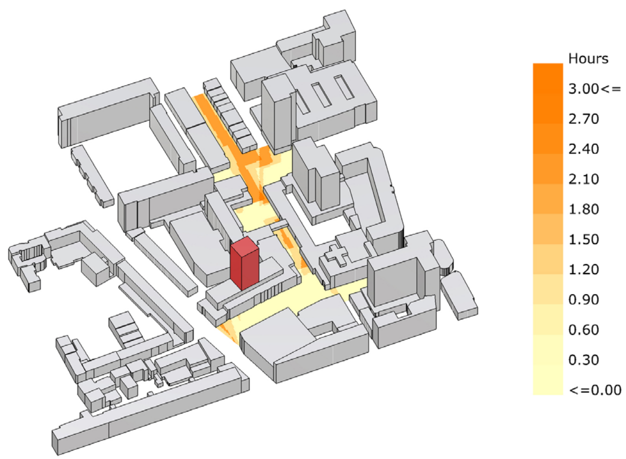


SCENARIO 1 >1h sunlight : 31%
>2h sunlight: 5.7%

Optimal locations regarding maximum sunlight in Lijbaan street

SCENARIO 2 >1h sunlight : 34%
>2h sunlight: 16%

- Most optimal position -



SCENARIO 3 >1h sunlight : 32%
>2h sunlight: 14%

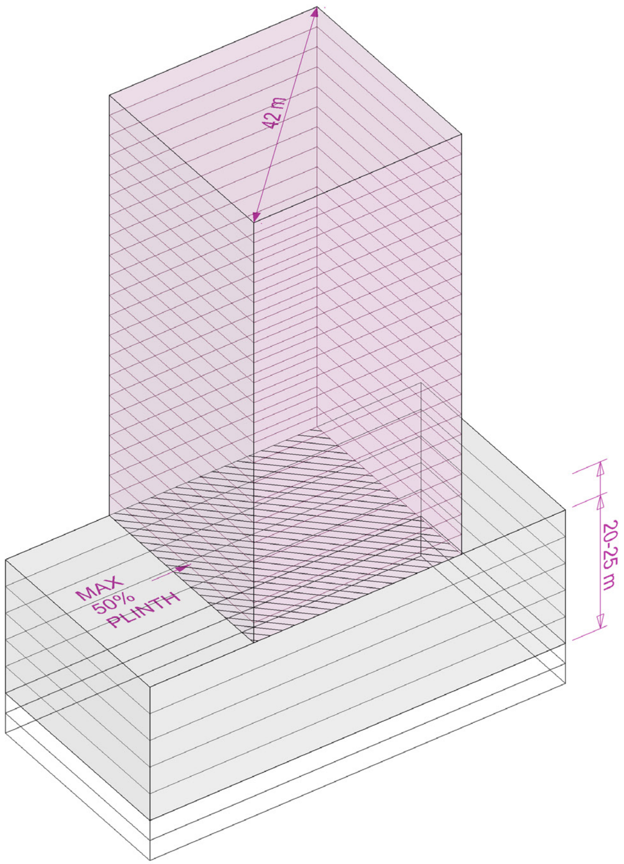
MAXIMUM VOLUME

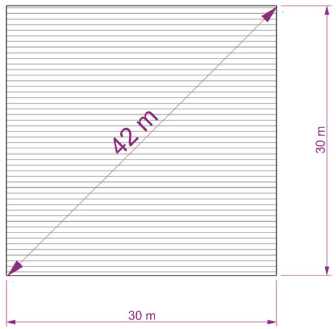
50% volume above plinth

Area: 900m2

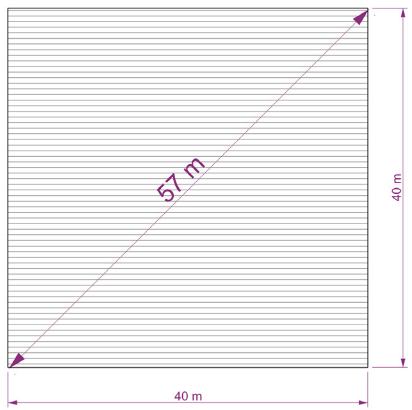
Depth: 30m

Diagonal 42m





RESIDENTIAL USE
GFA 900m2

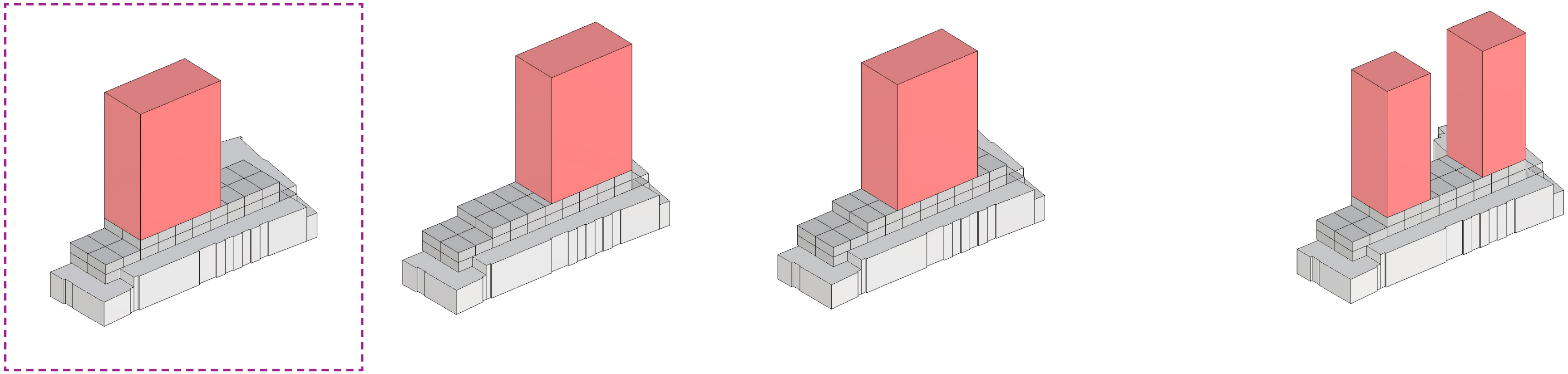


OFFICE USE
GFA 1600m2

SCHEMATIC SHAPES REGARDING POLICY MEASURES

DISK

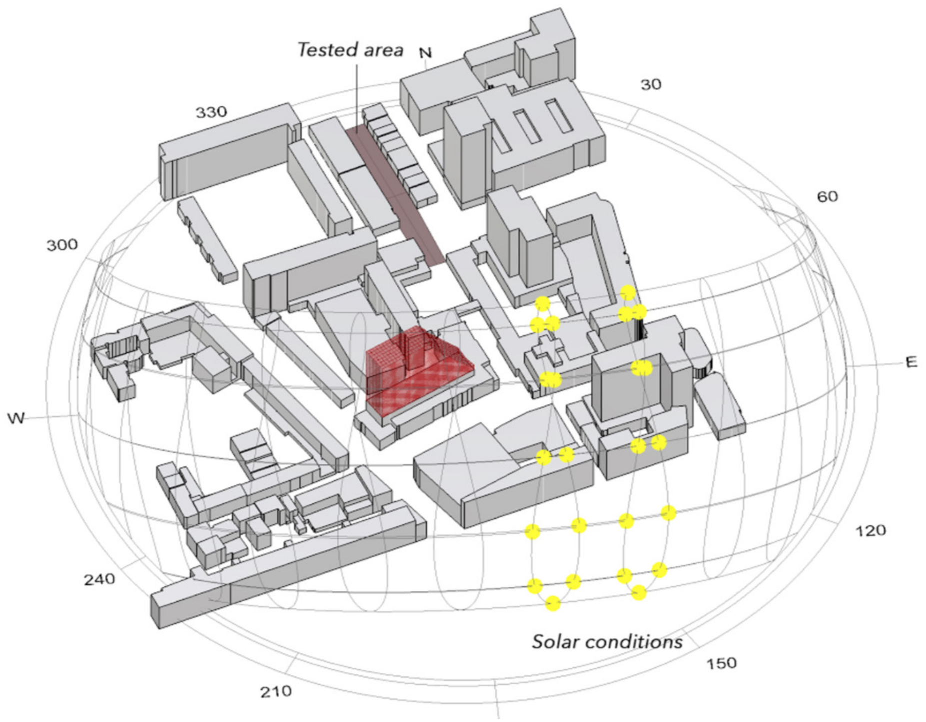
2 ISOLATED TOWERS

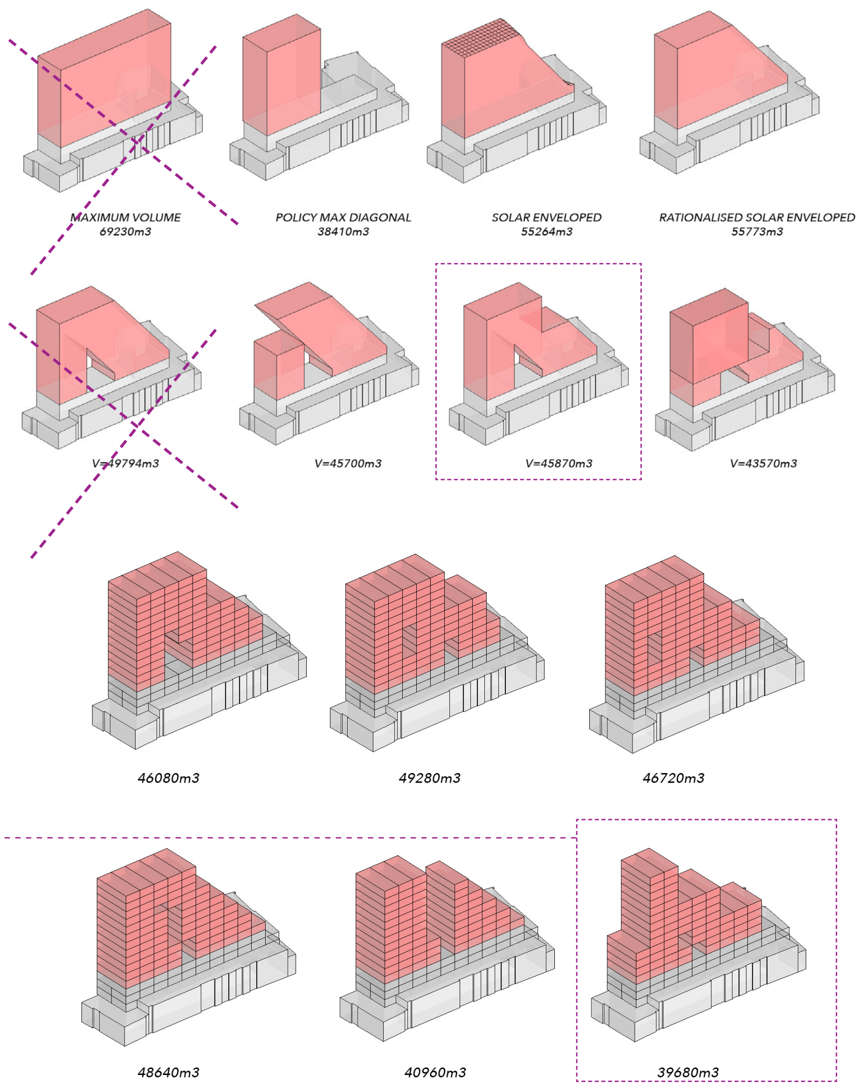


LESS SHADOW IMPACT

SOLAR ENVELOPE *11-12 p.m. JAN - DEC*

Maximum sunlight in Lijnbaan street





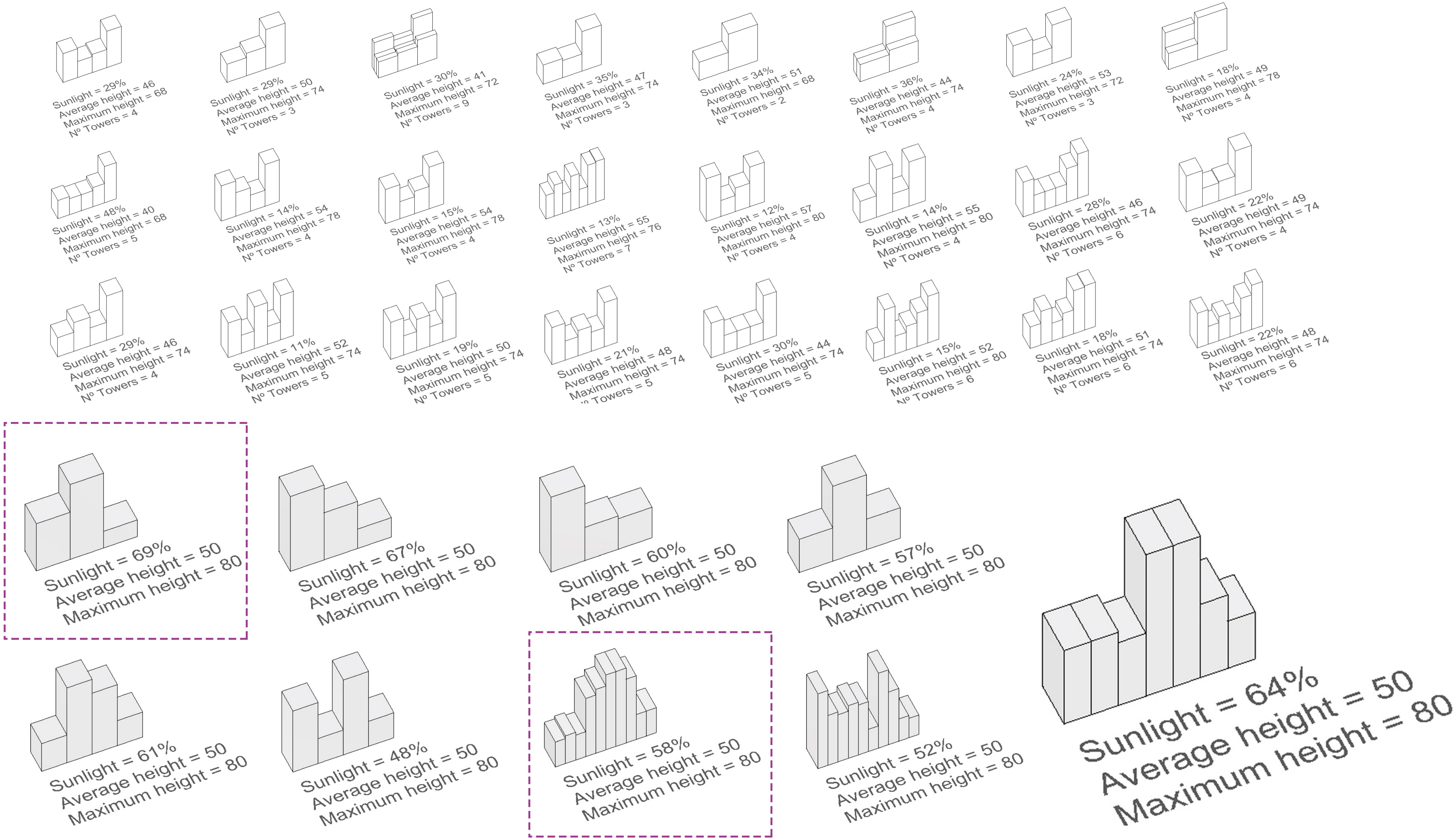
MIN SHADOW IMPACT (Rotterdam policy)
MAX VOLUME (Economics)
MIN 42M DIAGONAL (Rotterdam policy)
1 SOLID MASS (Architectural)

SOLAR ENVELOPE *ALL YEAR*

More than 50m height average

At least 25% boundaries higher than 70 meters

Maximum sunlight on Lijnbaan street



TO WHAT EXTENT CAN ENGINEERED TIMBER INSPIRE THE ARCHITECTURE OF A TTE?

TIMBER CONCEPT

WOOD AND TIMBER ARE NOT THE SAME THING

WOOD


Tree in nature


Dried logs

Natural

Calm

Soft

TIMBER


Blocked-glue laminated elements


Erection of Cross-Laminated Timber

Precission

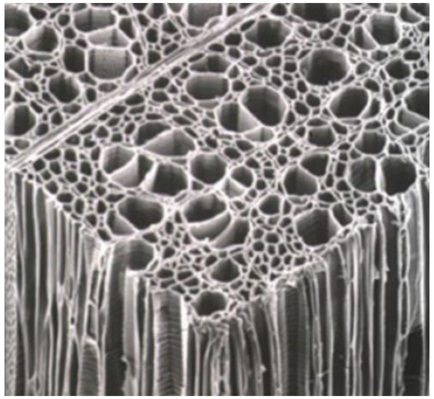
Prefabrication

Assembly

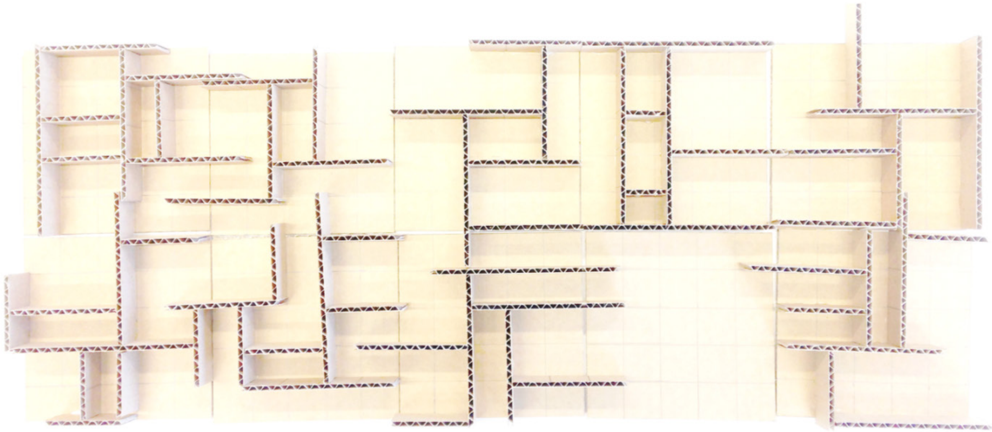
A QUEST FOR MORE TECHNICAL PRECISION

TIMBER CONCEPT

Wood micro-structure

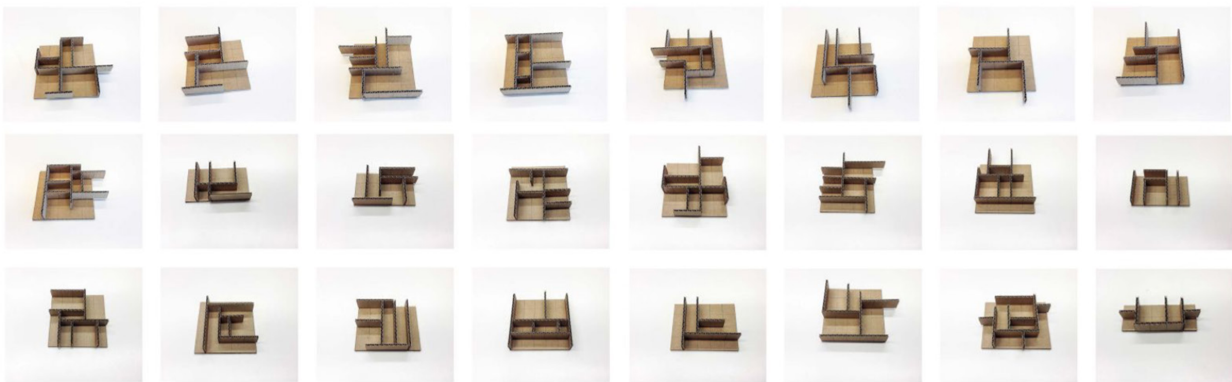


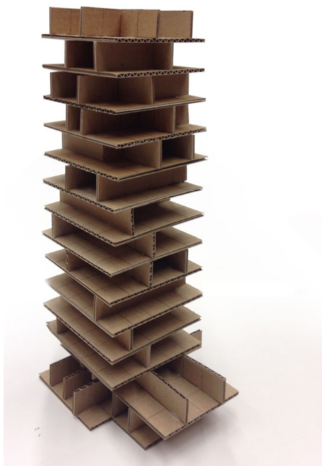
CLT macro-structure



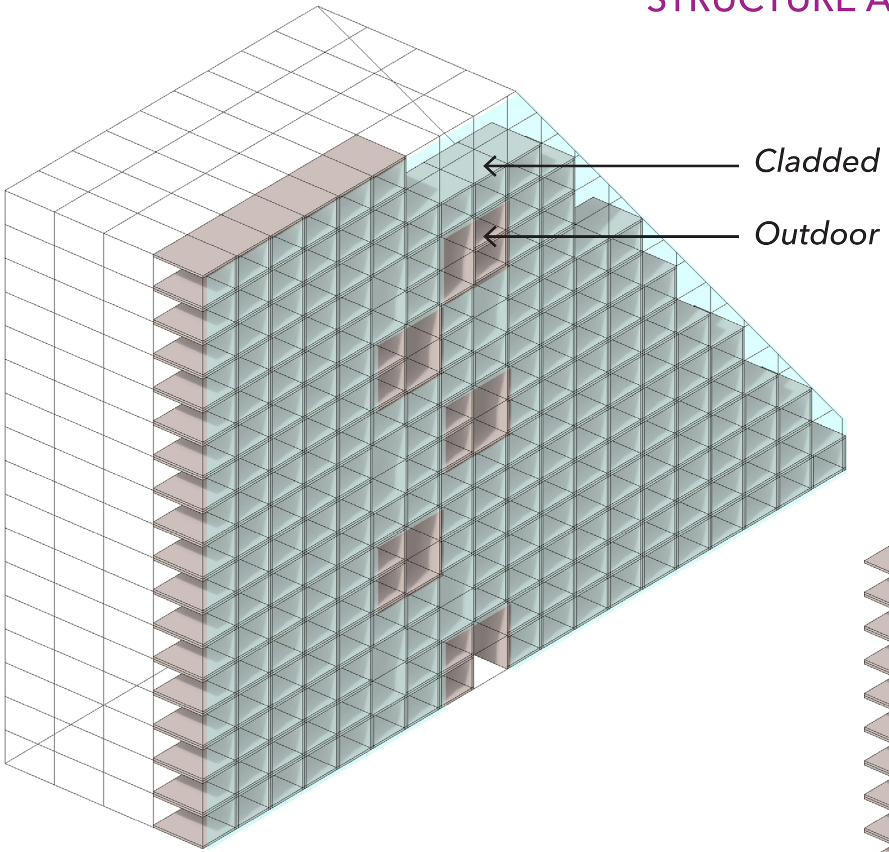
ORGANIC CELLULAR
PATTERNS

STRAIGHT CELLULAR
PATTERNS

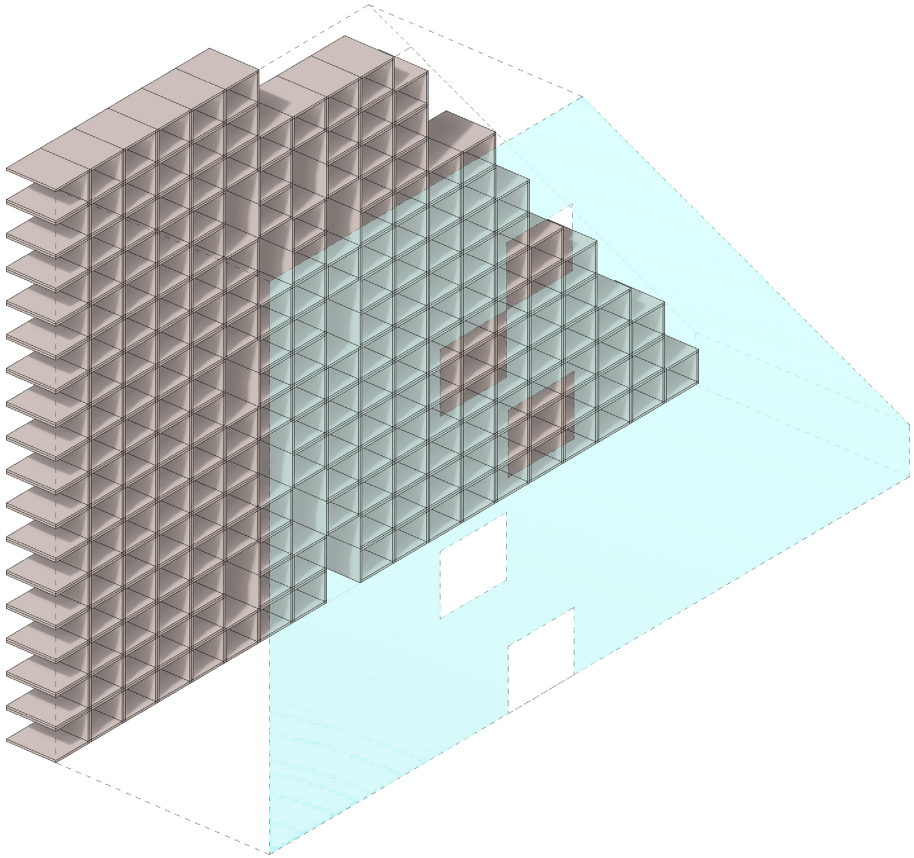




STRUCTURE AS ARCHITECTURE



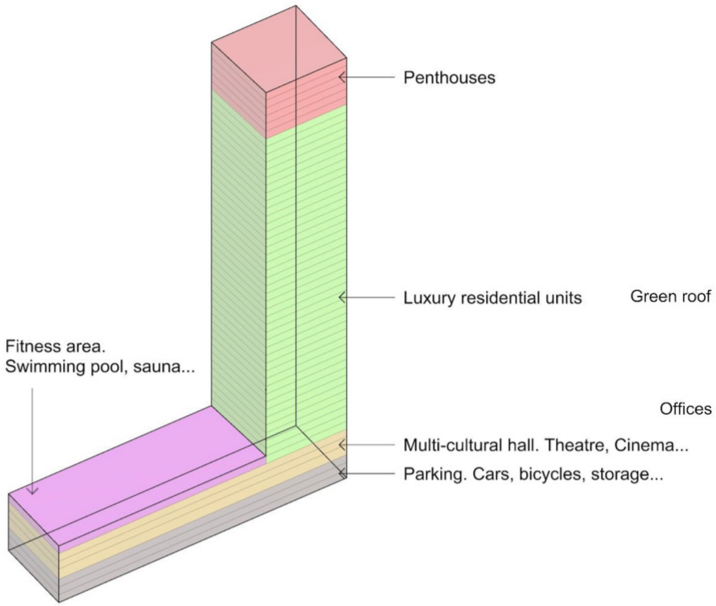
The expression of the structure is the main leitmotiv for the architecture of the building.

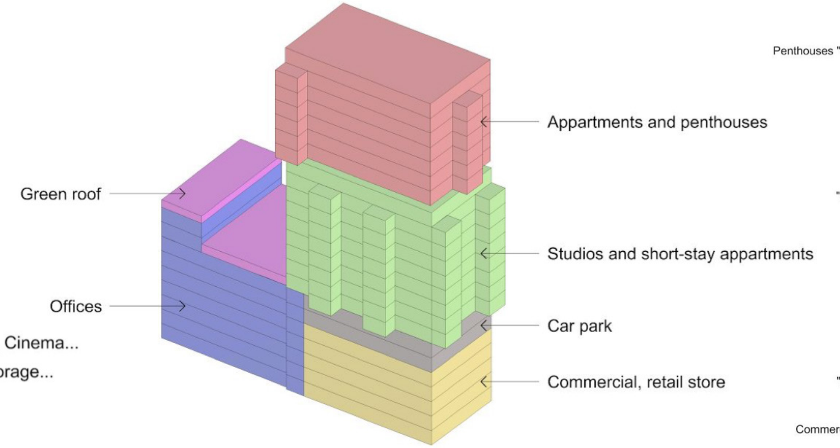


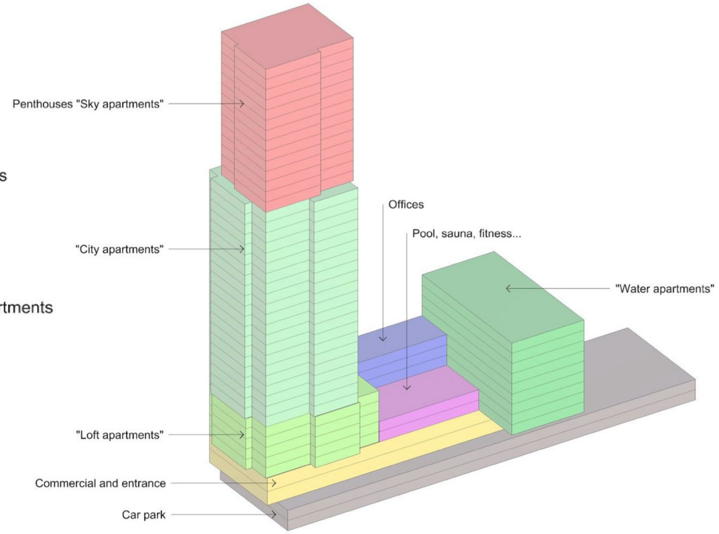
WHAT ARE THE CURRENT MARKET AND USER DEMANDS FOR A TALL BUILDING IN ROTTERDAM?

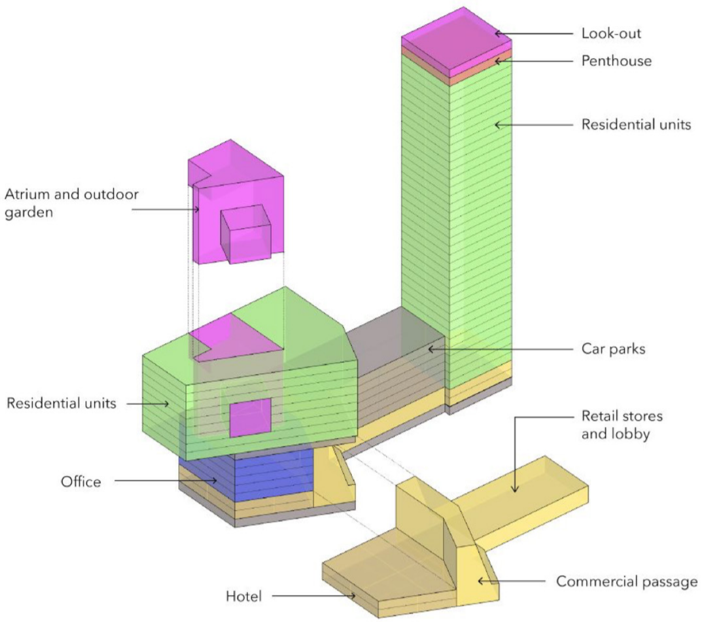
RECENT RESIDENTIAL HIGH-RISE

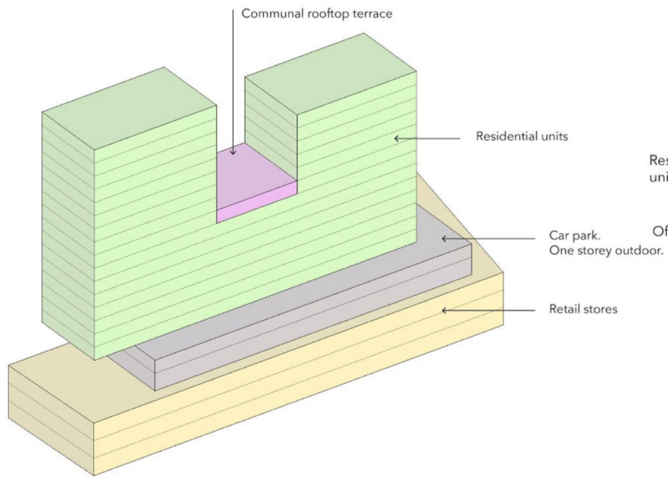
PROGRAMME

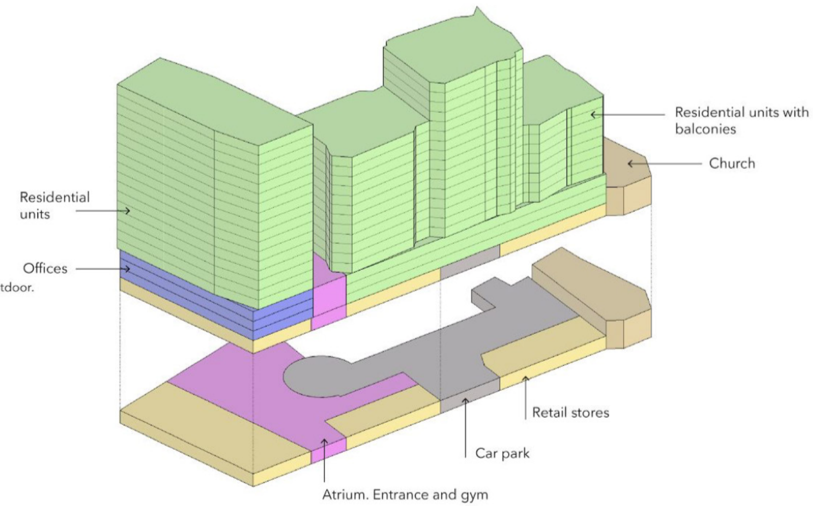

Penthouses
Luxury residential units
Fitness area.
Swimming pool, sauna...
Multi-cultural hall. Theatre, Cinema...
Parking. Cars, bicycles, storage...


Appartments and penthouses
Green roof
Studios and short-stay appartments
Offices
Car park
Commercial, retail store


Penthouses "Sky apartments"
Offices
"City apartments"
Pool, sauna, fitness...
"Water apartments"
"Loft apartments"
Commercial and entrance
Car park


Look-out
Penthouse
Residential units
Atrium and outdoor
garden
Car parks
Residential units
Retail stores
and lobby
Office
Commercial passage
Hotel


Communal rooftop terrace
Residential units
Car park.
One storey outdoor.
Retail stores


Residential units with
balconies
Church
Residential
units
Offices
Retail stores
Car park
Atrium. Entrance and gym

PROGRAMME

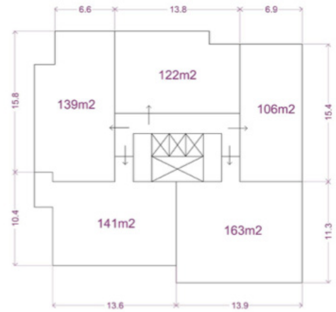
Increase exclusivity and luxury towards the top

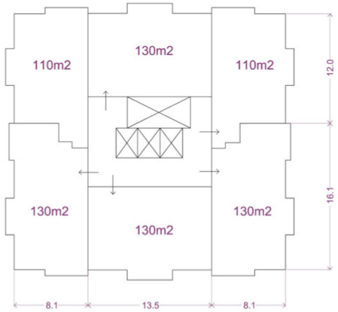
Communal spaces. Indoor or outdoor

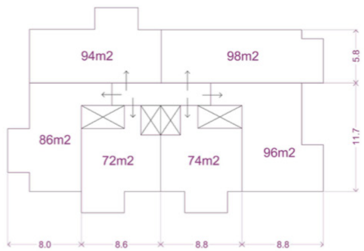
Commercial and multi-use plinth

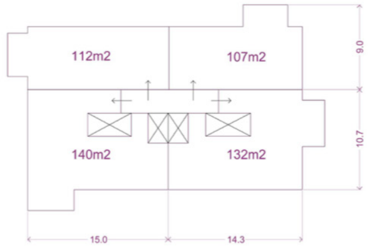
Car-park above commercial plinth

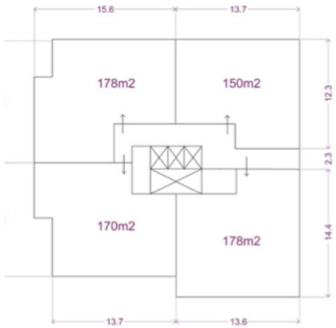
FLOOR LAYOUT

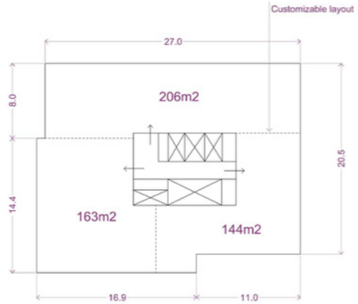


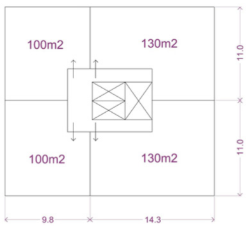


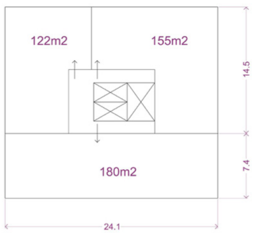


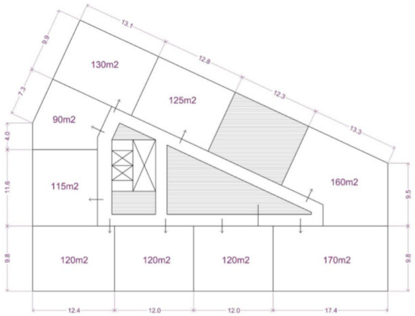


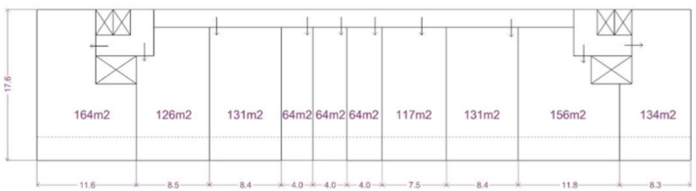


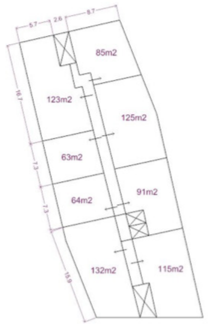


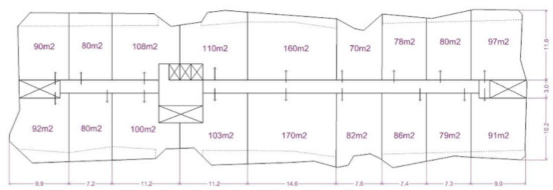












FLOOR LAYOUT

High variety of housing units

80-170m2

Increase size units towards the top

Efficient vertical transportation

URBAN

Located in high-rise zone

Minimum shadow impact

PLINTH

Respect fabric continuity

(occupy full plot)

20-25 meters high

Urban-attractive programme

(Retail or cultural programme)

VOLUME

50% max volume above plinth

Area: 900m2

Depth: 30m

Diagonal 42m

ARCHITECTURAL

Green rooftops

PROGRAMME

Increase exclusivity and luxury towards the top

Communal spaces. Indoor or outdoor

Commercial and multi-use plinth

Car-park above commercial plinth

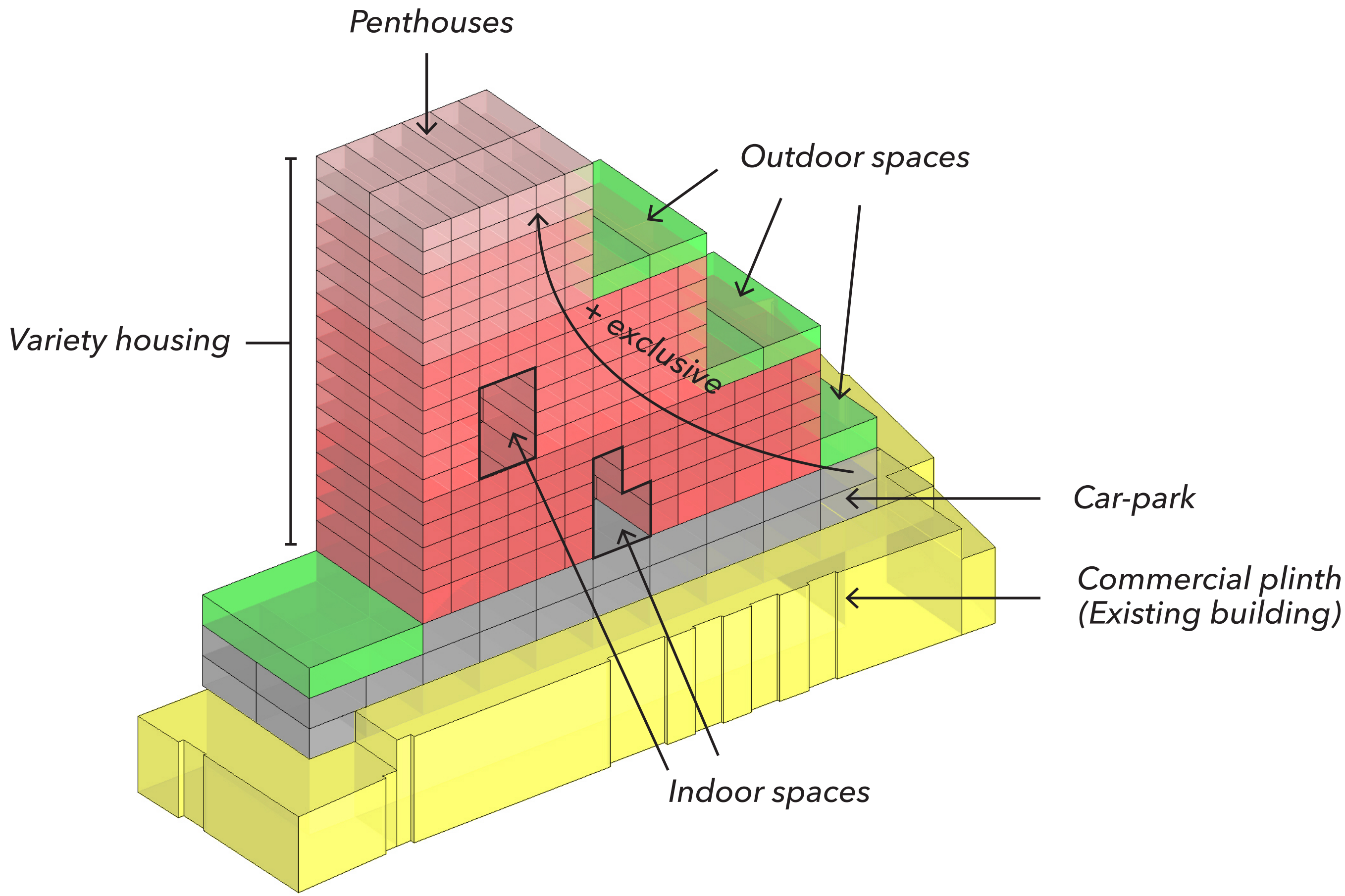
FLOOR LAYOUT

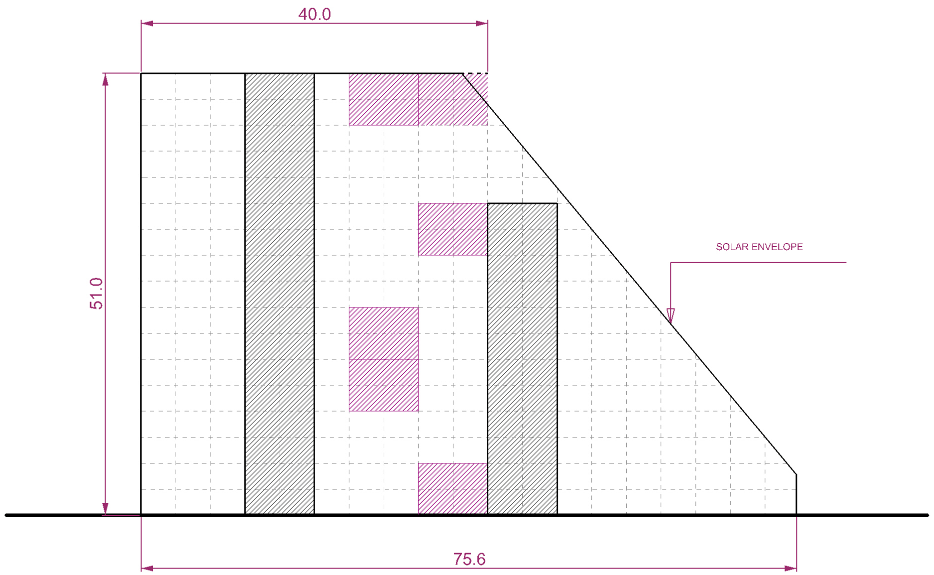
High variety of housing units

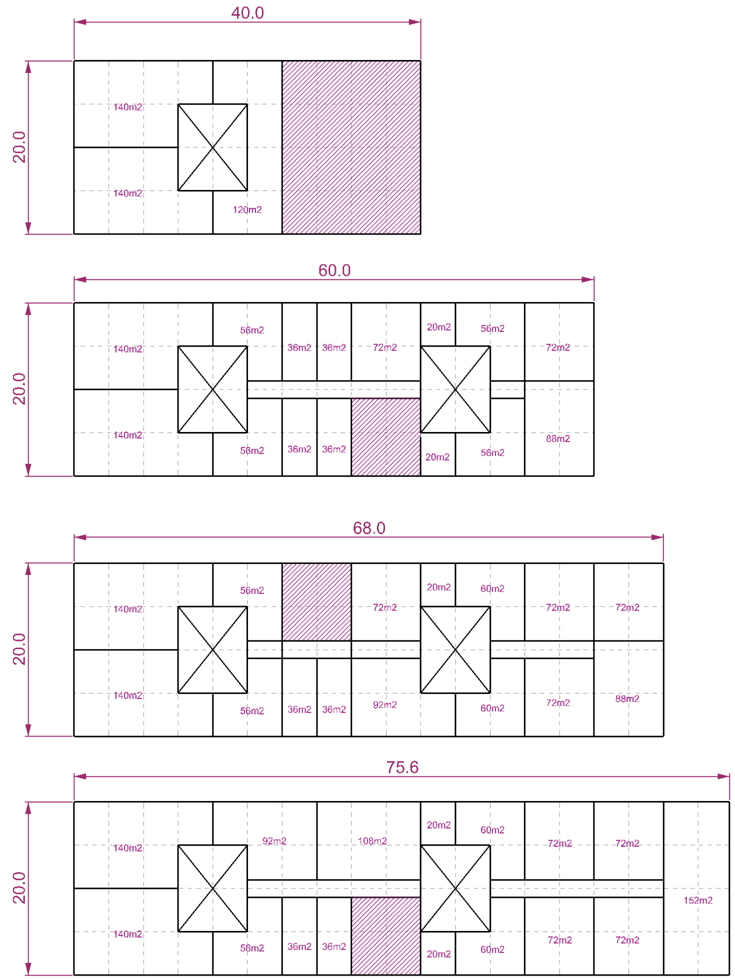
80-170m2

Increase size units towards the top

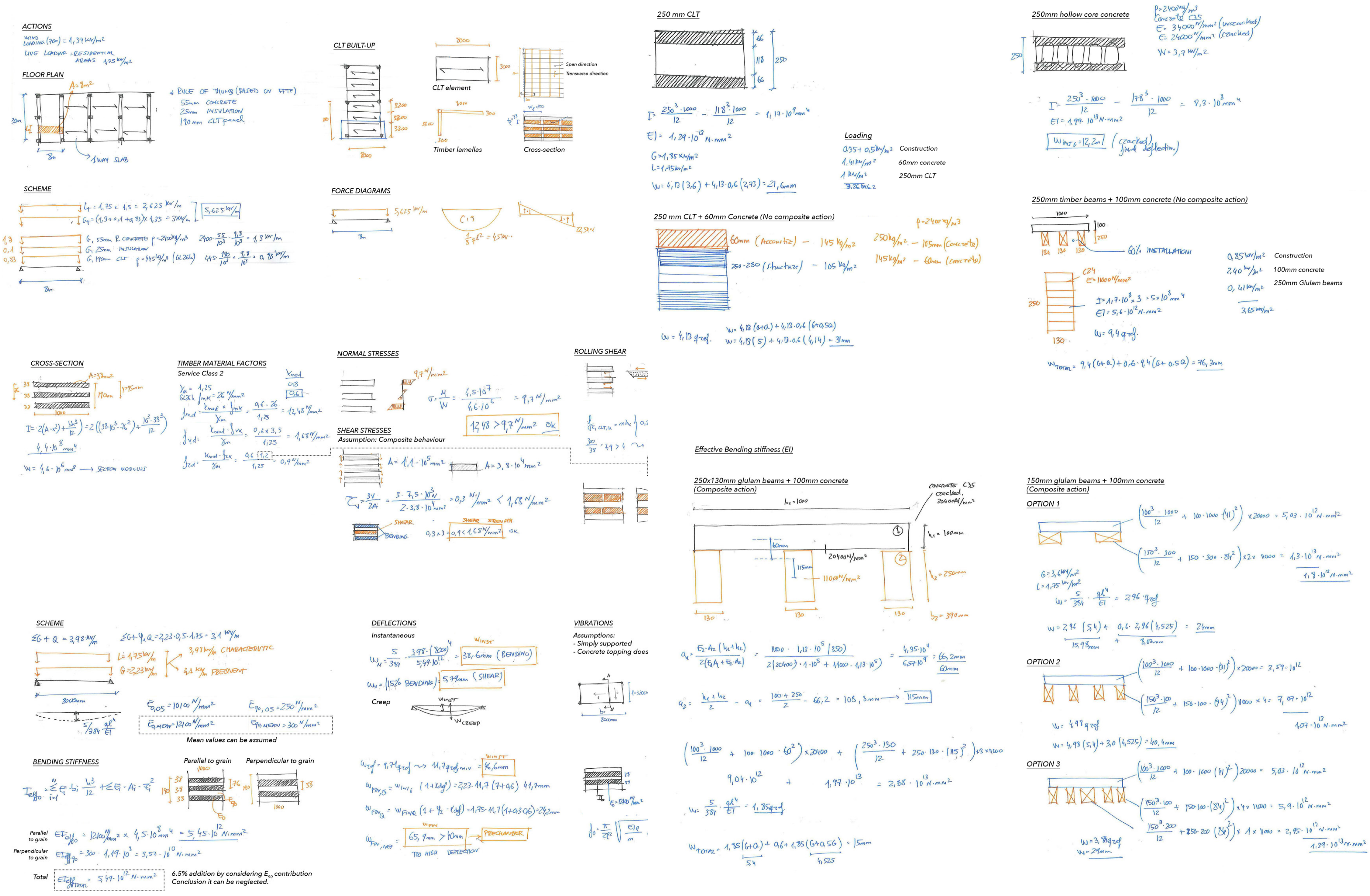
Efficient vertical transportation

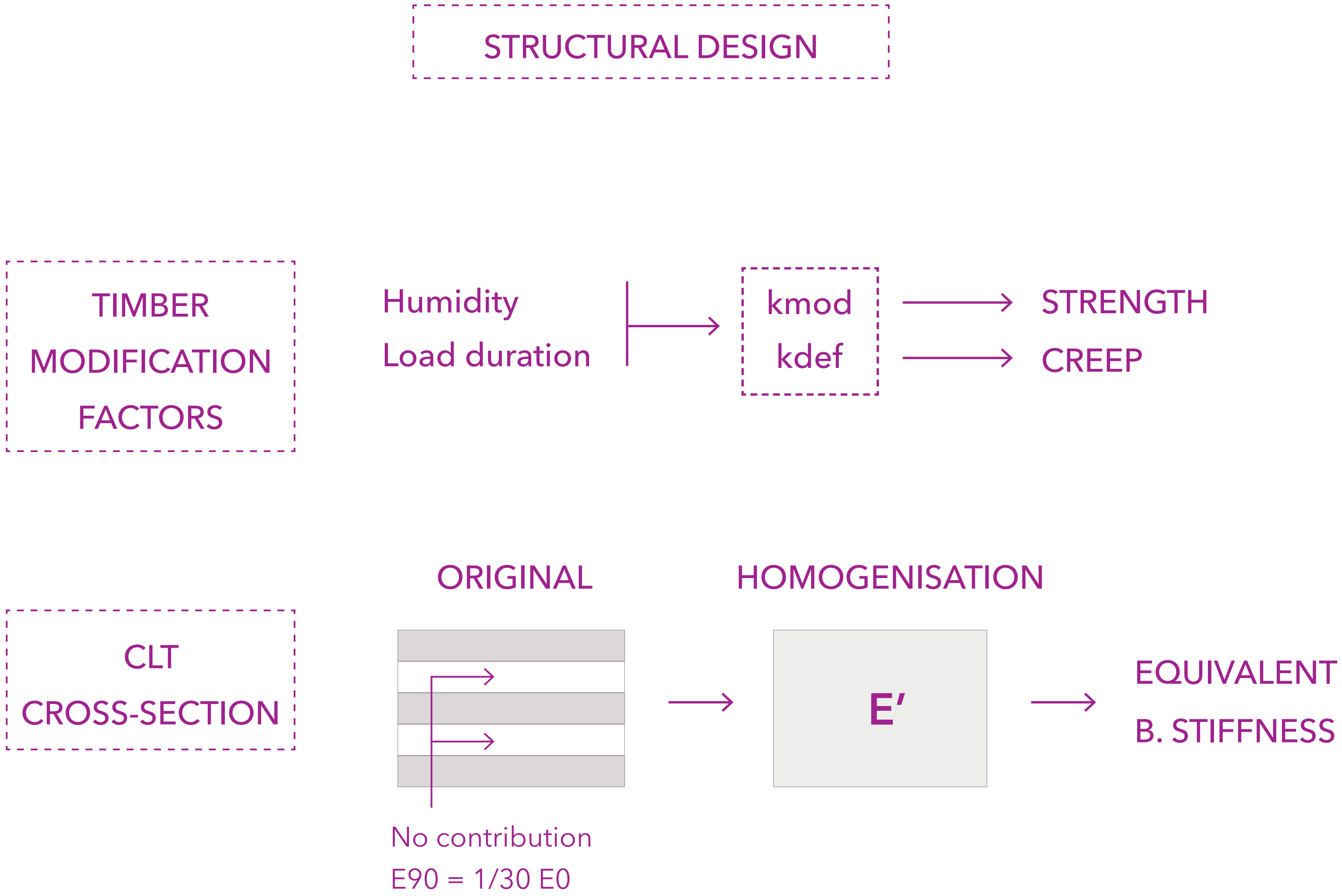

Penthouses
Outdoor spaces
Variety housing
+ exclusive
Car-park
Commercial plinth
(Existing building)
Indoor spaces


40.0
51.0
SOLAR ENVELOPE
75.6


40.0
20.0
140m2
140m2
120m2
60.0
20.0
140m2
56m2
36m2
36m2
72m2
20m2
56m2
72m2
140m2
56m2
36m2
36m2
20m2
56m2
88m2
68.0
20.0
140m2
56m2
72m2
20m2
60m2
72m2
72m2
140m2
56m2
36m2
36m2
92m2
60m2
72m2
88m2
75.6
20.0
140m2
92m2
108m2
20m2
60m2
72m2
72m2
152m2
140m2
56m2
36m2
36m2
20m2
60m2
72m2
72m2

STRUCTURE STUDY

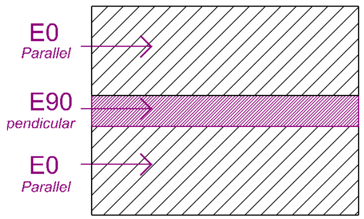

ACTIONS
FLOOR PLAN
SCHEME
CLT BUILT-UP
CLT element
Span direction
Transverse direction
Timber lamellas
Cross-section
FORCE DIAGRAMS
250 mm CLT
Loading
Construction
60mm concrete
250mm CLT
250 mm CLT + 60mm Concrete (No composite action)
250mm hollow core concrete
250mm timber beams + 100mm concrete (No composite action)
Construction
100mm concrete
250mm Glulam beams
CROSS-SECTION
TIMBER MATERIAL FACTORS
Service Class 2
NORMAL STRESSES
SHEAR STRESSES
Assumption: Composite behaviour
ROLLING SHEAR
Effective Bending stiffness (EI)
250x130mm glulam beams + 100mm concrete
(Composite action)
150mm glulam beams + 100mm concrete
(Composite action)
OPTION 1
OPTION 2
OPTION 3
SCHEME
Mean values can be assumed
BENDING STIFFNESS
Parallel to grain
Perpendicular to grain
Parallel to grain
Perpendicular to grain
Total
6.5% addition by considering E90 contribution
Conclusion it can be neglected.
DEFLECTIONS
Instantaneous
Creep
VIBRATIONS
Assumptions:
- Simply supported
- Concrete topping does


STRUCTURAL DESIGN
TIMBER
MODIFICATION
FACTORS
Humidity
Load duration
kmod
kdef
STRENGTH
CREEP
CLT
CROSS-SECTION
ORIGINAL
HOMOGENISATION
E'
EQUIVALENT
B. STIFFNESS
No contribution
E90 = 1/30 E0

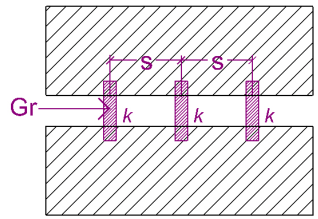
INTERACTION LAYERS

80% DECREASE IN BENDING STIFFNESS

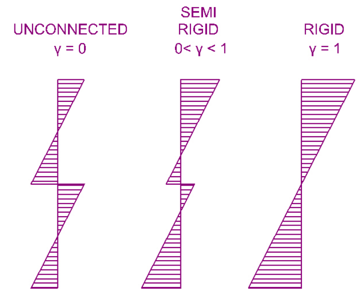
Stiffness imaginary fasteners (k*s) = Rolling shear stiffness (Gr) transverse layers



CLT 3-LAYERS



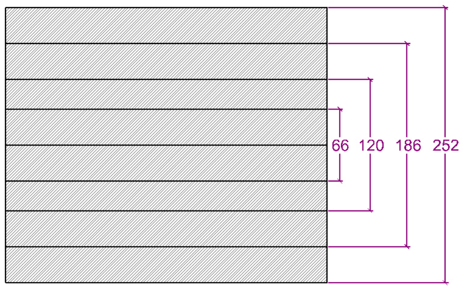
IMAGINARY FASTENERS



DEGREE OF INTERACTION

COMPOSITE THEORY

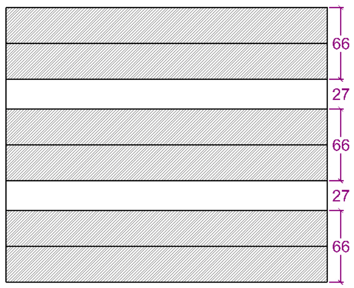
(Blass 2005)



K1 = 0.73
Bending stiffness= 1.14e+13Nmm2
79% Composite action

GAMMA METHOD

(Eurocode 5)



No connection γ = 0
EI= 8.64e+11Nmm2
6% Composite action

Semi-rigid γ = 0.85
EI= 1.22e+13Nmm2
85% Composite action

Fully-rigid γ = 1
EI= 1.43e+13Nmm2
100% Composite action

γ = 0.96
Bending stiffness= 1.40e+13Nmm2
97% Composite action

FLOOR SYSTEM

190mm CLT - 8 meters SPAN

NORMAL STRESSES

SHEAR STRESSES

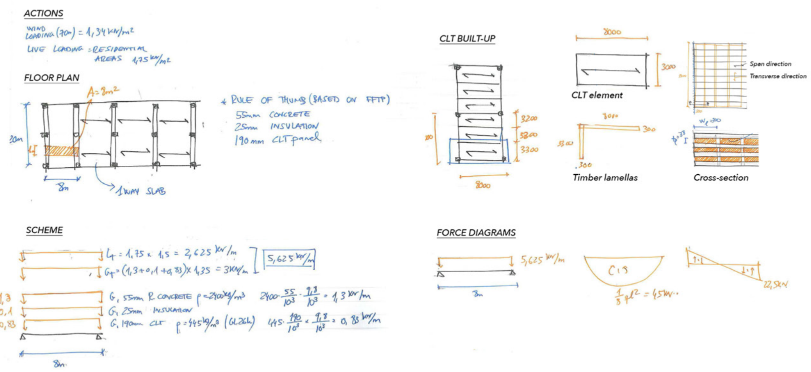
NOT OK

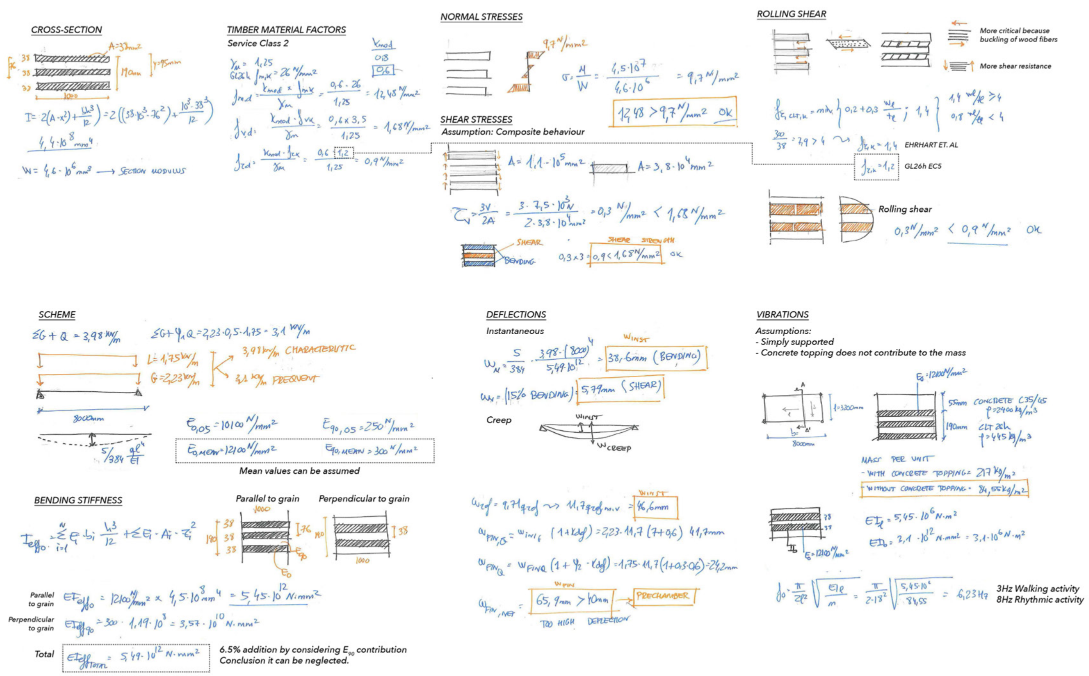
ROLLING SHEAR

DEFLECTION

VIBRATION

FIRE



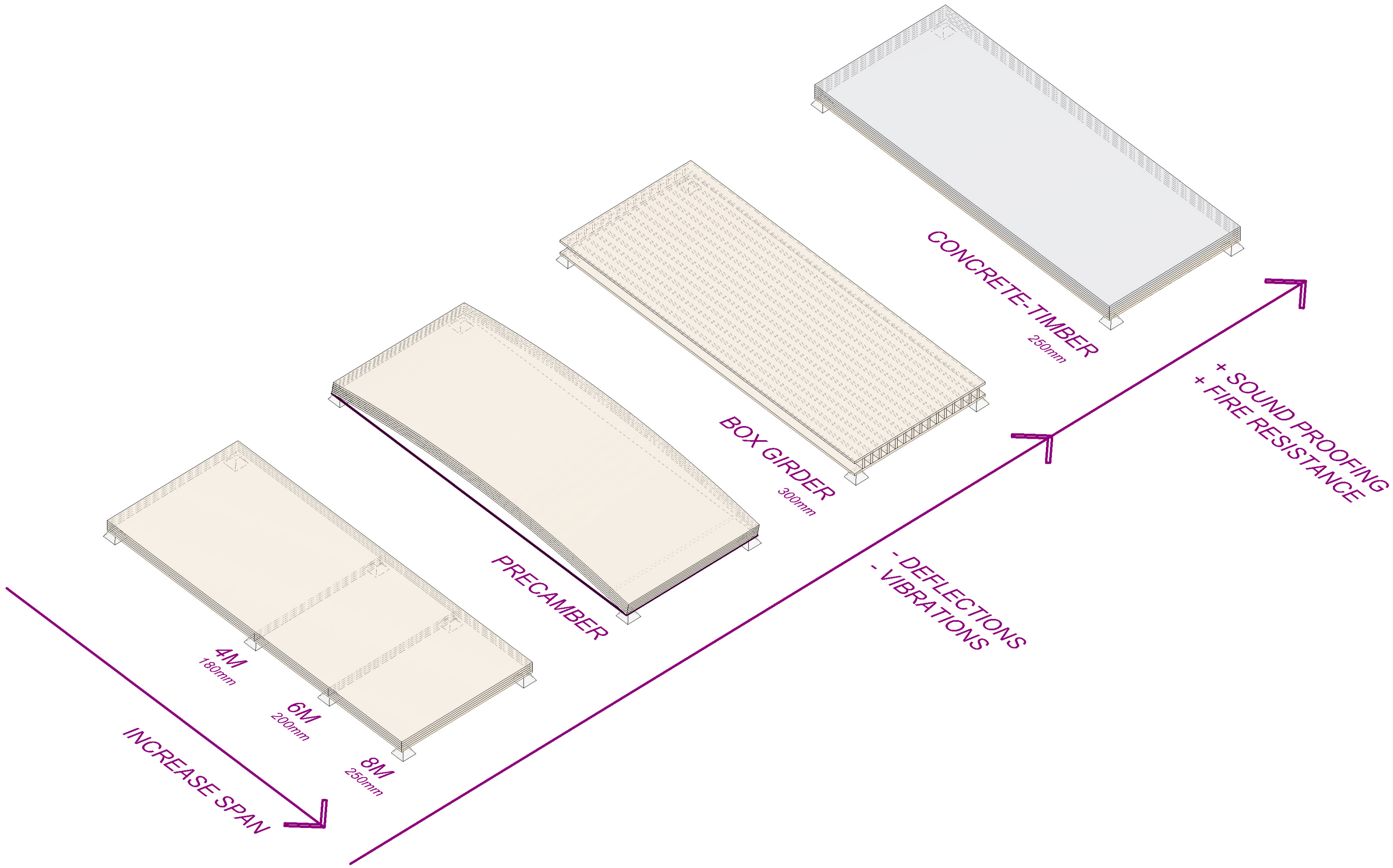


FLOOR SYSTEM

REDUCE SPAN

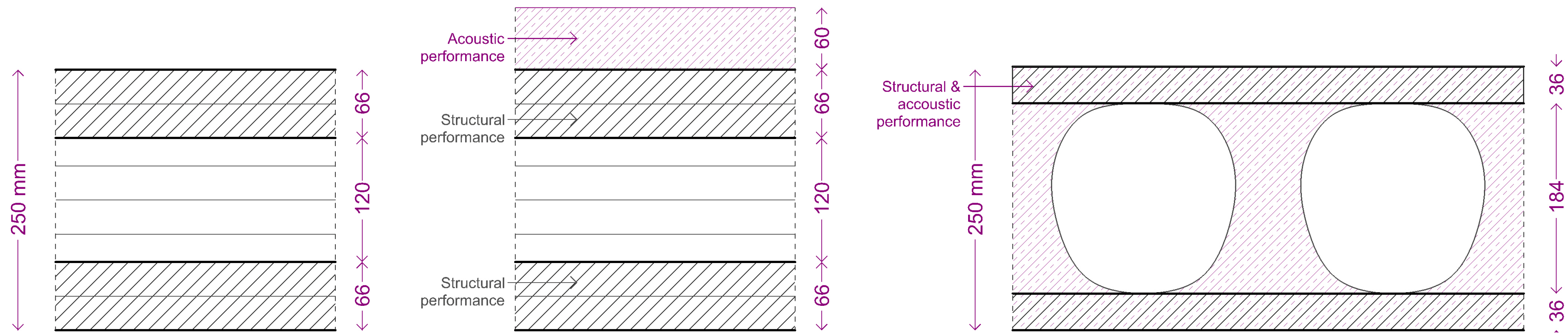
INCREASE FLOOR DEPTH

STIFFER MATERIAL



FLOOR SYSTEM

8m span



250mm CLT

250mm CLT + Concrete

Concrete hollow core

21.66mm

31.02mm X

19.04mm

DEFLECTION

VIBRATION

FIRE

SOUND

REDUCE SPAN

ADDITIONAL LAYERS

✓

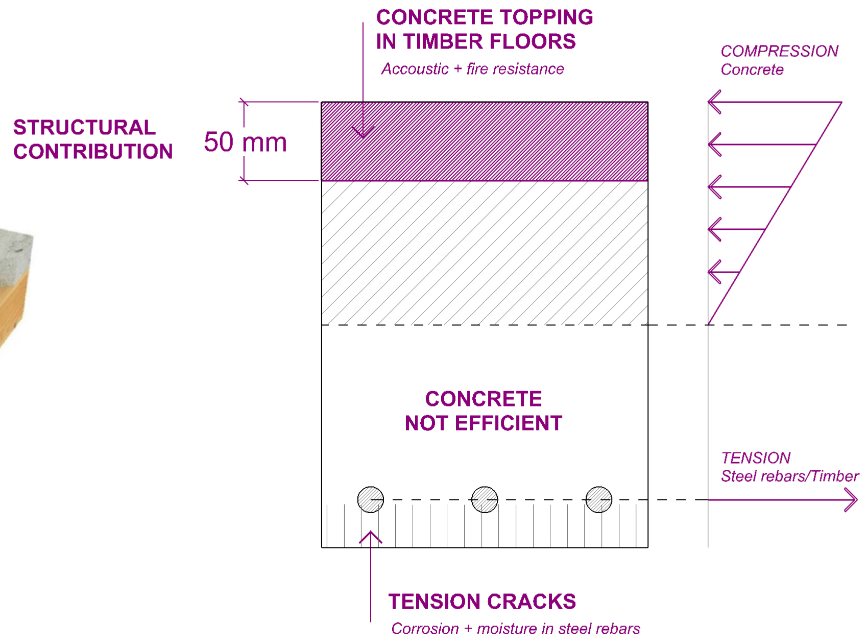
FLOOR SYSTEM

CONCRETE + TIMBER COMPOSITE

50 - 100 mm concrete topping + shear connectors

50% REDUCTION DEFLECTIONS

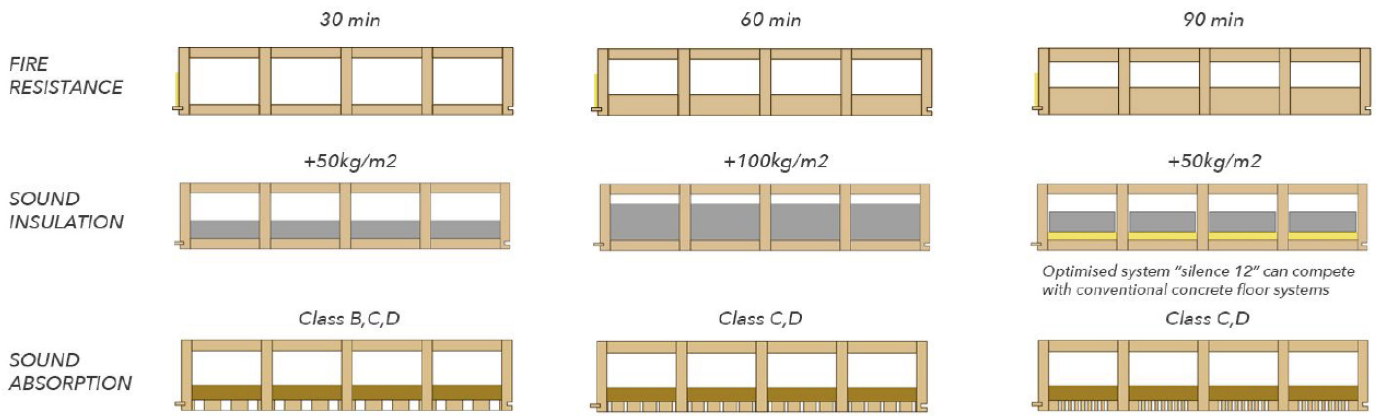
CONTRIBUTION TO FIRE AND SOUND PERFORMANCE



FLOOR SYSTEM

LIGNATUR

	CLT	LIGNATUR
STRUCTURE	✓	✓
SOUND	✗	✗
FIRE	✗	✗ ✗
CUSTOMISATION	✗	✓



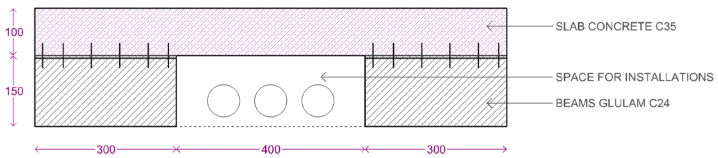
FLOOR SYSTEM

150MM GLULAM + 100 CONCRETE

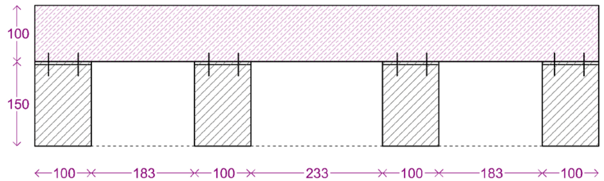
SOUND ✓

FIRE ✓

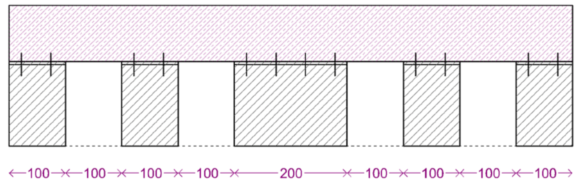
STRUCTURE ✗



24 mm



40.4 mm



29 mm

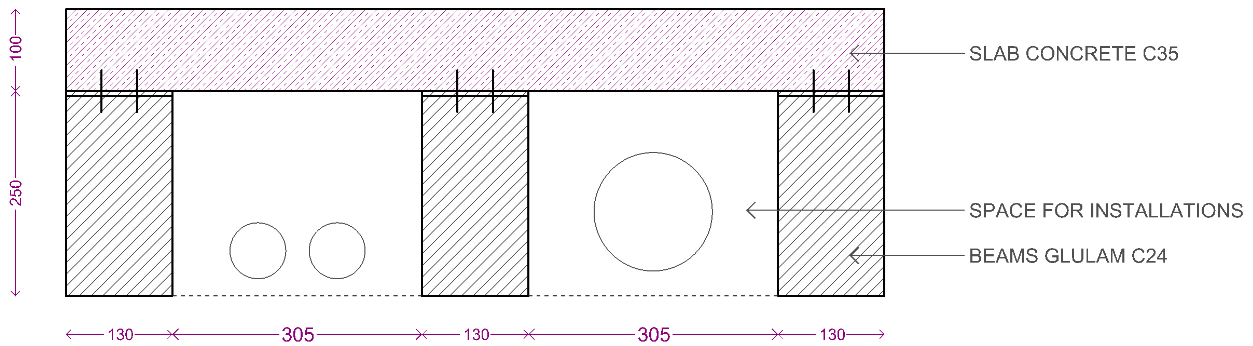
FLOOR SYSTEM

250MM GLULAM + 100 CONCRETE

SOUND ✓

FIRE ✓

STRUCTURE ✓



FLOOR SYSTEM

100MM CLT - 3M SPAN

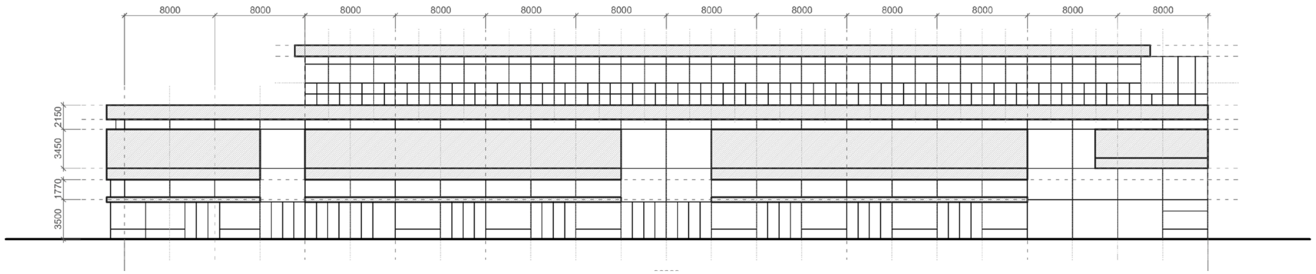
250MM CLT - 6M SPAN

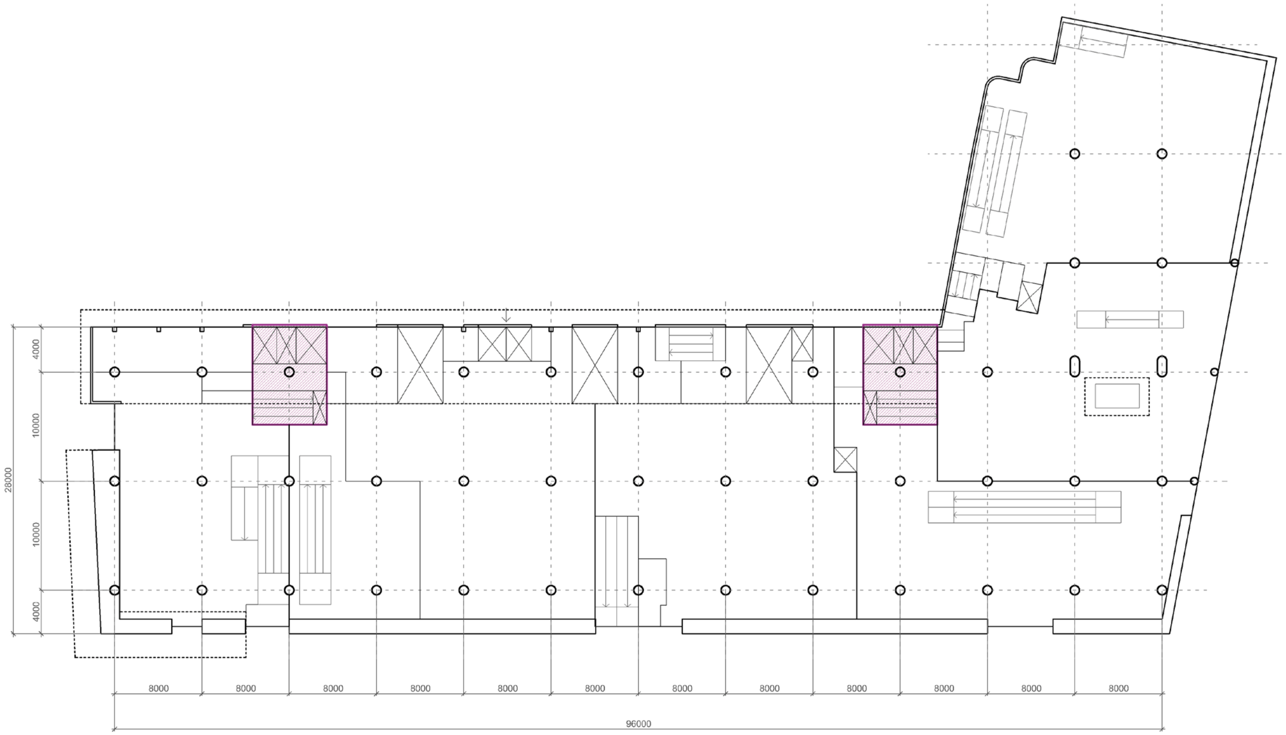
→ ADDITIONAL LAYERS FOR SOUND & FIRE

COMPOSITE GLULAM + TIMBER - 8M SPAN

TO WHAT EXTENT THE EXISTING BUILDING AFFECTS THE STRUCTURE OF THE TTE?

EXISTING BUILDING





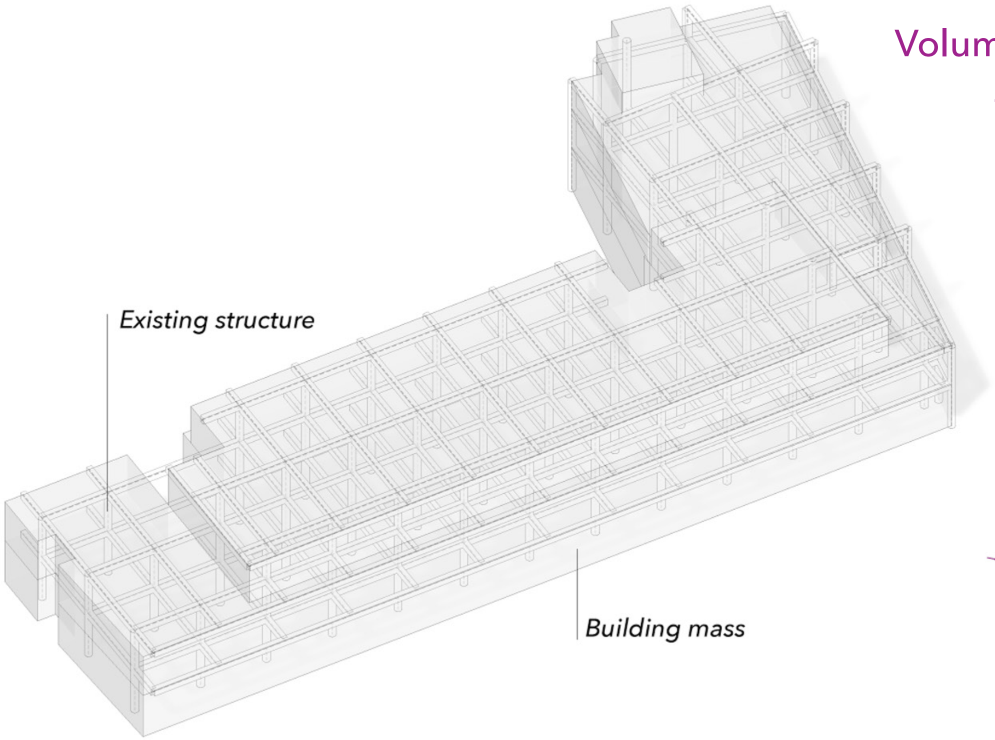
TER MEULEN

Heritage for city of Rotterdam

Important commercial location

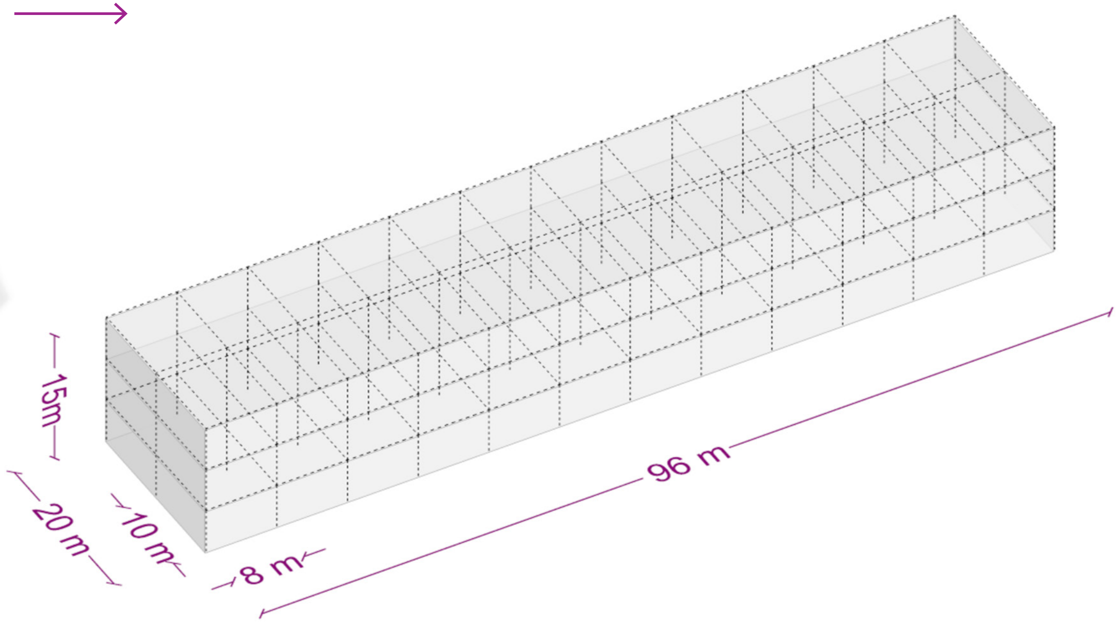
Boundaries 96x20m

Existing grid 8x10m

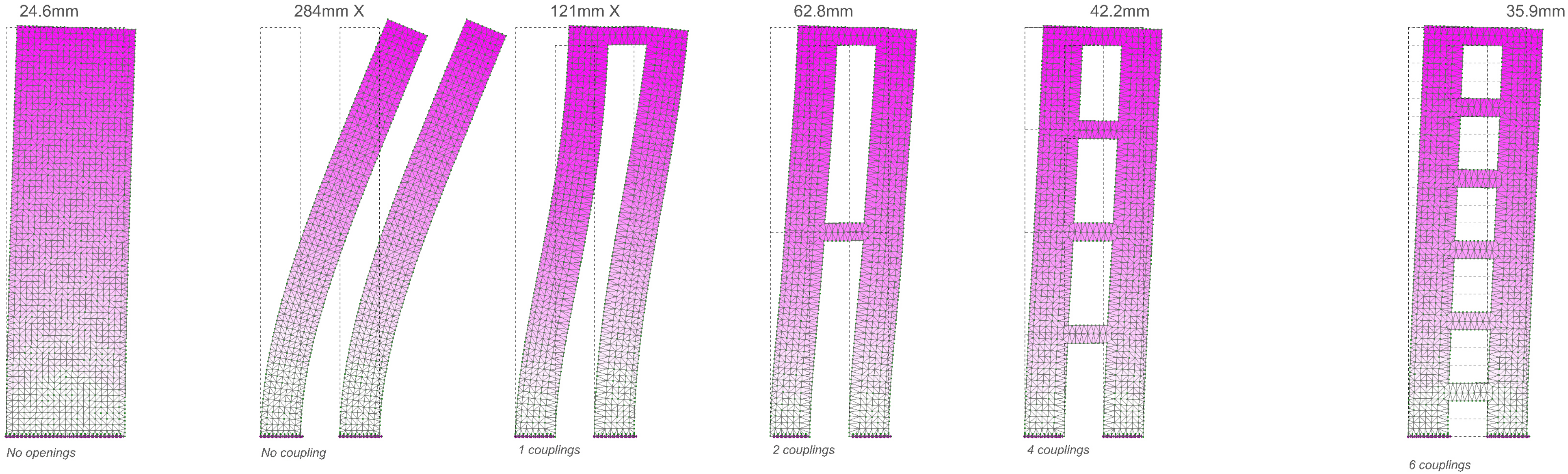


Volume simplication

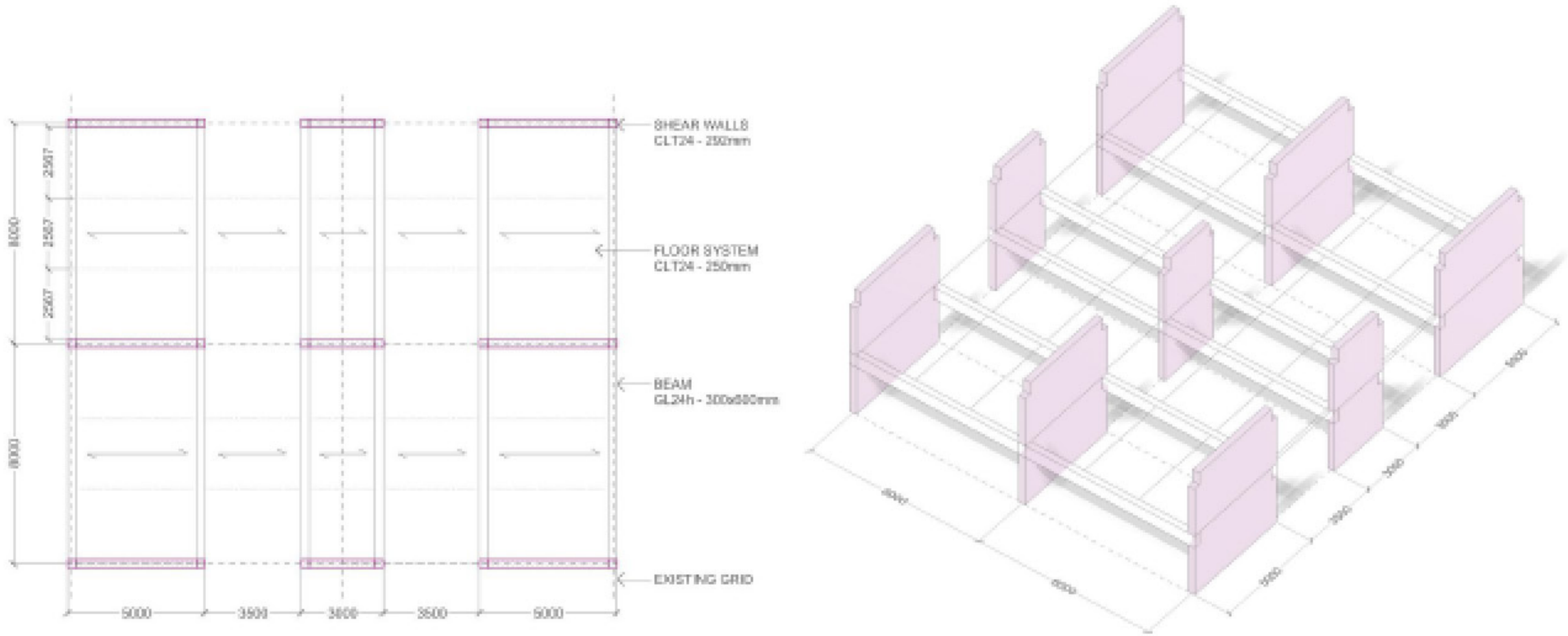
→



LATERAL SYSTEM



<u>*26 shear walls - 5 meters + 13 shear walls - 3 meters*</u>



Floor plan and 3D scheme with uncoupled shear walls (Own elaboration)

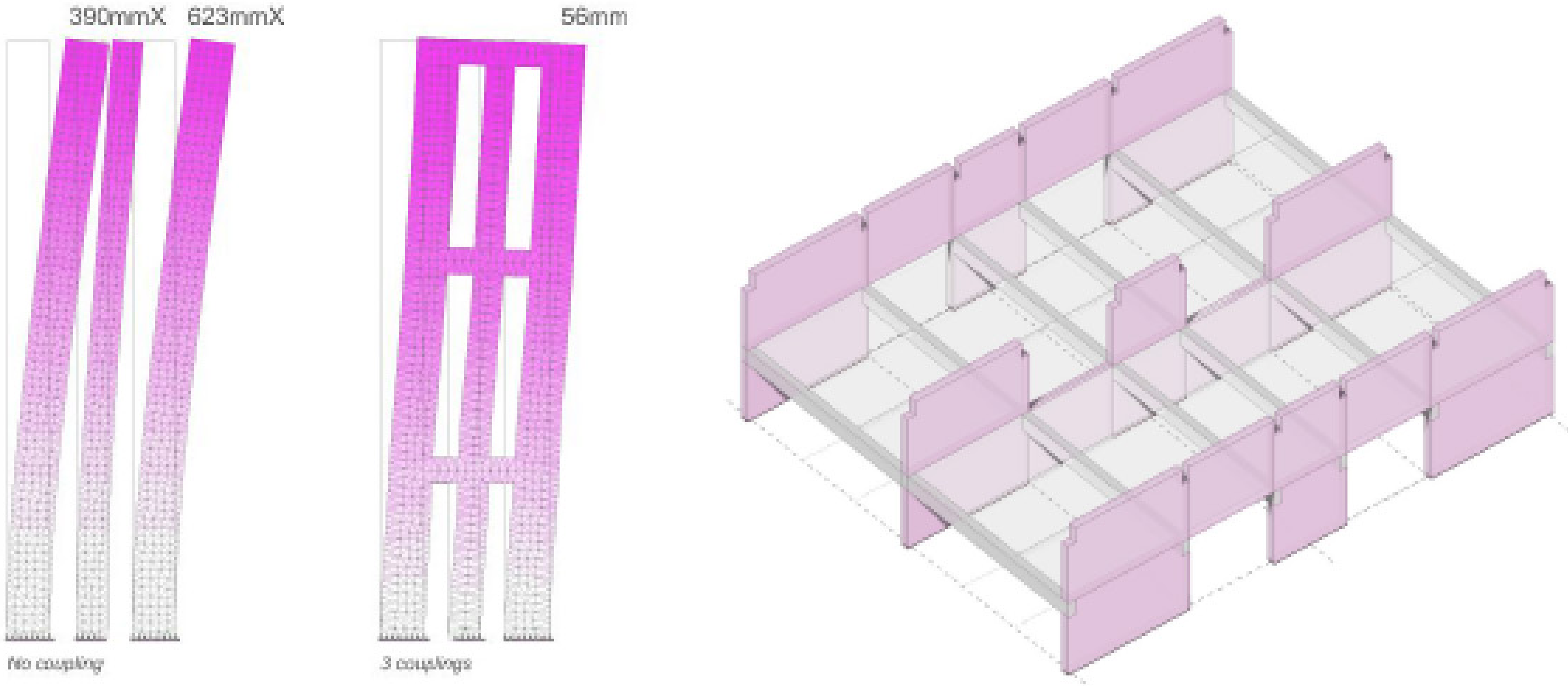
- Wind load distribution of each separate shear wall is proportional to the bending stiffness

Shear wall	Second moment of area Nmm2	Wind loading	Deflections (mm)
5 meters	2.06e+12	45%	623mm X
3.5 meters	4.5e+11	10%	390 X

Need at least three couplings (storey height) along height of the building.

Couplings

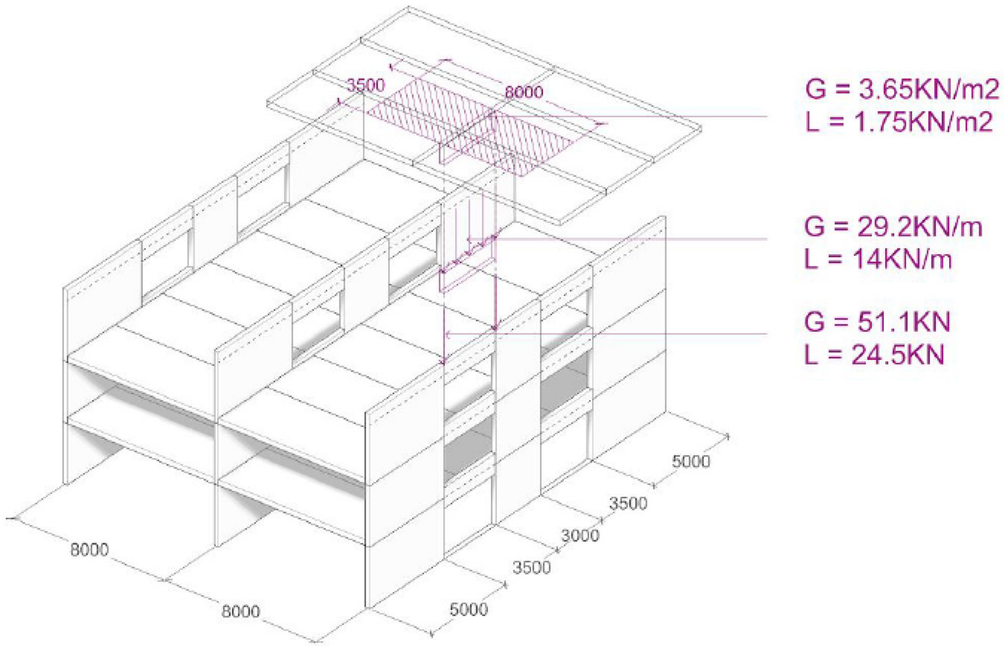
Alternate couplings in different storeys

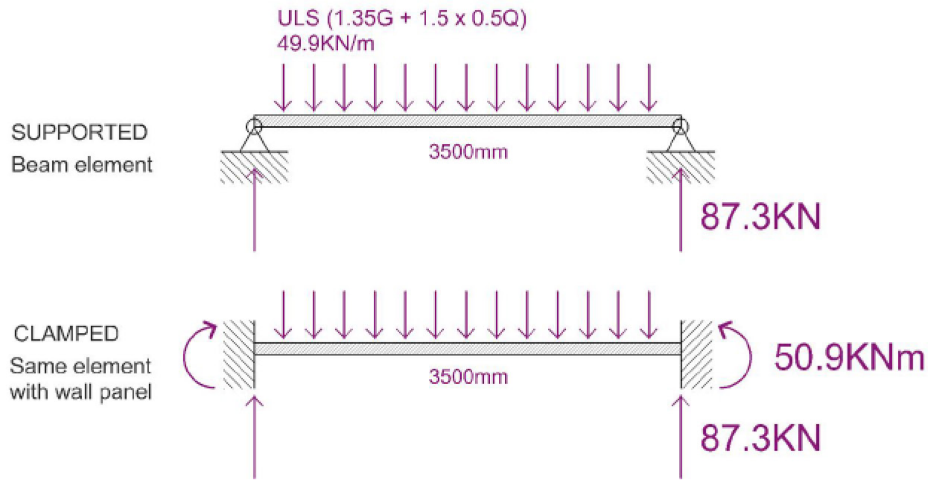


Storey height couplings (Own elaboration)

LINTEL DESIGN

3.5m span





LINTEL DESIGN

3.5m span

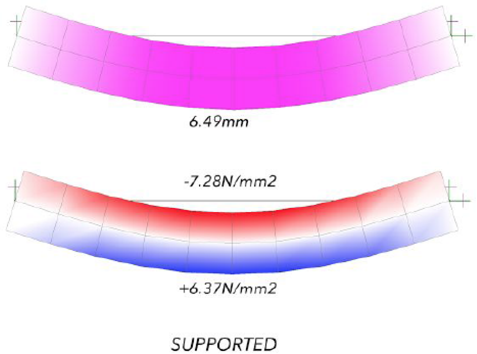
500-600m DEPTH

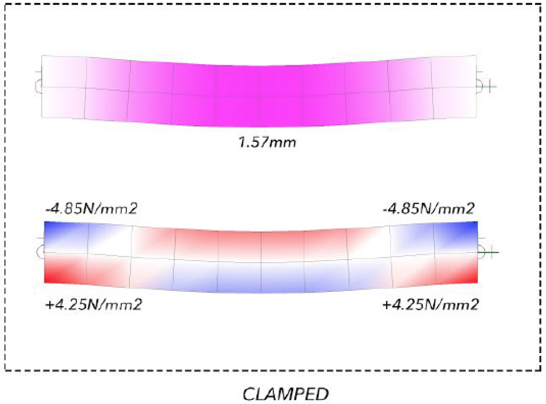
Fully rigid connections are very complex and costly

Simply supported easier option

Intermediate "partly rigid" stiffness = 0.5

Less deflections and stresses
However, full connections are usually very difficult and costly to achieve in practice, especially in timber



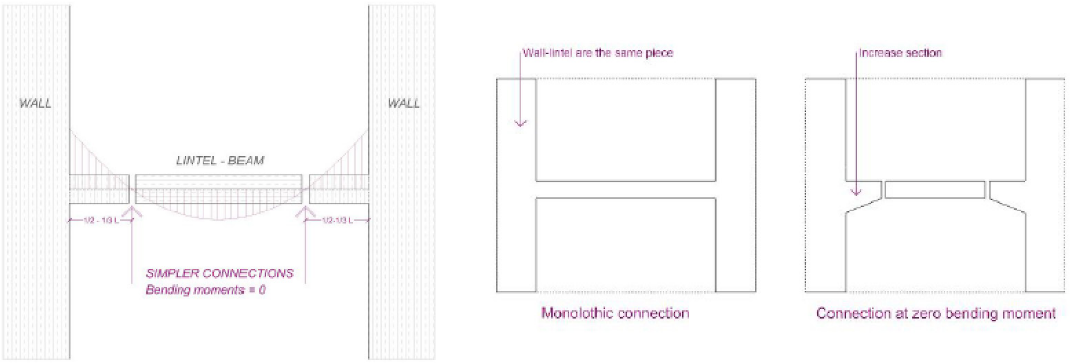


Depth of lintel beam	Bending stiffness (reducing 80% composite action)	Final deflections (including creep) SIMPLE SUPPORTED	Final deflections (including creep) CLAMPED
1000mm	1.452e+14Nmm2	0.87mm OK	0.174mm OK
500mm	1.815e+13Nmm2	6.492mm OK	1.30mm OK
400mm	9.3+13Nmm2	13.6mm	2.72mm OK

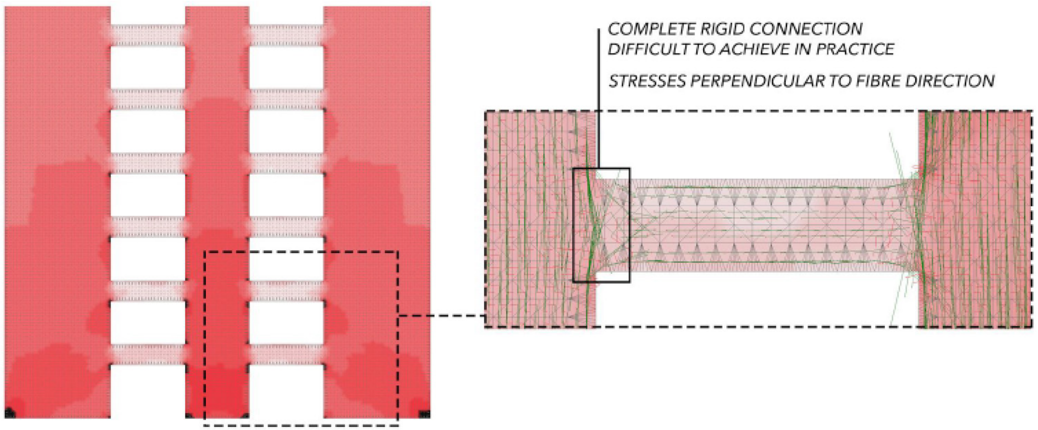
Summary of hand calculations. Deflection limit L/400 = 8.75mm

LINTEL DESIGN

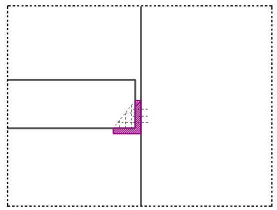
CONNECTION OPTIONS



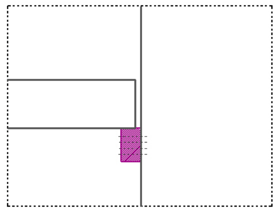
Monolithic dintel (left) and connection at L/2-3 for the span for simpler connection



SIMPLE SUPPORTED

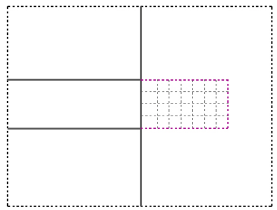


Steel hanger or bracket

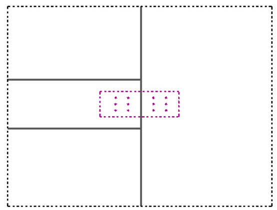


Timber bearing block

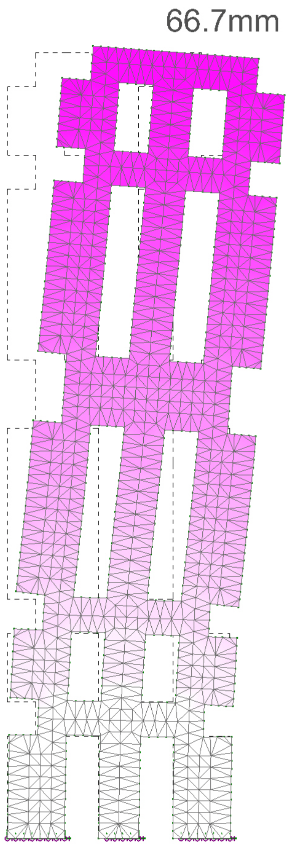
"PARTLY" RIGID



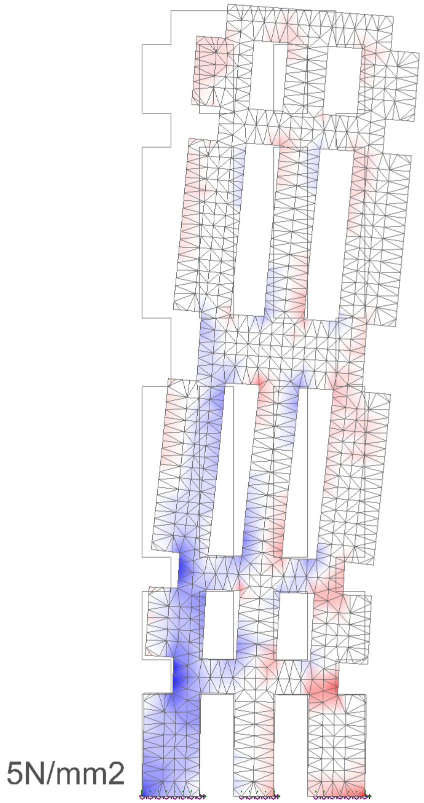
Elements interlocking



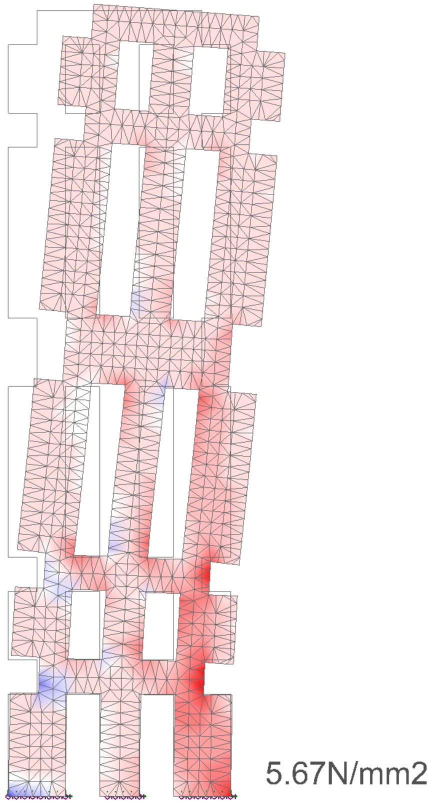
Embedded steel plate



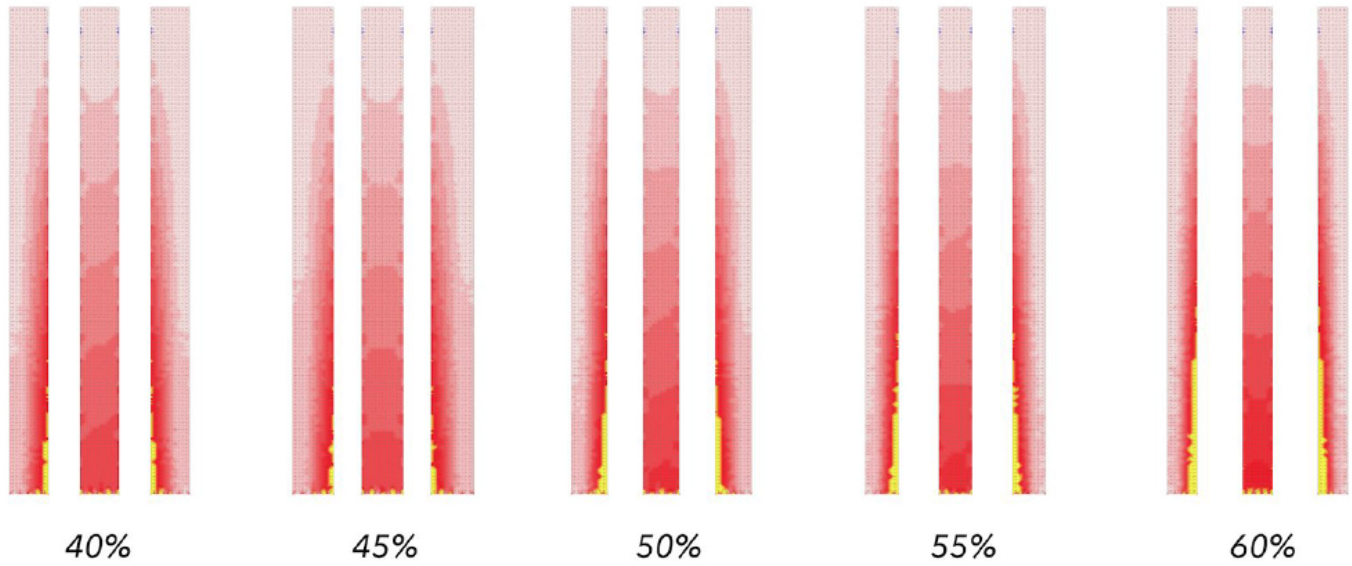
Displacements



Tension forces



Compression forces


40%
45%
50%
55%
60%

THE END