GLASS *that* STRENGTHENS FLOORS, FACILITATES CHANGE, *and* TELLS STORIES

TRANSLATION:
A CASE FOR STRUCTURAL GLASS TO RETROFIT THE ROOF OF THE FENIX II, ROTTERDAM

THESIS MENTORS:
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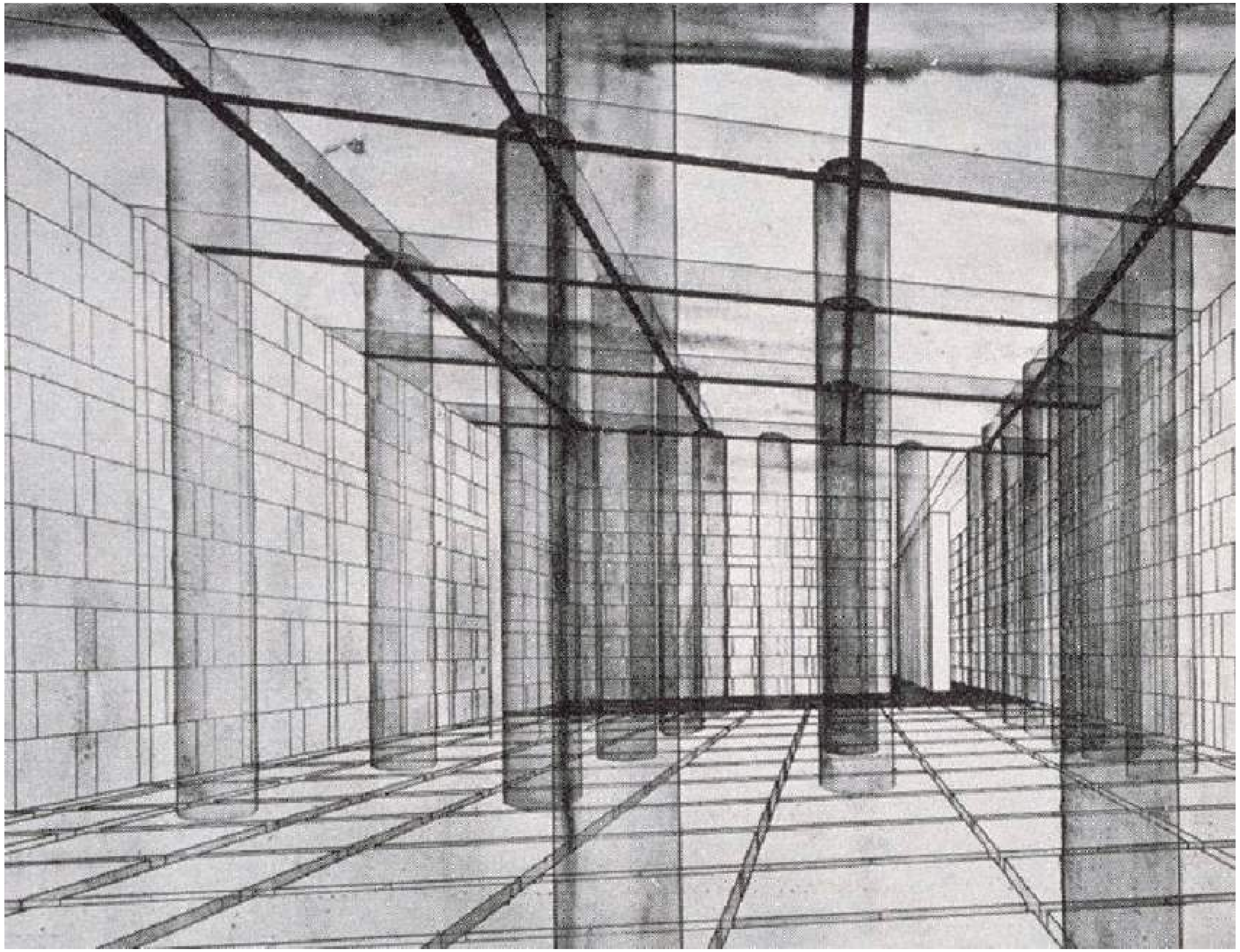
STEFANIE POON
P5
22 JUNE 2021

GLASS

CONCRETE

OLD BUILDINGS

STRUCTURAL GLASS



Danteum, 1938
Giuseppe Terragni

STRUCTURAL GLASS

Apple 5th Ave, 2019
Foster + Partners

STRUCTURAL GLASS

Glass II, 2017
MIT Media Lab

STRUCTURAL GLASS

Hermès, 2001
Renzo Piano

Ports, 2015
UUfie

Crystal Houses, 2016
MVRDV

MFA Houston, 2020
Steven Holl & Associates

TRANSPARENCY

160 Transparency: Literal and Phenomenal

Transparency 1591 1. The quality or condition of being transparent; diaphen-eity; pellucidity 1615. 2. That which is transparent 1591. b. *spec.* A picture, print, inscription or device on some translucent substance, made visible by means of light behind 1807. c. A photograph or picture on glass or other transparent substance intended to be seen by transmitted light 1874. 3. A burlesque translation of the German title of address *Durchlaucht* 1844.

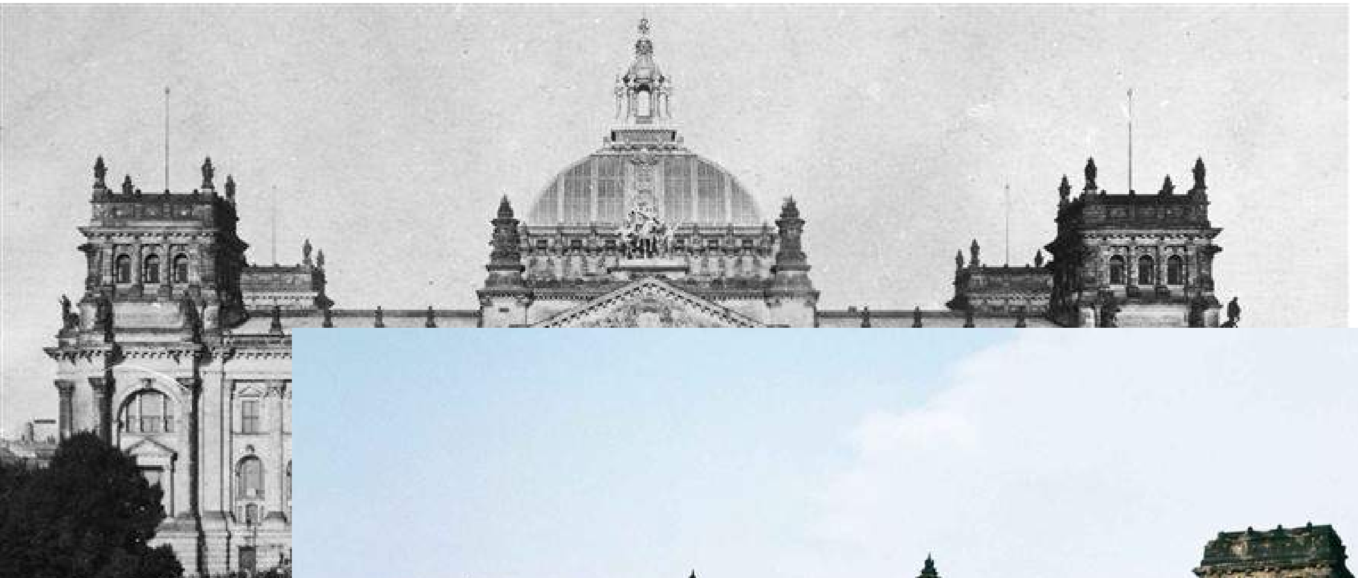
If one sees two or more figures overlapping one another, and each of them claims for itself the common overlapped part, then one is confronted with a contradiction of spatial dimensions. To resolve this contradiction one must assume the presence of a new optical quality. The figures are endowed with transparency: that is, they are able to interpenetrate without an optical destruction of each other. Transparency however implies more than an optical characteristic, it implies a broader spatial order. Transparency means a simultaneous perception of different spatial locations. Space not only recedes but fluctuates in a continuous activity. The position of the transparent figures has equivocal meaning as one sees each figure now as the closer, now as the further one.[1]

Perspecta (Vol. 8), 1963
Colin Rowe and Robert Slutzky

Basilica di Siponto, 2016
Edoardo Tresoldi

Massendemonstration vor dem Reichstagsgebäude
Bildarchiv Preussischer Kulturbesitz

GLASS INTERVENTIONS IN HISTORIC BUILDINGS



The Reichstag after WWII
Josef Heinrich Darchinger, 1958

GLASS INTERVENTIONS IN HISTORIC BUILDINGS

GLASS INTERVENTIONS IN HISTORIC BUILDINGS

Menokin House
Machado Silvetti

GLASS INTERVENTIONS IN HISTORIC BUILDINGS

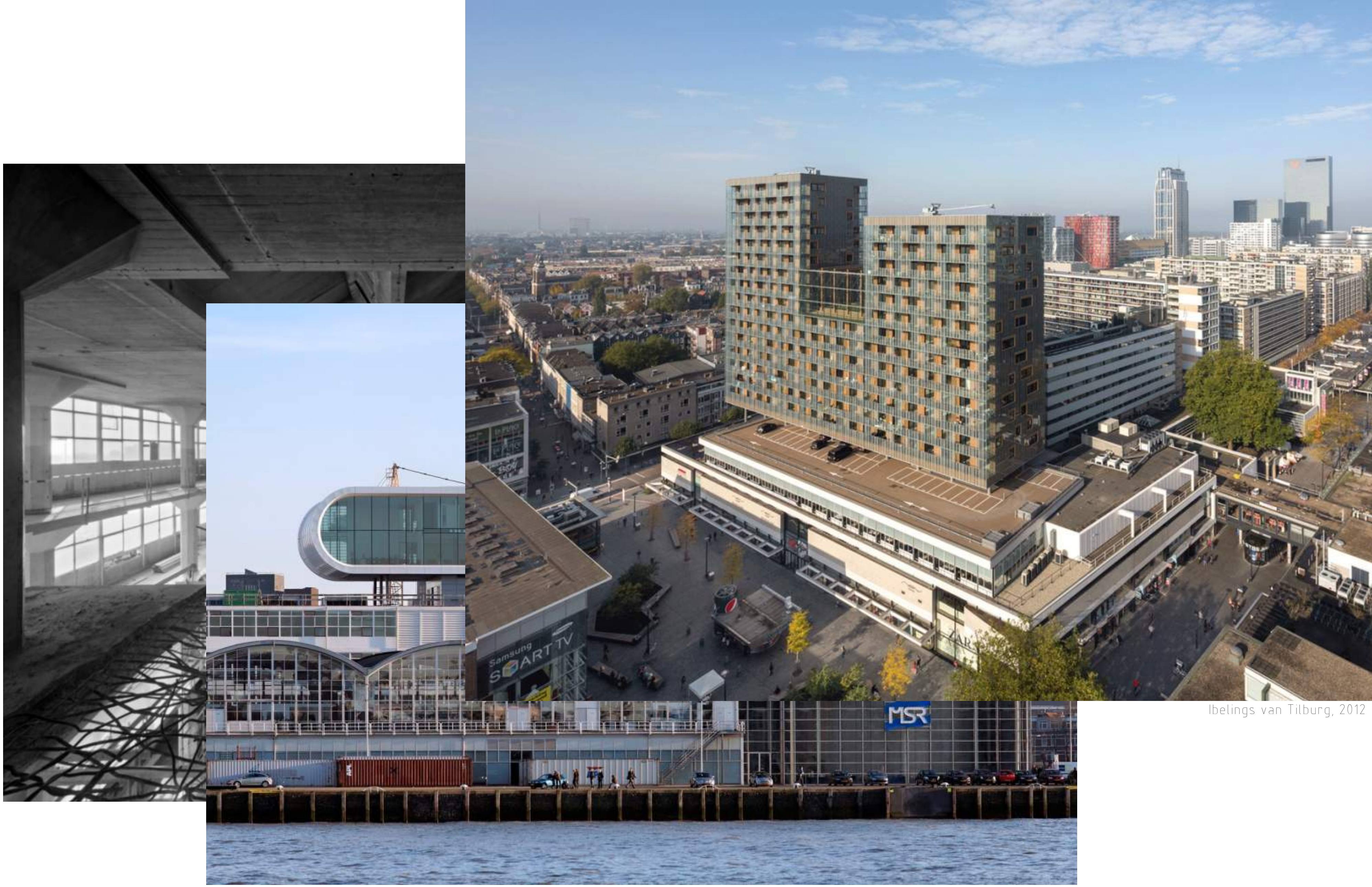
Menokin House
Machado Silvetti

HTTPS://WWW.MENOKIN.ORG/RAISE-THE-GLASS-CAMPAIGN

Las Palmas
Rotterdam, 1953
Van den Broek & Bakema

REUSE OF HISTORIC CONCRETE BUILDINGS

Benthem Crouwel Architekten, 2008



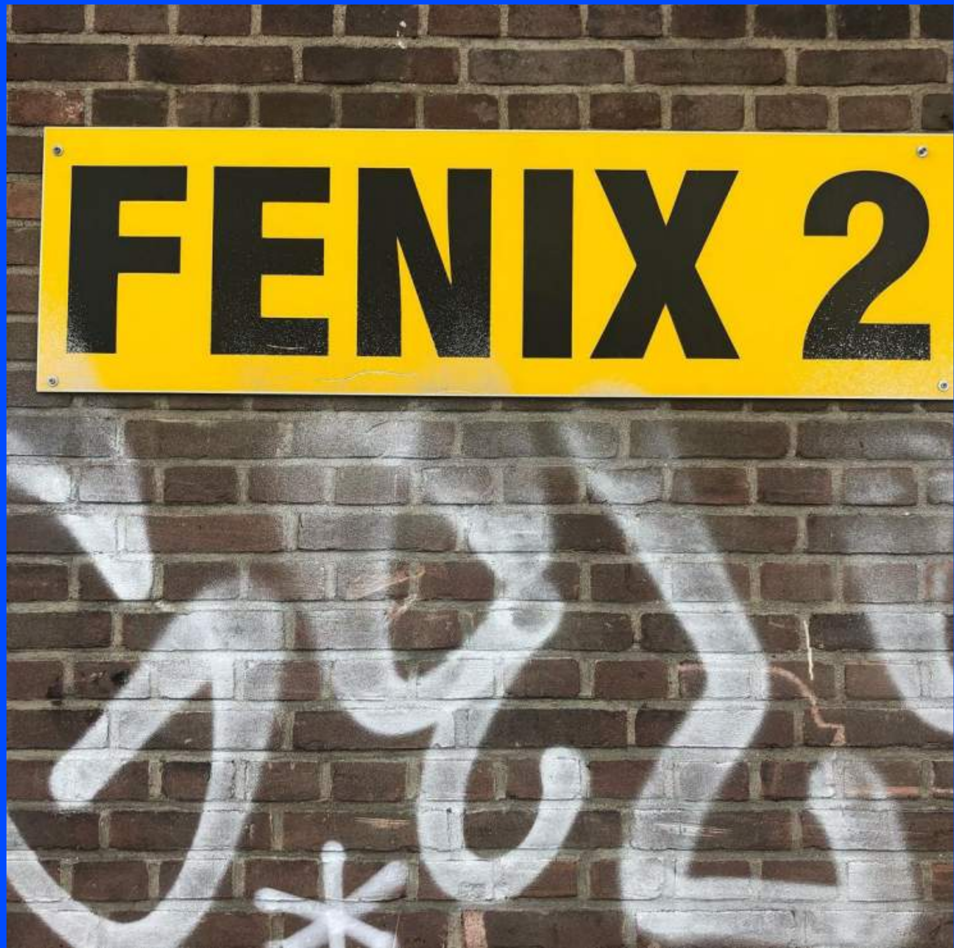
Ibelings van Tilburg, 2012

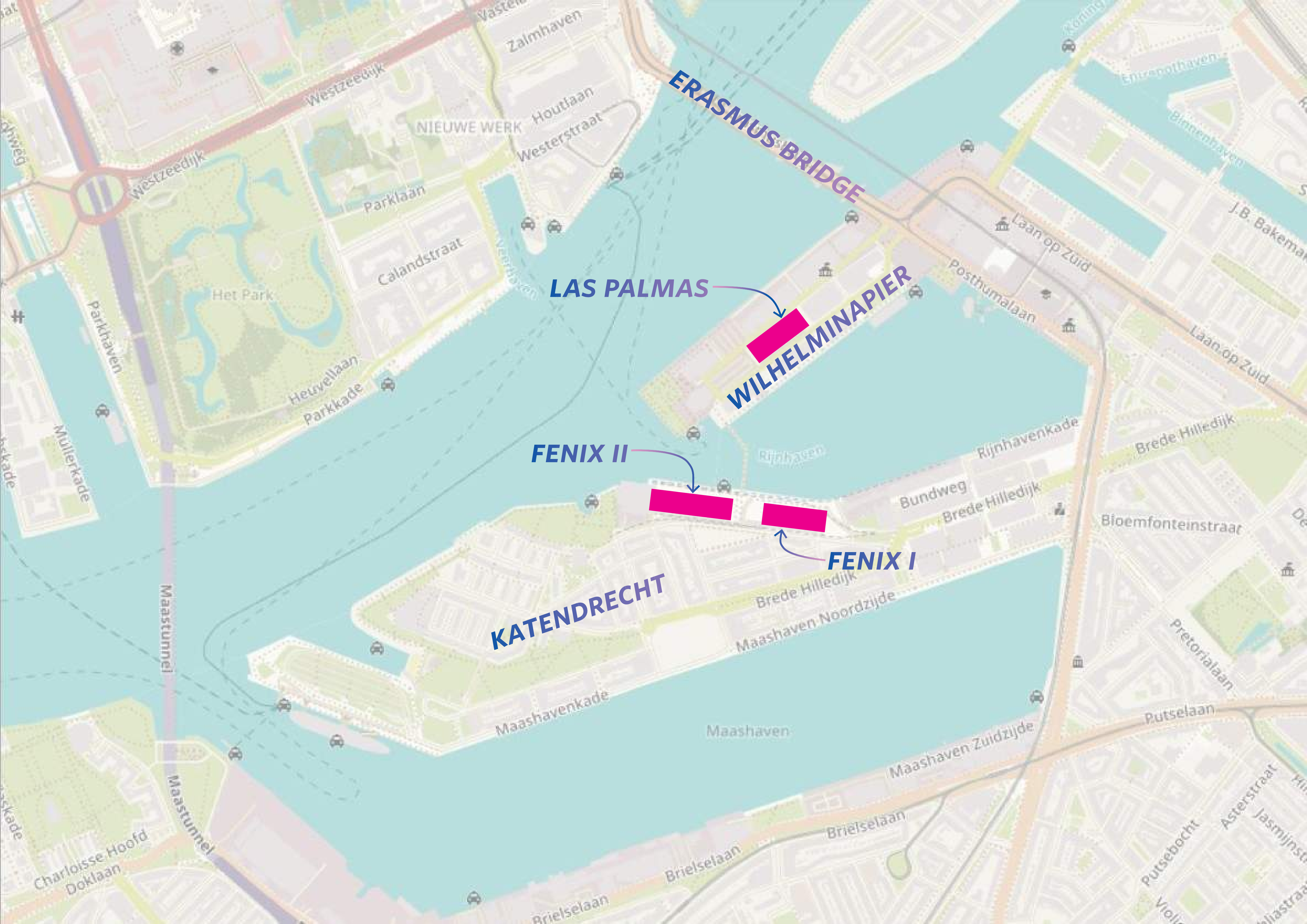



MAD Architects, 2020

TO WHAT EXTENT CAN STRUCTURAL GLASS COMPONENTS BE USED TO STRENGTHEN CONCRETE HERITAGE BUILDINGS, IN LIEU OF THE PREVAILING CONVENTIONAL METHODS?

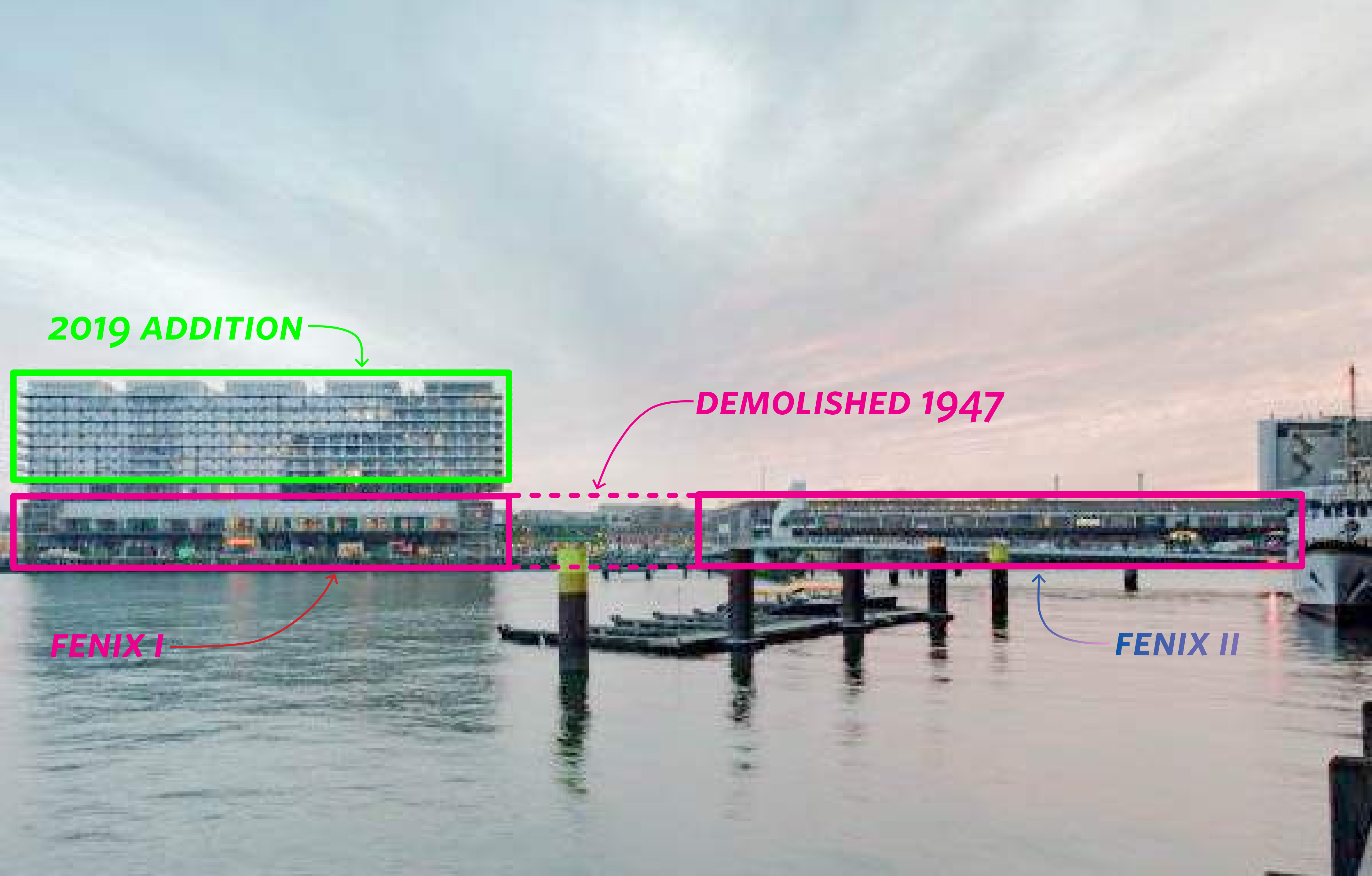
CASE STUDY





ERASMUS BRIDGE
LAS PALMAS
WILHELMINAPIER
FENIX II
FENIX I
KATENDRECHT
Zalmhaven
Westzeedijk
NIEUWE WERK
Houtlaan
Westerstraat
Parklaan
Calandstraat
Het Park
Parkhaven
Heuvellaan
Parkkade
Müllerkade
Maastunnel
Laan op Zuid
Posthumalaan
J.B. Bakema
Rijnhavenkade
Rijnhaven
Brede Hilledijk
Bundweg
Bloemfonteinstraat
Maashaven Noordzijde
Maashavenkade
Maashaven
Maashaven Zuidzijde
Putselaan
Pretorialaan
Brielselaan
Charloisse Hoofd
Doklaan
Putsebocht
Asterstraat

CASE STUDY: FENIX II


2019 ADDITION
DEMOLISHED 1947
FENIX I
FENIX II

Ronde van Katendrecht
1958

Ronde van Katendrecht
2018

CASE STUDY: FENIX II

CASE STUDY: FENIX II

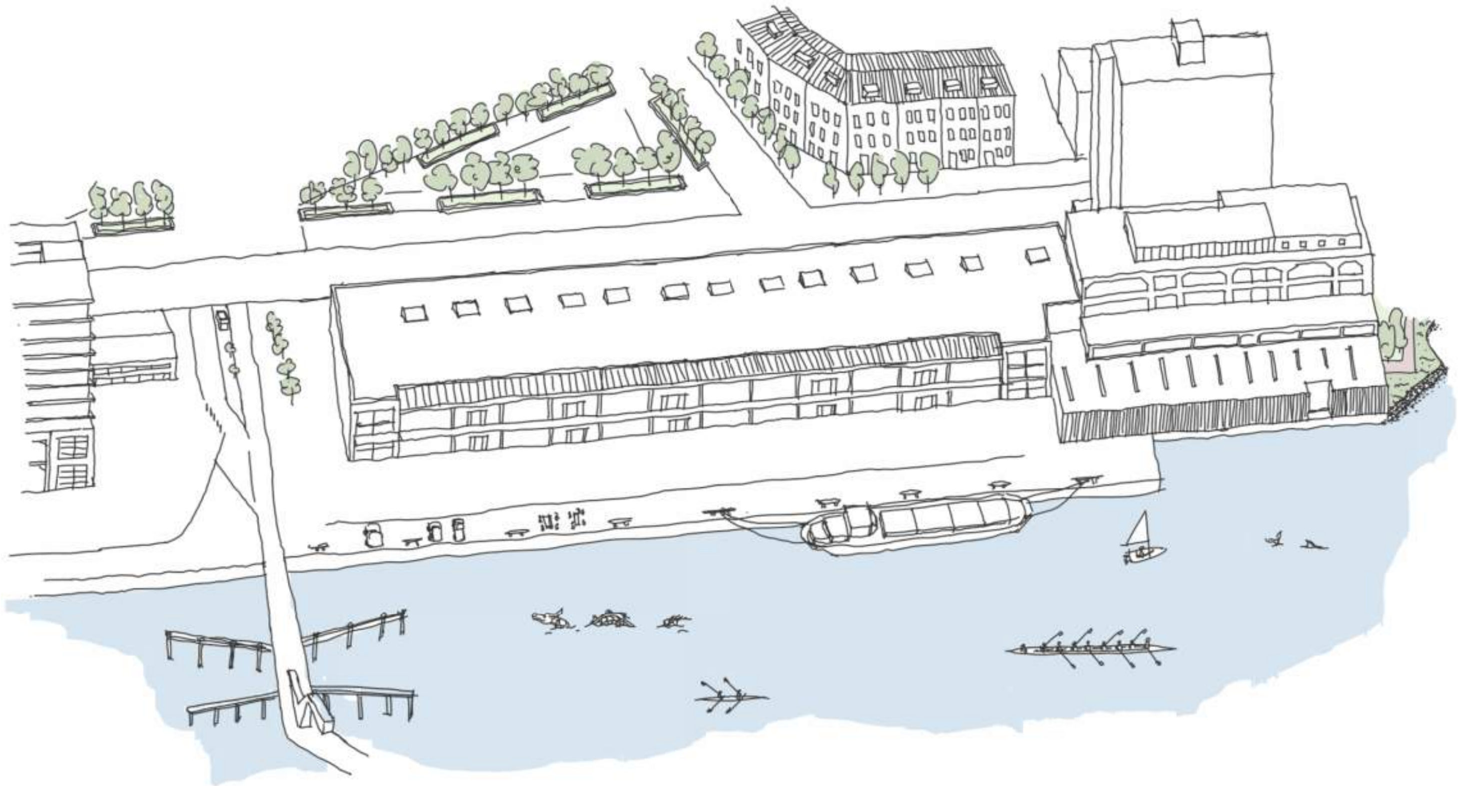
Current state of demolition
Olympia Apostolopoulou, yesterday

CASE STUDY: FENIX II

Rijnhaven facade
Bouwkundig Weekblad, 1931

Roof construction
Archief Holland-Amerika Lijn, Rotterdam

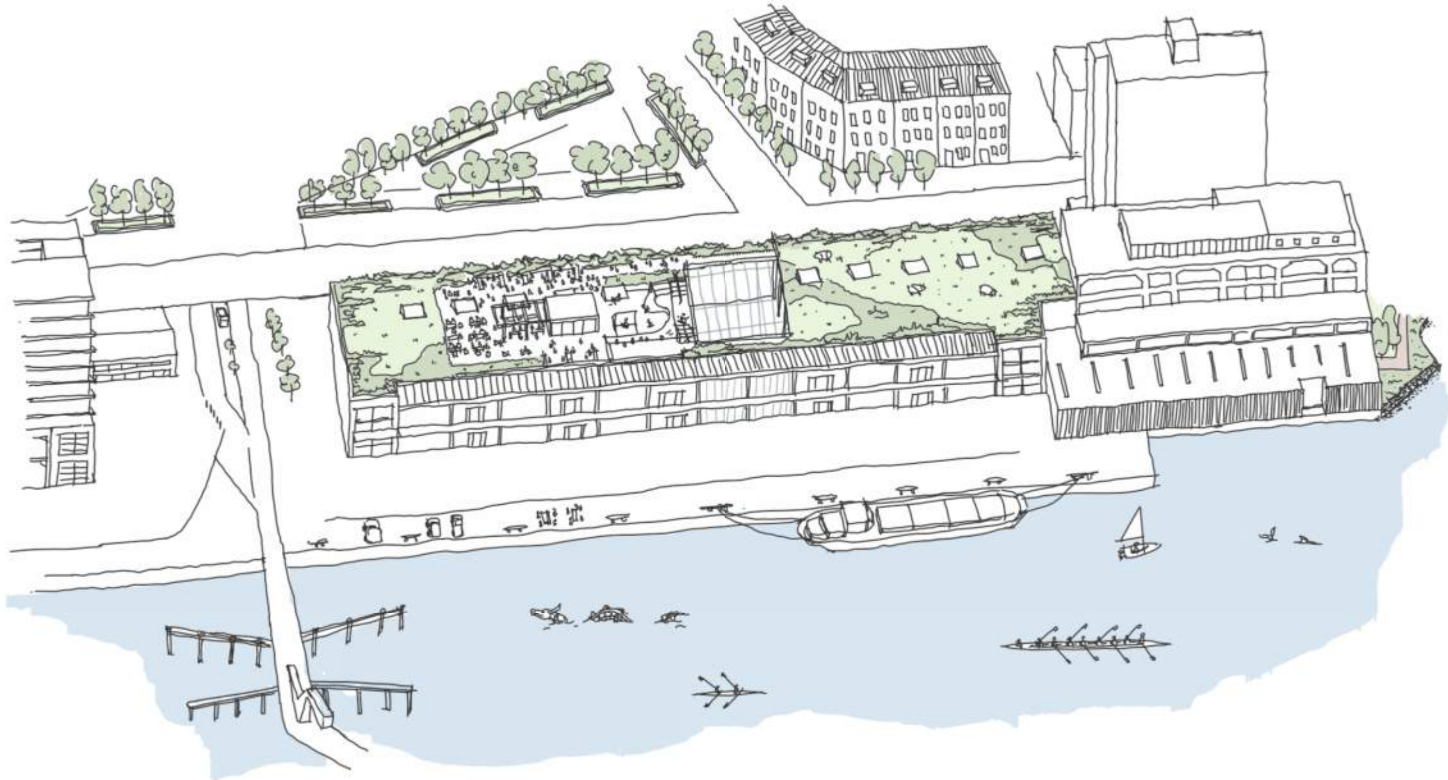
CASE STUDY: FENIX II



ORIGINAL ROOF DESIGN LOAD: 4.98 kN/m²

maintenance
service
rain/snow

CASE STUDY: PROPOSED NEW USES

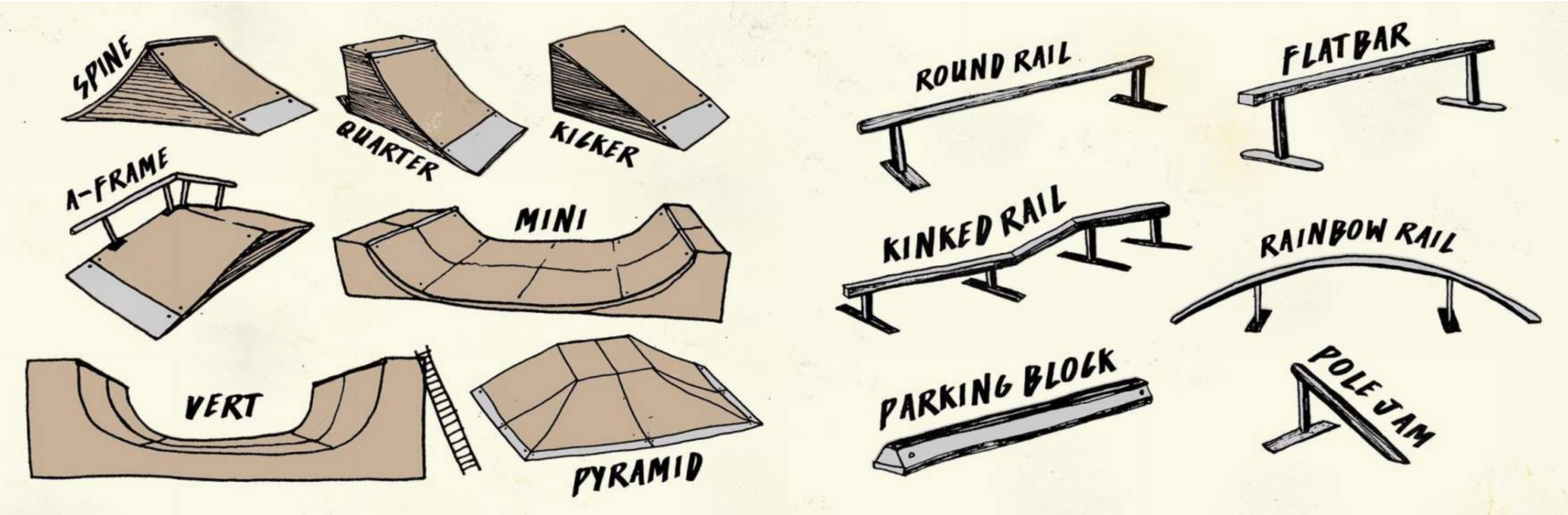


***NEW DESIGN LOADS:* 10.8 kN/m²**
11.0 kN/m²
12.5 kN/m²

CASE STUDY: PROPOSED NEW USES

ROOF GARDEN

CASE STUDY: PROPOSED NEW USES



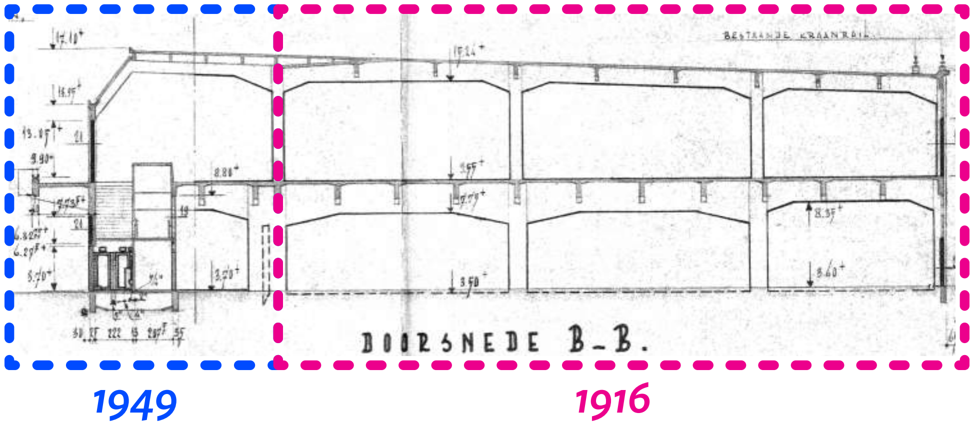
SKATEBOARDING

BAR/CAFE/EVENTS

1. ANALYZE ORIGINAL STRUCTURE

Riet Garcia-Bruns
Stichting Historisch Katendrecht

EXISTING CONCRETE / ABT FENIX I

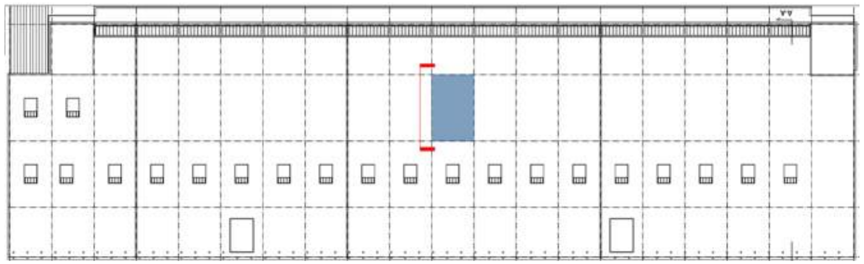


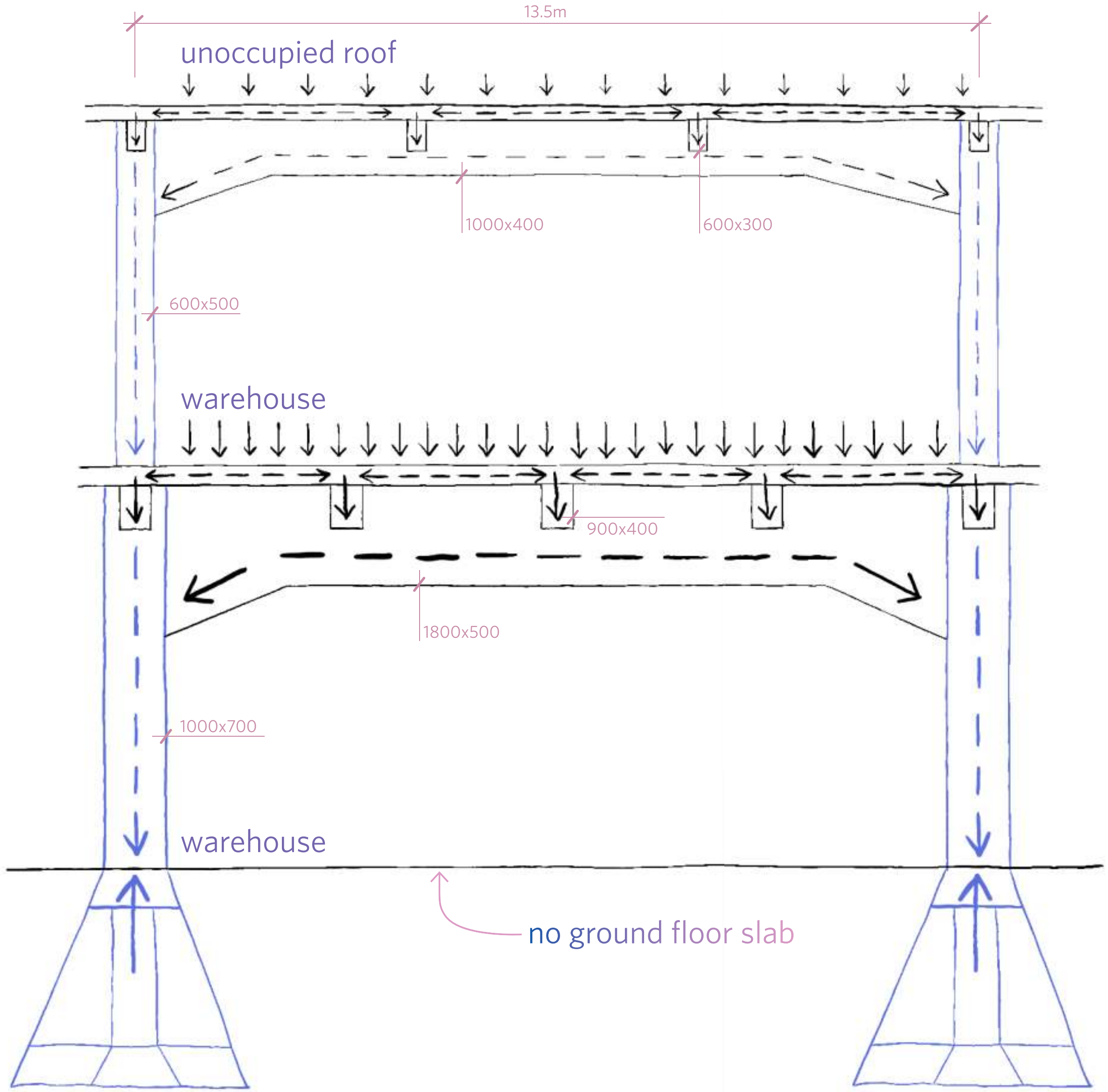
constructieonderdeel	bouwdeel	genormeerde betonsterkteklasse
		conform bijlage D NEN-EN 1990
kolommen	nieuw	C35/40
	oud	C12/15
	oud incl. gevelzijde Veerlaan	C12/15
balken	nieuw	C20/25
	oud	C15/20
	oud incl. gevelzijde Veerlaan	C12/15
vloeren	nieuw	C25/30
	oud	C20/25

Capaciteit bestaande constructie

- "ontdekking" originele berekening (VB = 5 kN/m² ipv 10 kN/m²)
- Werkelijke betonkwaliteit bepaald (kernen geboord) -> lage sterkte
- Bekende wapening (1916) onbekende wapening (1949)
- Andere mechanicaschema's (doorgezaagde balken, belasting erbij)

EXISTING CONCRETE / TYPICAL BAY


roof plan



$M = \frac{1}{10} \times 33900 \times 8.6 = 29200$ Kgm

$Z = 0.90 - 0.13 = 0.77$ M

10 – 22 ∅ = 38.00

$Tb = \frac{2m}{Z \times b \times d} = \frac{2 \times 29200}{0.77 \times 160 \times 13} = \underline{36.5}$ Kg per cM.^{2}

$Ty = \frac{m}{Z \times fy} = \frac{29200}{0.77 \times 38} \doteq \underline{1000}$ Kg per cM^2

$Ts = \frac{1.5 \times 16950}{40 \times 130} = \underline{4.9}$ Kg per cM^2

Dakplaatoverspanning 4.10 M Tb = 60 Ty = 1000

0.289 $\sqrt{m}$

0.411 $\sqrt{m}$

Mob. belasting 140 Kg.

eigen gewicht 240 "

380 Kg.

Pos. Moment

$M = \frac{1}{10} \times 380 \times 4.1^2 = 640$ Kgm.

$h - a = 0.289 \sqrt{m} = 7.33$ cM

$fy = 0.411 \sqrt{m} \times \frac{7.33}{8.5} = 8.97$ c.M^2

8 Staven 12 ∅ = 9.04

$\frac{1}{3}$ bovenmet.

$M = \frac{1}{10} \times 33900 \times 8.6 = 29200$ Kg m

$Z = 0.90 - 0.13 = 0.77$ M

$10 - 22\phi = 38.00$

$Fb = \frac{2m}{Z \times b \times d} = \frac{2 \times 29200}{0.77 \times 160 \times 13} = 36.5$ Kg per c M^2

$Fy = \frac{m}{Z \times fy} = \frac{29200}{0.77 \times 38} = 1000$ Kg per c M^2

$Ts = \frac{1.5 \times 16950}{40 \times 130} = 4.9$ Kg per c M^2

Dak plaatoverspanning 4.10 M Fb = 60 Fy = 1000

$0.289 \sqrt{m}$

$0.411 \sqrt{m}$

Mob. belasting	140 Kg
eigen gewicht	240 "
	380 Kg

DESIGN LOAD

Pos. Moment

$M = \frac{1}{10} \times 380 \times 4.1^2 = 640$ Kgm

$h - a = 0.289 \sqrt{m} = 7.33$ c.M

$fy = 0.411 \sqrt{m} \times \frac{7.33}{8.5} = 8.97$ c.M^2

AREA OF REINFORCEMENT

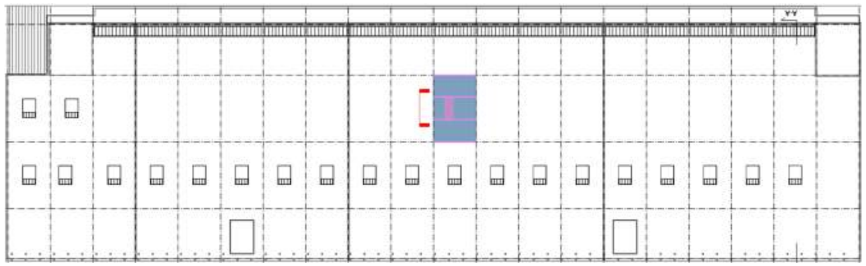
8 staven 12ϕ = 9.04

$\frac{1}{3}$ bovennet.

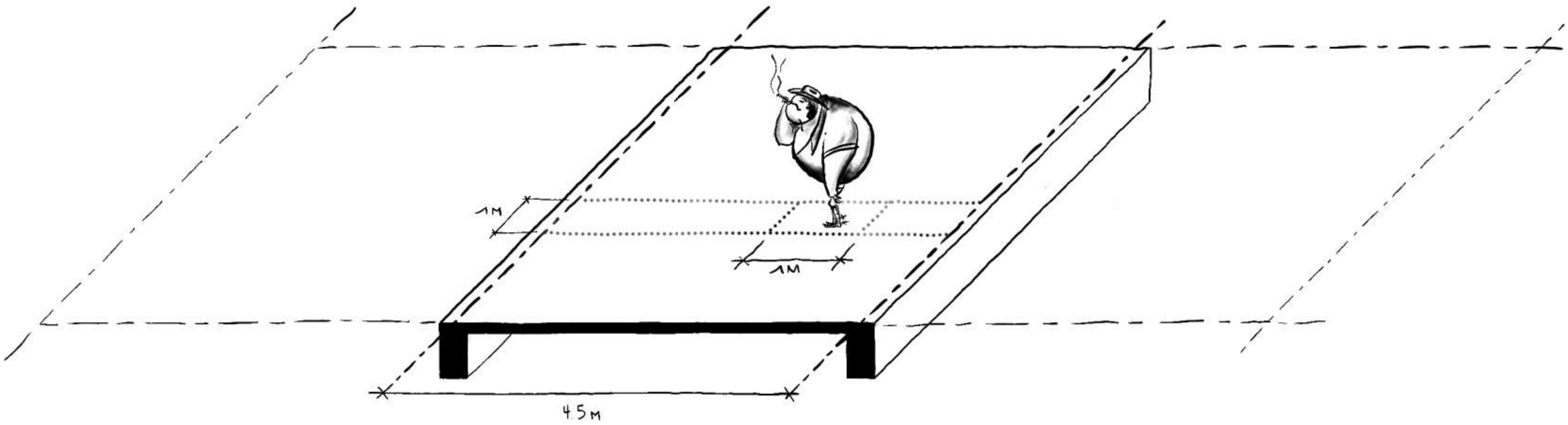
EXISTING CONCRETE / DESIGN LOADS AT ROOF

Concrete self-weight
100m slab = 2.4 kN/m²

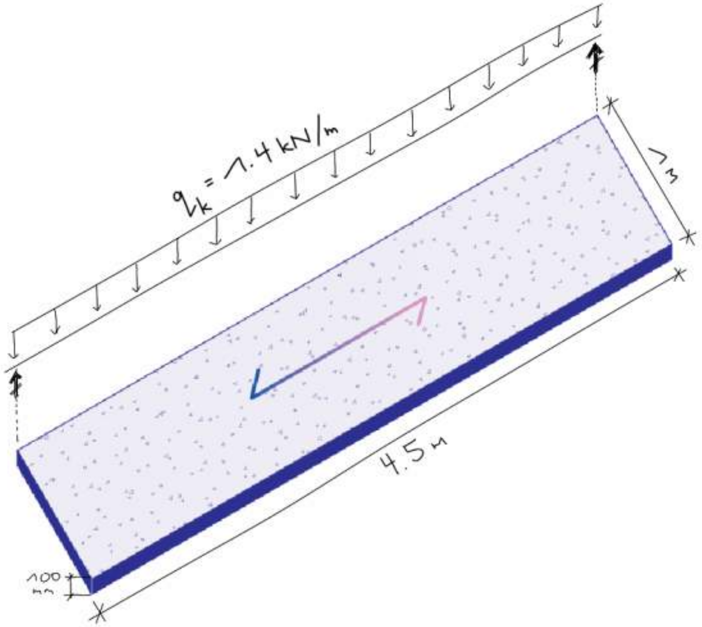
Service live load
1.4 kN/m²
equivalent to:
weight of one fat cowboy per m²

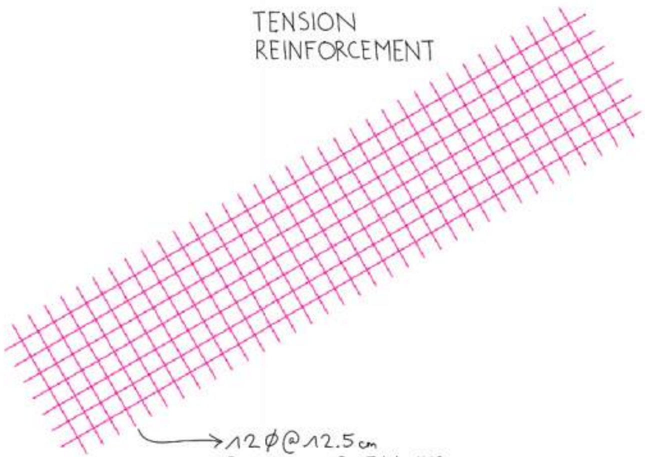


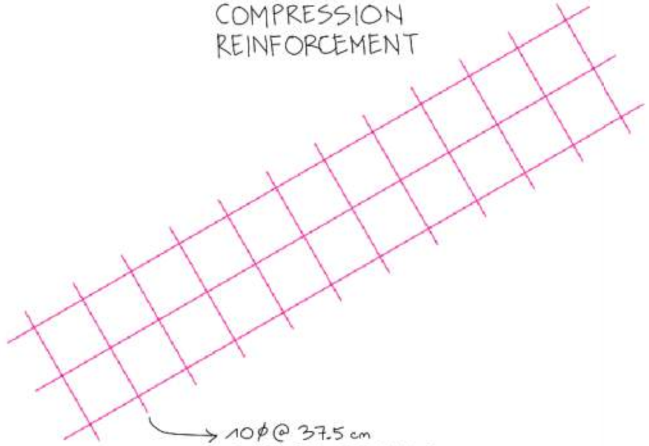
roof plan



EXISTING CONCRETE / SLAB







Dak Kinderbinten 30 x 60.

Bint 35.

Overspanning 8.60 M.

DESIGN LOAD

Mob. belasting incl. eigengewicht 18800 Kg.

Pos. Moment.

$M = \frac{1}{10} \times 18800 \times 8.6 = 16200$ Kgm.

$Z = 0.60 - 0.10 = 0.50$

AREA OF REINFORCEMENT

$T_b = \frac{2m}{bdz} = \frac{2 \times 16200}{280 \times 10 \times 0.5} = \underline{23.2 \text{ KG per c M}^2}$

3-25 ϕ = 14.73
5-22 ϕ = 19
33.73.

$T_y = \frac{m}{f_y z} = \frac{16200}{33.73 \times 0.5} = \underline{9.65 \text{ Kg per c M}^2}$

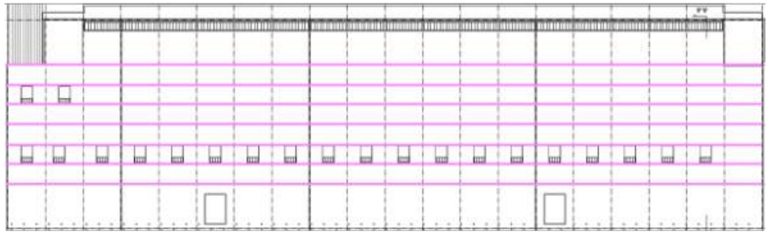
Neg. Moment Consolehoogte 0.90 M.

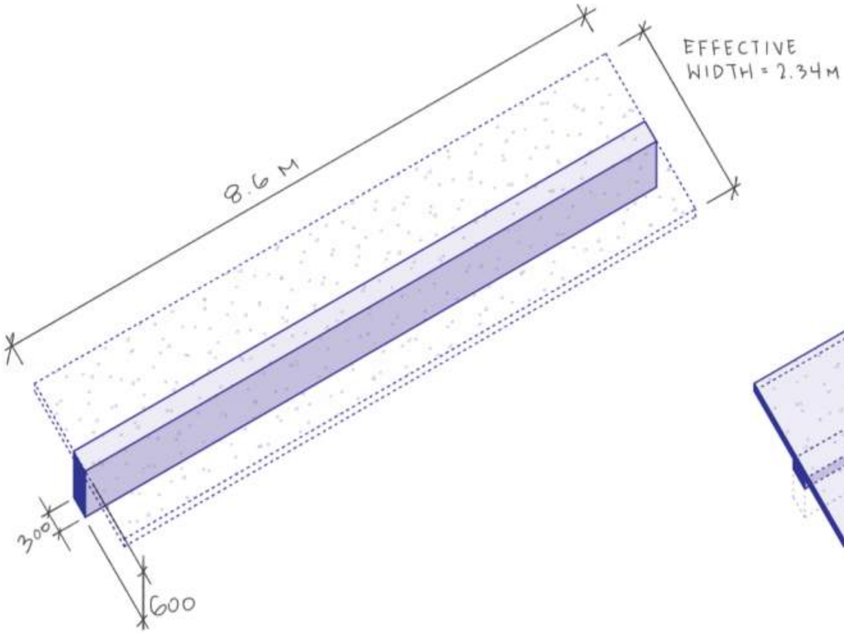
$M = \frac{1}{8} \times 18800 \times 8.6 = 20200$ Kgm

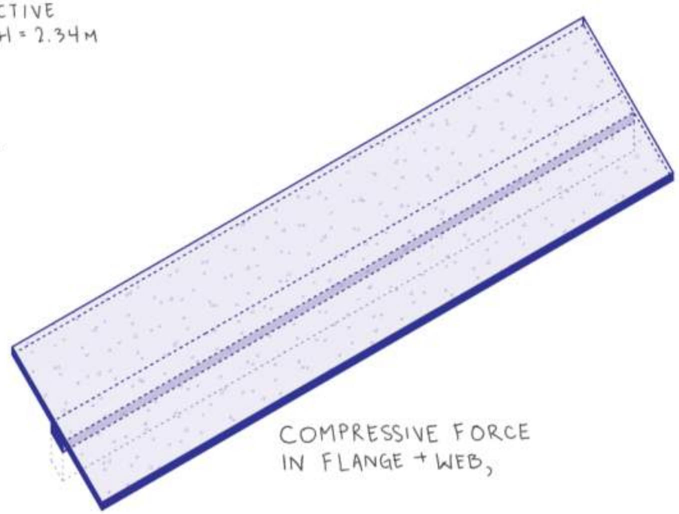
$x = \frac{nf_y}{b}\left[-1 + \sqrt{1 + \frac{2b(h-a)}{nf_y}}\right] = \frac{15 \times 2.974}{30}\left[-1 + \sqrt{1 + \frac{60 \times 85}{15 \times 29.74}}\right] = 377$

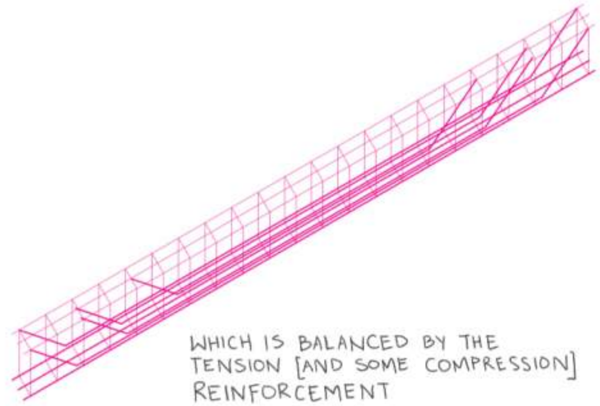
3-19 ϕ = 8.52
2-25 ϕ = 9.82
3-22 ϕ = 11.4
29.74.

EXISTING CONCRETE / BEAM

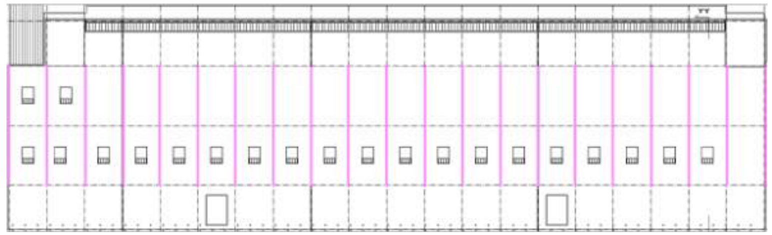


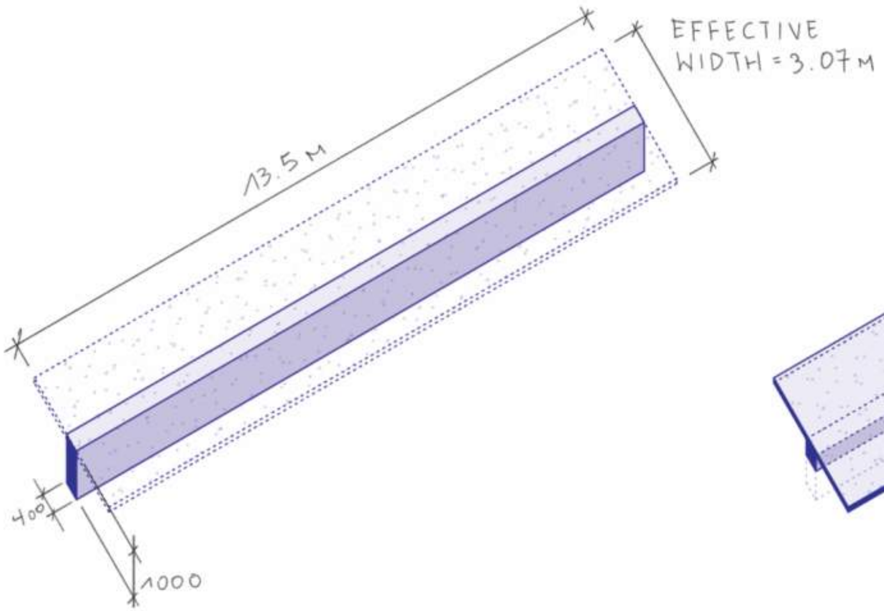


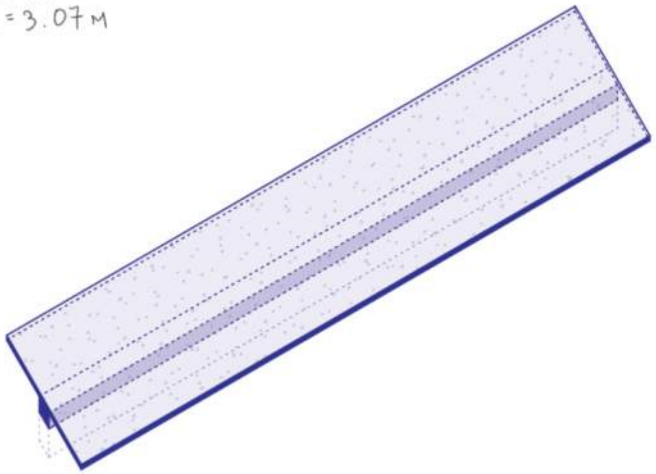


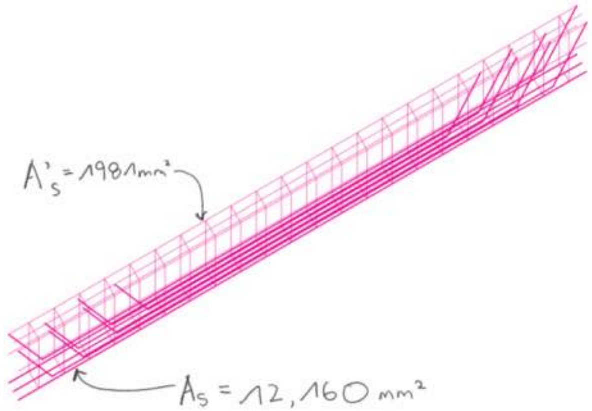


EXISTING CONCRETE / GIRDER









EXISTING CONCRETE / UTILIZATION

	Moment	Reinforcement	Deflection
SLAB	0.8	1.07	0.53
BEAM	0.85	0.73	0.3
GIRDER	0.41	0.48	0.26

EXISTING CONCRETE / UTILIZATION

	Moment	Reinforcement	Deflection	
SLAB	0.8	1.07	0.53	***WITH 4.98 KN/M²***
BEAM	0.85	0.73	0.3	
GIRDER	0.41	0.48	0.26	

EXISTING CONCRETE / UTILIZATION

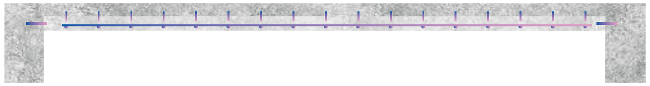
	Moment	Reinforcement	Deflection	
SLAB	0.8	1.07	0.53	**WITH 4.98 kN/m^2**
BEAM	0.85	0.73	0.3	**SOME EXCESS CAPACITY**
GIRDER	0.41	0.48	0.26	

EXISTING CONCRETE / UTILIZATION

	Moment	Reinforcement	Deflection	
SLAB	0.8	1.07	0.53	***WITH 4.98 kN/m²***
BEAM	0.85	0.73	0.3	***SOME EXCESS CAPACITY***
GIRDER	0.41	0.48	0.26	***BUT MORE HERE***

2. INITIAL DESIGN

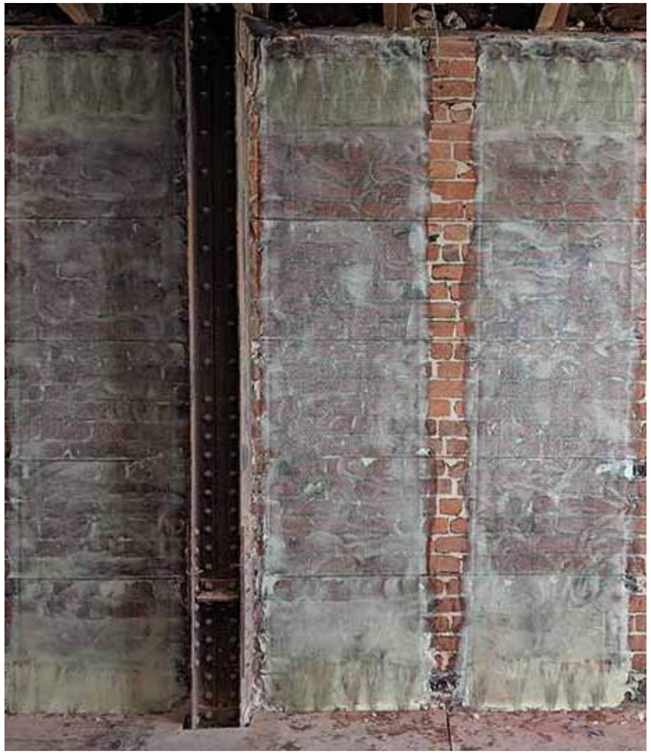
PREVAILING METHODS OF STRENGTHENING



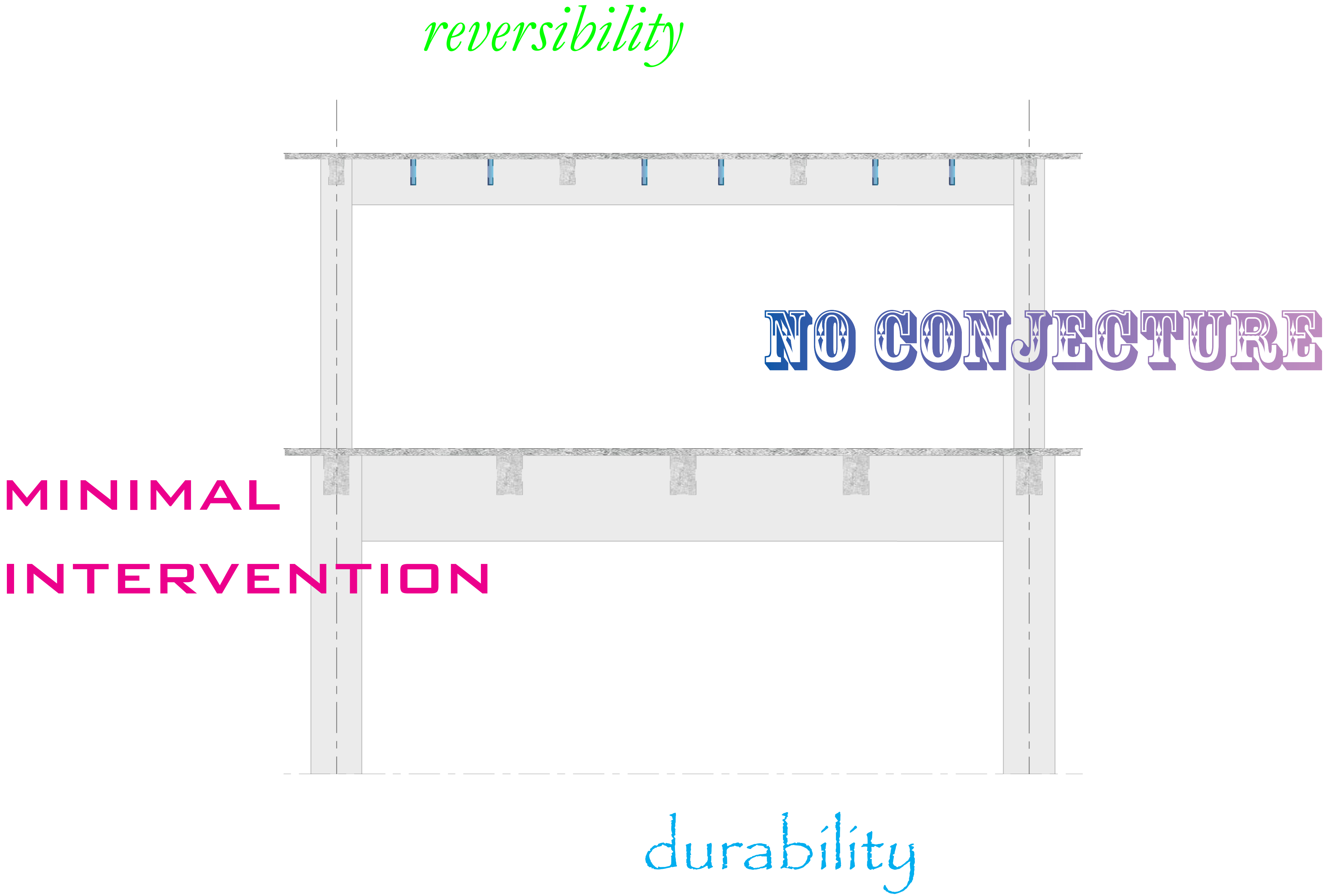
extend cross section
- invasive
- irreversible
+ same material

steel
- alters perception of existing space
+ can carry heavier loads
+ reversible

fiber-reinforced polymers (GFRP/CFRP)
- less effective than other options
- irreversible
+ no change to cross-section



USE GLASS

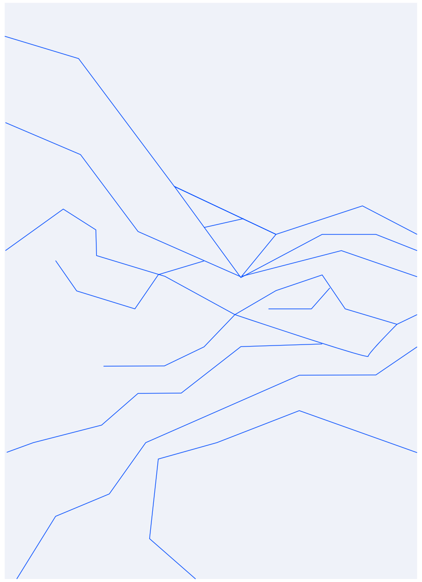


reversibility
NO CONJECTURE
MINIMAL
INTERVENTION
durability

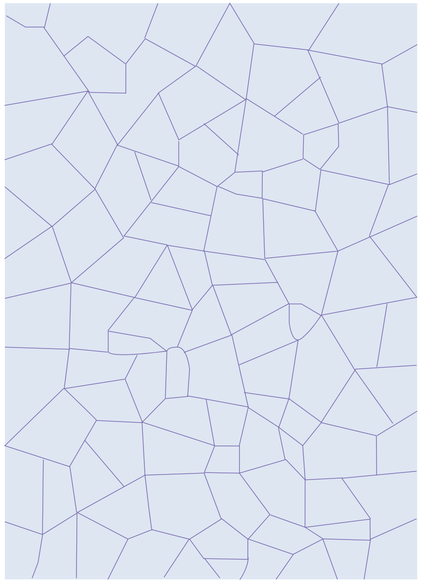
TYPES OF GLASS

annealed
- low strength
+ breaks into large shards

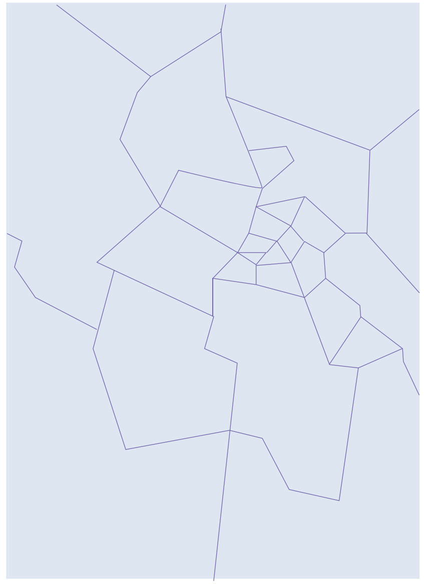
heat-strengthened
+ keeps strength, maintains residual capacity at fracture



fully tempered
- crumbles, loses stiffness
+ high bending strength



laminated
- difficult to recycle
+ holds together when broken



pre-stressed

45 MPa — 70 MPa — 120 MPa

low → high strength

DESIGN LOAD

Concrete self-weight +

100m slab = 2.4 kN/m

New use*

*in cowboy notation

1. Green roof

1 cowboy and 2 horses

Permanent:	roofing	0.5 kN/m^2	estimated
	0.3m dirt	4.5 kN/m^2	packed earth
Variable:	service	1.0 kN/m^2	EN 1991, H
	some animals	0.3 kN/m^2	unit weight 2 pigs

Total factored: 10.8 kN/m

2. Skatepark

2 cowboys and 2 horses

Permanent:	roofing	0.5 kN/m^2	estimated
Variable:	areas physical activity	5.0 kN/m^2	EN 1991, C4

Total factored: 11.0 kN/m

3. Bar

3 cowboys and 2 horses

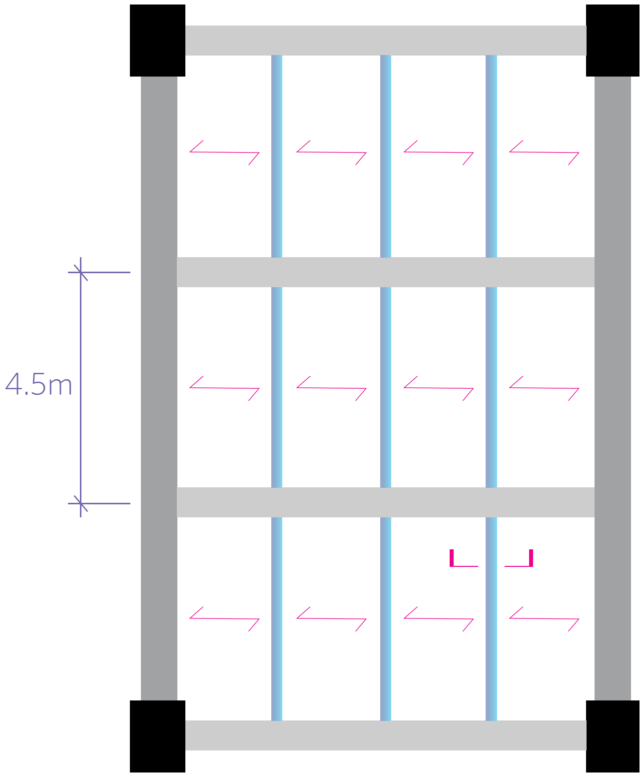
Permanent:	roofing	0.5 kN/m^2	estimated
Variable:	areas physical activity	5.0 kN/m^2	EN 1991, C4
	partitions	1.0 kN/m^2	estimated

Total factored: 12.5 kN/m

DESIGN STUDY 1

Add new beams between secondary concrete beams:

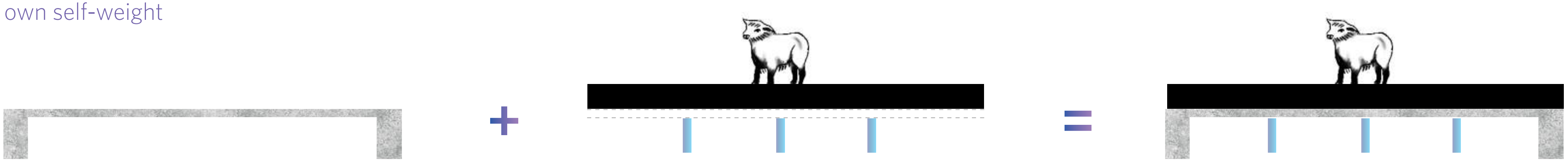
1. shortest span = save material
2. change direction of slab span



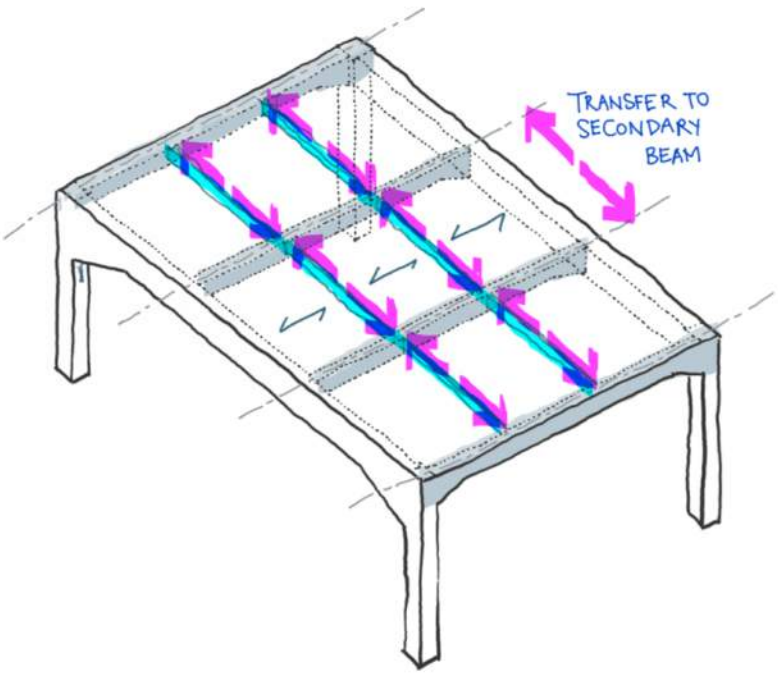
Size glass beams to accept all new loads:

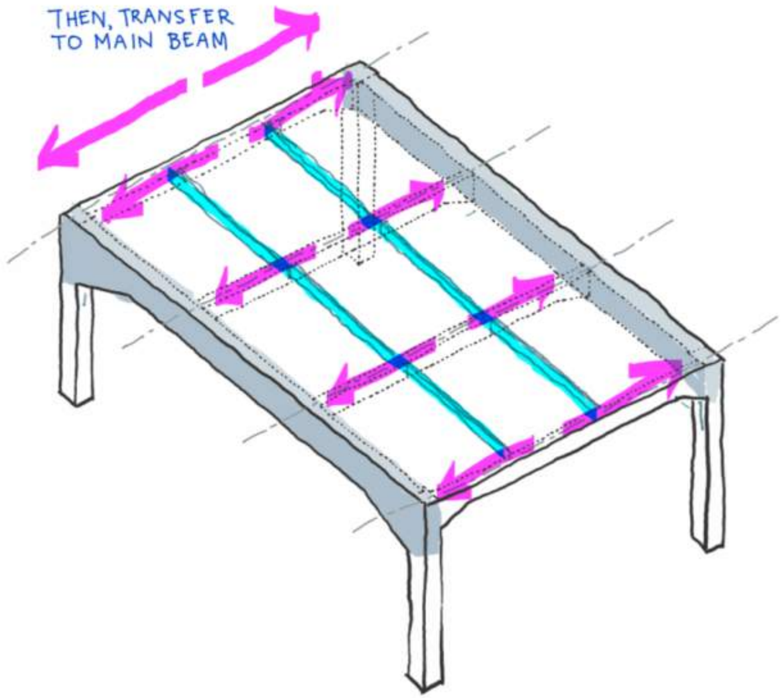
existing concrete slab carries own self-weight

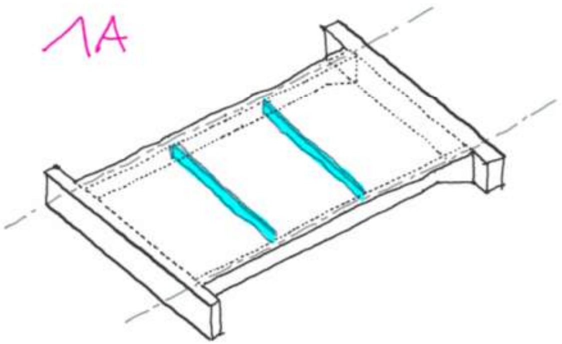
new beams carry new loads

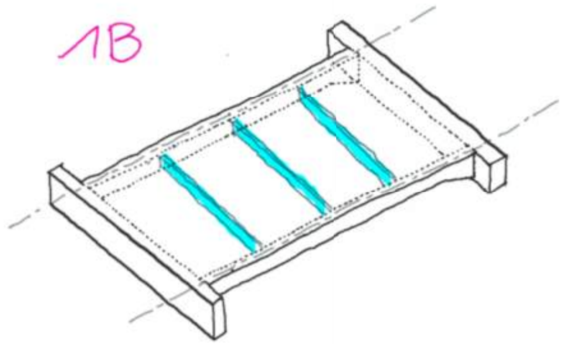


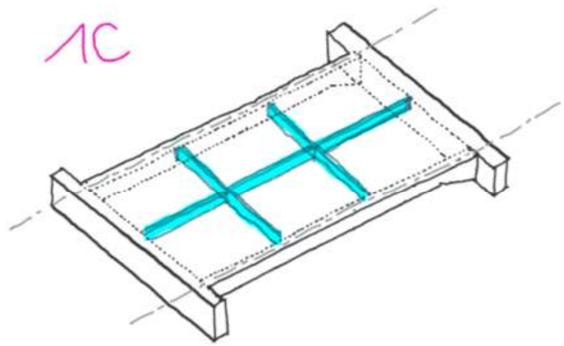
DESIGN STUDY 1







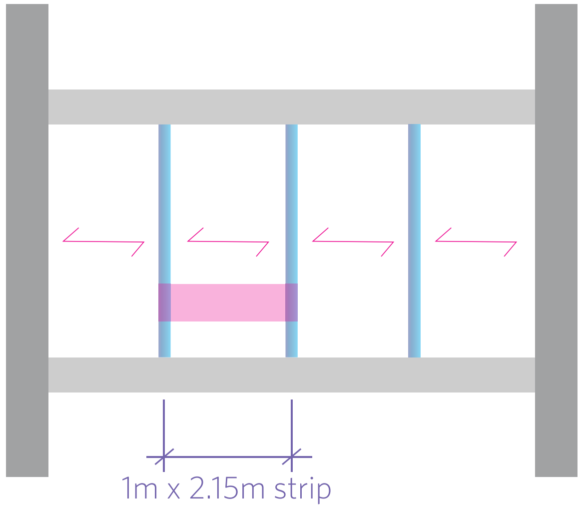




NEW GLASS BEAM

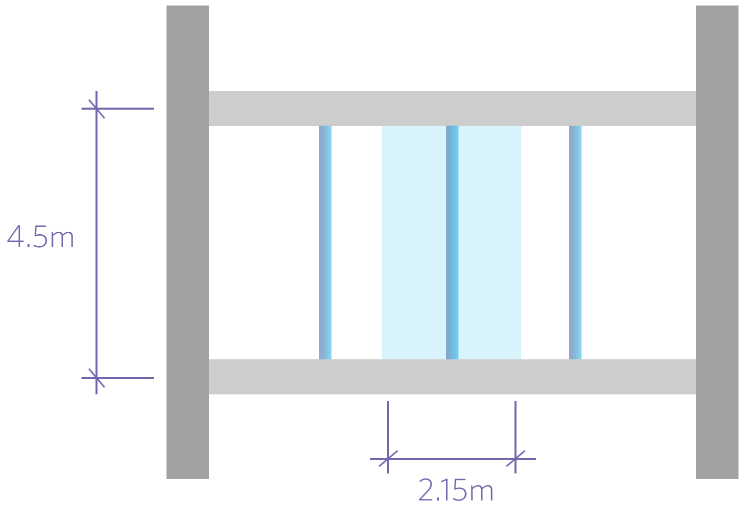
EXISTING CONCRETE BEAM

DESIGN STUDY 1 / CHECK SLAB, BEAM



Check concrete slab is still ok in bending

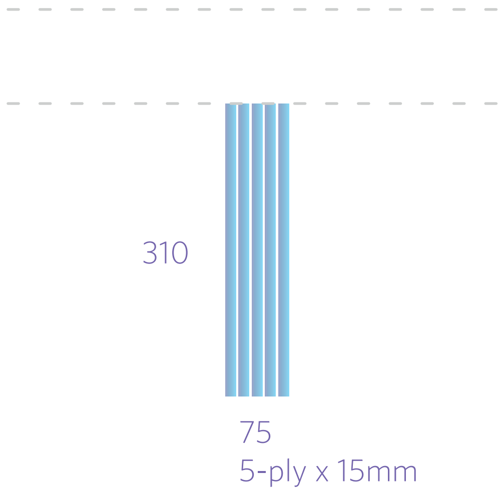
include self-weight of slab + new loads



Check utilization and deflection of glass beam

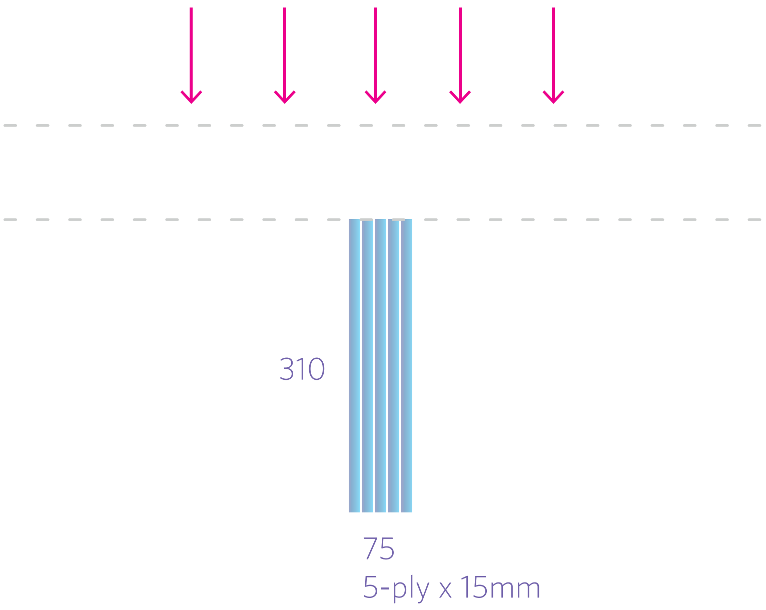
include only new loads

at the bar:
with a tributary
width of 2.15m,
use 75x310mm

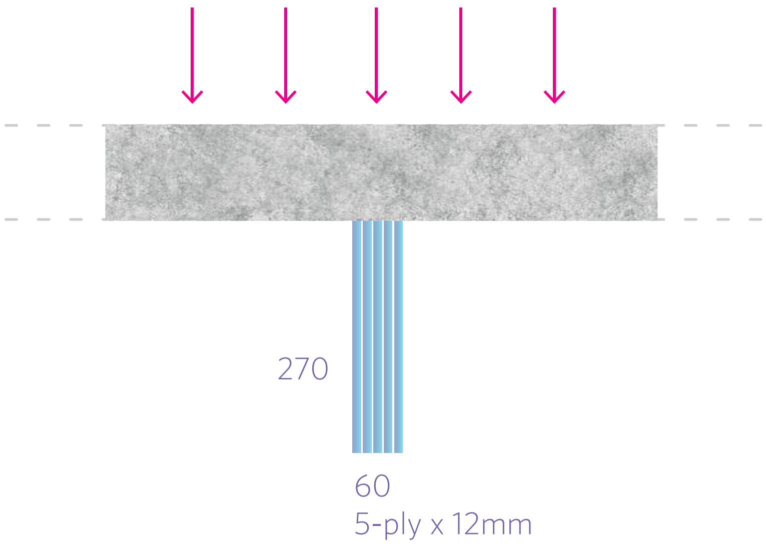


DESIGN STUDY 2 / REDUCE SECTION BY COMPOSITE ACTION

Instead of all new loads to glass,



let an effective width of the concrete slab act as a T-section flange.



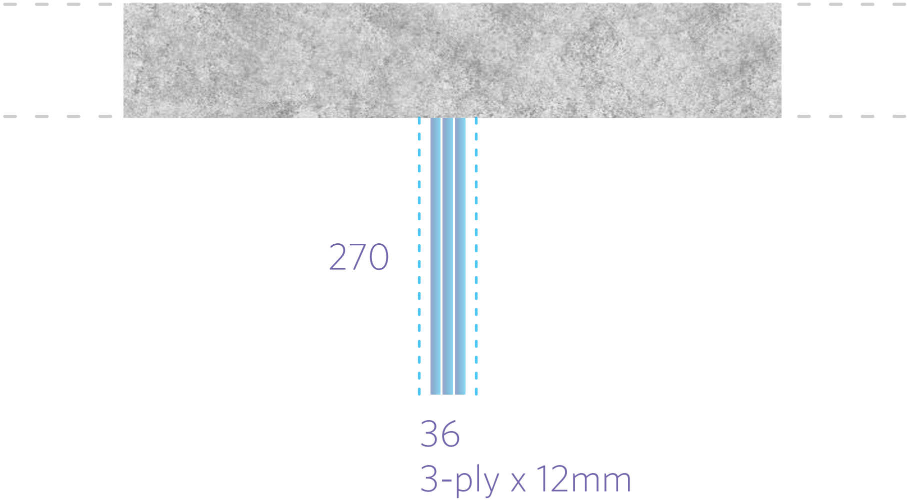
75x310mm → **60x270mm** **= 30%**

governing in bending | deflection governing | reduction in material

DESIGN STUDY 2 / ACCIDENTAL LOADS *buitengewonesituaties met brand, EN 1990

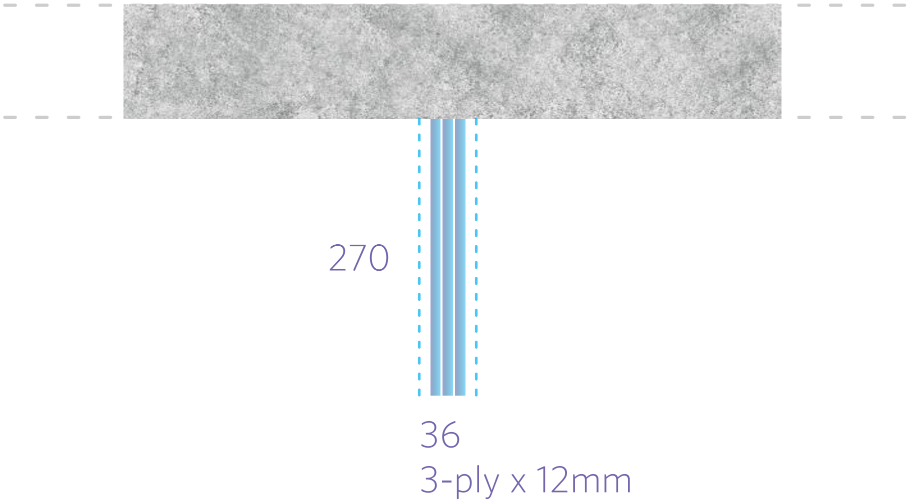
Check the beam if two plies didn't function in an accidental limit state, such as fire

Bar:



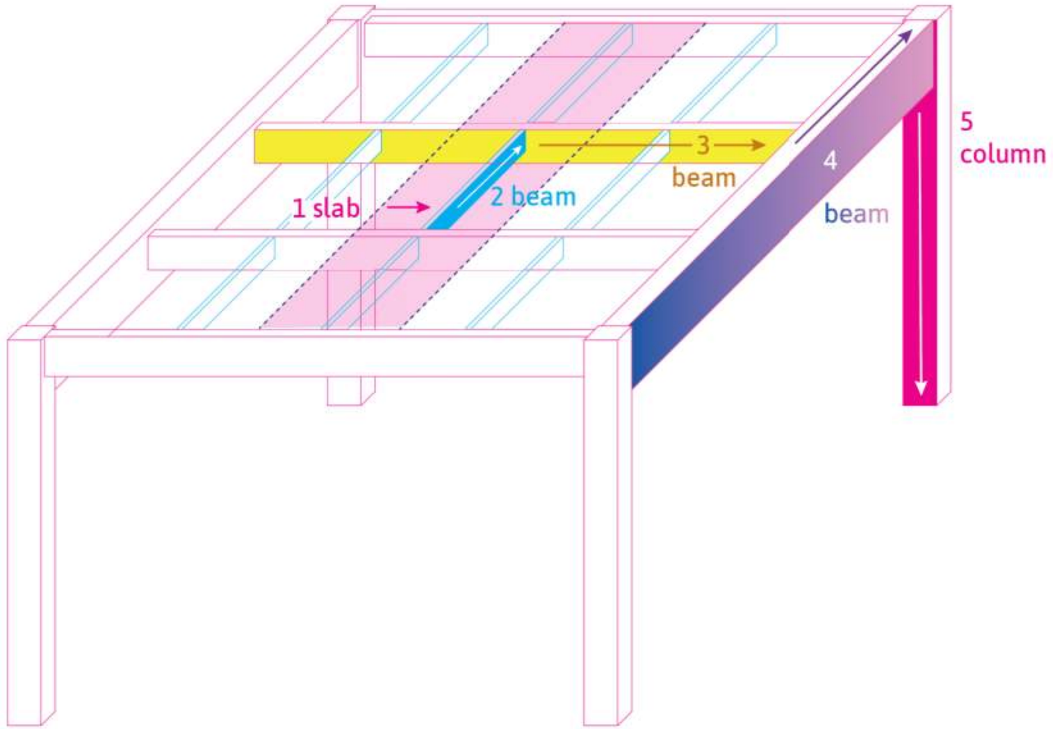
UC: 0,50

Garden:

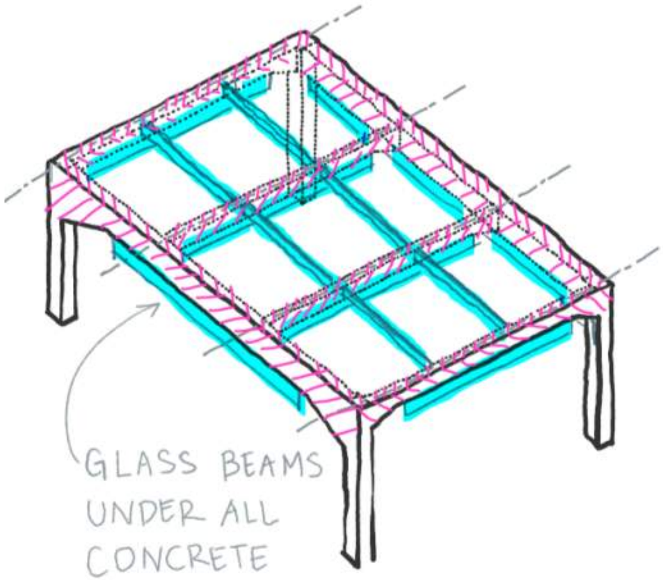


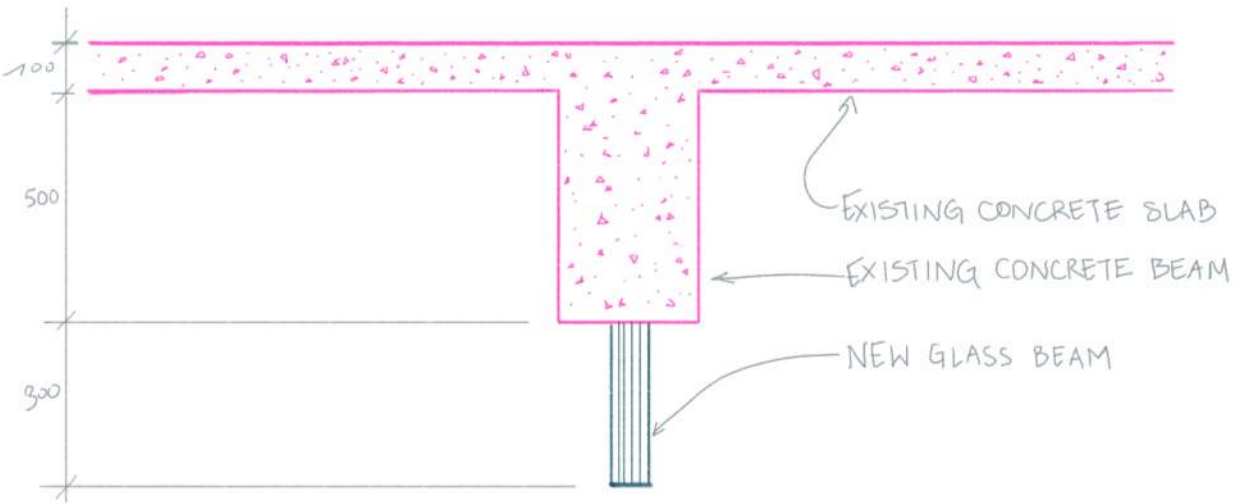
UC: 0,92

DESIGN STUDY 1 / EXISTING BEAM STRENGTHENING



DESIGN STUDY 1 / EXISTING BEAM STRENGTHENING

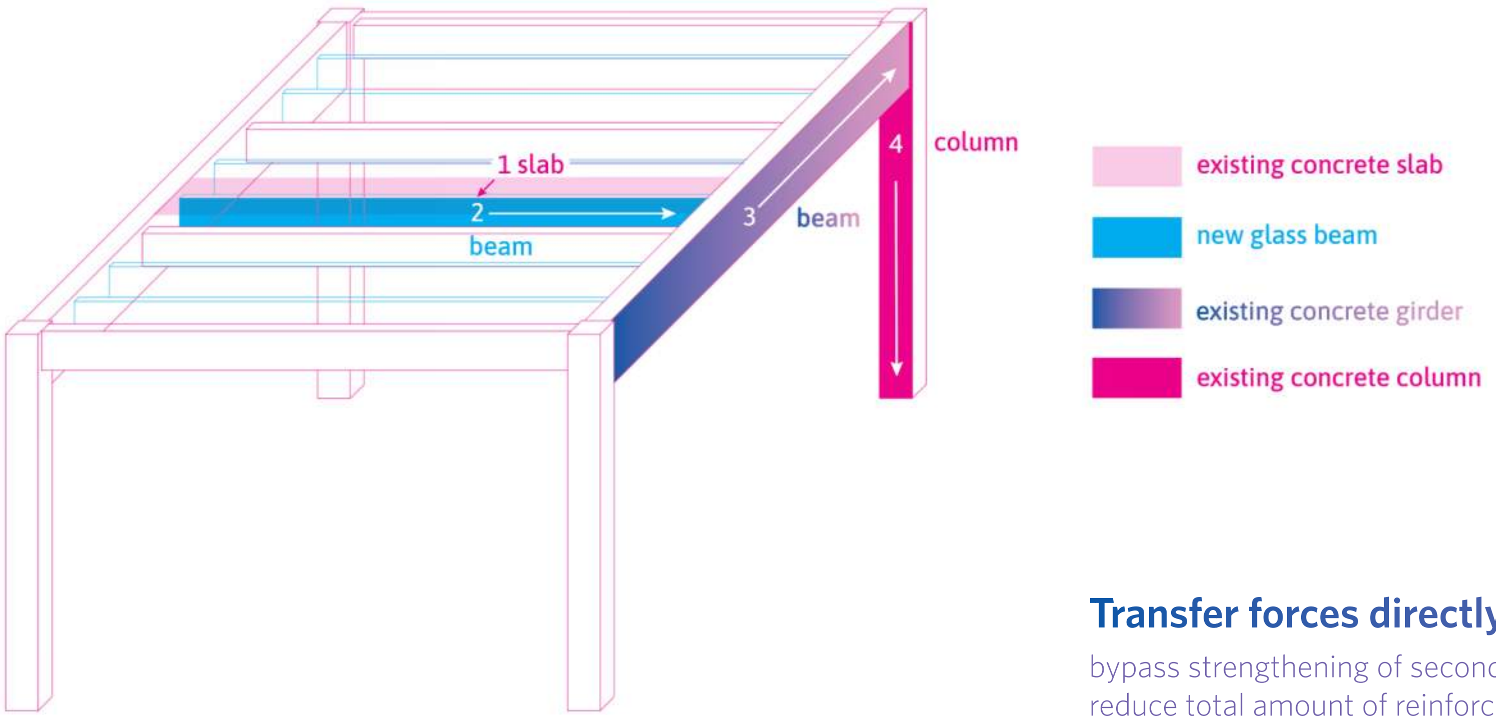




EFFECTIVE WIDTH - EXISTING CONCRETE T-SECTION

3. FINAL DESIGN

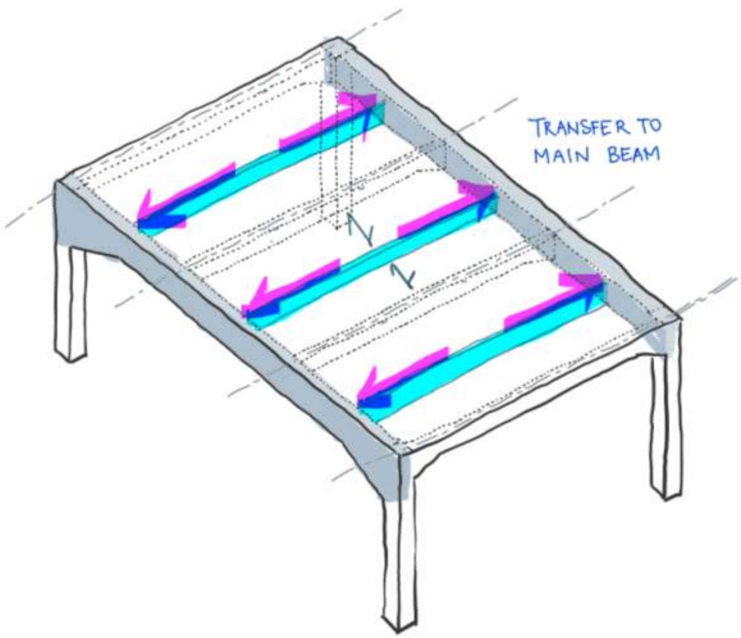
DESIGN STUDY 2 / GRAVITY LOAD PATH

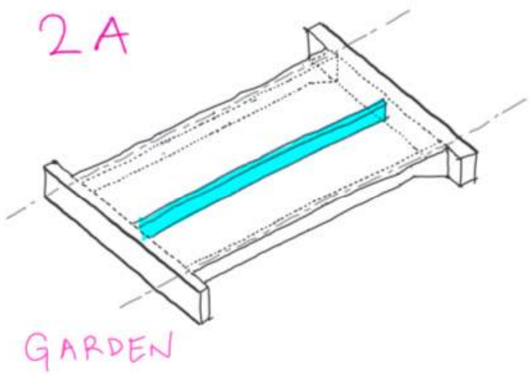


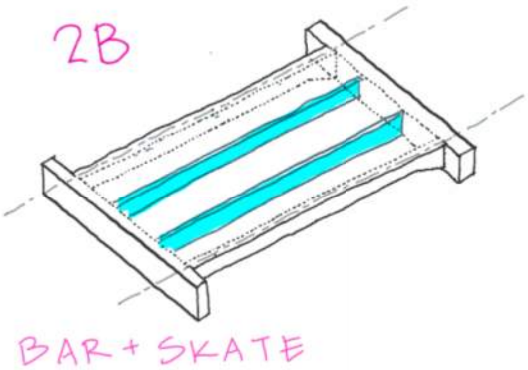
Transfer forces directly to girder:

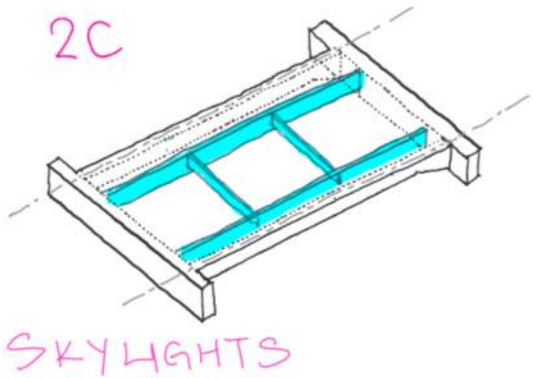
bypass strengthening of secondary beams
reduce total amount of reinforcement required

DESIGN STUDY 2 / CONFIGURATIONS PER USE





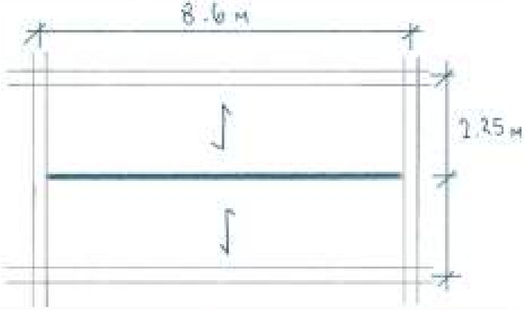
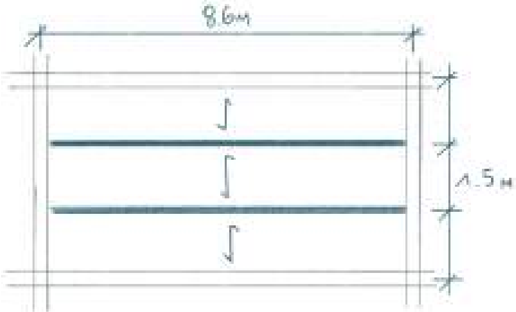
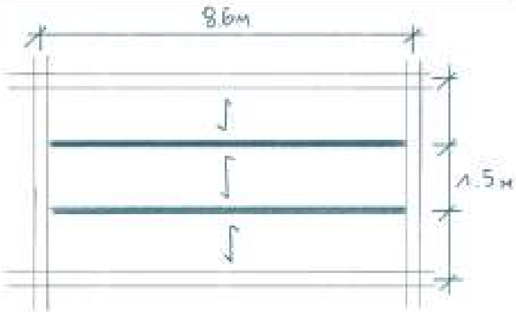




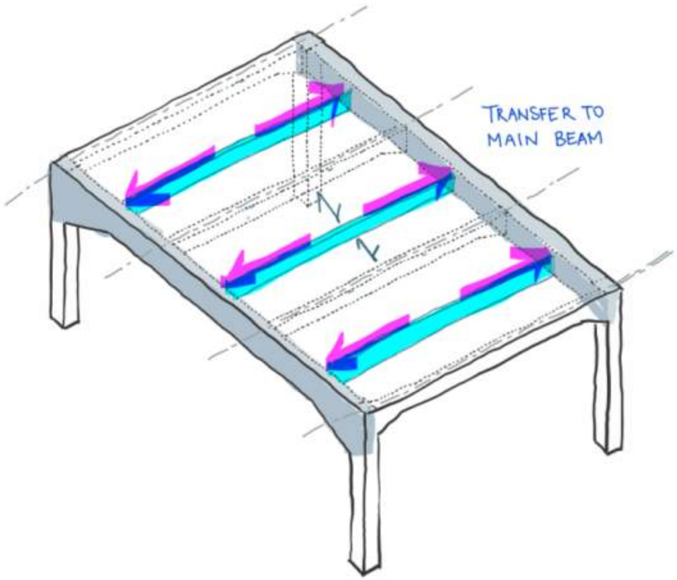
NEW GLASS BEAM

EXISTING CONCRETE

DESIGN STUDY 2 / CONFIGURATIONS PER USE

	Q_{ULS}	Geometry	Configuration
Roof Garden	11.42 *kN/m*	84x410 mm 7-ply x 12 mm	
Skatepark	12.98 *kN/m*	84x450 mm 7-ply x 12 mm	
Cafe/Bar	15.36 *kN/m*	84x500 mm 7-ply x 12 mm	

DESIGN STUDY 2 / EXISTING BEAM STRENGTHENING



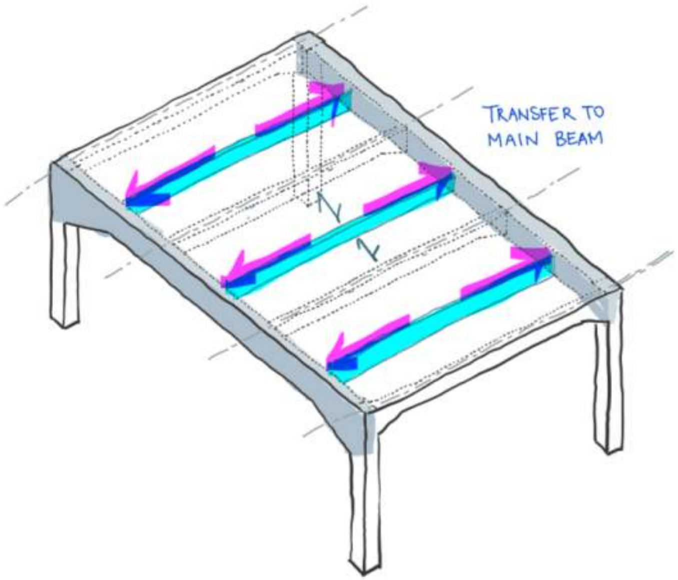
Original utilization of girder: 0.41

4.98 kN/m^2

Utilization with new loads added:

Garden	1.27
Skate	1.40
Bar	1.61

DESIGN STUDY 2 / EXISTING BEAM STRENGTHENING



Original utilization of girder: 0.41

4.98 kN/m^2

Utilization with new loads added:

Garden	1.27
Skate	1.40
Bar	1.61

MIGHT BE OK WITH FRP

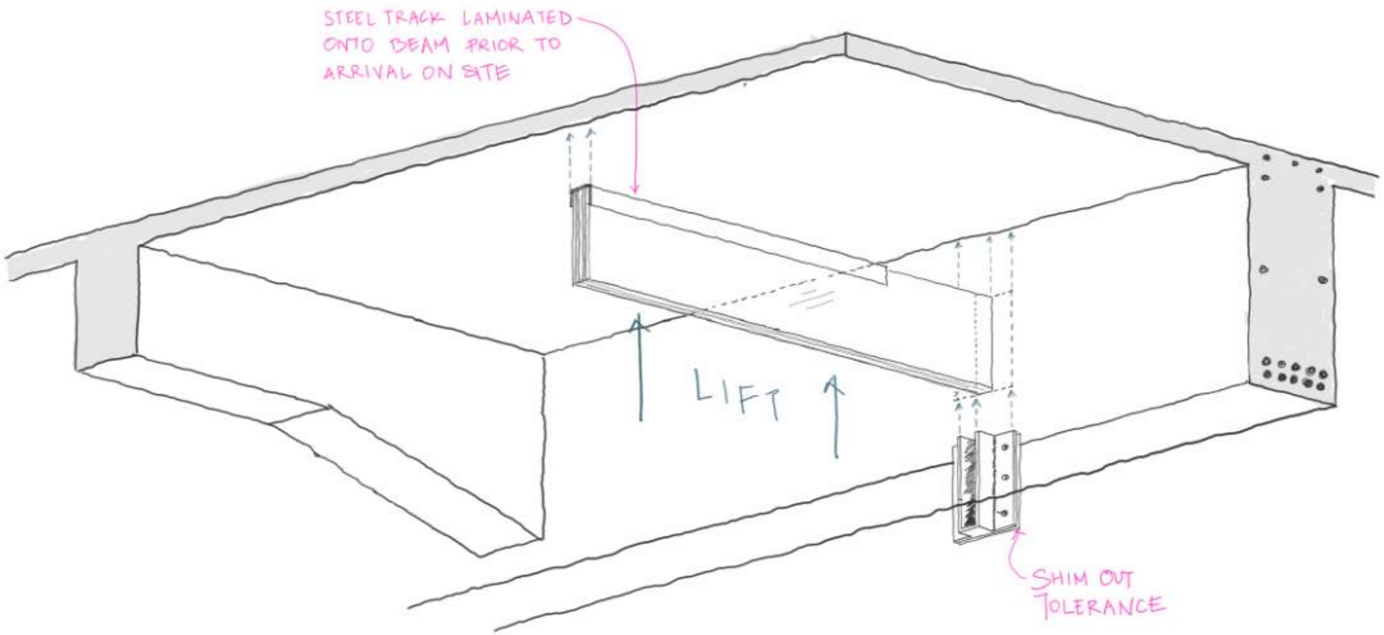
USE STEEL,
ADD COLUMNS?

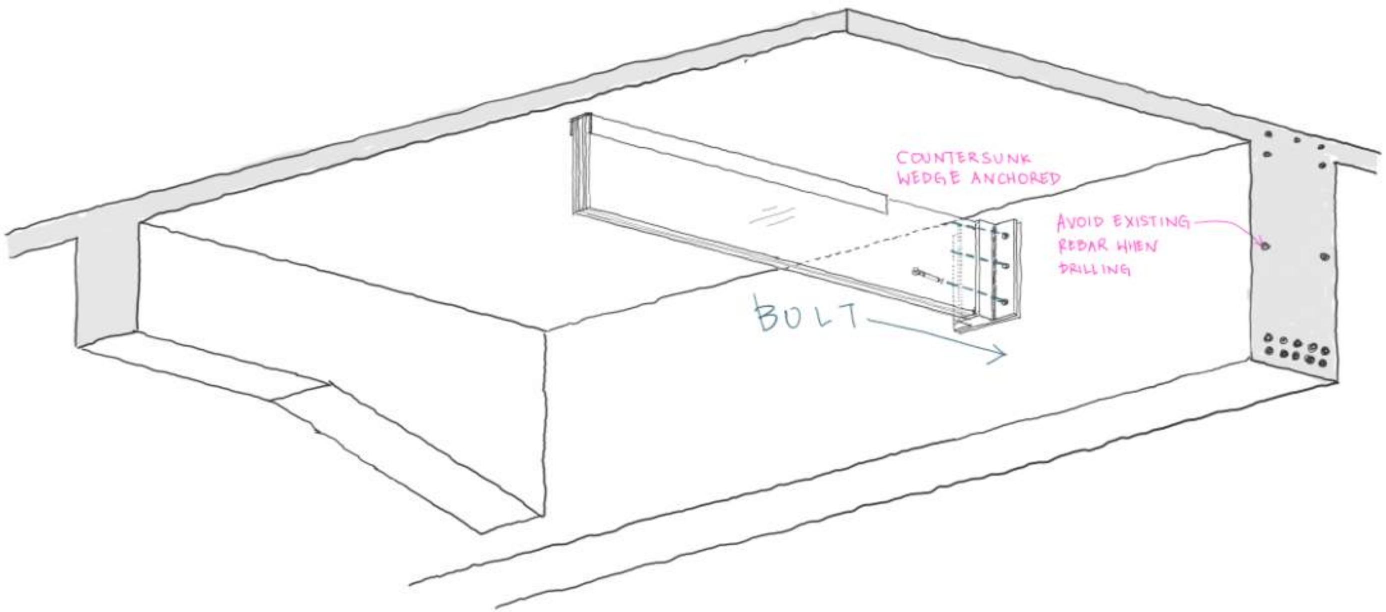
4. ASSEMBLY

DETAILING + CONNECTION DESIGN SHOULD BE:

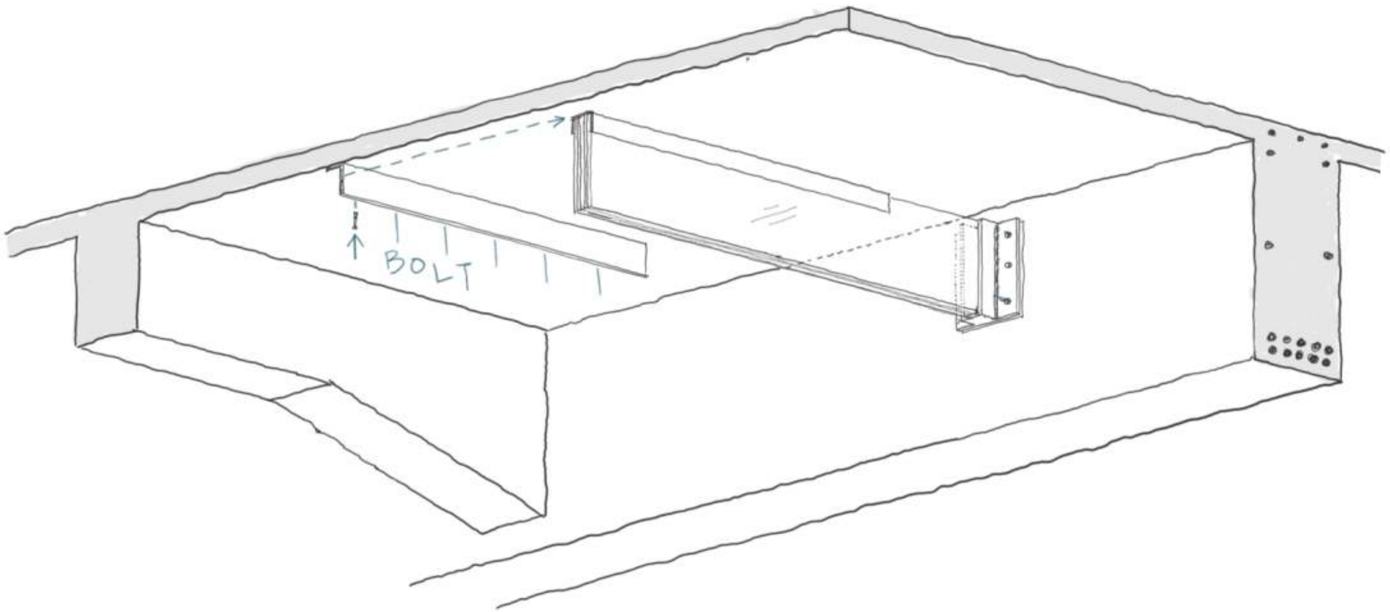
1. reversible
2. no holes in glass
3. do not remove substrate material
4. mechanical connections

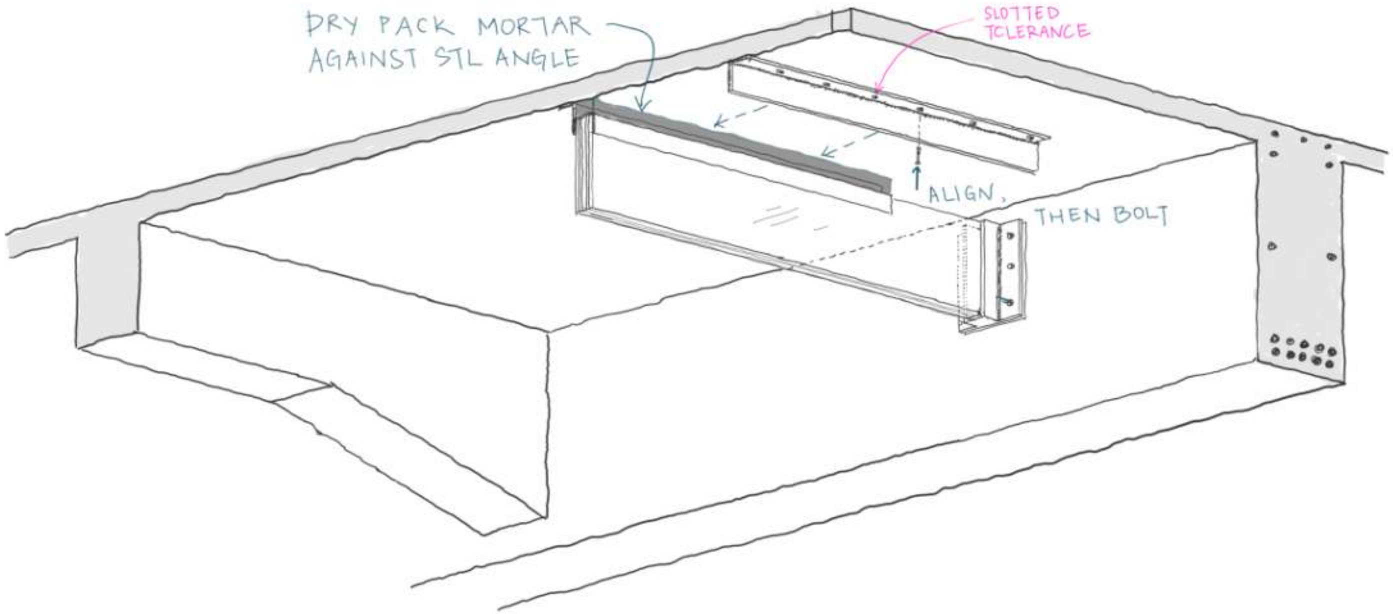
RAISE + BOLT BEAM ENDS TO EXISTING CONCRETE BEAM



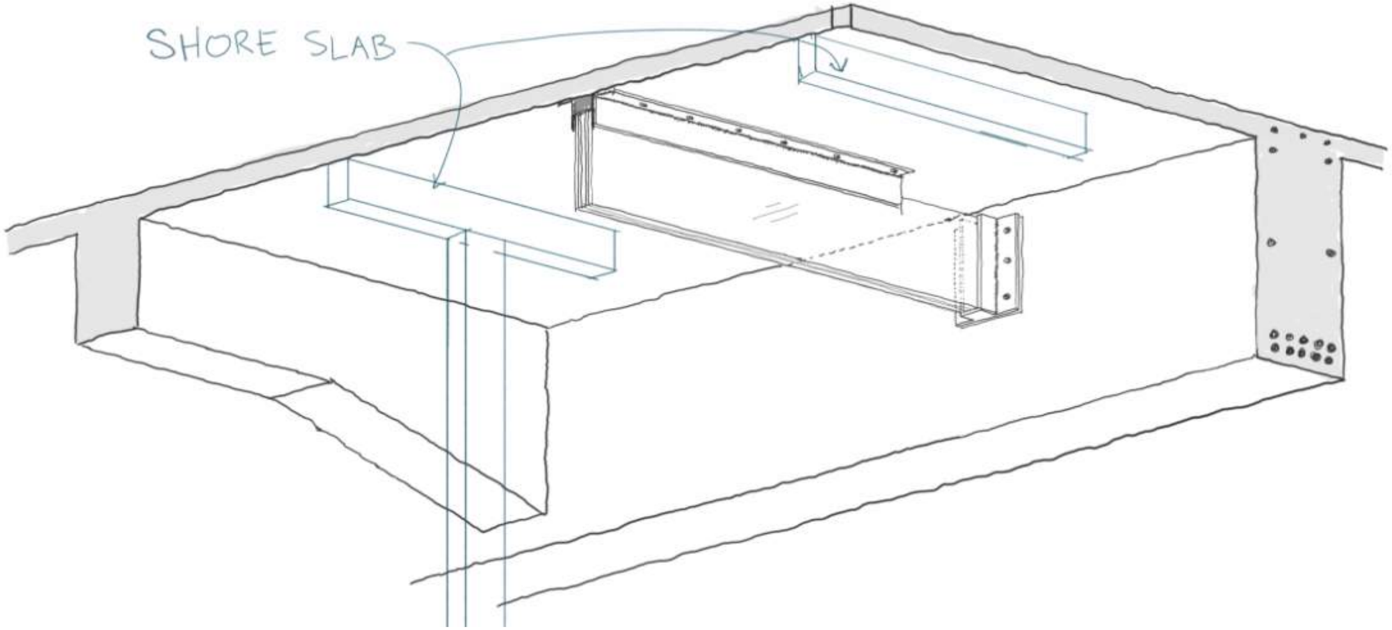


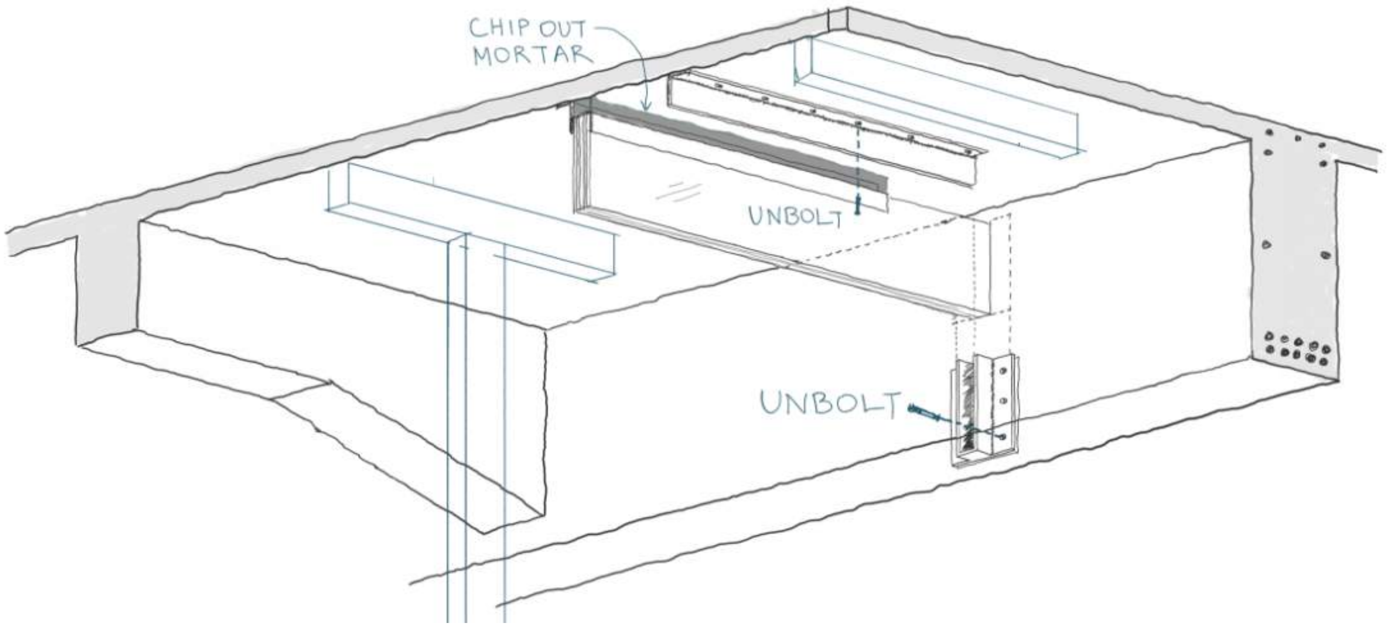
BOLT STEEL ANGLES TO SLAB, MORTAR BETWEEN GLASS AND CONCRETE





REVERSE INTERVENTION





SUMMARY

Existing concrete structure
- slab section and reinforcement governs capacity
- some room for increase in beams and girders
- even though large dimensions, low strength concrete [L1 loads not as high as originally designed]

Layout
- secondary beams not enough capacity to hold new loads
- girders have most excess capacity: redirect new loads here
- bias toward glass-concrete connections for sake of simplicity in installation
- use more beams with smaller sections for redundancy at congregation areas

Existing beam strengthening
- at least the girders must be strengthened
- this could mean FRP, new steel elements, new columns, separate structures

Glass design
- monolithic and rectangular section
- laminated HS glass for strength and residual capacity at fracture
- plies no thicker than 15mm
- fire generally mediated through addition of sacrificial layers

Composite vs. not
- material savings of 30-40% when acting as fully composite but this requires sufficient anchorage
- more anchorage may result in more steel components, affecting aesthetic

RECOMMENDATIONS

Verify assumptions
- determine whether columns and foundations would require strengthening
- evaluate materials for strengthening existing elements and whether it should be glass

Study composite
- connection design to allow fully composite action
- if in historic buildings, fastener should also be reversible

Section design
- develop options other than monolithic glass
- optimize geometry
- try reinforcement with other materials or post-tensioning

Fire resistance
- determine whether backup transfer mechanisms should be in place
- how to protect sides and bottom of beam from cracking due to high heat

Experimental testing
- test preliminary designs on substrate replicating existing condition
- ideally test on actual building pieces
- compare to calculations and modelling

CLASS

that

STRENGTHENS FLOORS,

FACILITATES CHANGE,

and

TELLS STORIES