

From Rubble to Resilience

A parametric approach to seismic assessment and resource-aware retrofit design for reinforced concrete frame residential buildings in Türkiye

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TU Delft - MSc. Building Technology Graduation Studio 2025-2026

15-06-2026



Image captured by: Adem Altan



Image captured by: Can Erok

An aerial photograph of a city street grid. In the center, a large, multi-story building is severely damaged, with its structure exposed and many windows missing. The surrounding buildings appear relatively intact but are slightly faded, making the central damaged building stand out as the focal point of the image.

Act 1 - Turkey's Seismic* Risk

*Seismic = caused by or relating to an earthquake (Collins Dictionary, n.d.)

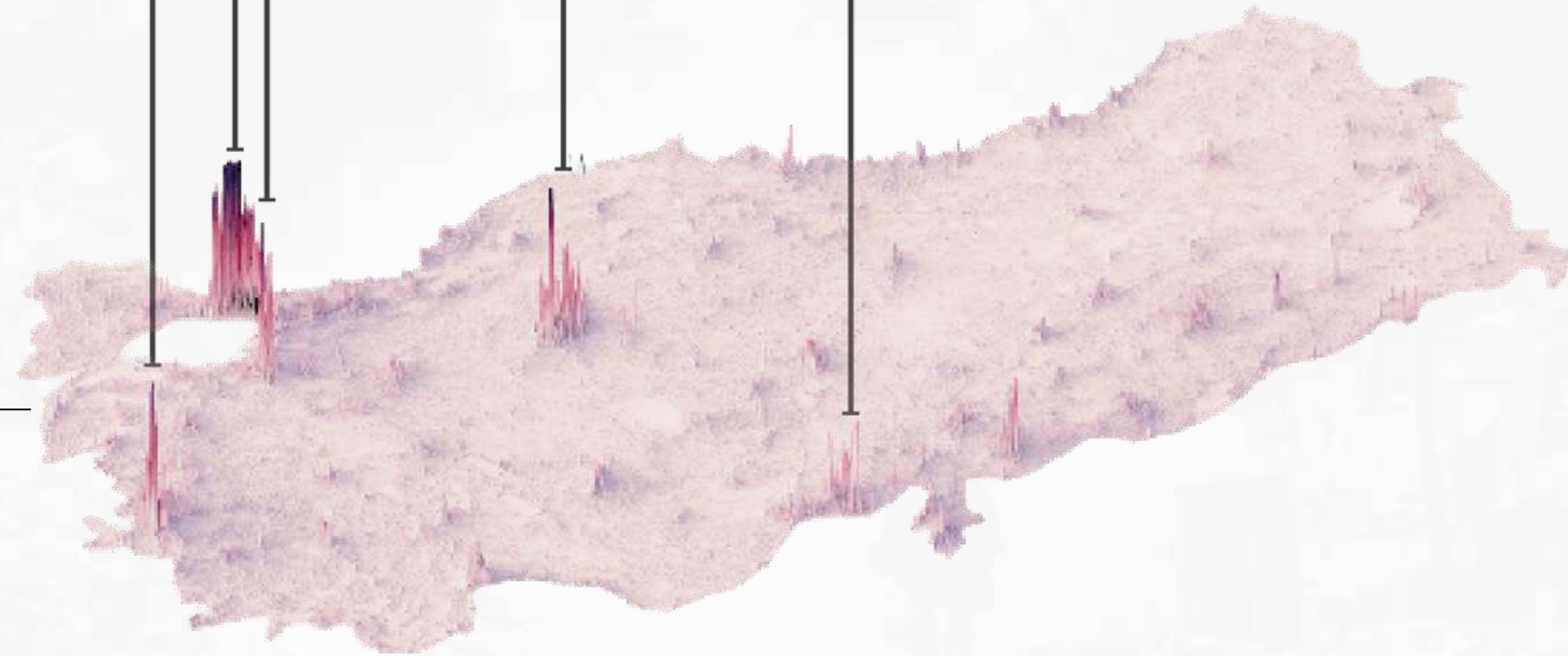
Turkey's Earthquake Risk at a Glance

Turkey's Seismic Risk

City: % of Turkey's population ——— Istanbul: ~18,7% Ankara: ~6,4% Adana: ~2,2%

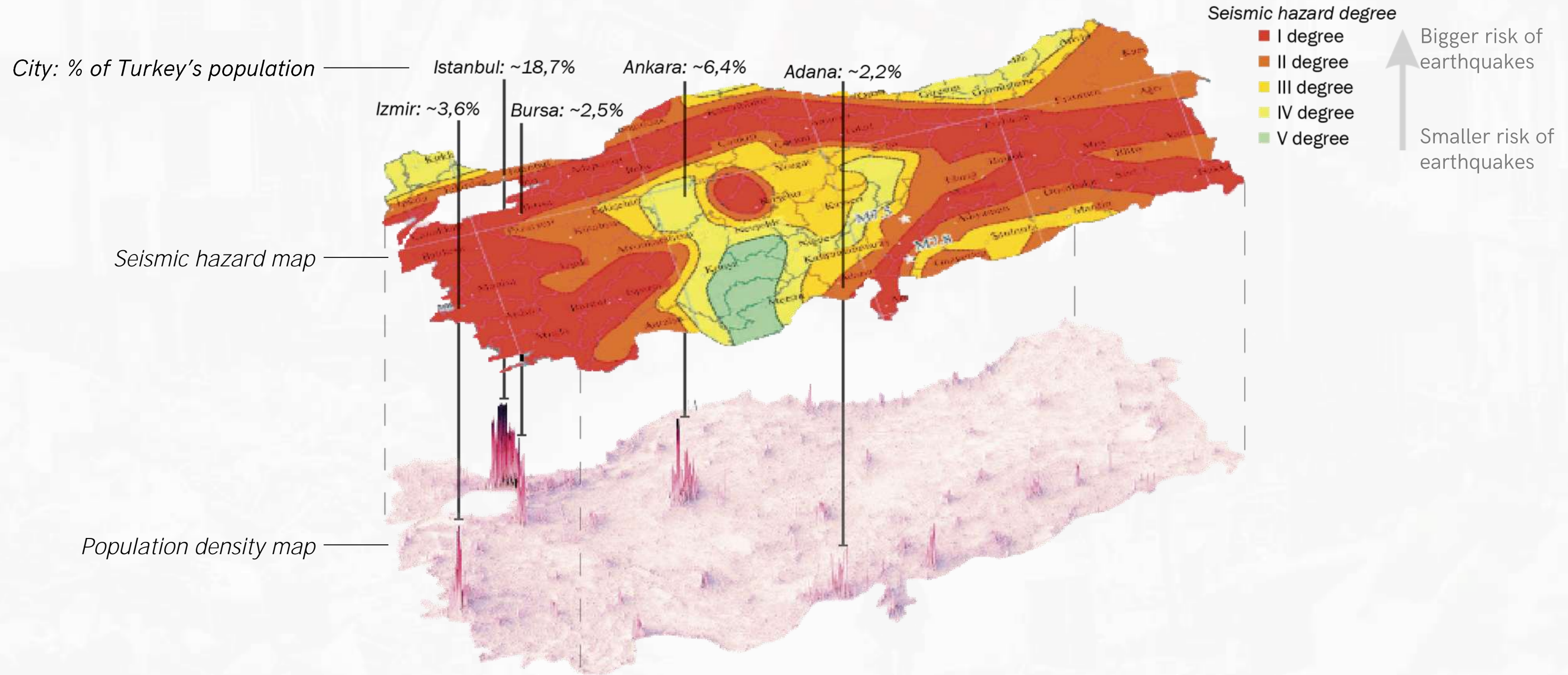
Izmir: ~3,6% Bursa: ~2,5%

Population density map ———



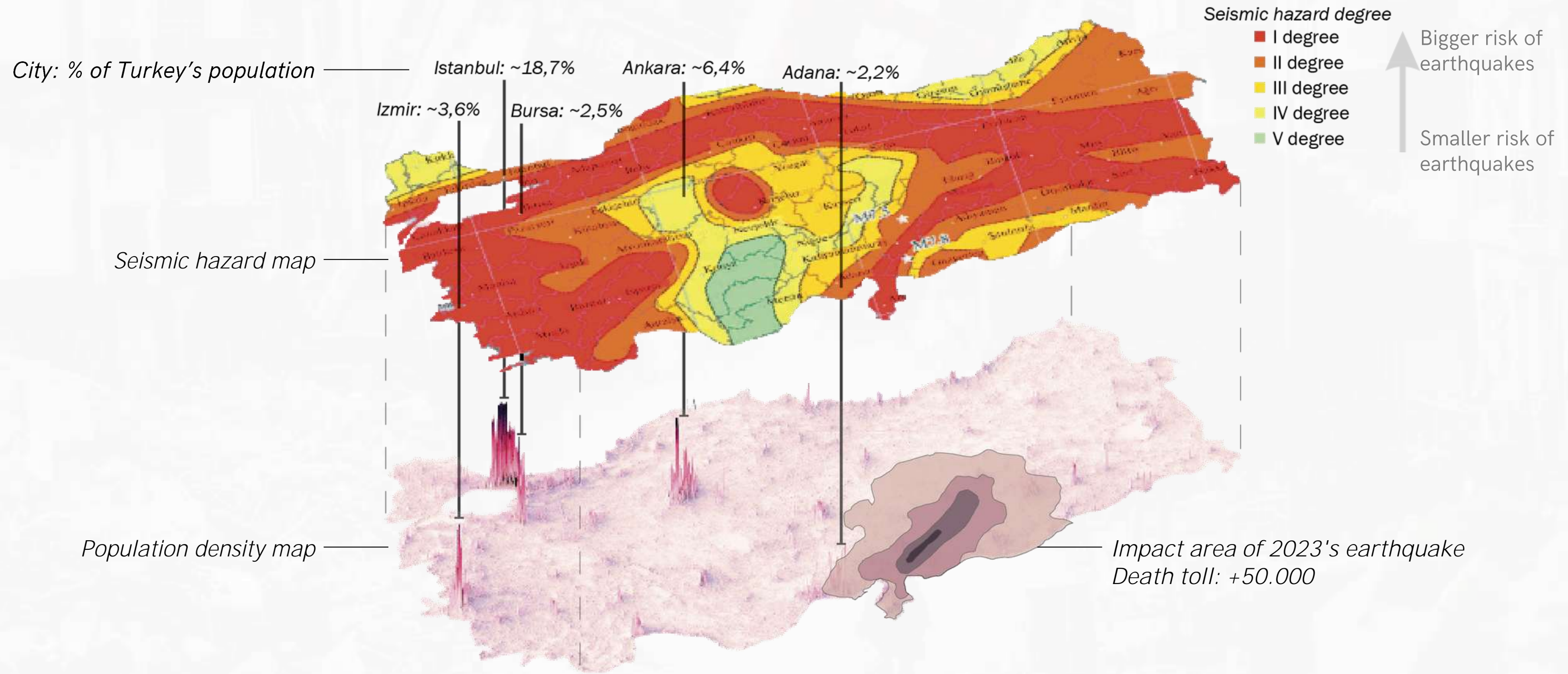
Turkey's Earthquake Risk at a Glance

Turkey's Seismic Risk



Where Seismic Hazard Meets Population Density

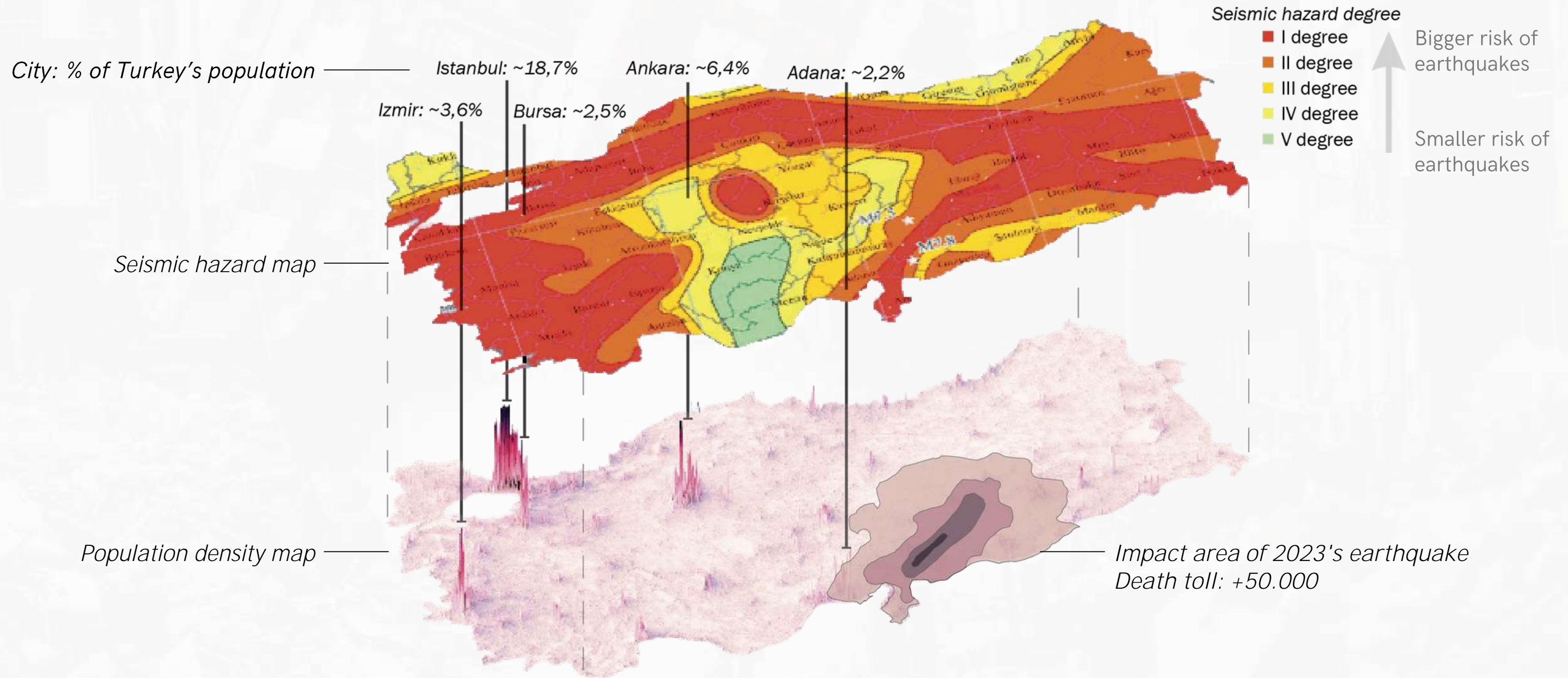
Turkey's Seismic Risk



*"The great Istanbul earthquake is at hand ... Although an exact date cannot be given, we are under the threat of an average earthquake with a magnitude of 7.2 until 2030."
(Prof. Dr. Celal Şengör, 2017)*

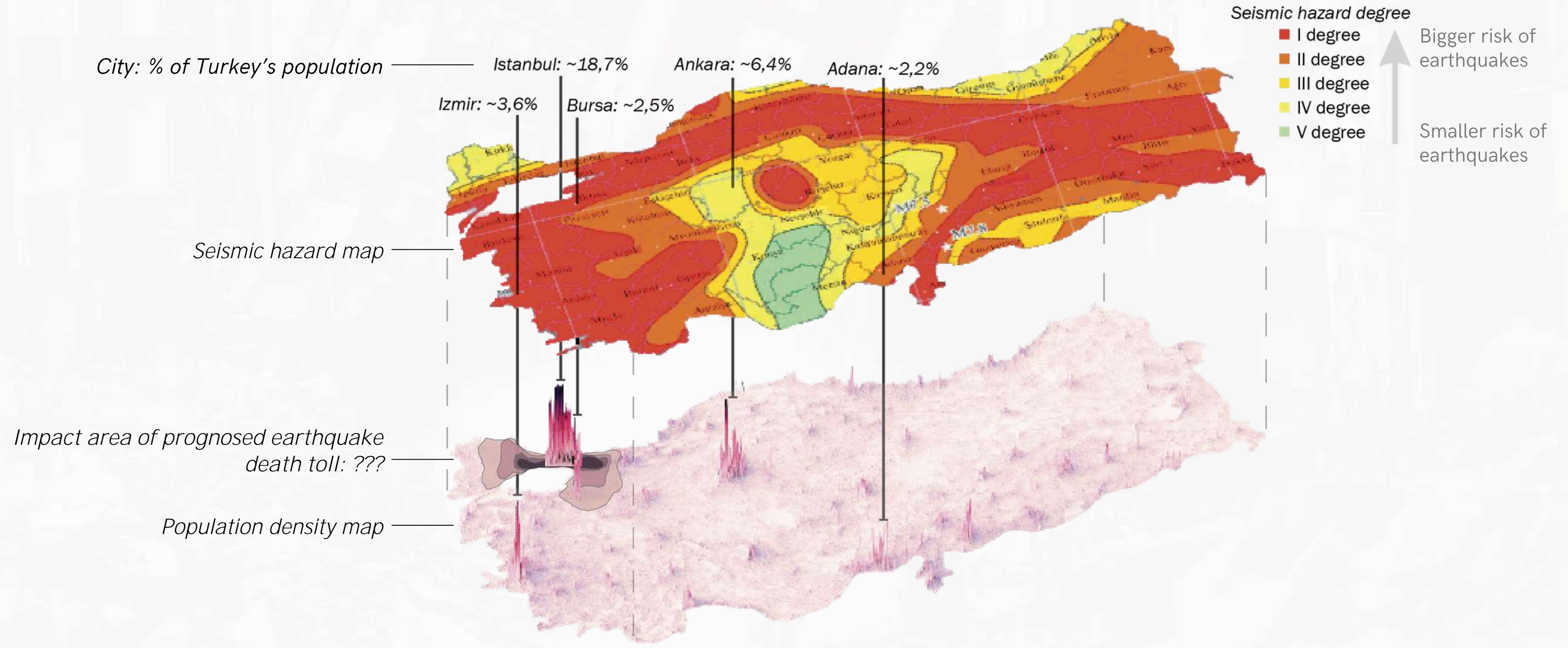
Why Istanbul as the Critical Focus Area

Turkey's Seismic Risk



Projected Impact of a Major Istanbul Earthquake

Turkey's Seismic Risk



(Adapted from Terence (2022); Güneş (2015))

An aerial, high-angle photograph of a city street grid, showing a dense pattern of buildings and streets. The image is faded and serves as a background. In the center of the grid, a small, dark silhouette of a person is walking.

Act 2 - The Proposal

The Current Analytical Bottleneck

The Proposal



6.7 million
Residential Buildings



US\$ 465 billion
Estimated Cost



Only
%4
was transformed

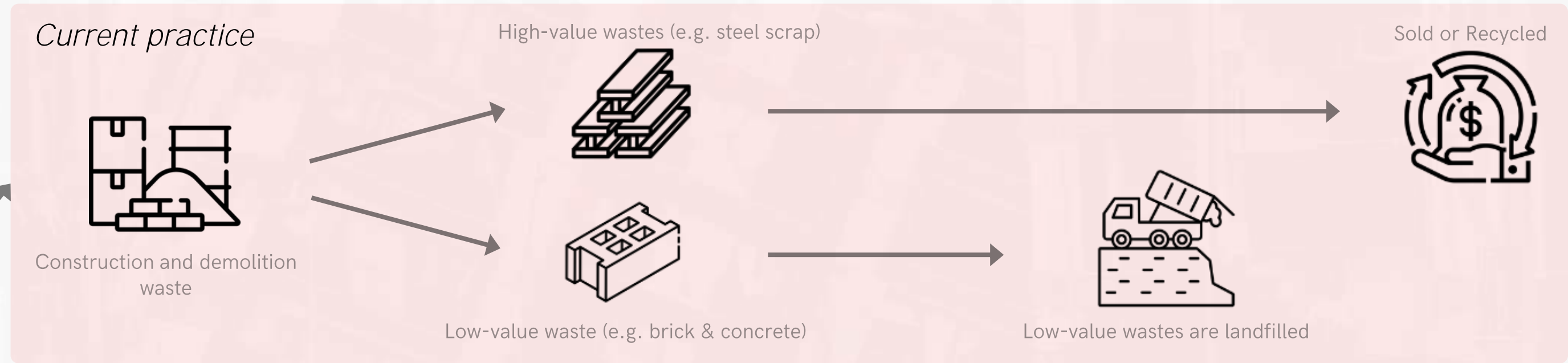
"How can seismic assessment for residential buildings in Türkiye be accelerated?"



Image captured by: Simon Townsley

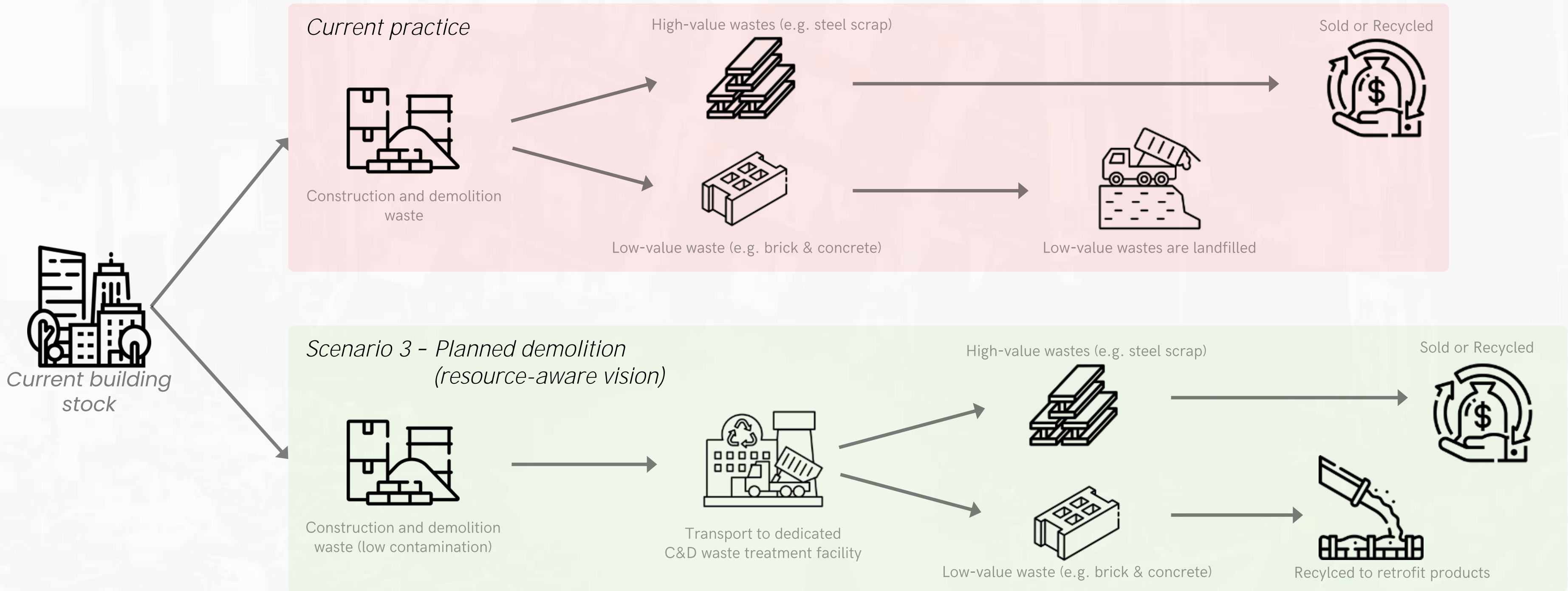
The Current Waste Paths

The Proposal



The Current Waste Paths

The Proposal




"How can a design strategy be developed to integrate recycled construction and demolition waste for the retrofitting of residential buildings?"

Main Research Question

The Proposal

"How can a system design strategy be developed to accelerate the seismic assessment and by extension retrofit design of mid-rise reinforced concrete frame buildings in Türkiye, while enabling the integration of recycled construction and demolition materials"

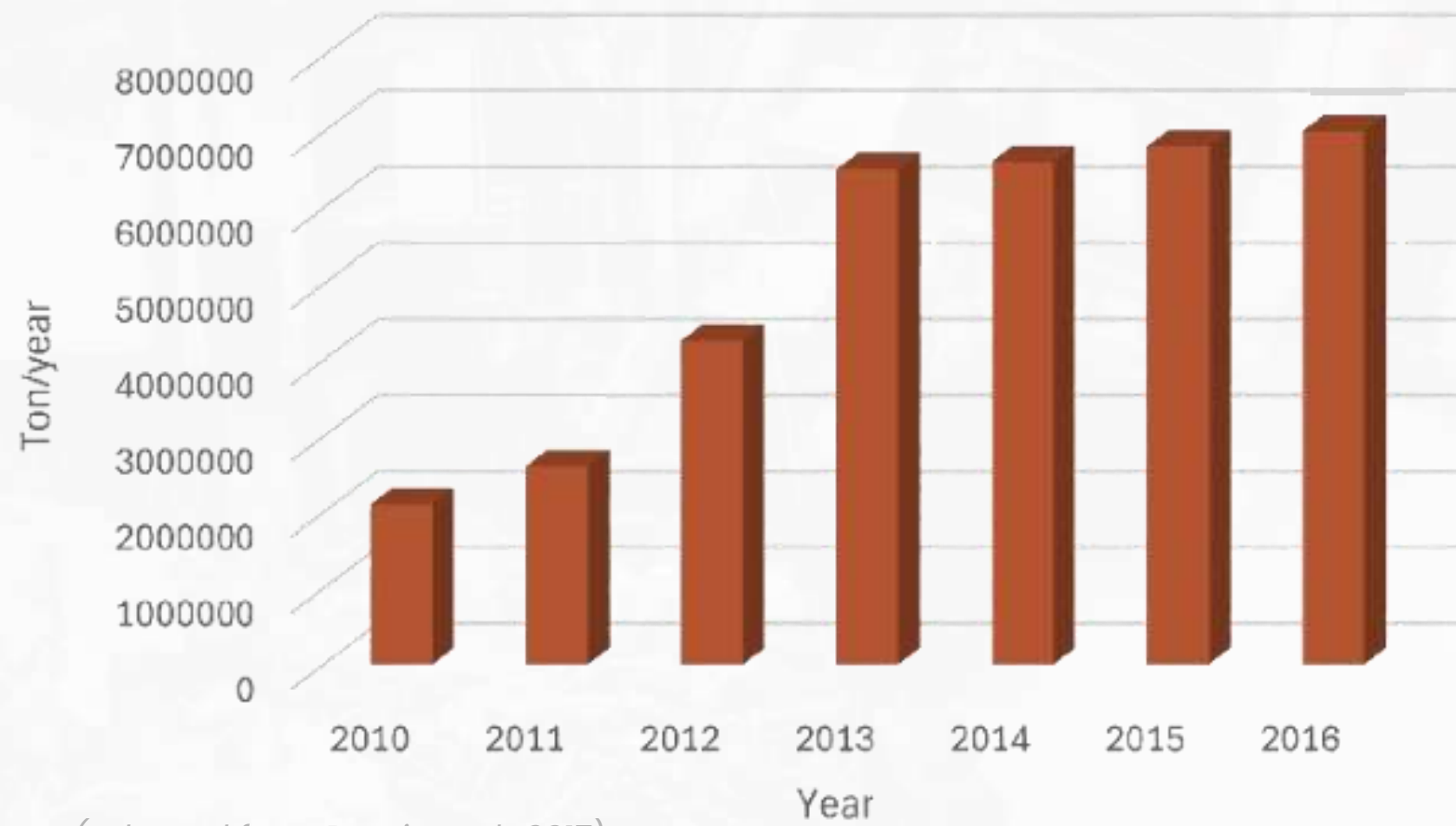


Act 3 -
The Two Pains

Construction and Demolition Waste in Numbers

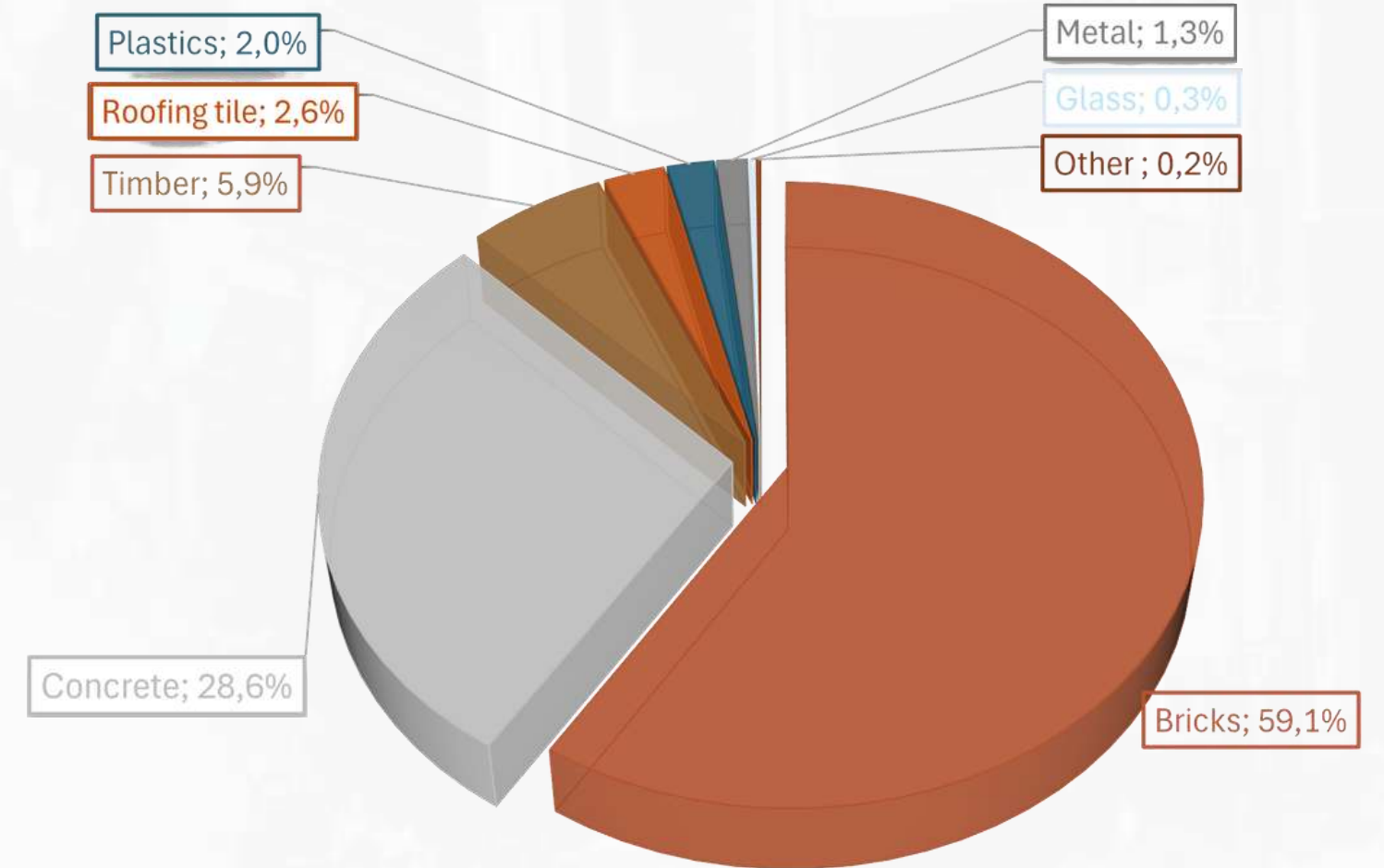
The Two Pains

Growth of Construction and demolition waste in Istanbul



(Adapted from Demir et al., 2017)

Division of structural materials in construction and demolition waste



(Adapted from Xiao et al., 2023)

Construction and Demolition Waste in Numbers

The Two Pains

- Landfilling remains the dominant disposal method ⁽¹⁾
- Recycling practices are fragmented and small-scale ⁽¹⁾
- Landfilling of C&D waste has numerous negative effects ⁽²⁾



(1) Arslan and Ulubeyli, 2019; (2) Bonifazi et al., 2025;

"From a professional perspective, implementation of the methodology from beginning to end for a building takes a small team formed by an engineer and technicians in the order of a month..." (Güneş, 2015).

Small Team

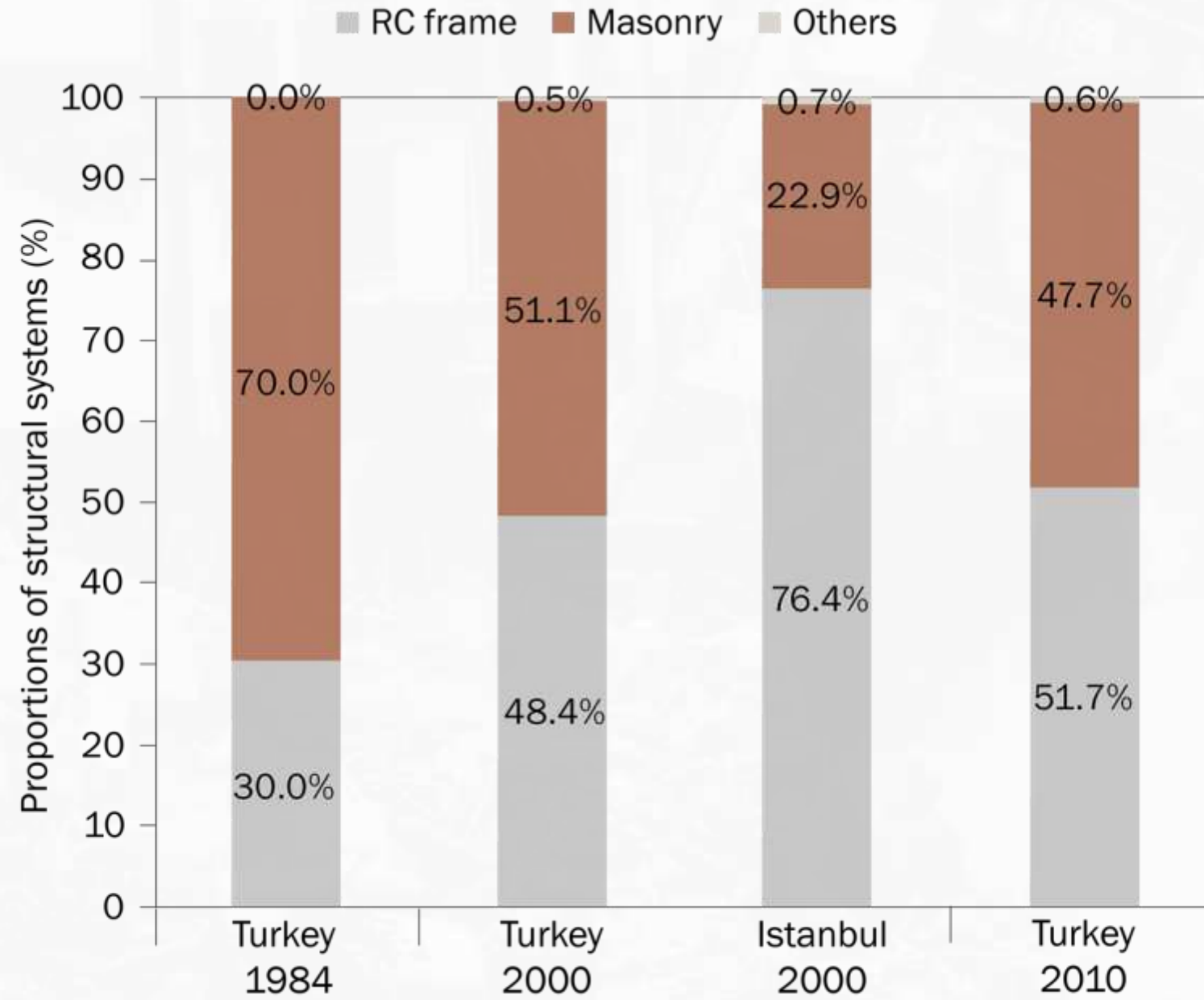
Engineers and Technicians

Can achieve results in

1 Month

The Dominant Typology

The Two Pains



(Adapted from Güneş, 2015)



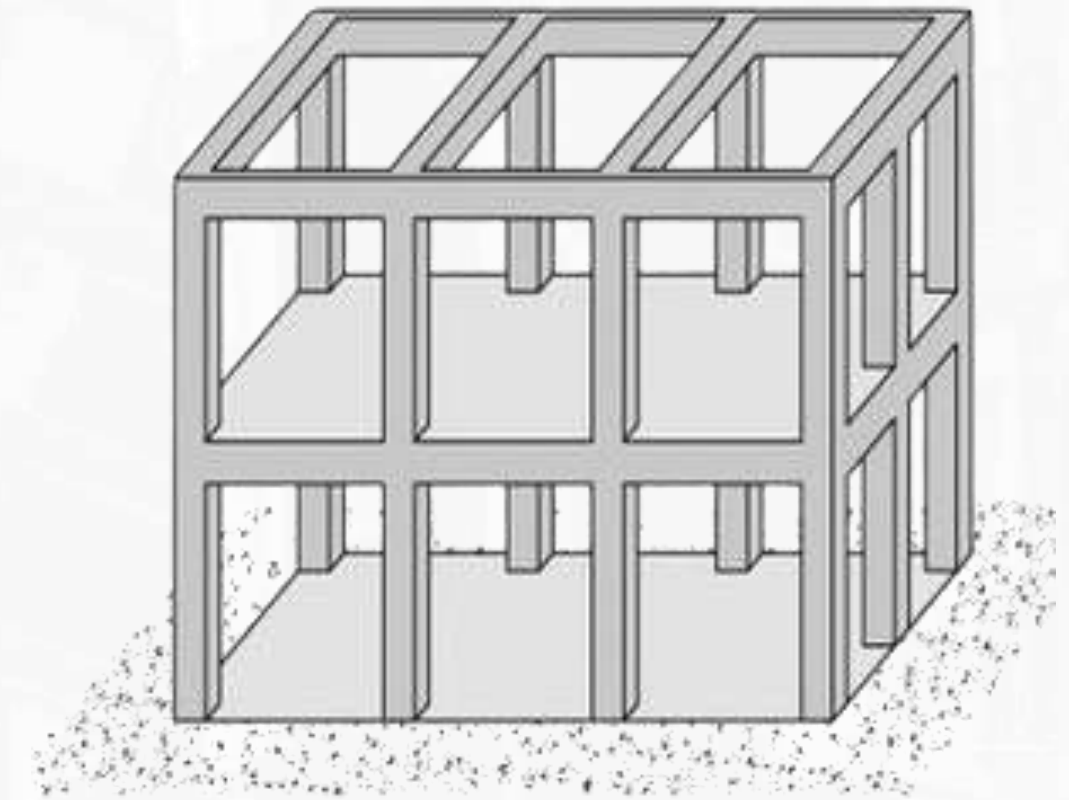
"Approximately 80 percent of Turkey's urban households live in mid-rise apartment blocks constructed of cast-in-situ, reinforced concrete with masonry infill." (Gulkan, 2002)

The Dominant Typology

The Two Pains



*"Approximately **80 percent of Turkey's urban households** live in mid-rise apartment blocks constructed of cast-in-situ, reinforced concrete with masonry infill." (Earthquake engineering research institute, 2002)*



*Typical moment resisting frame building.
From: Global Earthquake Model Foundation (2023)*



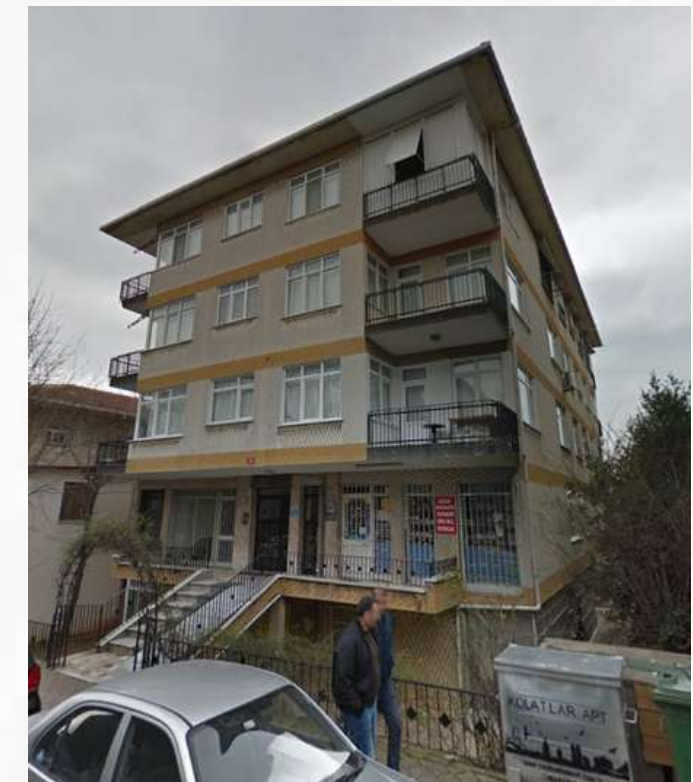
*Avcılar district, European side
(Google earth, 2020)*




*Beşiktaş district, European side
(Google earth, 2025)*



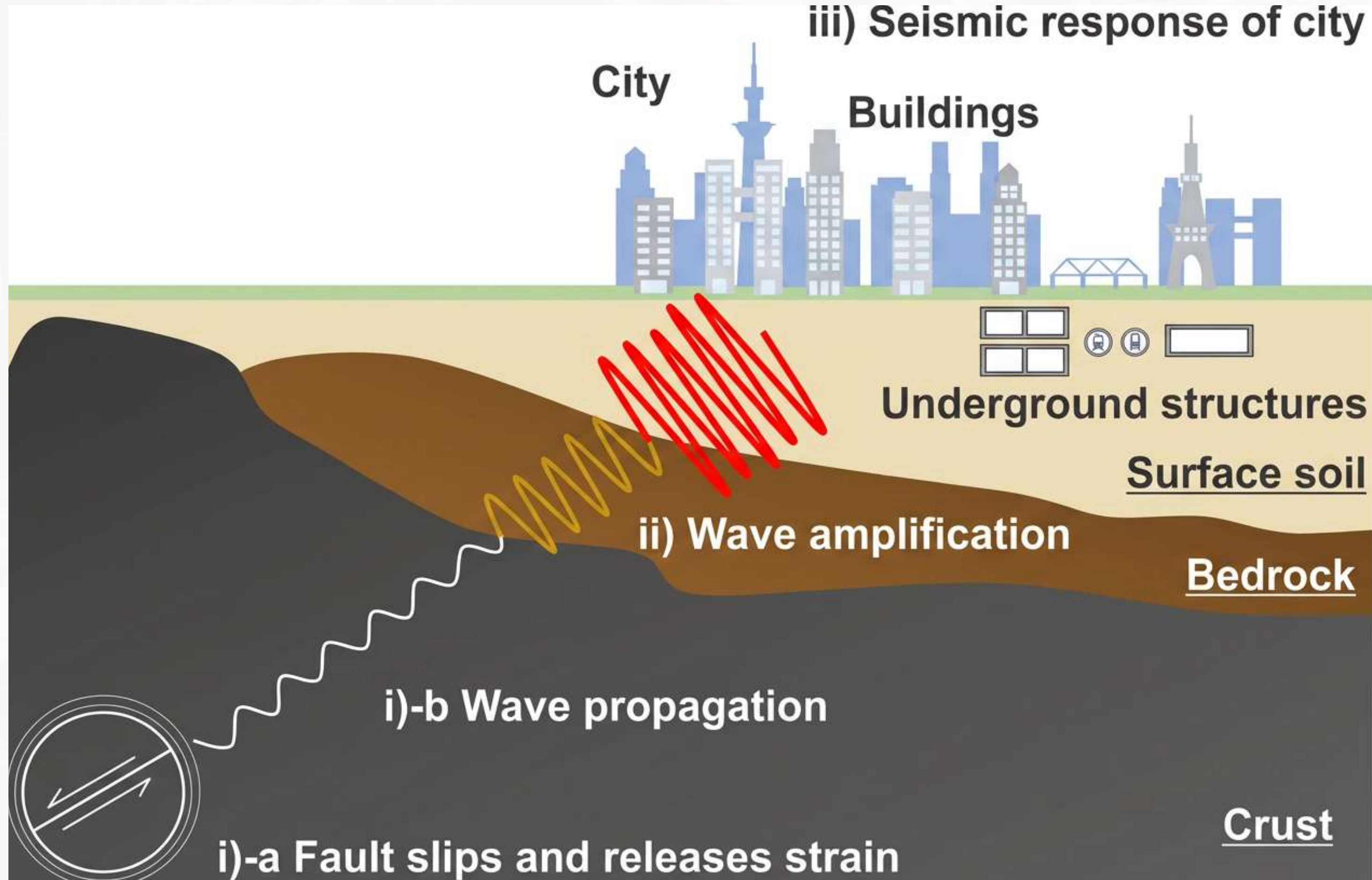
*Üsküdar district, Asian side
(Google earth, 2014)*



*Kadıköy district, Asian side
(Google earth, 2018)*



Intermezzo -
How and why this type of building fails



From Ground Motion to Building Response

Intermezzo



Soft Storey Collapse

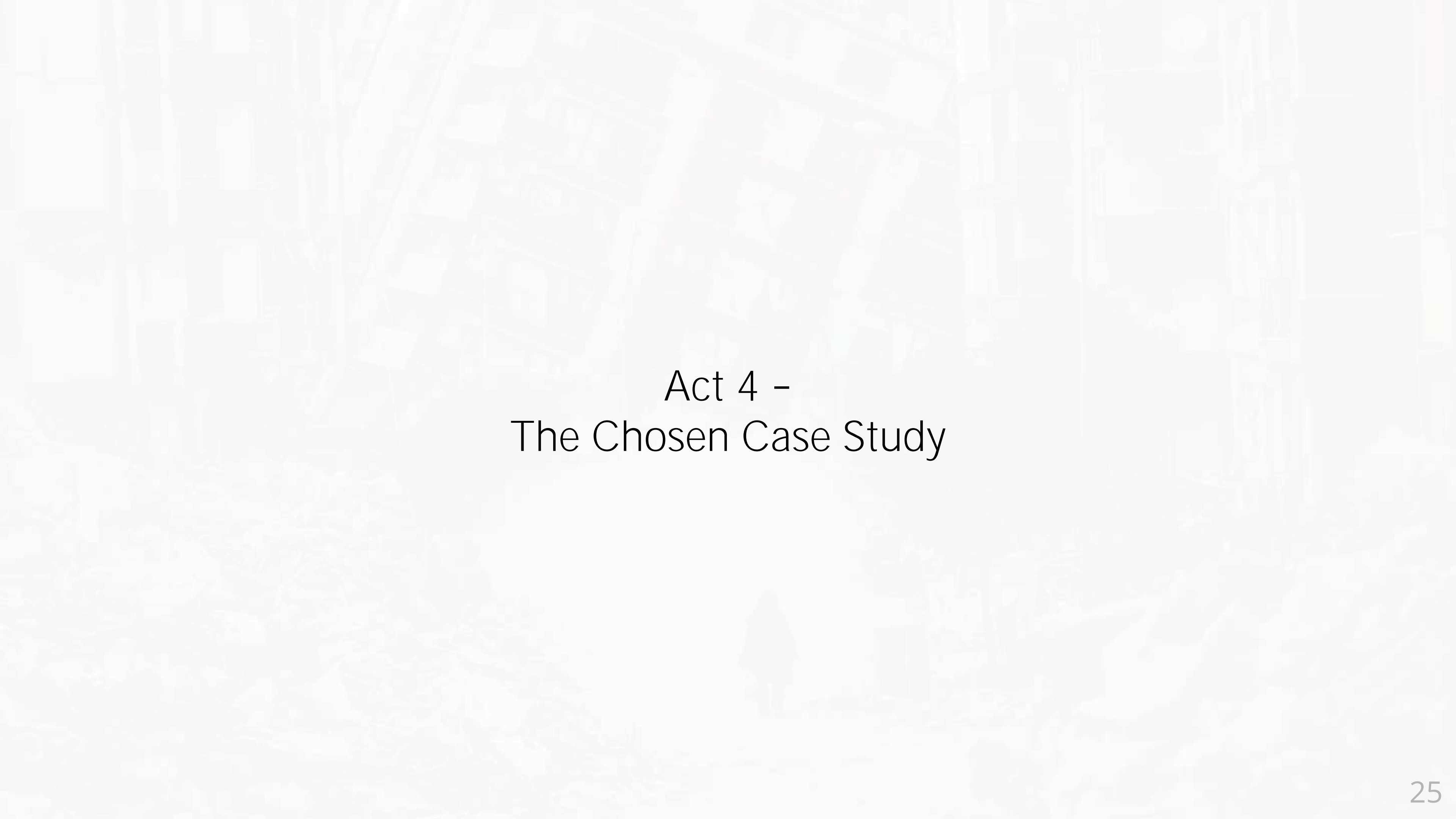
Intermezzo

Soft storey collapse during an earthquake





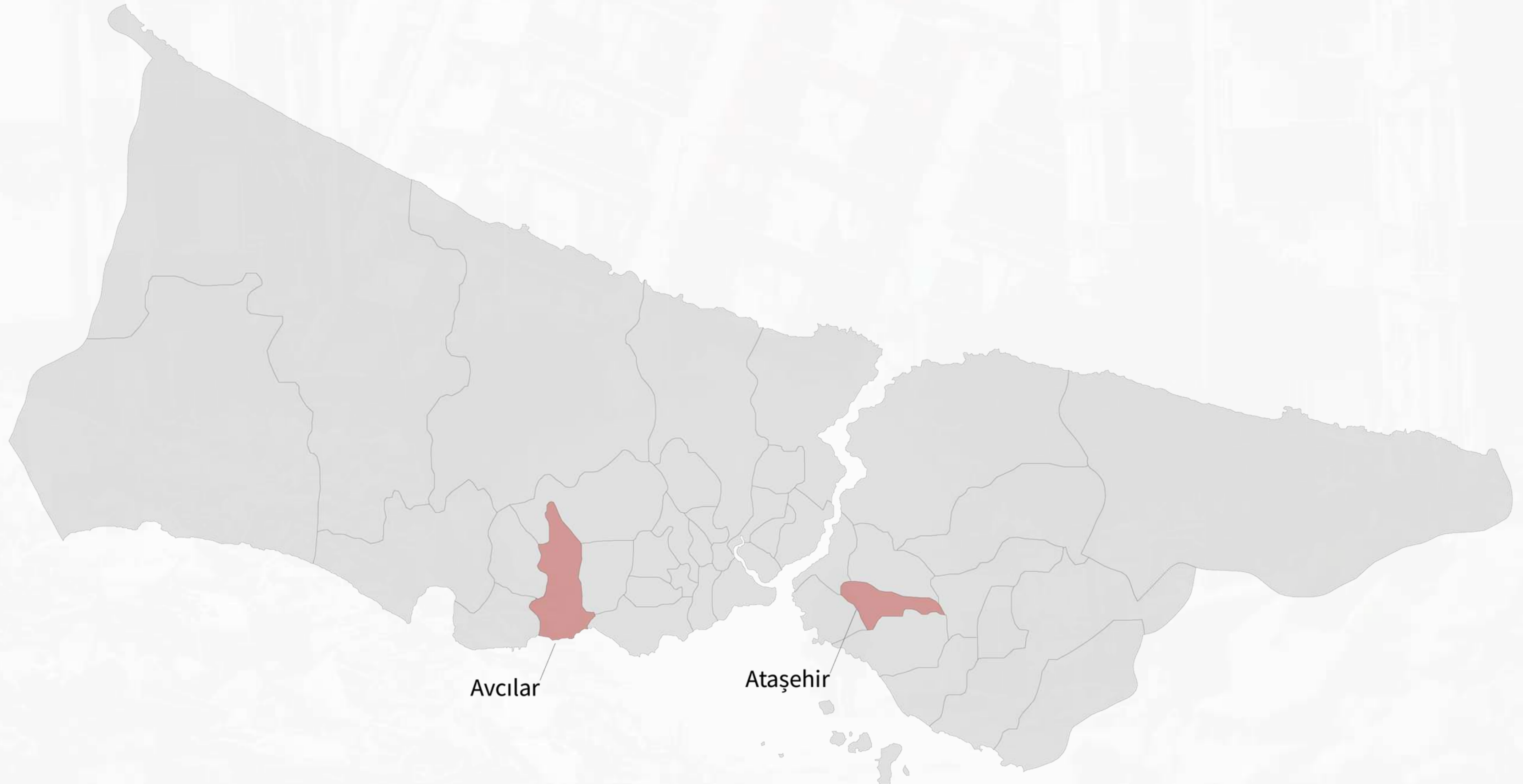
Image captured by: Visual Journalism Team, BBC News (2023)

An aerial, high-angle photograph of a city street grid, showing a dense pattern of buildings and streets. The image is faded and serves as a background. In the center of the grid, a small, dark silhouette of a person is walking.

Act 4 - The Chosen Case Study

Comparing Seismic Vulnerability: Avcılar vs Ataşehir

The Chosen Case Study



Avcılar

Ataşehir

Comparing Seismic Vulnerability: Avcılar vs Ataşehir

The Chosen Case Study



(Ariogroup, n.d.)

Avcılar district

<i>Population:</i>	416,529 (2023) ⁽¹⁾
<i>Socio-economic rank:</i>	66 ⁽²⁾
<i>Household income p/m:</i>	64.871 ₺ ⁽³⁾
<i>Dominant soil type:</i>	Soft alluvial soil ^(4, 5)



From: www.emlakplatform.com.tr

Ataşehir district

<i>Population:</i>	437.221 (2023) ⁽¹⁾
<i>Socio-economic rank:</i>	9 ⁽²⁾
<i>Household income p/m:</i>	132.417 ₺ ⁽³⁾
<i>Dominant soil type:</i>	Rock ^(4, 5)

(1) Citypopulation.de, 2023; (2) SEGE district ranking report, 2022;
(3) Endeksa, n.d.; (4) İstanbul Büyükşehir Belediyesi, 2005; (5) Yıldırım et al., 2010;

Comparing Seismic Vulnerability: Avcılar vs Ataşehir

The Chosen Case Study



Kozlik (2025)

Avcılar district

<i>Population:</i>	416,529 (2023) ⁽¹⁾
<i>Socio-economic rank:</i>	66 ⁽²⁾
<i>Household income p/m:</i>	64.871 ₺ ⁽³⁾
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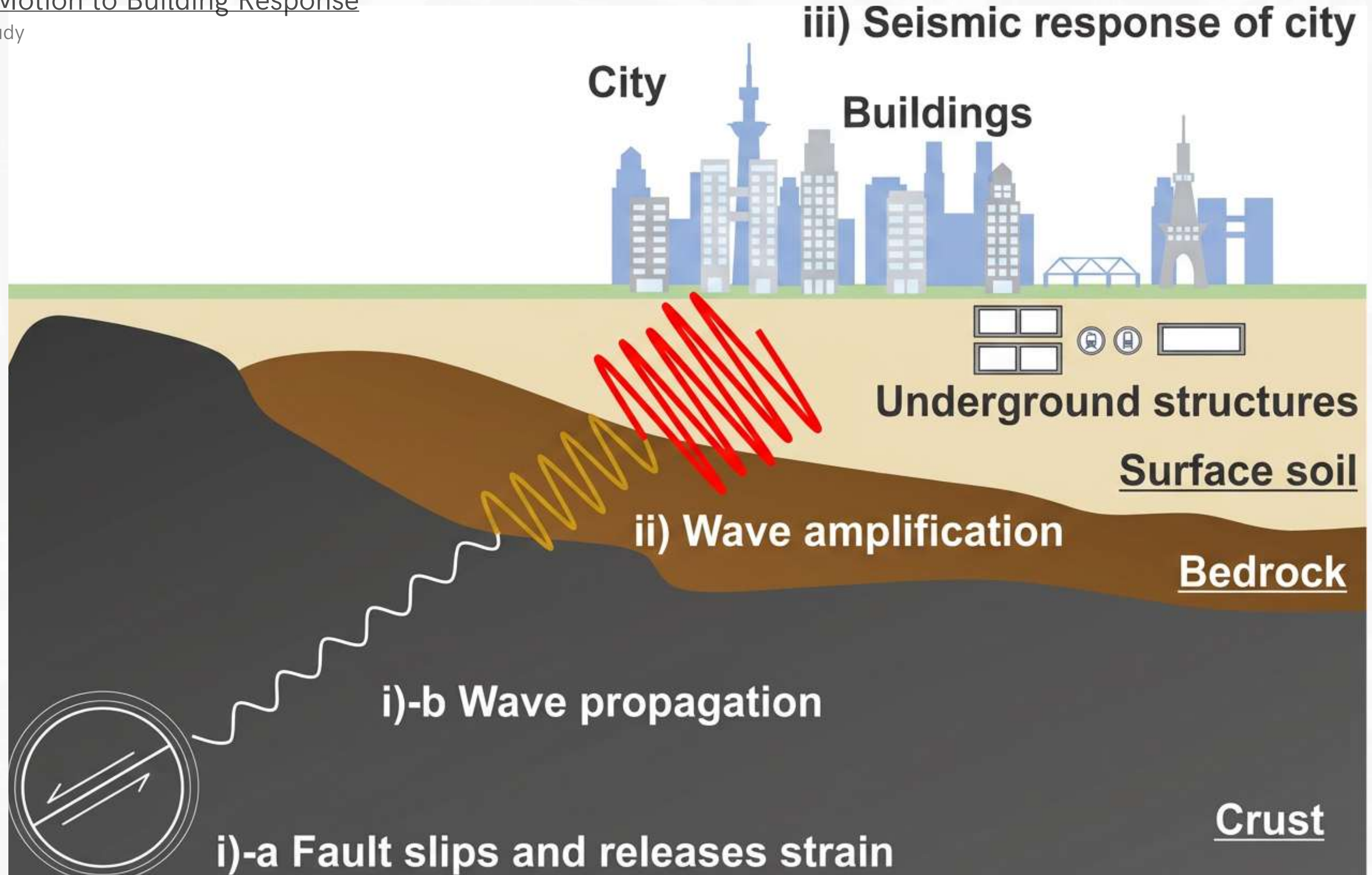


Wisconsin Geological and Natural History Survey (n.d.)

Ataşehir district

<i>Population:</i>	437.221 (2023) ⁽¹⁾
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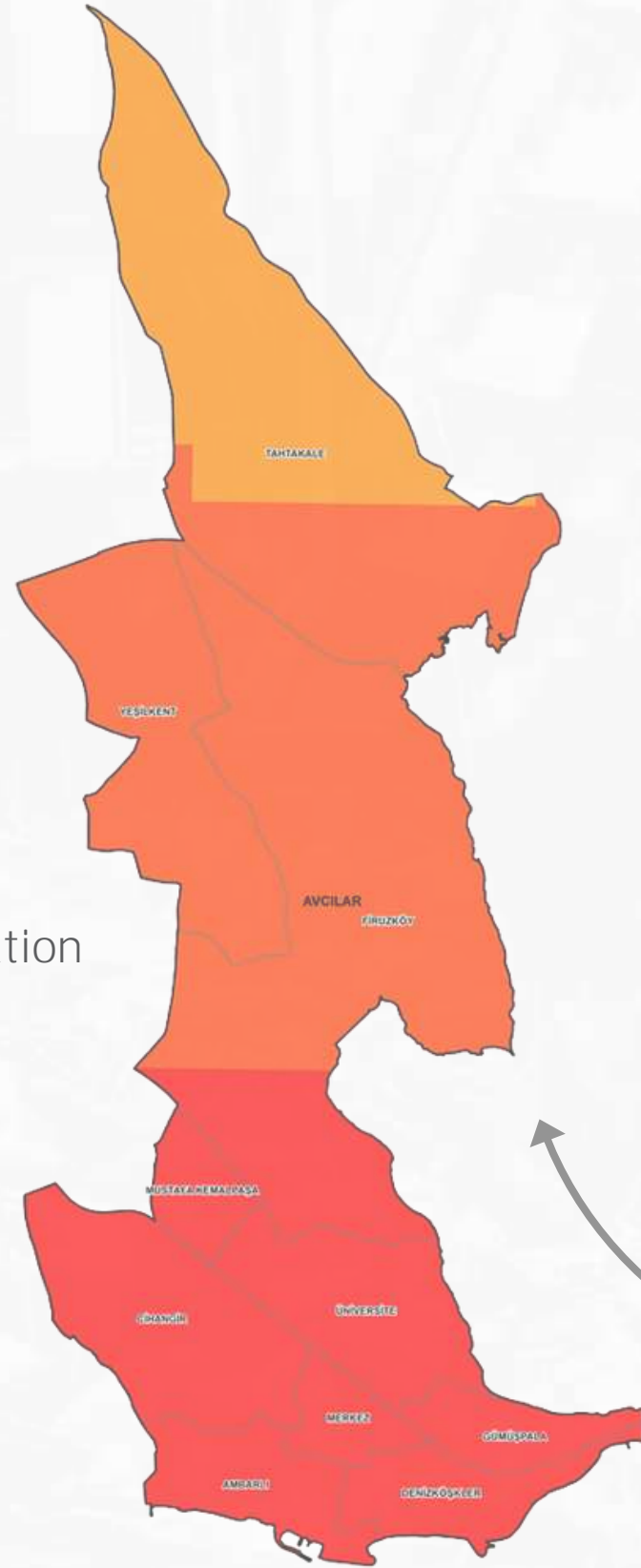
(1) Citypopulation.de, 2023; (2) SEGE district ranking report, 2022;
(3) Endeksa, n.d.; (4) İstanbul Büyükşehir Belediyesi, 2005; (5) Yıldırım et al., 2010;



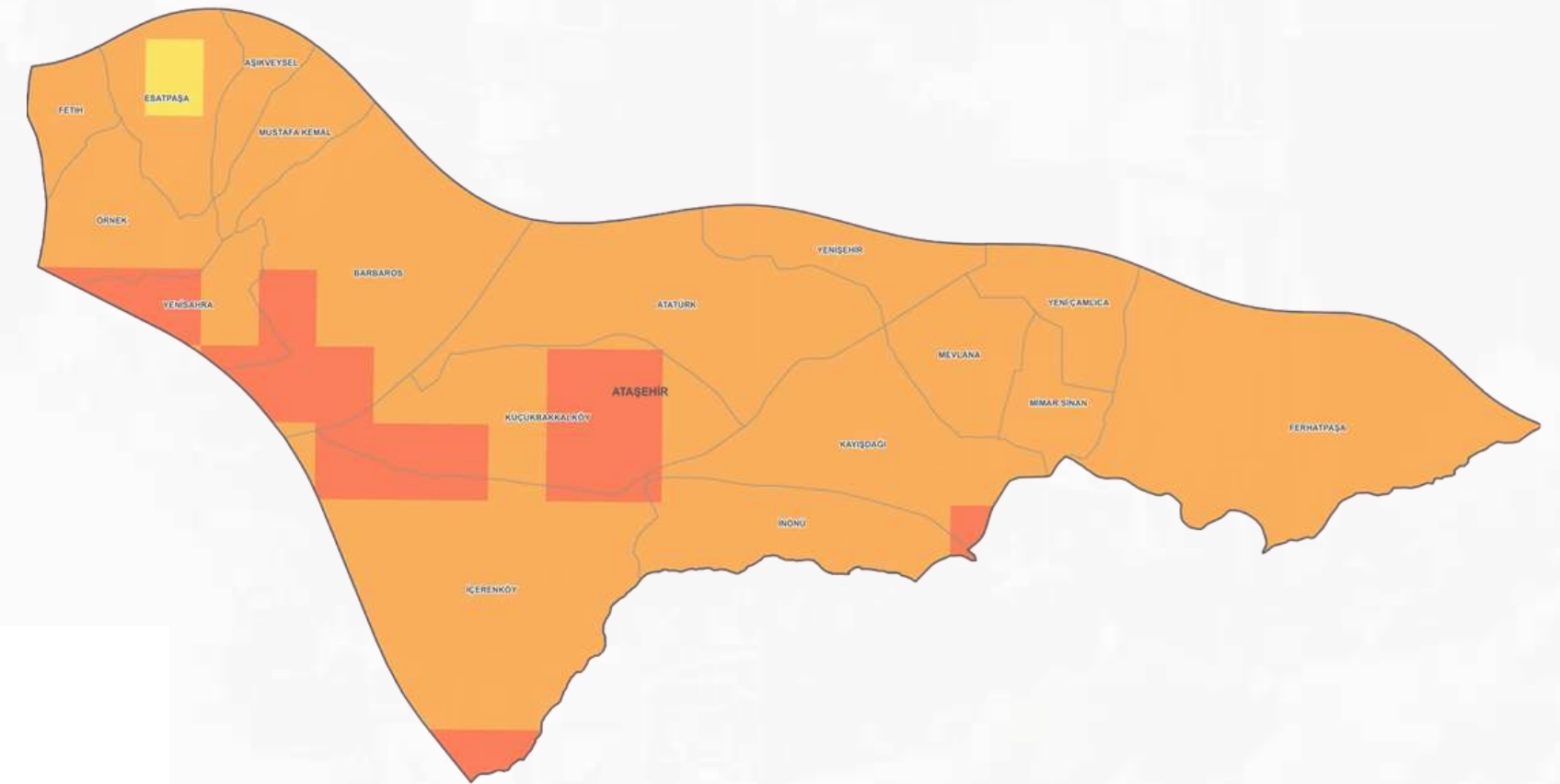
Seismic Hazard: Peak Ground Acceleration

The Chosen Case Study

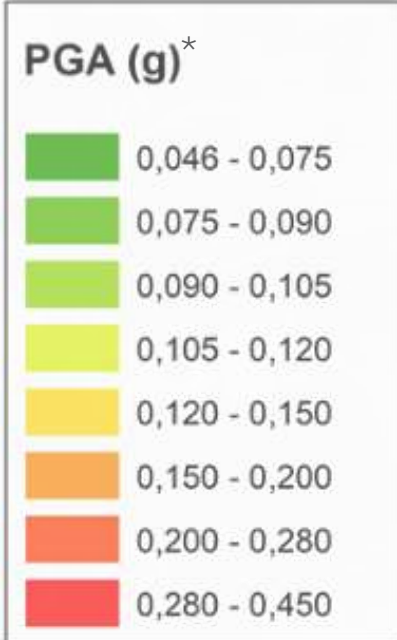
Avcılar district



Ataşehir district



*Peak ground acceleration



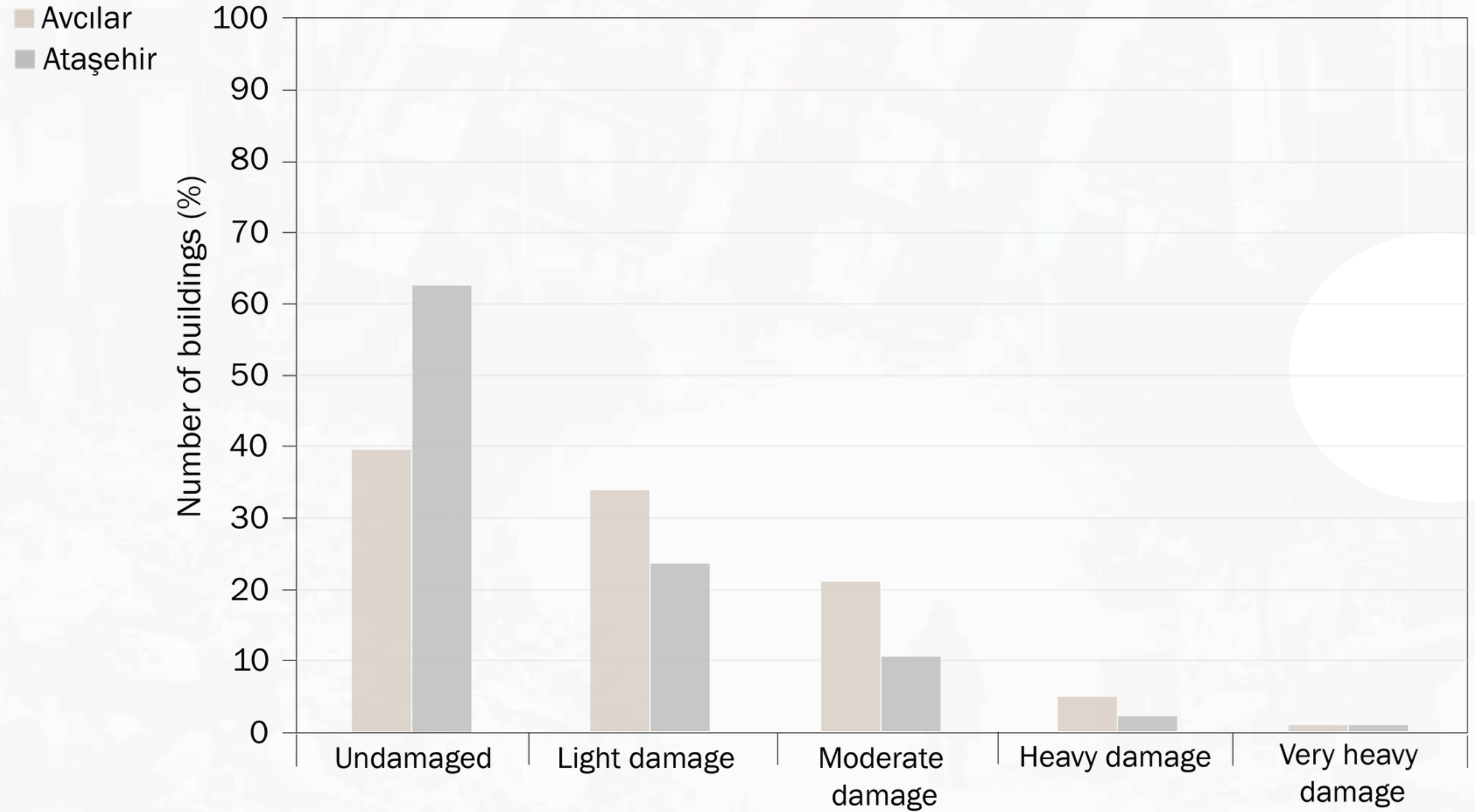
Ground-shaking amplification potentially up to 2.5 times greater due to soil conditions! ⁽¹⁾

Left image: İstanbul Büyükşehir Belediyesi, 2020a

Right image: İstanbul Büyükşehir Belediyesi, 2020b; (1) Kalkan and Gülkan, 2023;

Seismic Hazard: Damage Assessment under 7.5 Mw Earthquake Scenario

The Chosen Case Study

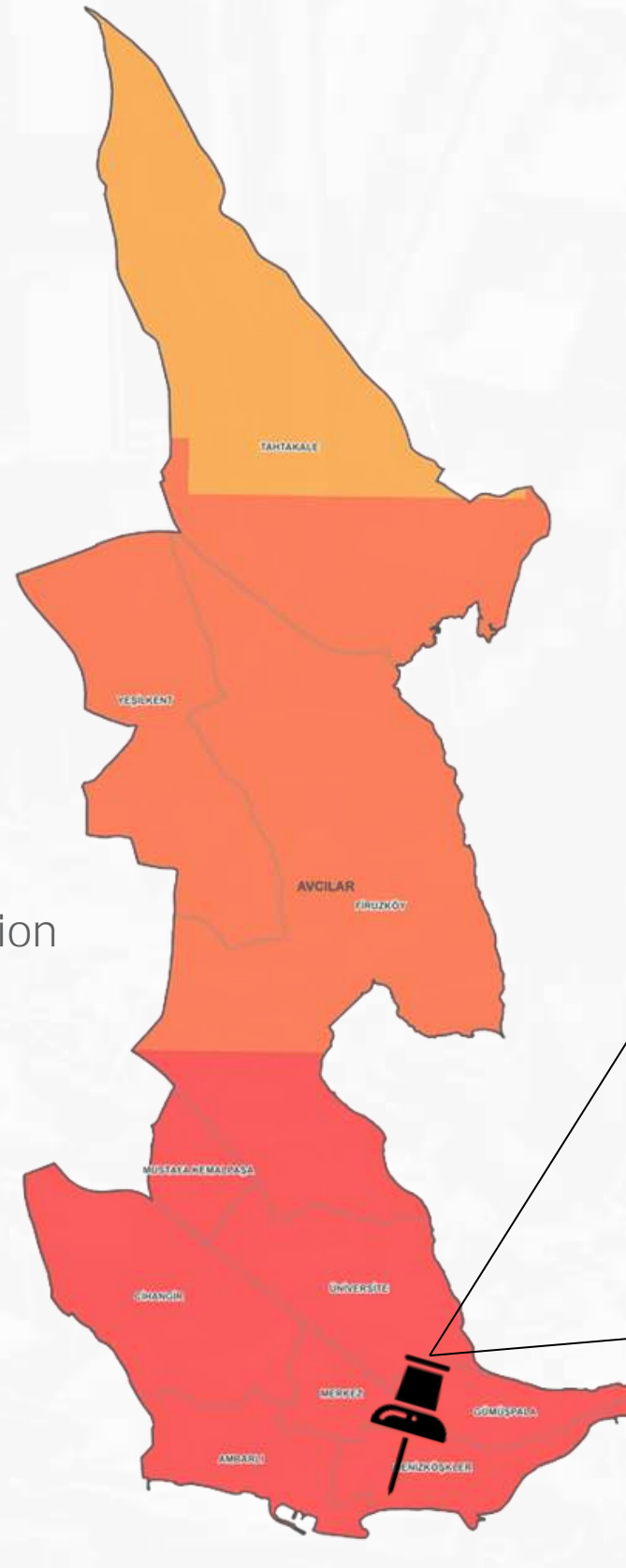


Case Study Building: Structural Characteristics

The Chosen Case Study

Denizköşkler, Dr. Sadık Ahmet Cd.

Avcılar district



*Peak ground acceleration



From: Google Earth, 2022

Left image: İstanbul Büyükşehir Belediyesi, 2020a

Right image: Google Earth, 2022

Act 5 - The Parametric* Workflow

*Parametric = a computational approach to architecture that uses algorithms and data to define, control, and optimize design outcomes (Karaağaç, 2025)

Step 1: Site-visit: Survey Input

The Parametric Workflow

Denizköşkler, Dr. Sadık Ahmet Cd.

Investigation during site visit

- General project information
- General building geometry
- Member information (columns & beams)
- Soil parameter information



From: Google Earth, 2022



Input of building
info

Step 2: Geometry Build-up

The Parametric Workflow

Automated!



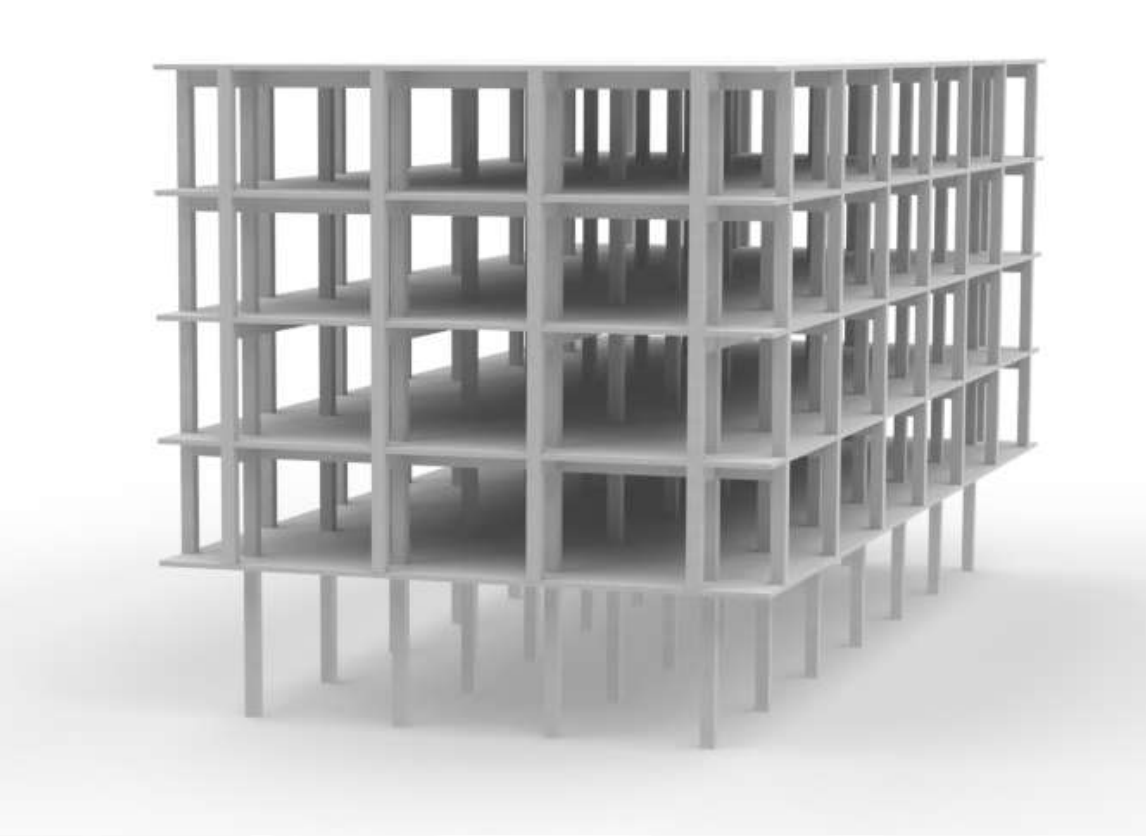
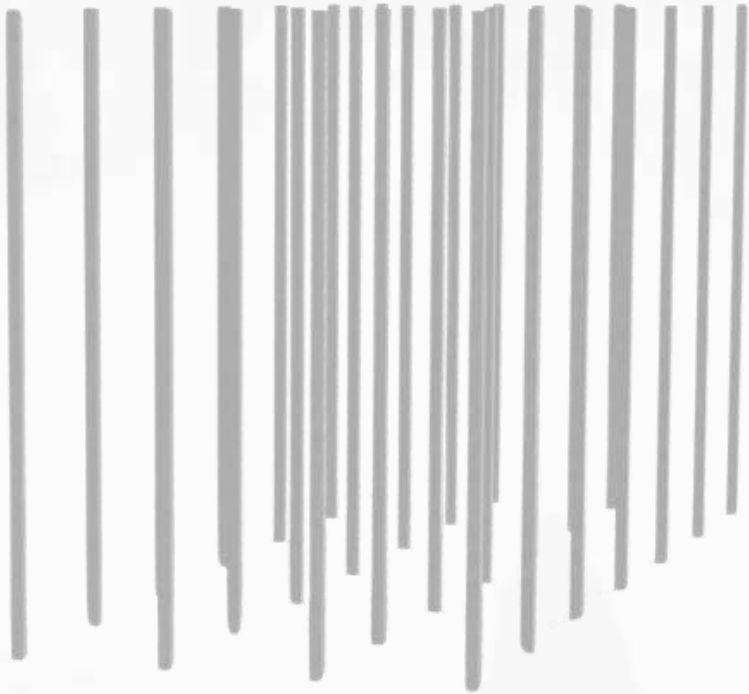
Import into



Modelling/
visualisation



Parametric
"coding"



Step 3: Calculation of Seismic Forces

The Parametric Workflow

- 2nd law of Newton

$$F = M \cdot a$$

Earthquake Force = Building Mass · Acceleration

- Building weight calculations (floor by floor)
- Earthquake force application (Turkish structural code based)

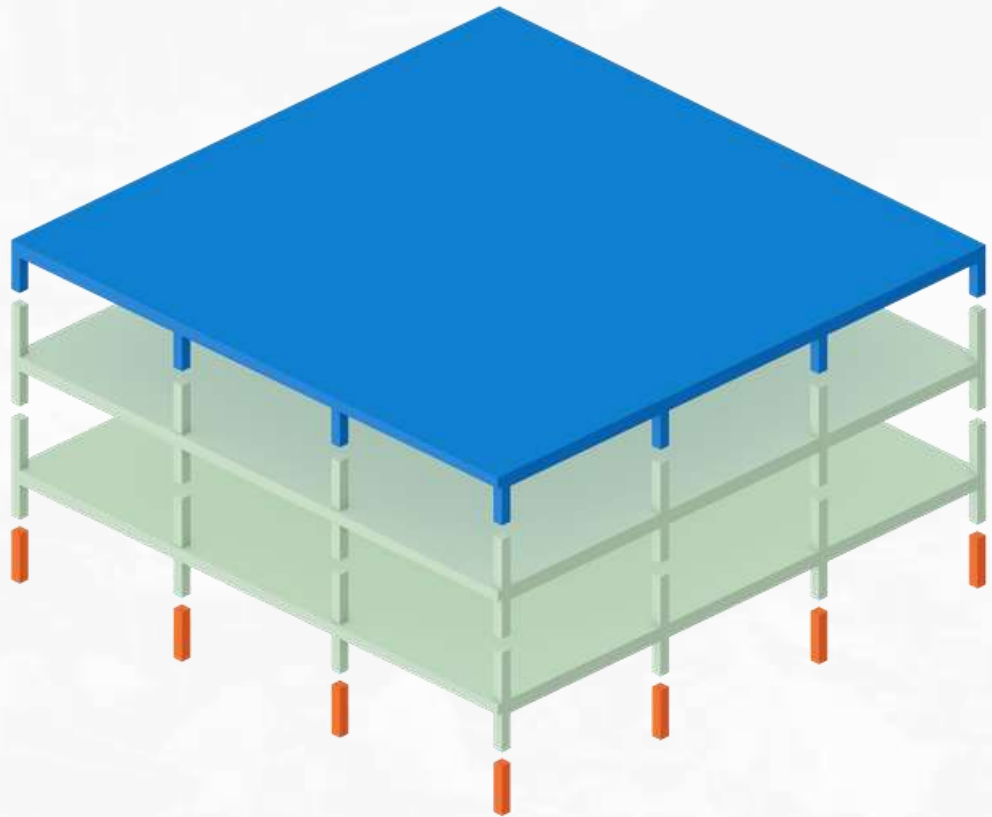
Automated!



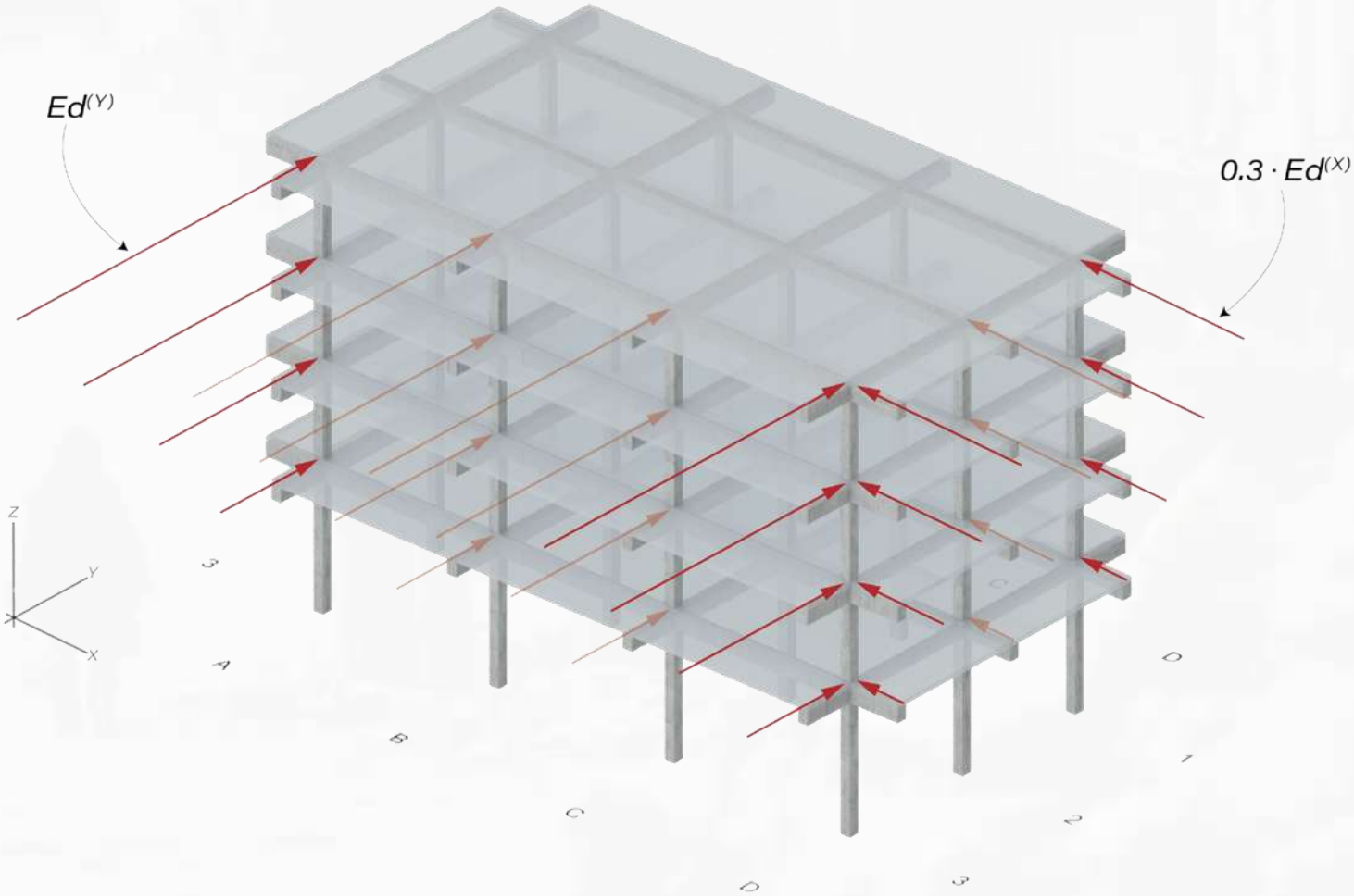
Parametric "coding"



Structural analysis



Division of weight calculations per floor
ground floor (red)
intermediate floor (green)
roof (blue)



Application of earthquake forces on the building according to the Turkish code

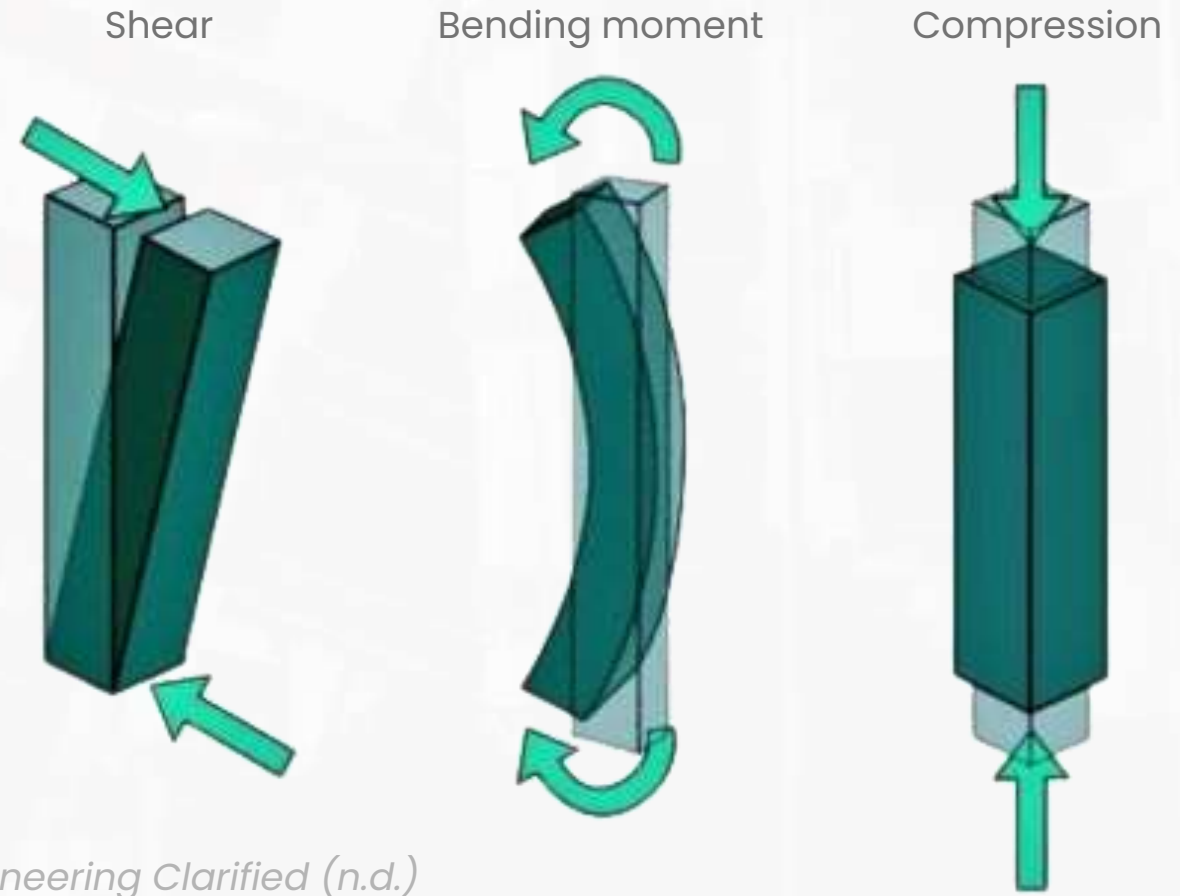
Step 4: Seismic Analysis: Current Situation

The Parametric Workflow

Automated!

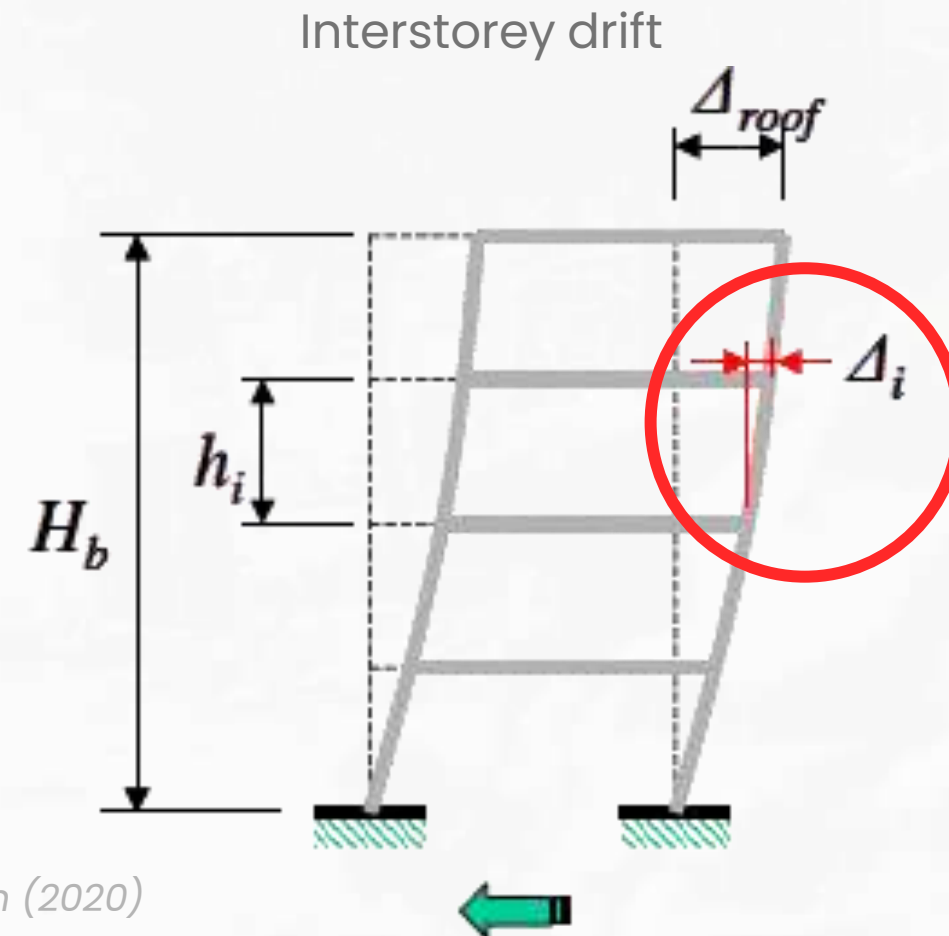


- Extraction of engineering design parameters
 - Internal forces
 - Shear - V
 - Bending moment - M
 - (Compression - N)
 - Interstorey drift



Engineering Clarified (n.d.)

- Unity check = $\frac{\text{Force}}{\text{Capacity}} \leq 1.0$

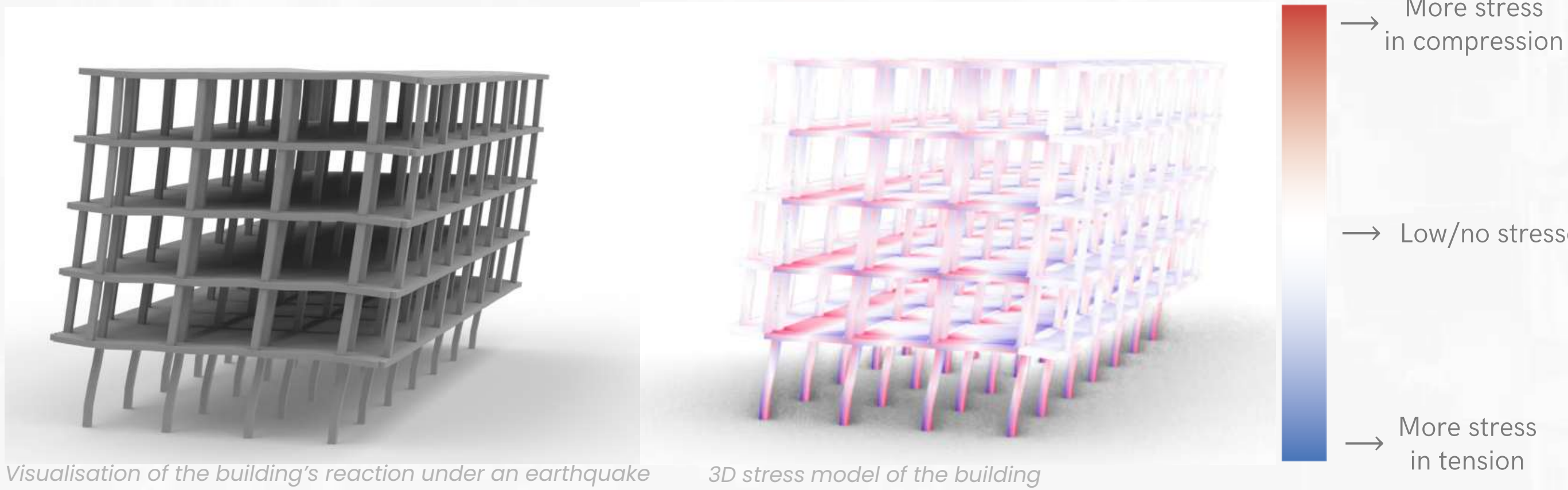


Bhat & Azam (2020)

Step 4: Seismic Analysis: Current Situation

The Parametric Workflow

Automated!



Visualisation of the building's reaction under an earthquake

3D stress model of the building

Current situation capacity check – soft-storey collapse mechanism identified

Unity check values (ULS_1)		
Parameter	Unity check value	PASS/FAIL
Columns - Shear (Vz/Vy)	1,48	FAIL
Columns - Moment (Mz/My)	0,39	PASS
Columns - Axial (compr./tens.)	0,63 / 0,46	PASS / PASS
Columns - Biaxial moment	0,49	PASS
Beams - Shear (Vz/Vy)	2,22	FAIL
Beams - Moment (Mz/My)	1,64	FAIL
Beams - Axial (compr./tens.)	0,03 / 0,15	PASS / PASS
Interstorey drift in X-direction	1,87	FAIL
Interstorey drift in Y-direction	0,53	PASS

Act 6 -
Integration: Fixing The Issue With Waste



Image captured by: Simon Townsley

From Waste to Material Input

Integration: Fixing The Issue With Waste

Step 1: Transportation to recycling plant:

- Primary source separation at construction/demolition site
- Reduces wear on machinery
- Improves final recycled aggregate quality
- Delivers it as a brick-dominant and a concrete-dominant waste pile



Step 2: Grizzly feeder

- Stabilizes material input into the process
- Filters out elements like:
 - soil and dirt
 - Other small contaminants
- Excavator filters out obvious oversized contaminants



Step 3: Manual sorting station:

- Primary quality control and contamination removal
- Removes residual non-mineral materials remaining after pre-sorting
- Typical contaminants: timber, packaging, hazardous residues, etc.
- Protects downstream equipment and improves product quality

Step 4: Jaw crusher

- Primary size reduction and first "liberation" of rebar
- Crushes input (concrete/brick) into a more uniform product:
 - Size: 10 to 350 mm
 - Shape: elongated, coarse, rough

Step 5: Overbelt magnetic separator #1

- Separates ferrous metals that were freed in the jaw crusher:
 - Rebars, bolts, nails, steel fragments
- Protects impact crusher from steel elements

Step 6: Impact crusher

- Stronger secondary crushing and better liberation of:
 - Remaining rebar from concrete
 - Mortar from concrete and bricks
- Crushes input into a uniform cubical product:
 - Size: 0 to 80 mm

Step 7: Overbelt magnetic separator #2

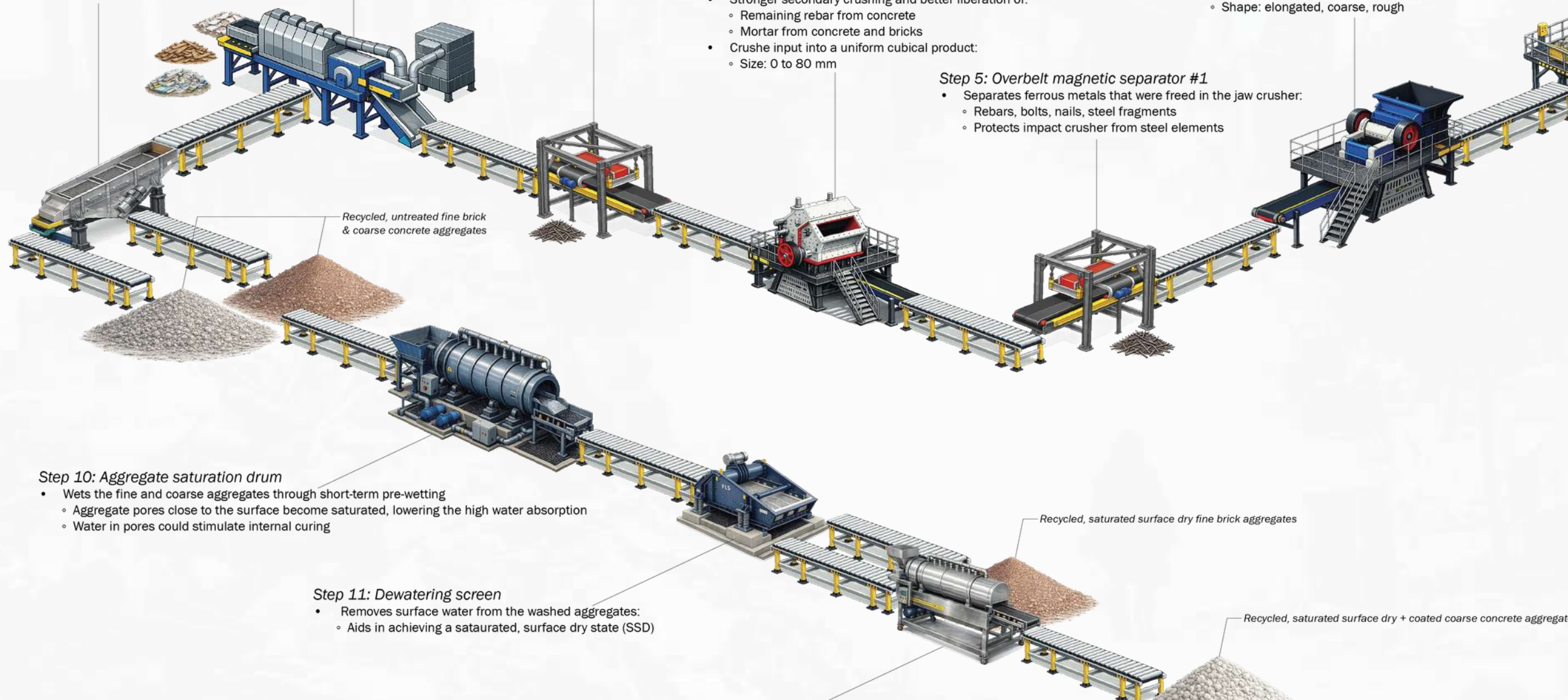
- Separates remaining ferrous metals like
 - Rebars, nails and small steel fragments

Step 8: Air drum separator (ADS)

- Separates elements based on material density and shape:
 - Lightweight elements: timber, plastics, gypsum
 - Heavy elements: concrete, bricks (both coarse and fine aggregates)

Step 9: Vibrating screen

- Separates elements based on particle size:
 - Coarse aggregates 4.75 mm < X < 37.5 mm
 - Fine aggregates < 4.75 mm
 - Aggregates larger than 37.5 mm can be re-circulated into the impact crusher



Recycled, untreated fine brick & coarse concrete aggregates

Recycled, saturated surface dry fine brick aggregates

Recycled, saturated surface dry + coated coarse concrete aggregates

Step 10: Aggregate saturation drum

- Wets the fine and coarse aggregates through short-term pre-wetting
 - Aggregate pores close to the surface become saturated, lowering the high water absorption
 - Water in pores could stimulate internal curing

Step 11: Dewatering screen

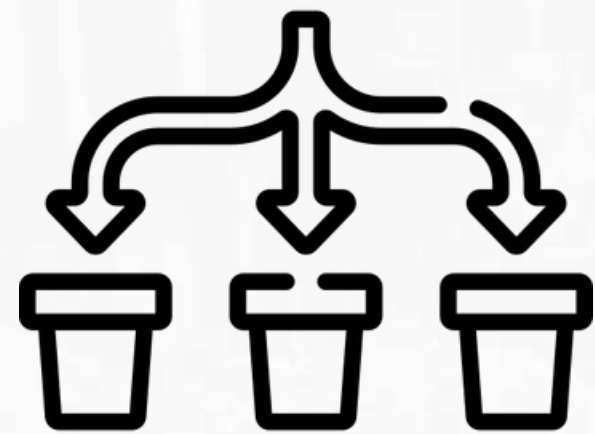
- Removes surface water from the washed aggregates:
 - Aids in achieving a saturated, surface dry state (SSD)

Step 12: Surface coating drum (coarse aggregates only)

- Applies a uniform coating to the coarse aggregates
 - Uses dry cement/fly ash + water mist
 - Continuous rolling coats aggregates

From Waste to Material Input

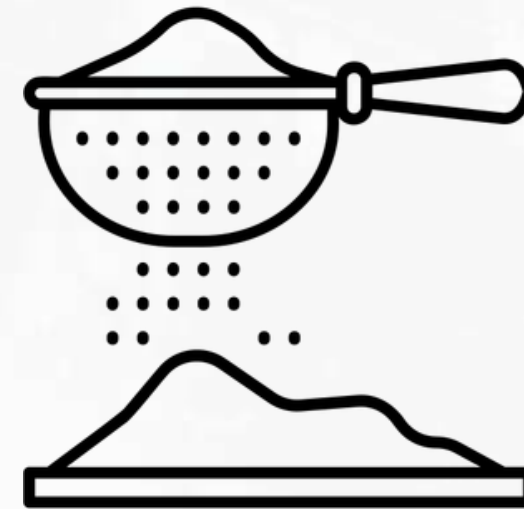
Integration: Fixing The Issue With Waste



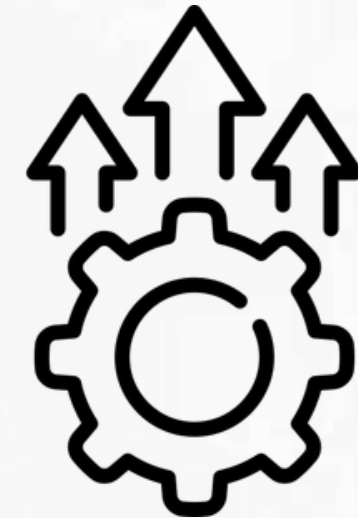
Sorting



Crushing



Sieving



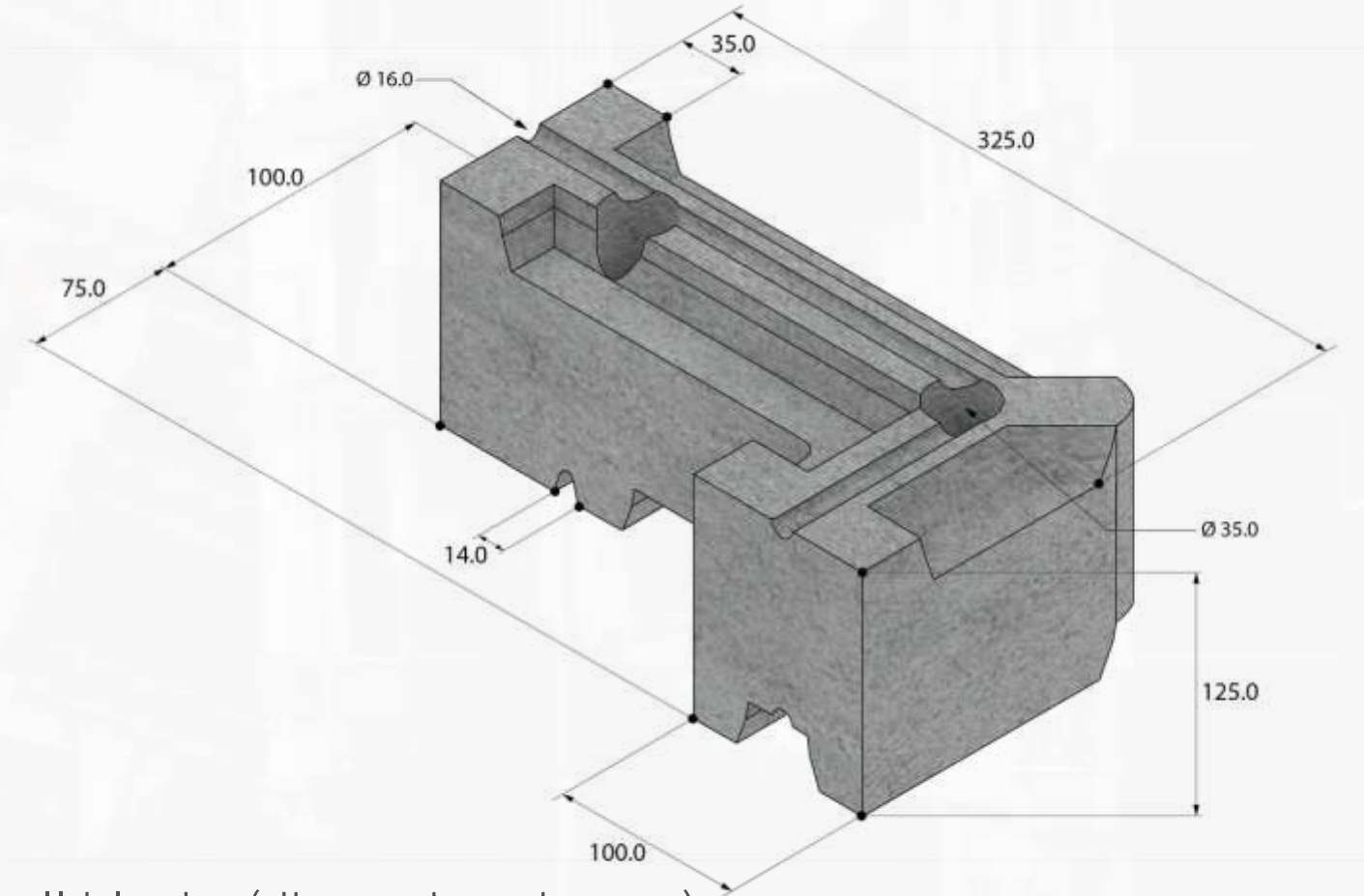
Upgrading

Precast Modular Blocks: the Design Philosophy

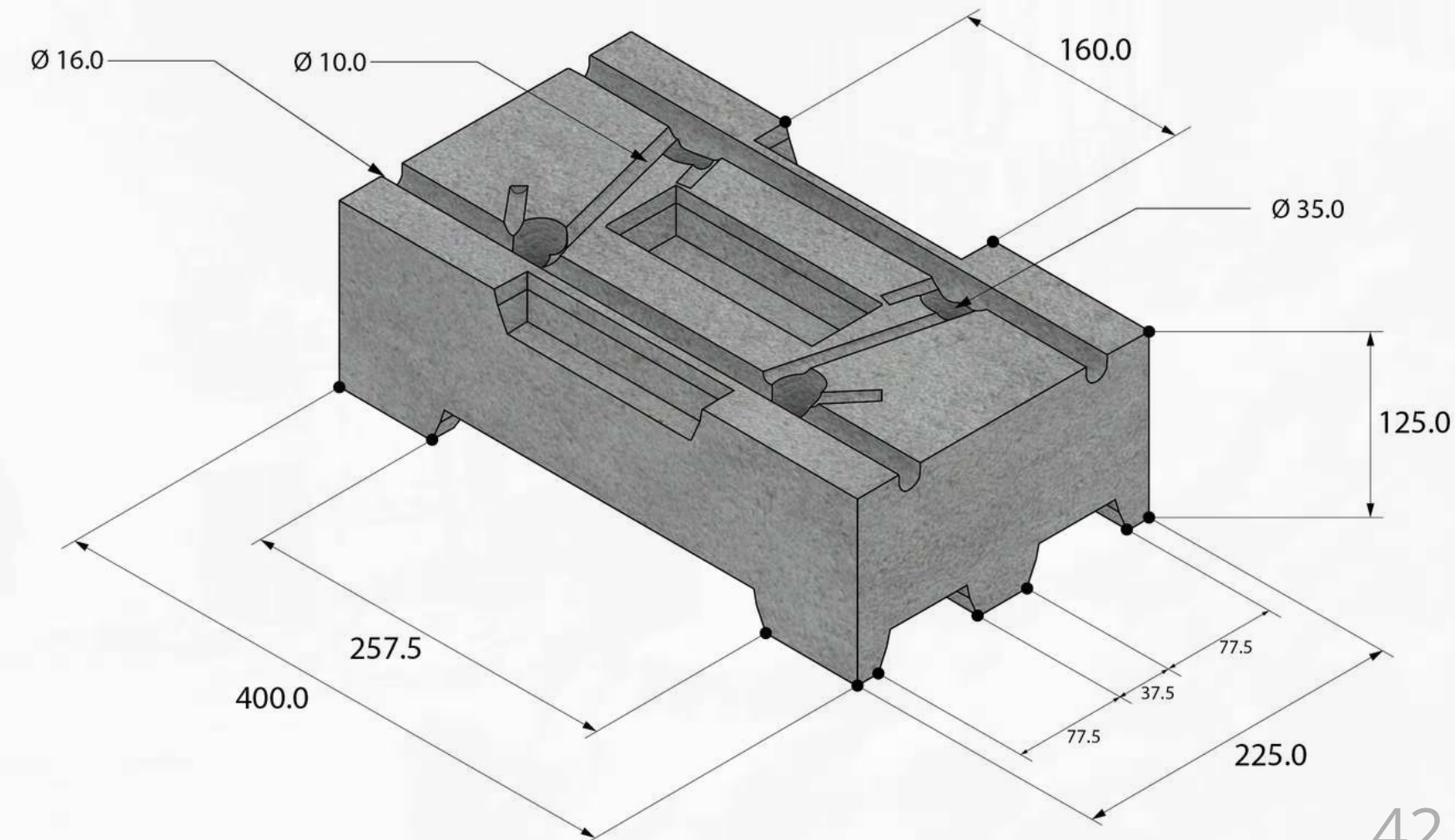
Integration: Fixing The Issue With Waste

1. Increasing shear bearing capacity
 - o Addition of shear teeth → interlocking
2. Ensuring reinforcement, accommodation & continuity
 - o Accommodation through geometry
 - o Ensuring continuity → Rebar couplers

Column jacketing blocks (dimensions in mm)



Shear wall blocks (dimensions in mm)

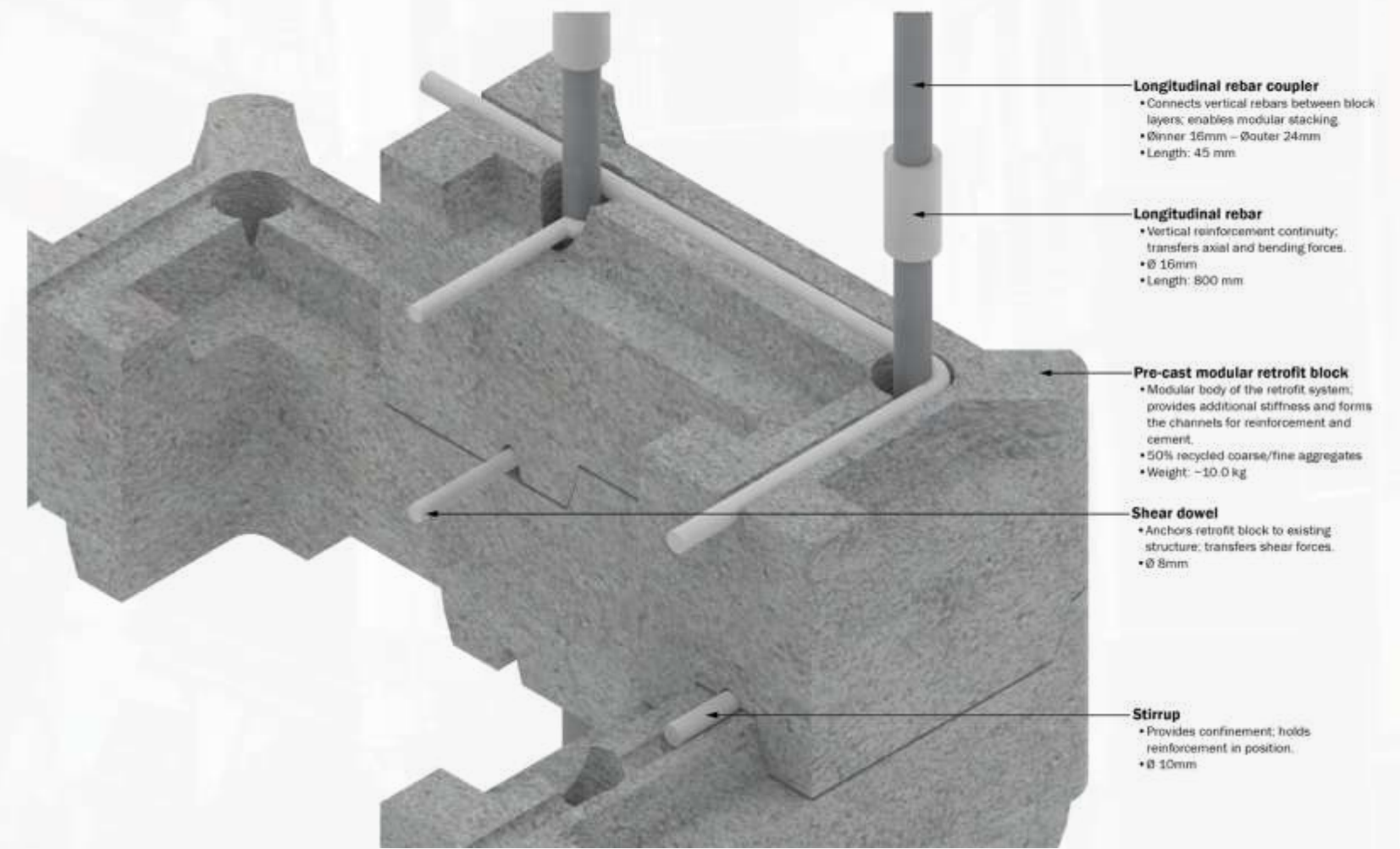


Precast Modular Blocks: the Design Philosophy

Integration: Fixing The Issue With Waste

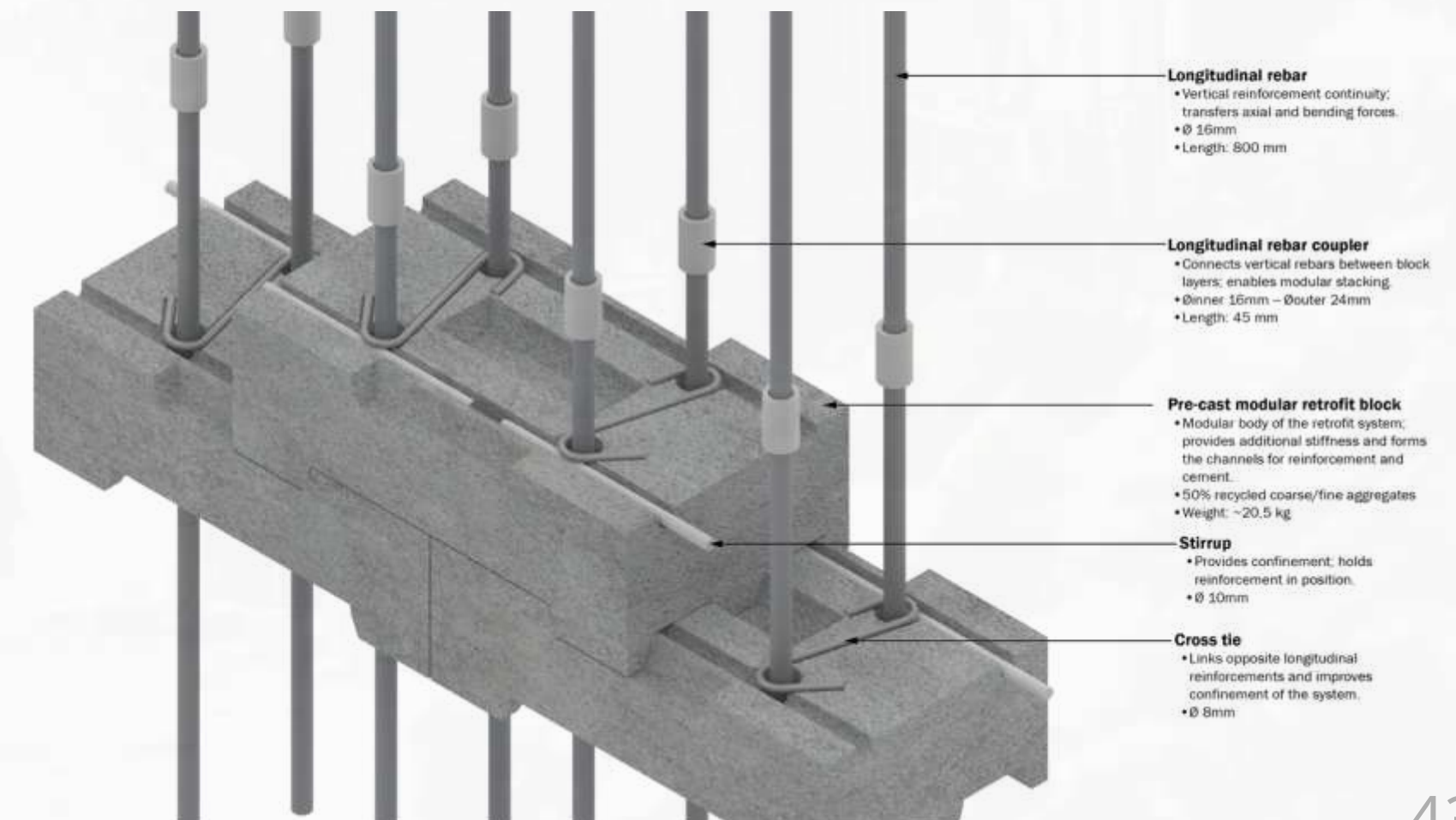
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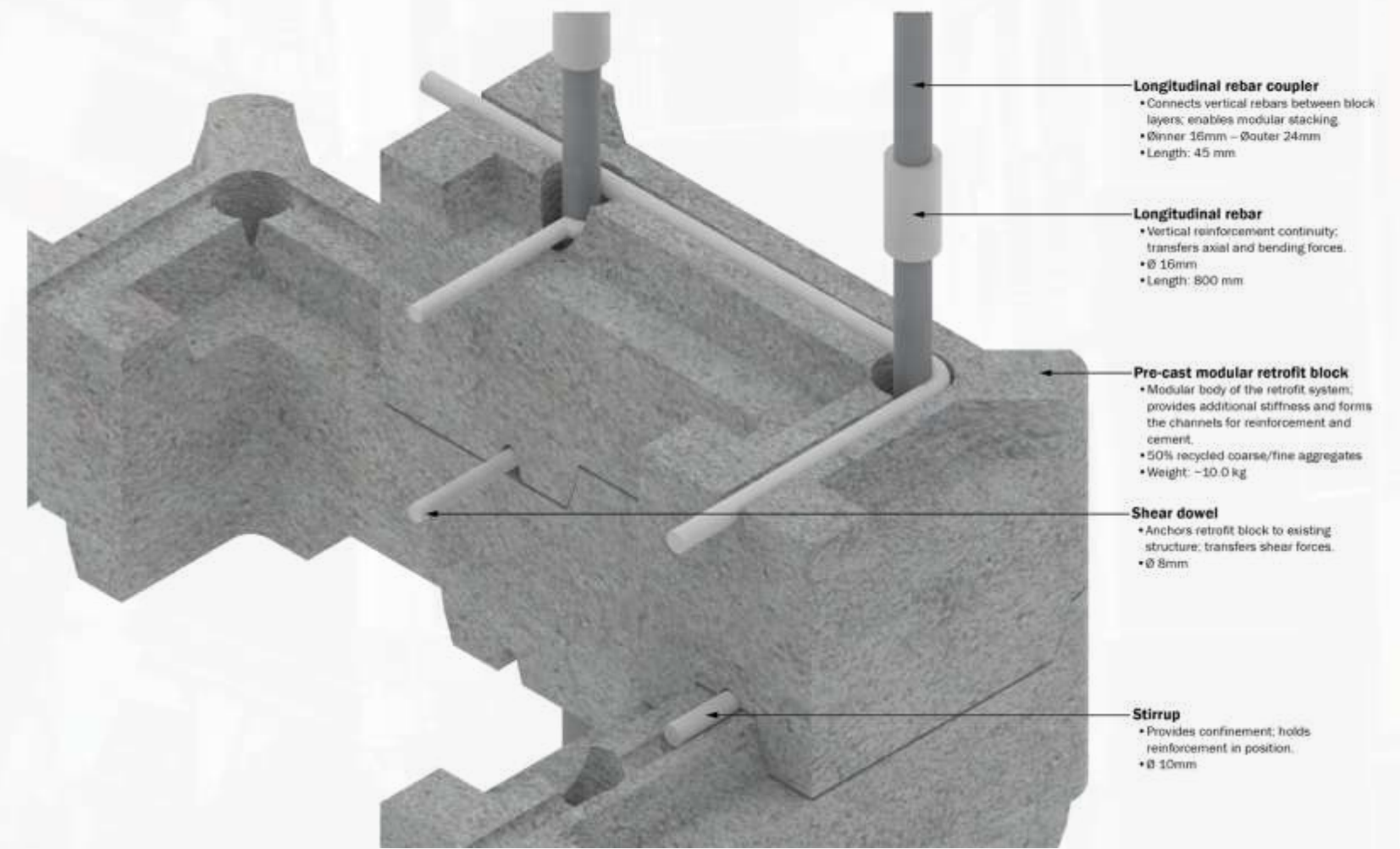


Precast Modular Blocks: the Design Philosophy

Integration: Fixing The Issue With Waste

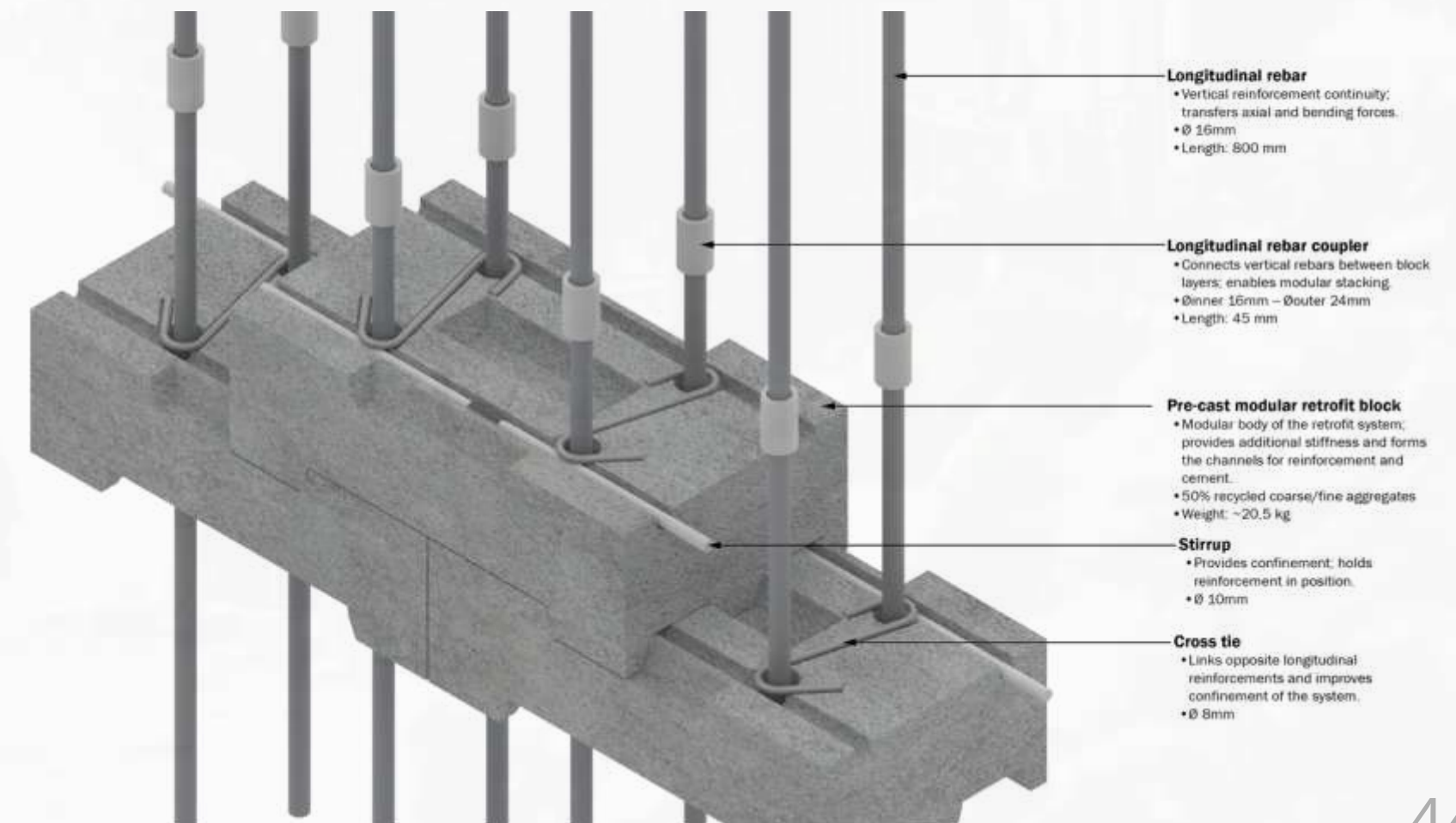
3. Ensuring a solid connection with old structure

- Shear transfer through
 - Shear dowels
 - Injection grout (column jacketing)
 - Cast-in-place frame (shear wall)



4. Material hierarchy

- Precast modular blocks → less stressed areas
- Cast-in-place concrete → more stressed areas



Precast Modular Blocks: the Design Philosophy

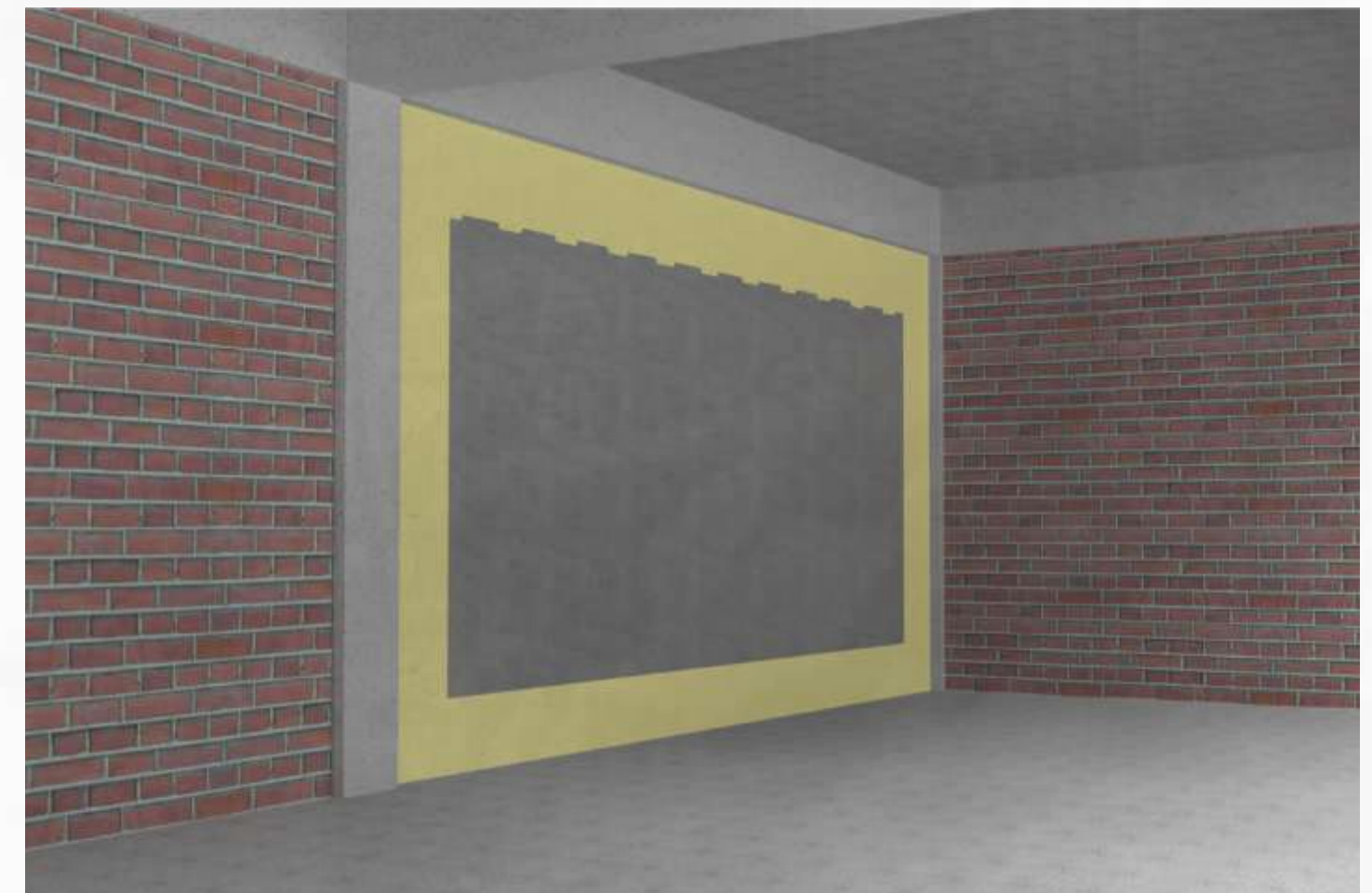
Integration: Fixing The Issue With Waste

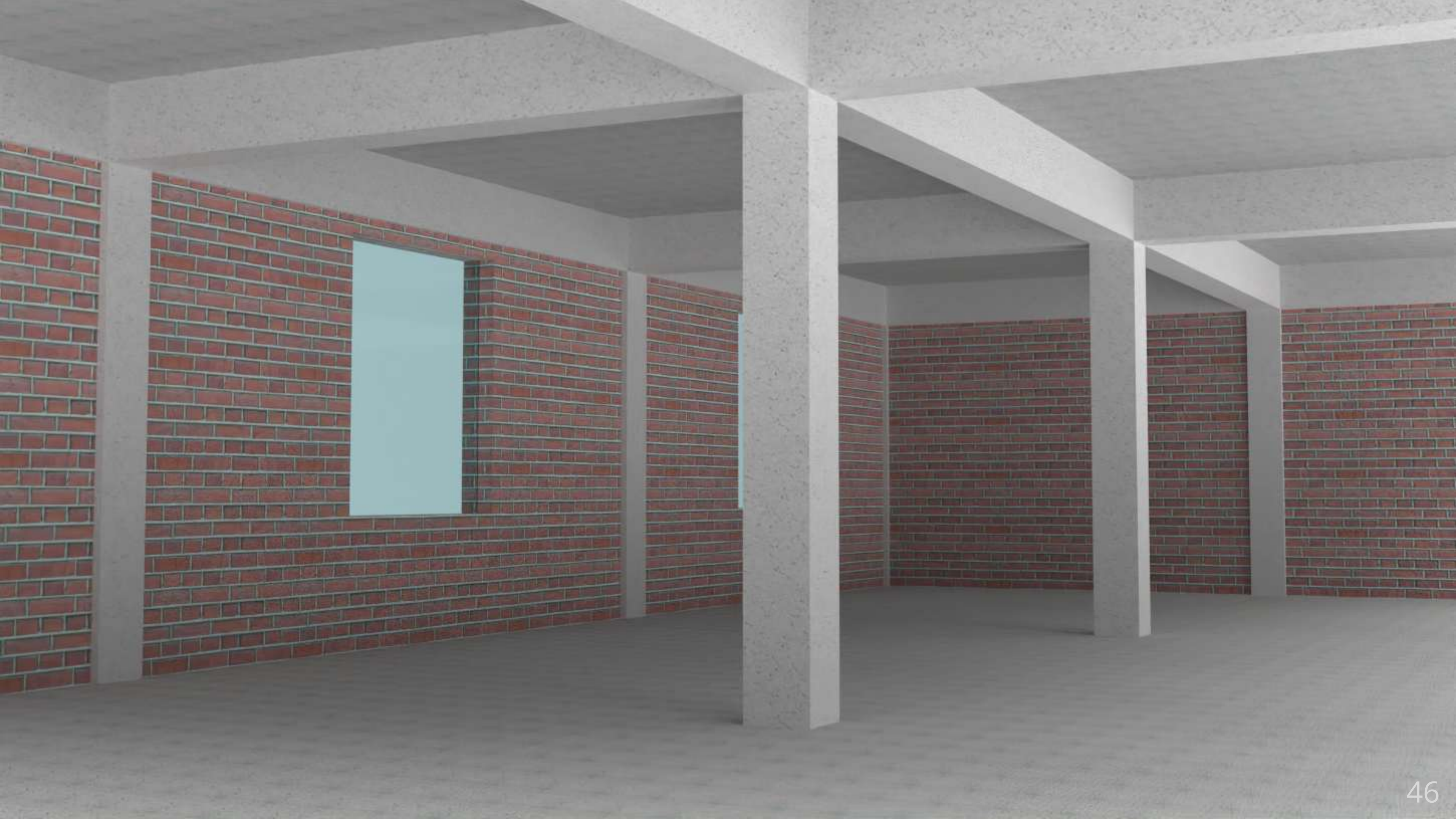
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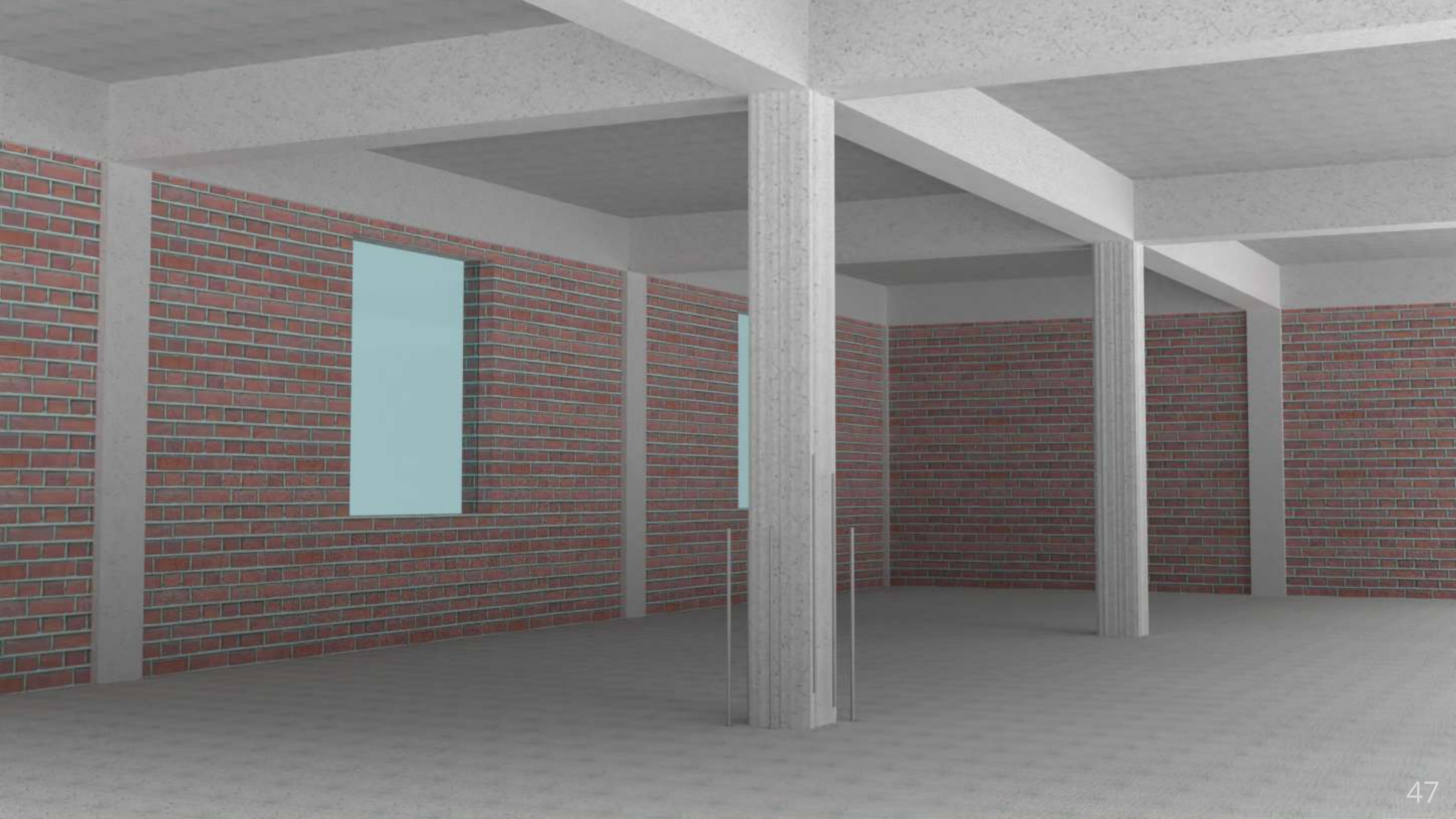
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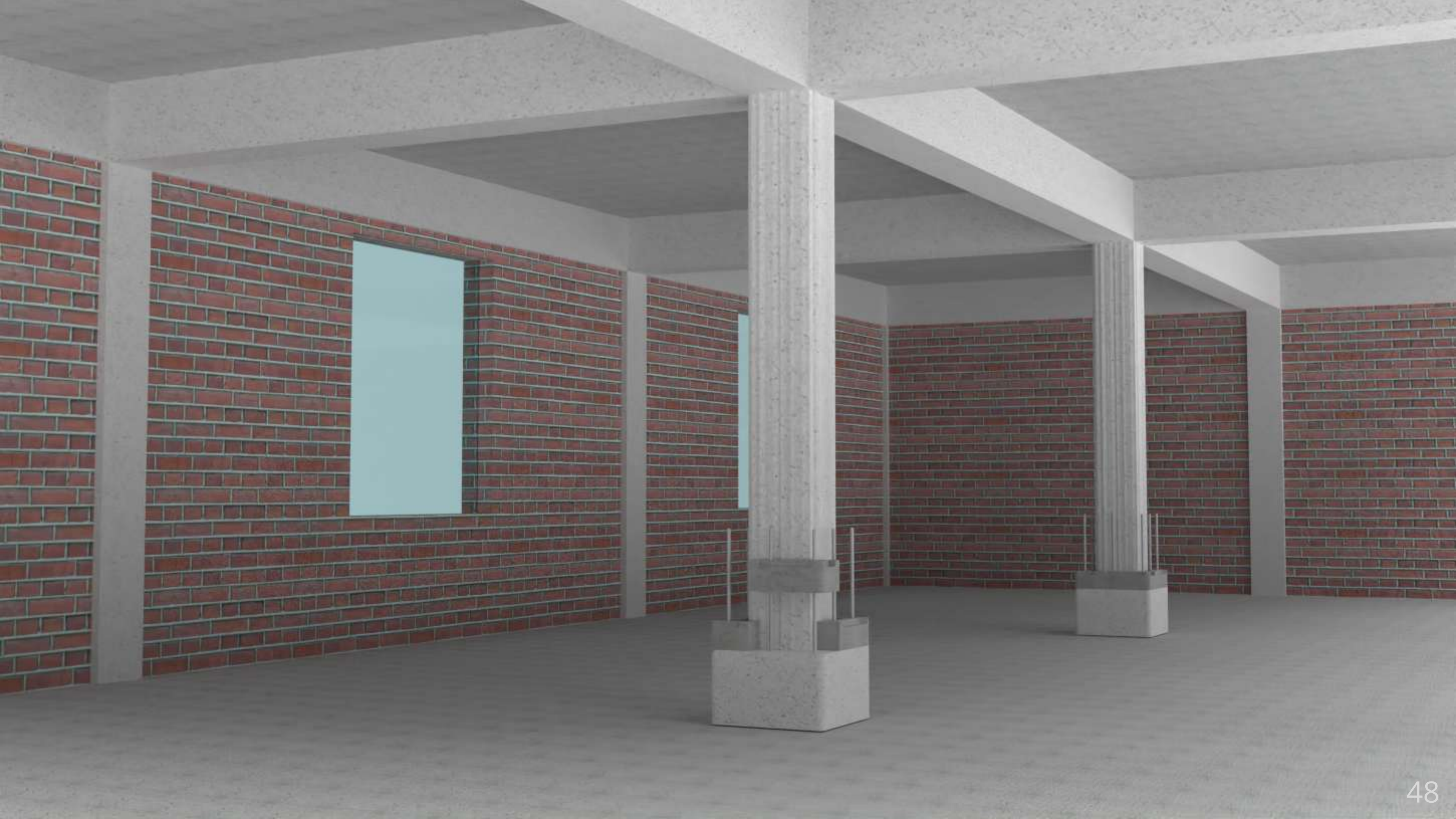
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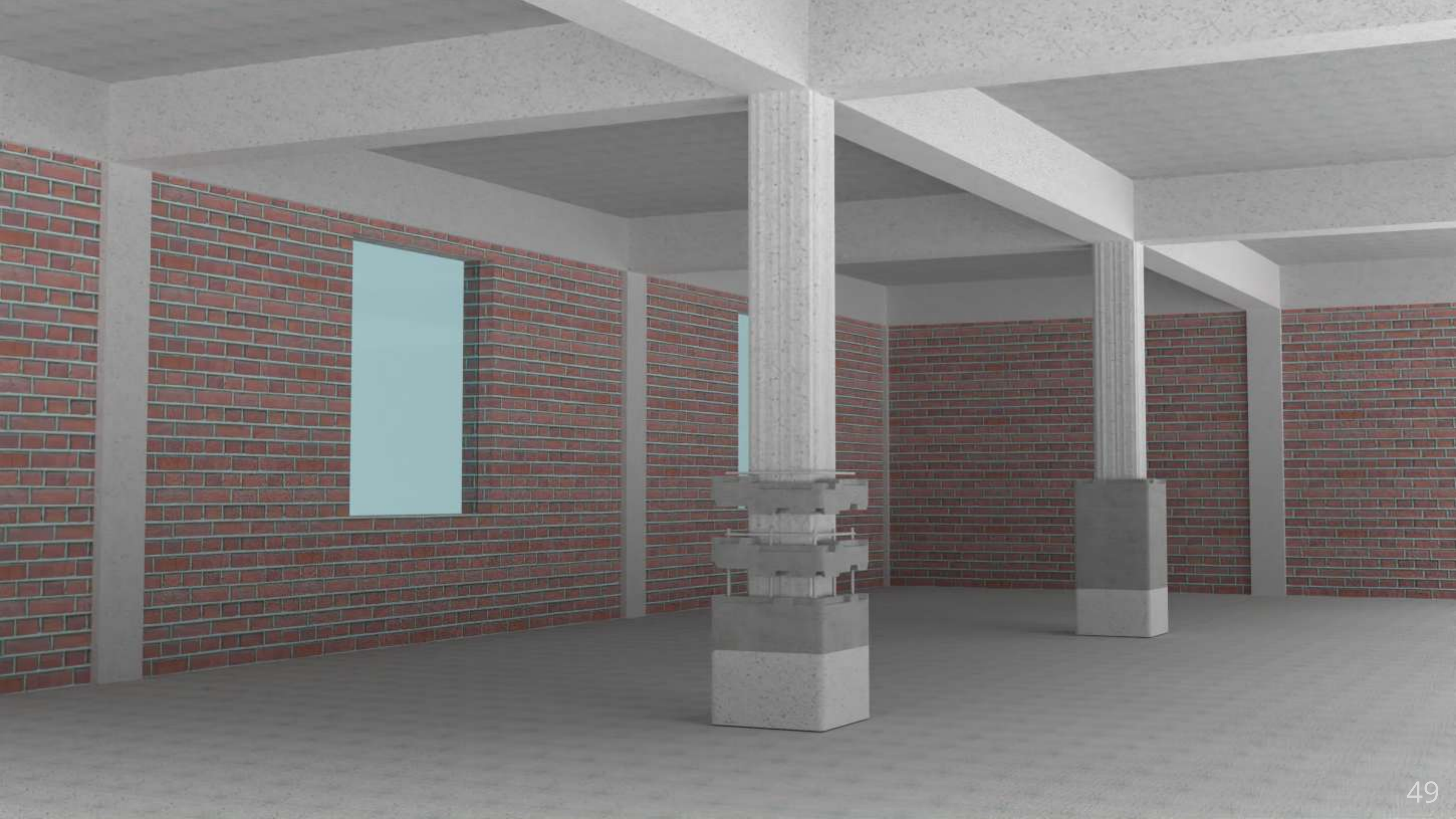
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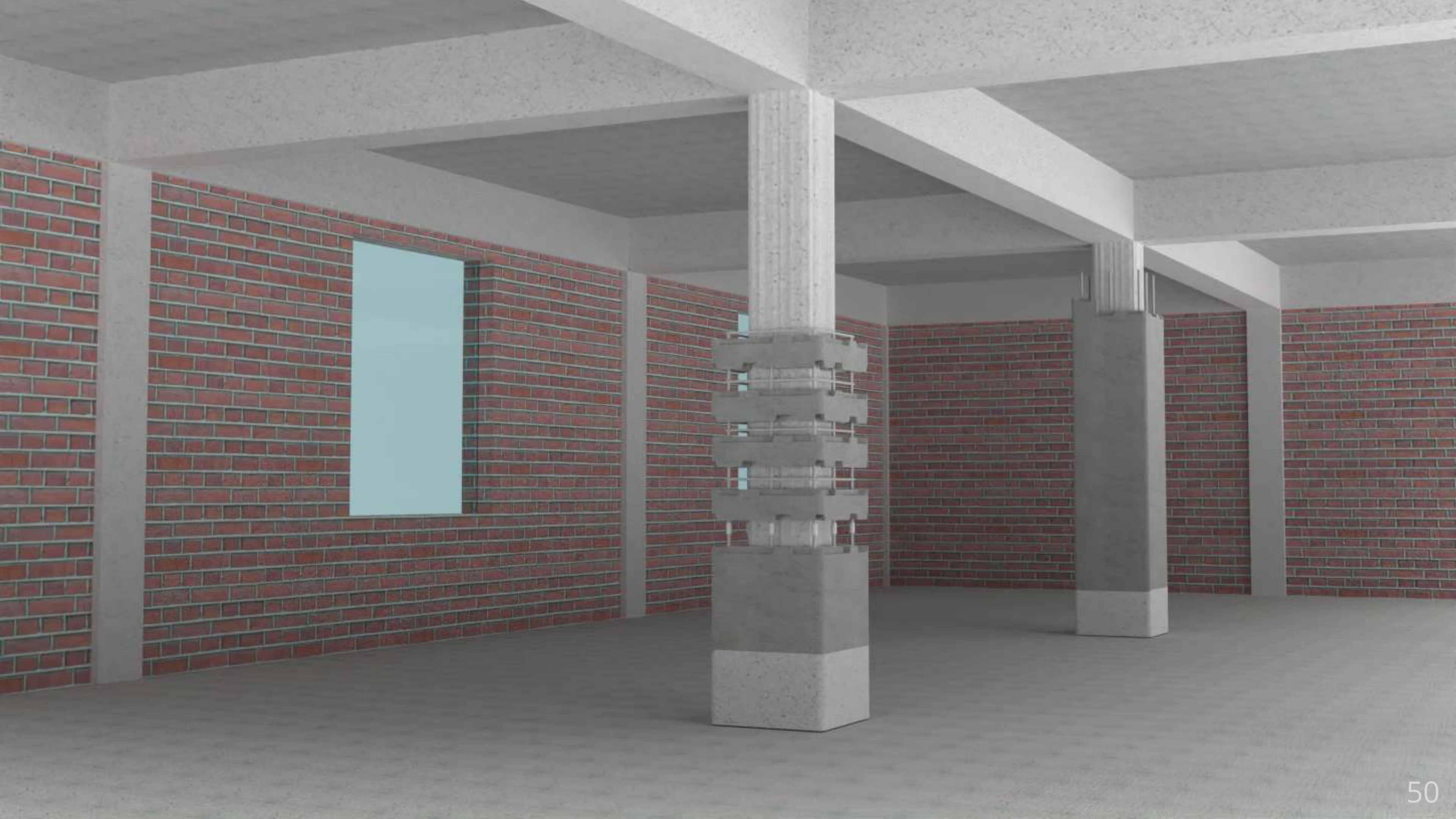


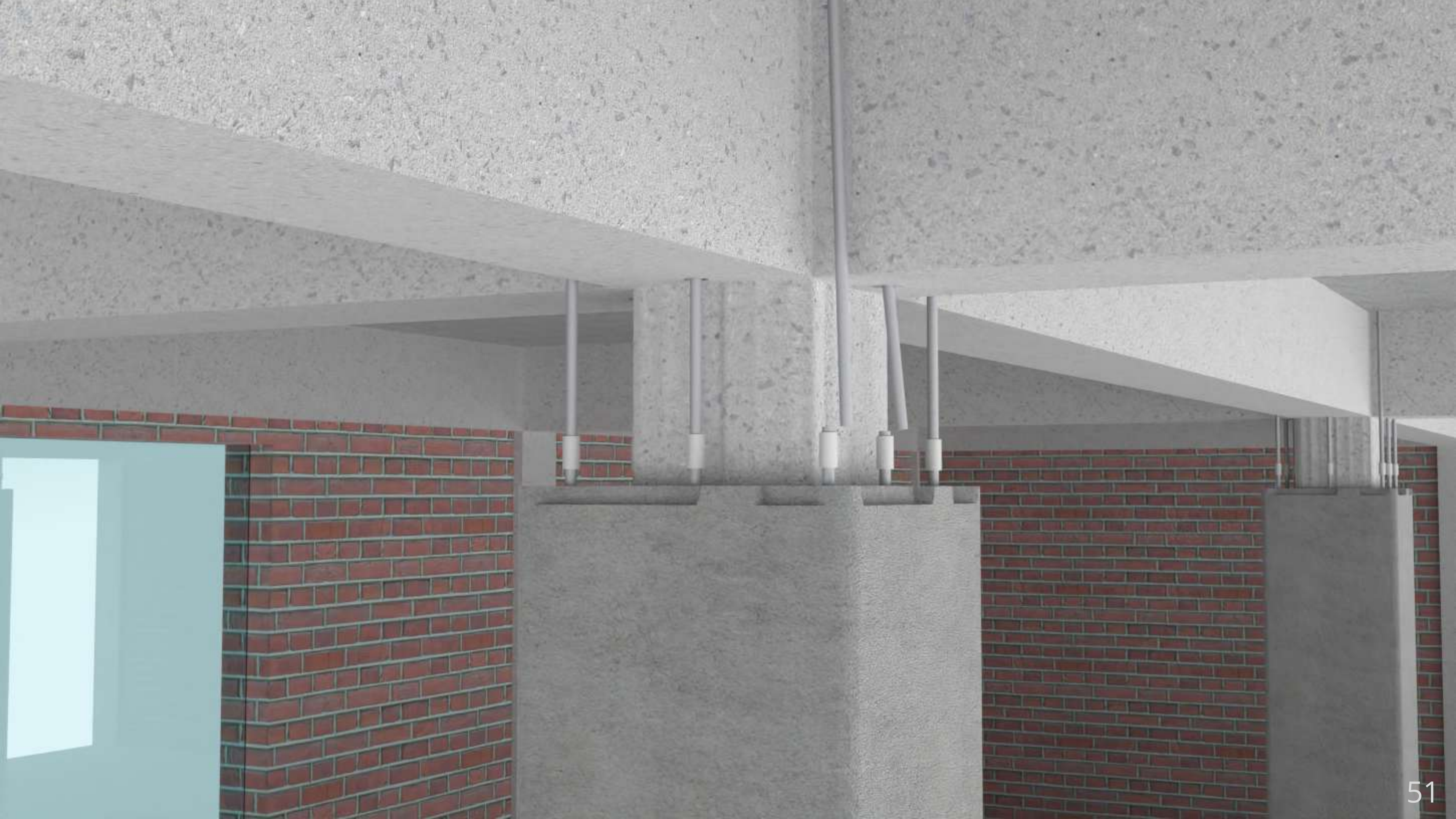






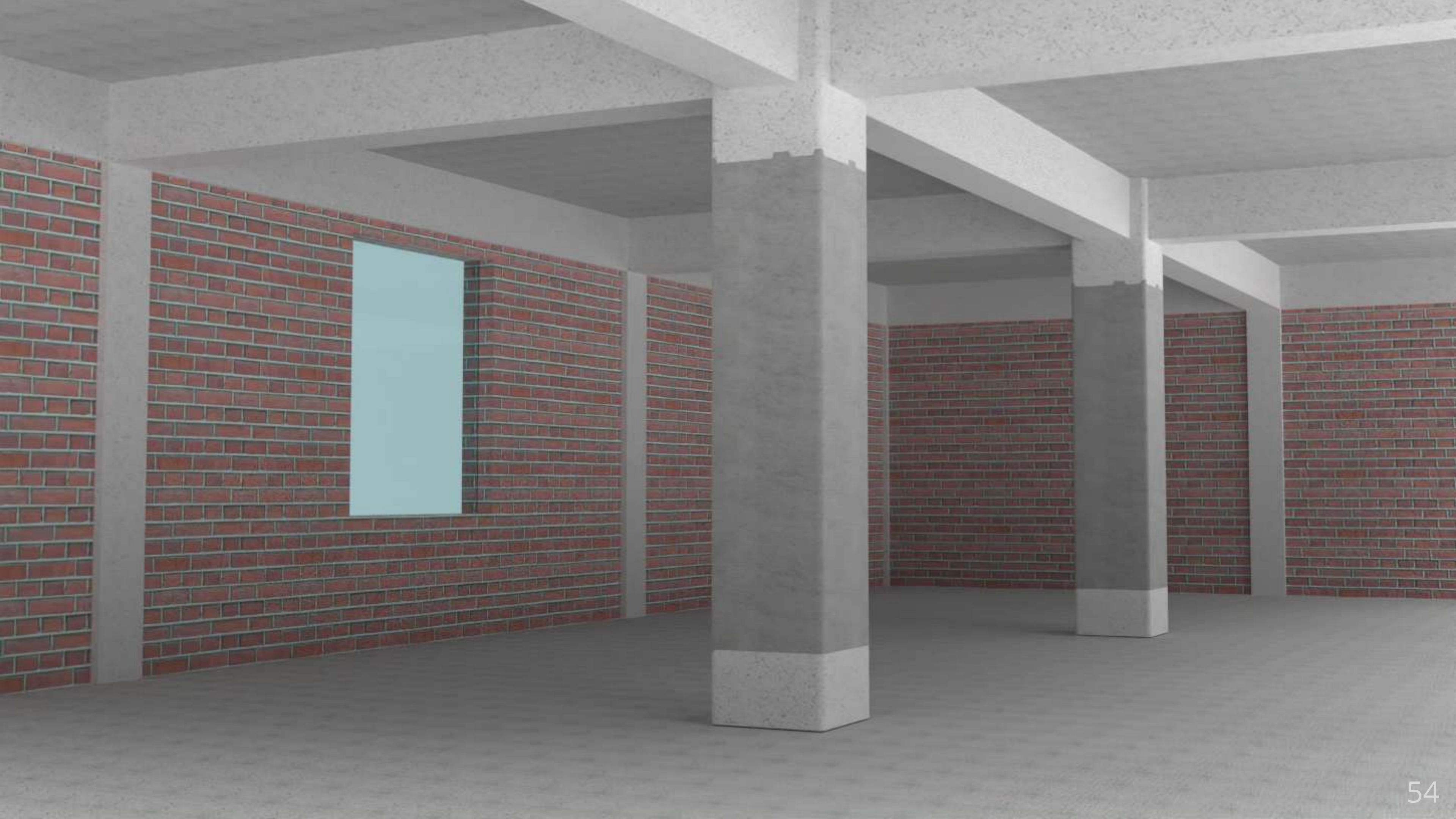








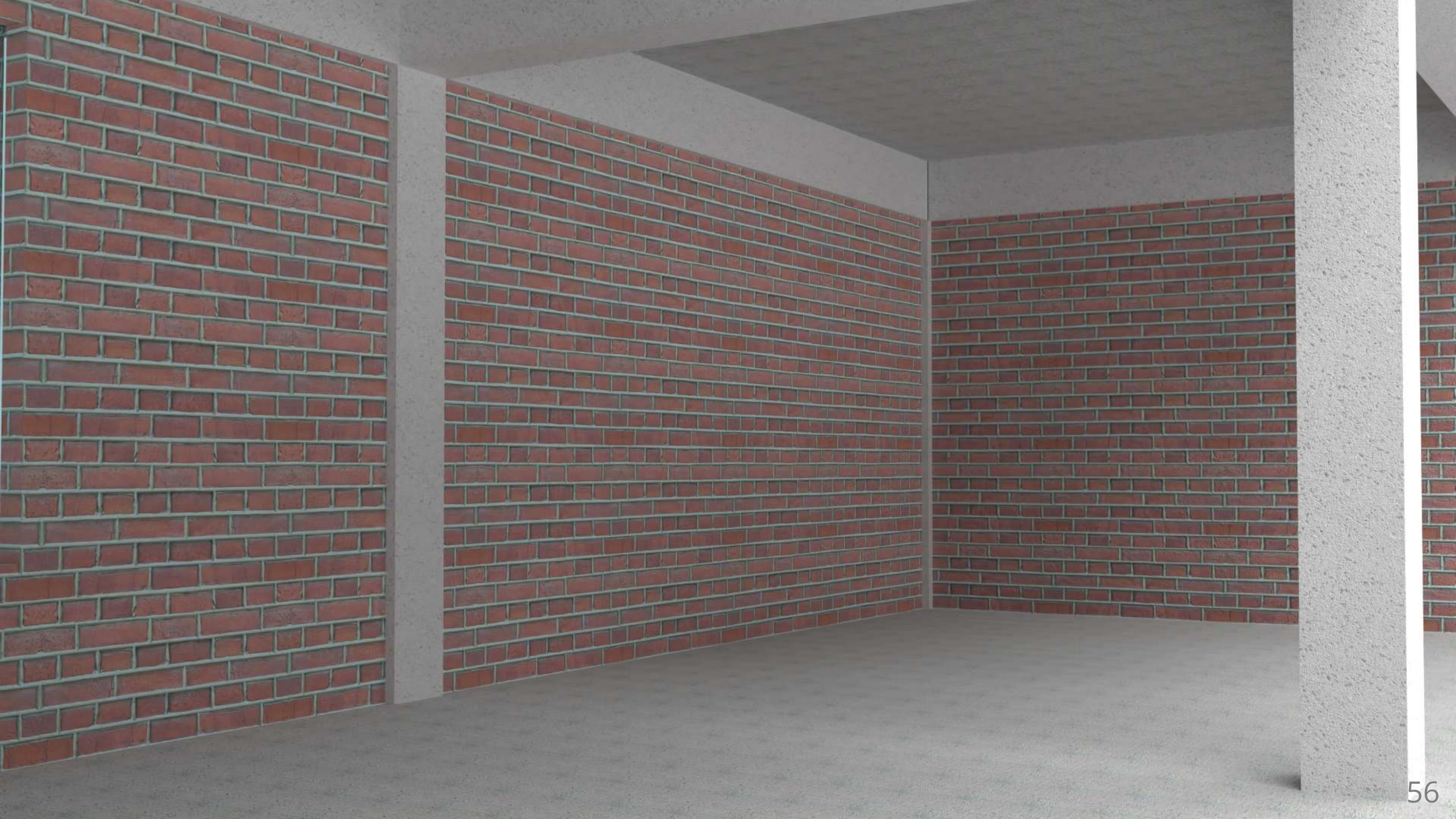


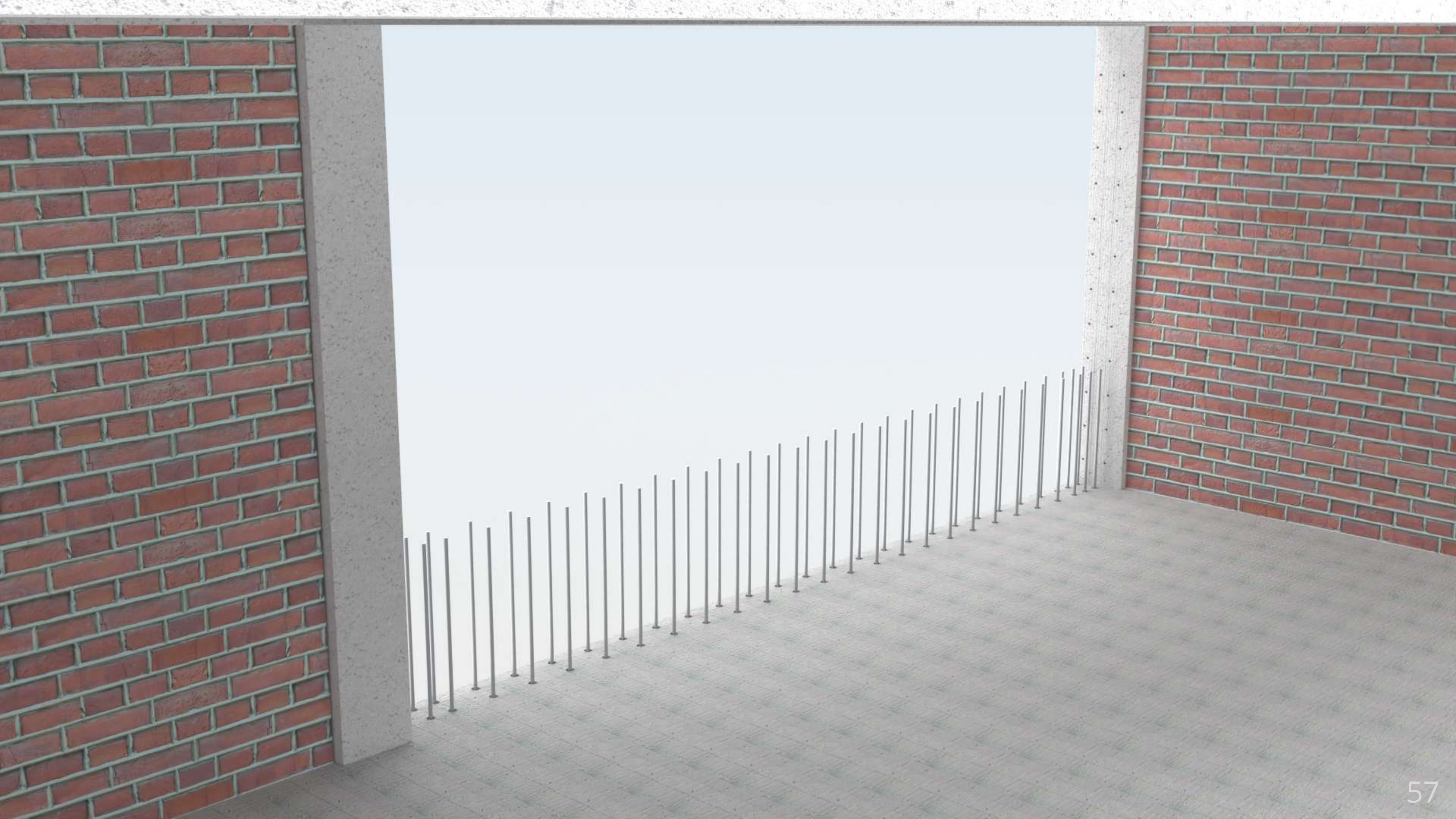


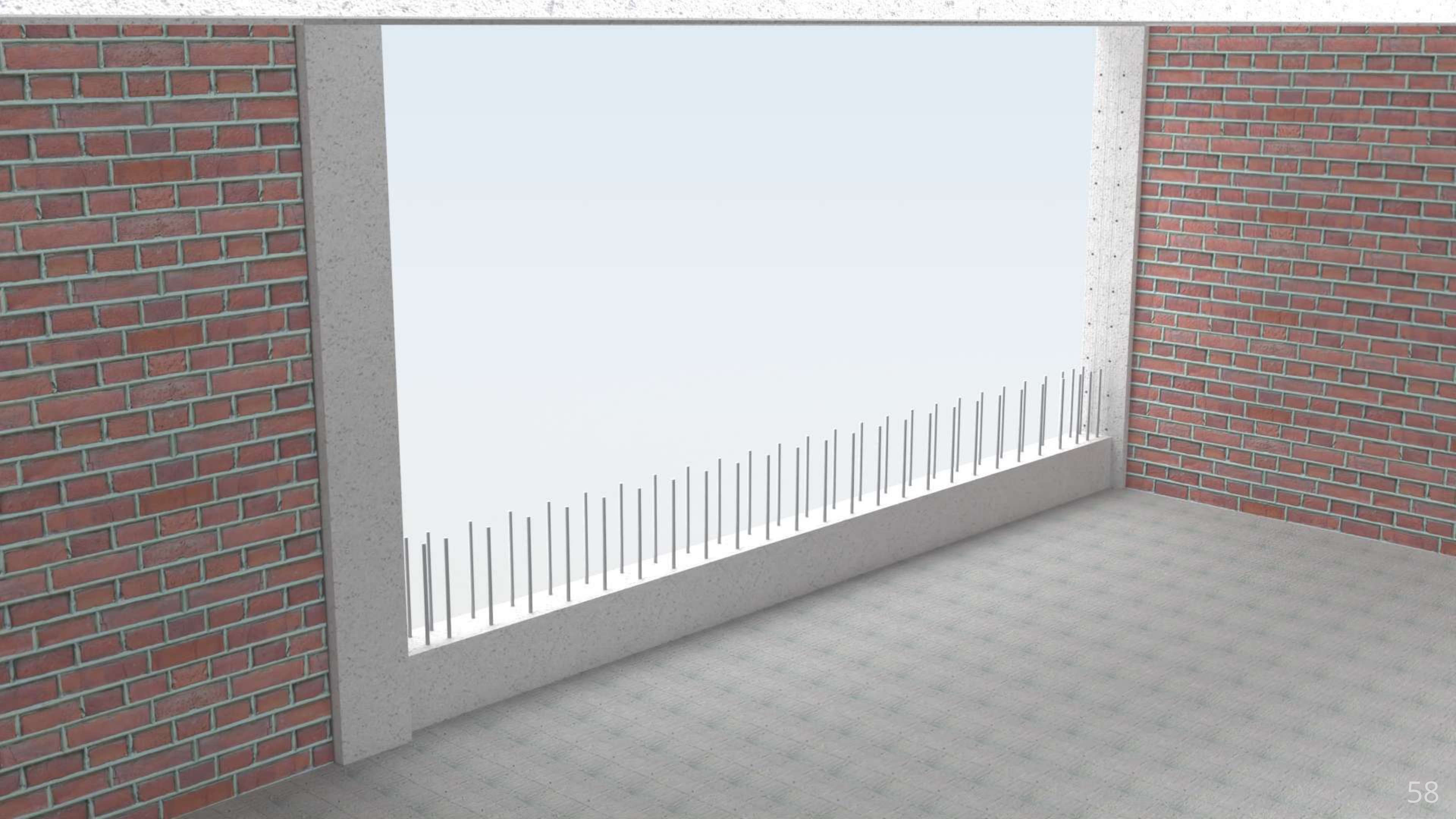
Current vs Retrofitted Situation - Column jacketing

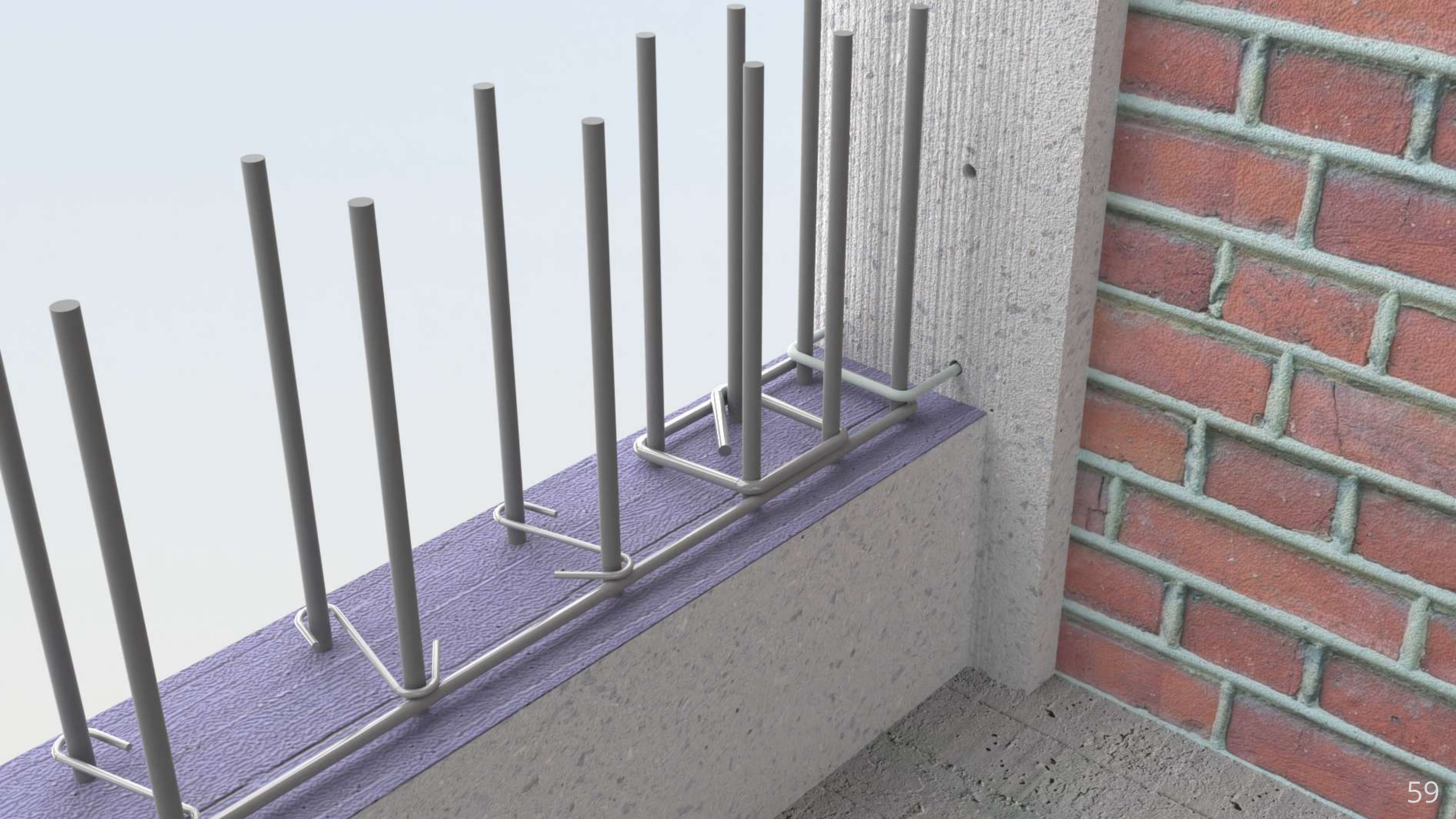
Integration: Fixing The Issue With Waste

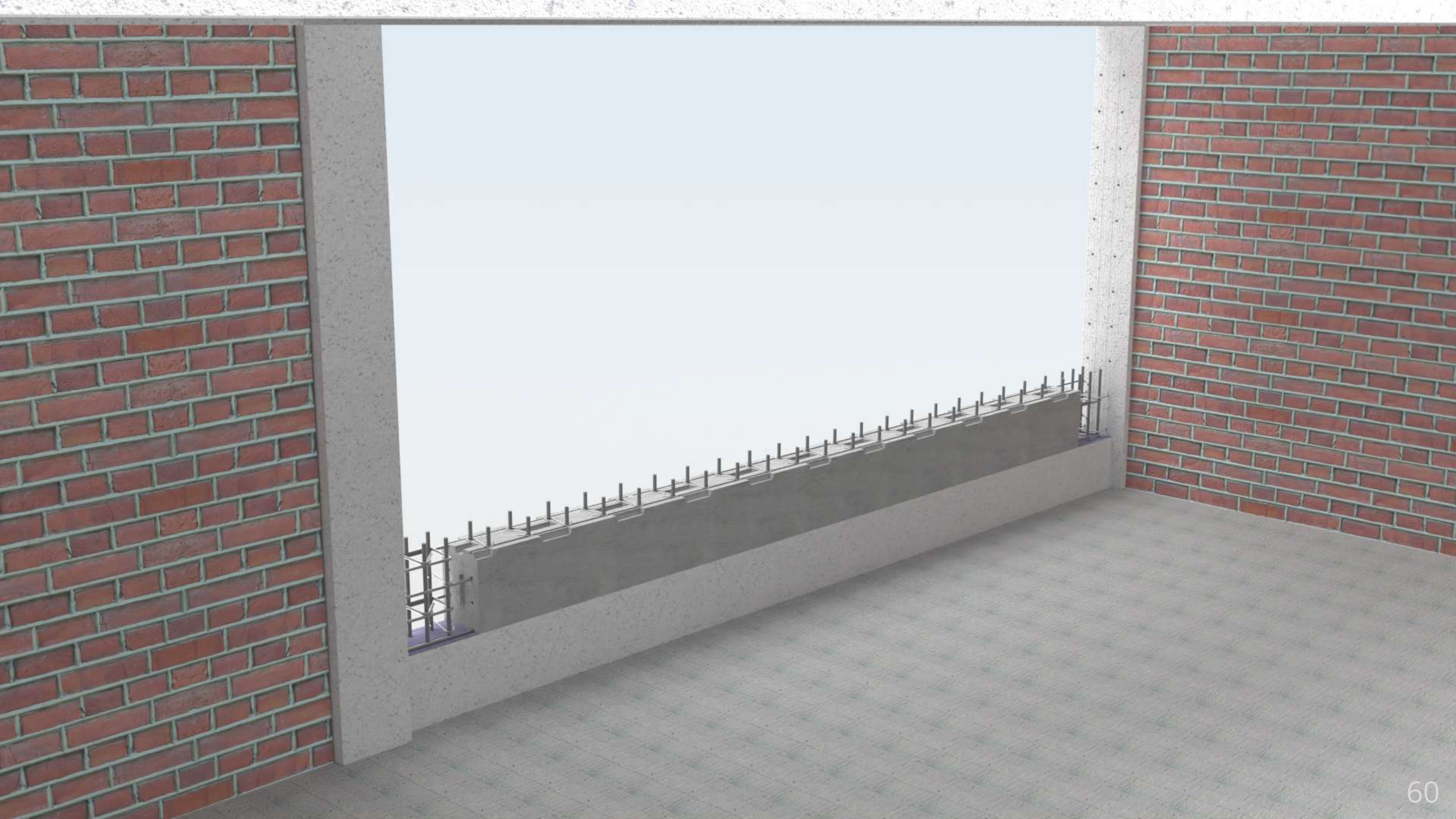




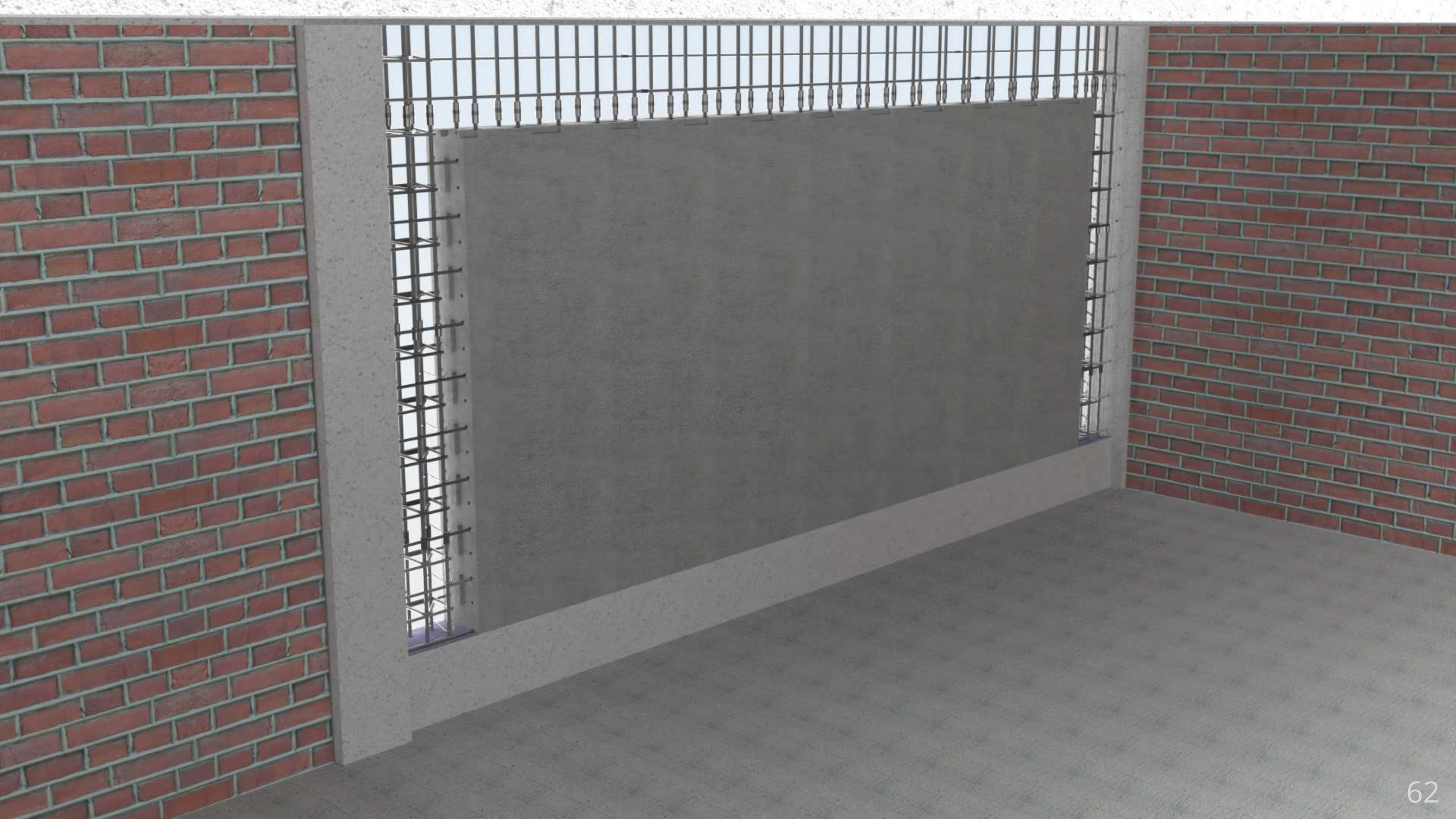






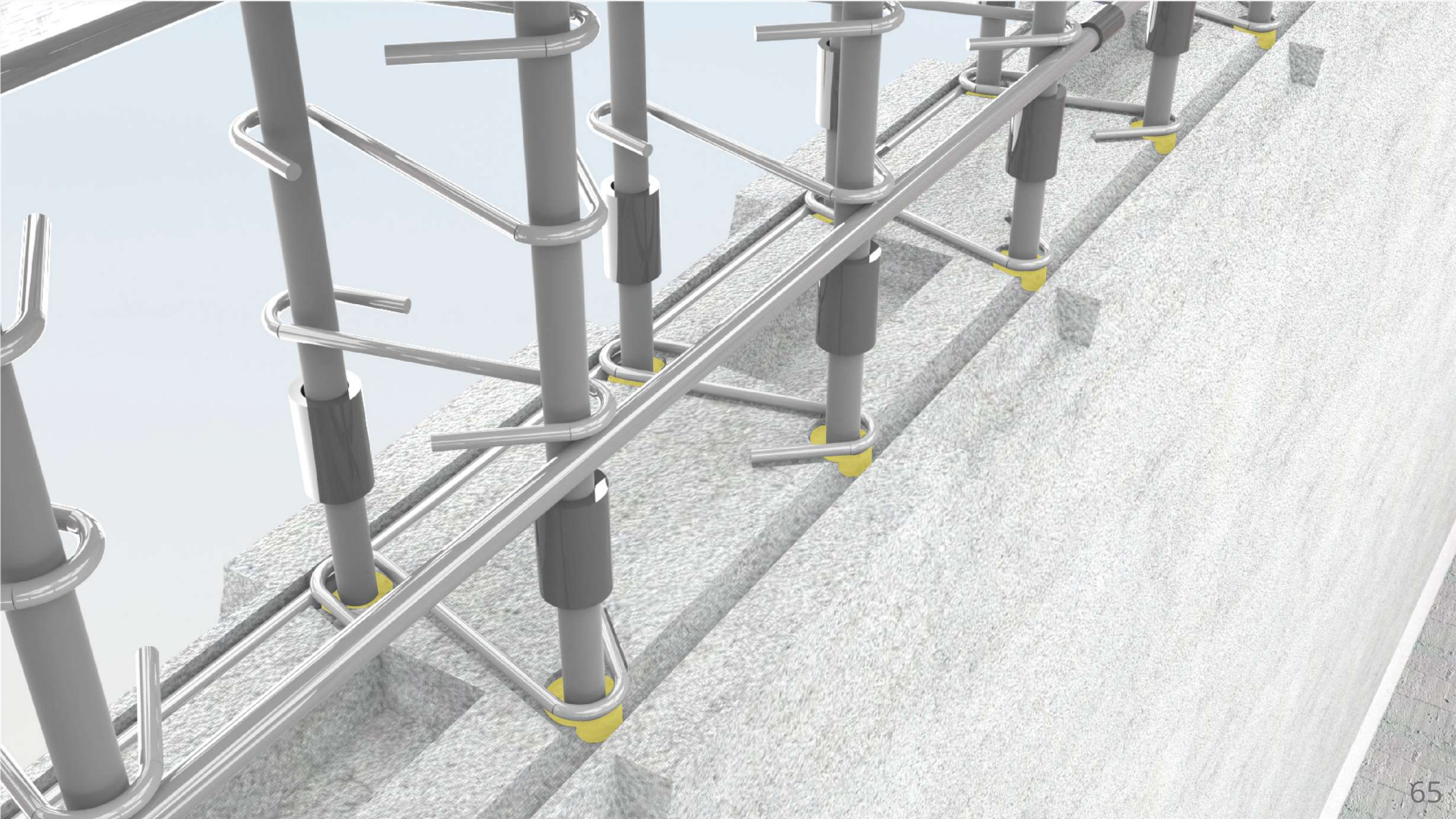


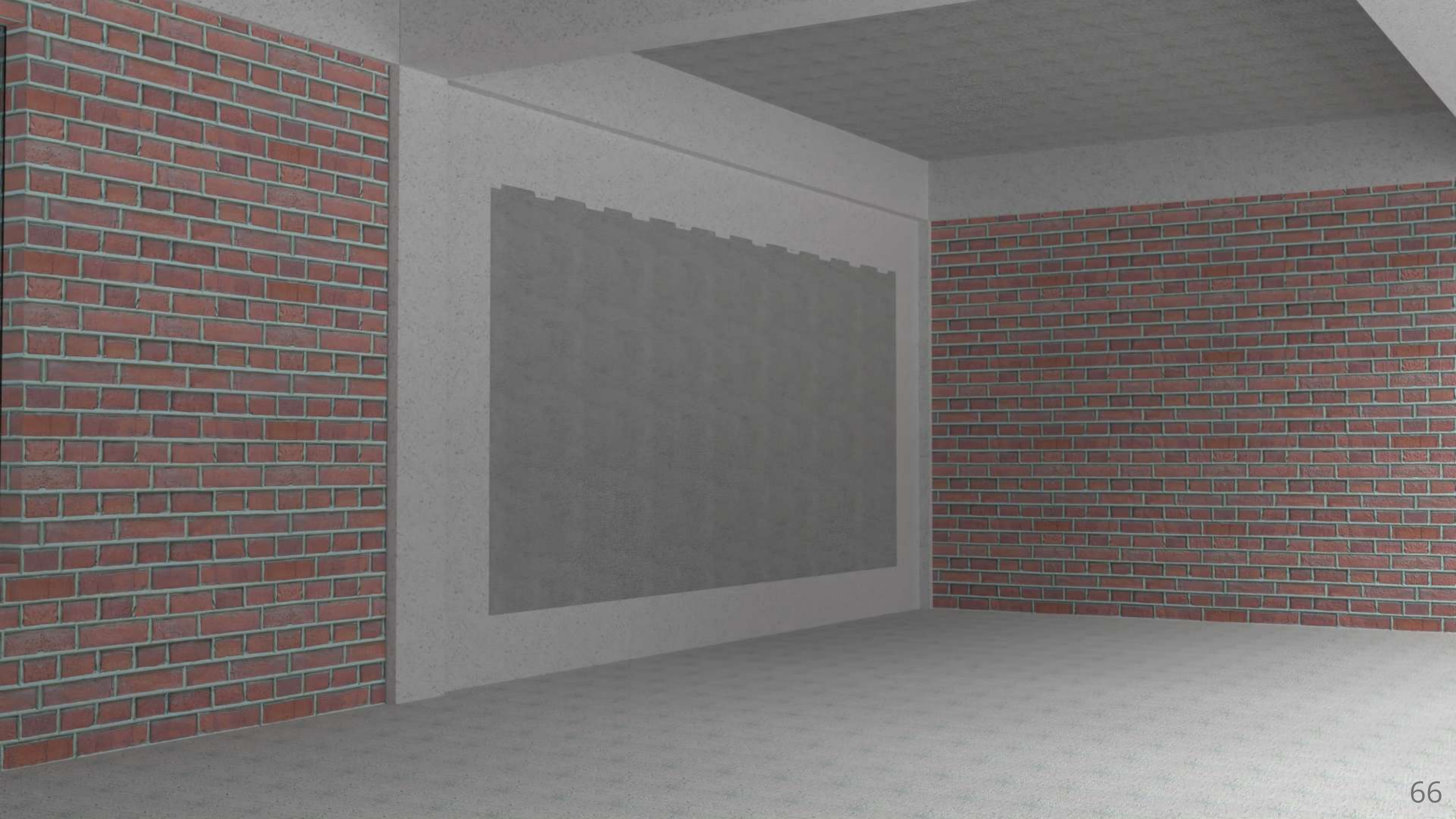













Current vs Retrofitted Situation - Shear wall

Integration: Fixing The Issue With Waste



An aerial, high-angle photograph of a city street grid, showing a dense pattern of buildings and streets. The image is faded and serves as a background. In the lower center, a small, dark silhouette of a person is walking across a street.

Act 7 - Creating Resilience

Step 5: Retrofit Strategy Selection

Creating Resilience

Engineer Input



Modelling/
visualisation

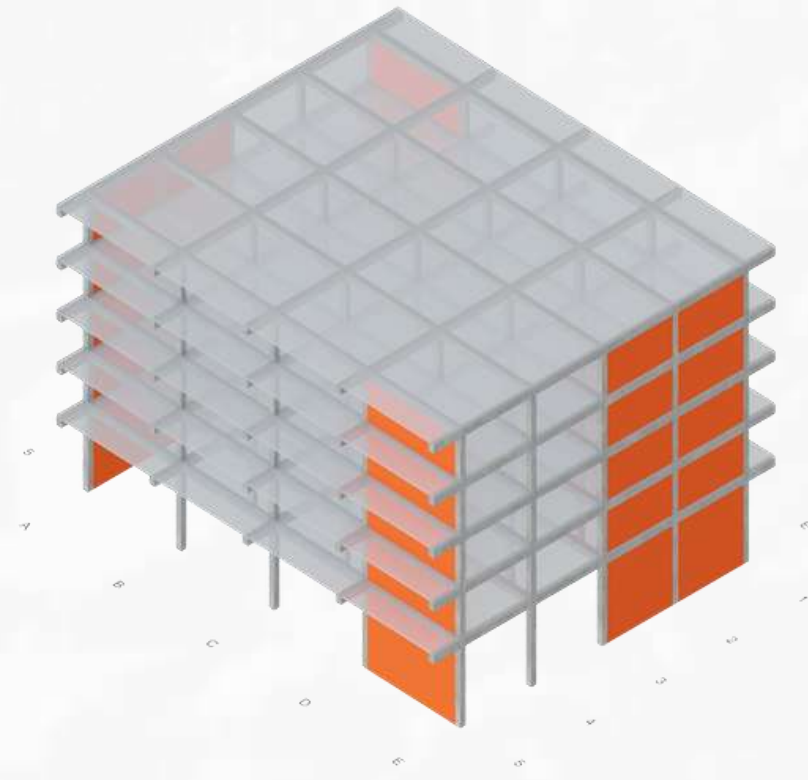
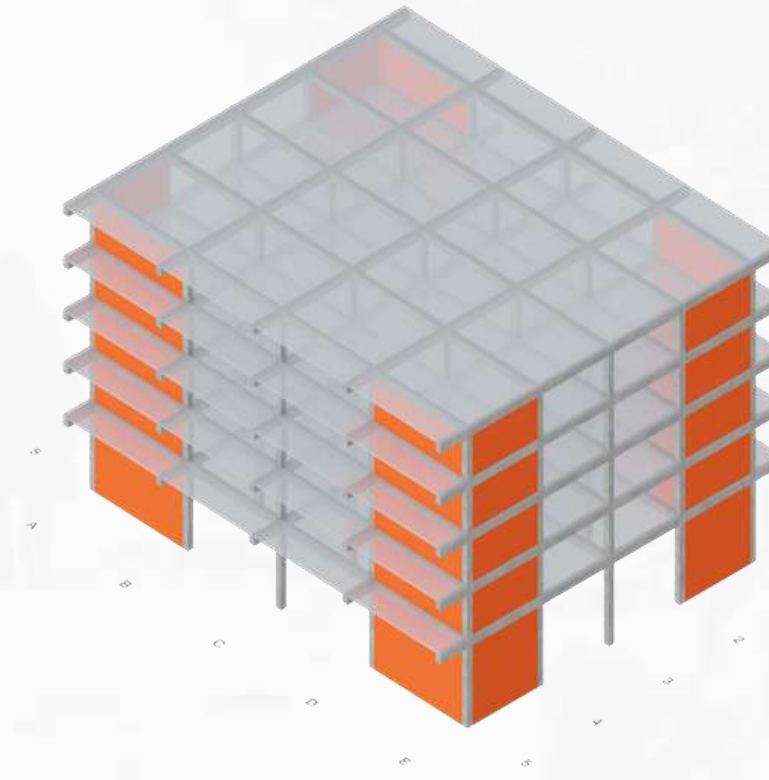
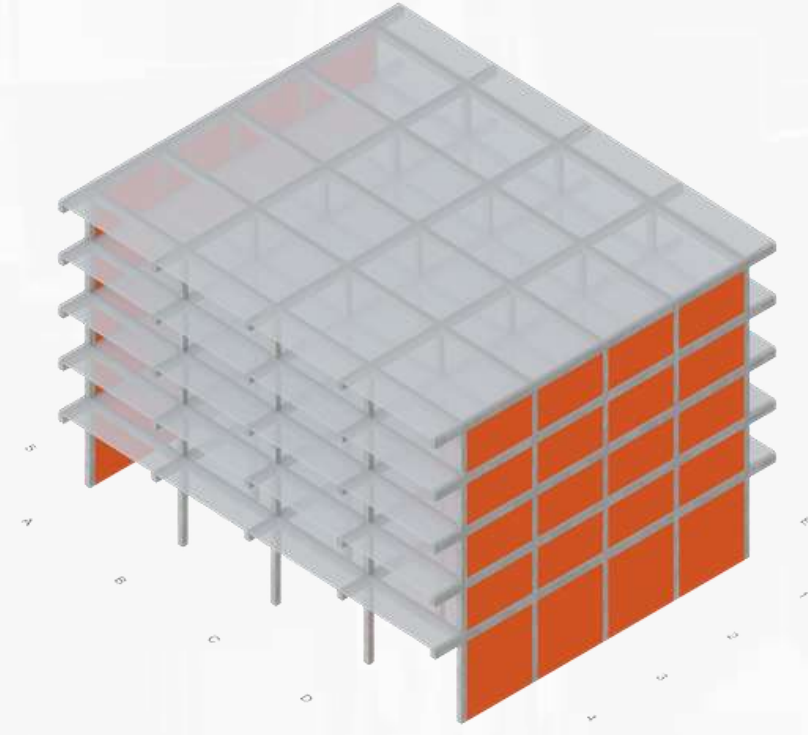
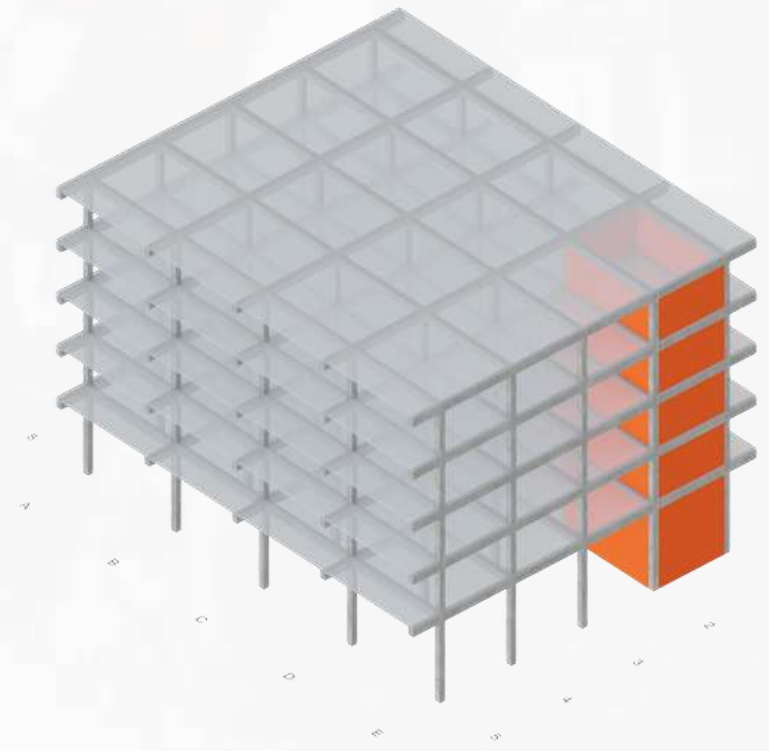


Parametric
"coding"

Application of retrofit strategy

- Shear wall options
 - 1. Building core
 - 2. Around perimeter (X-, Y- or both directions)
 - 3. At building corners
 - 4. Free choice
 - The engineer can decide their own strategy

- Additionally decides
 - Vertical continuity
 - Shear wall thickness
 - Reinforcement data



Step 5: Retrofit Strategy Selection

Creating Resilience

Engineer Input



Modelling/
visualisation

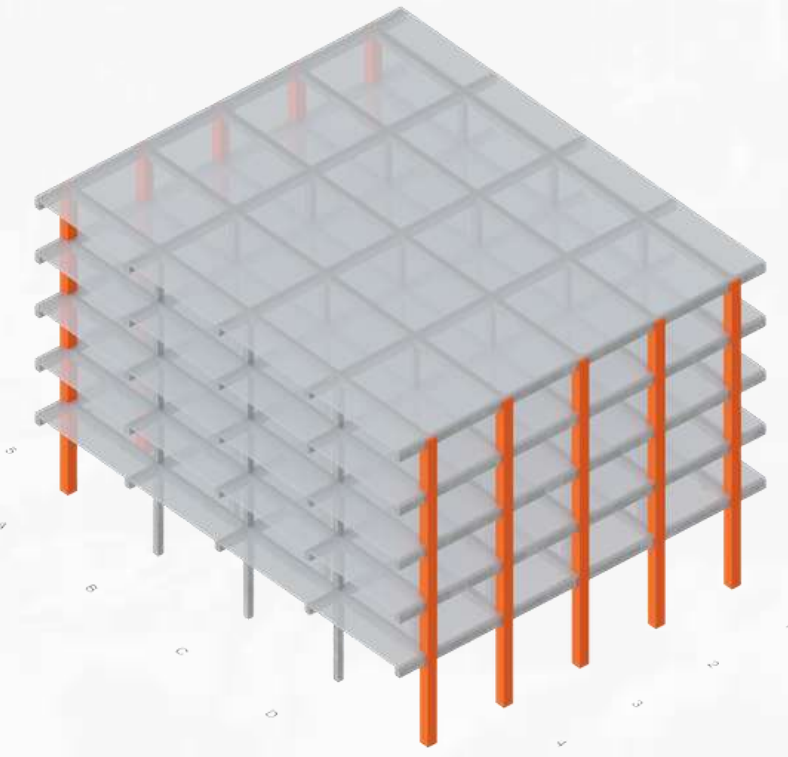
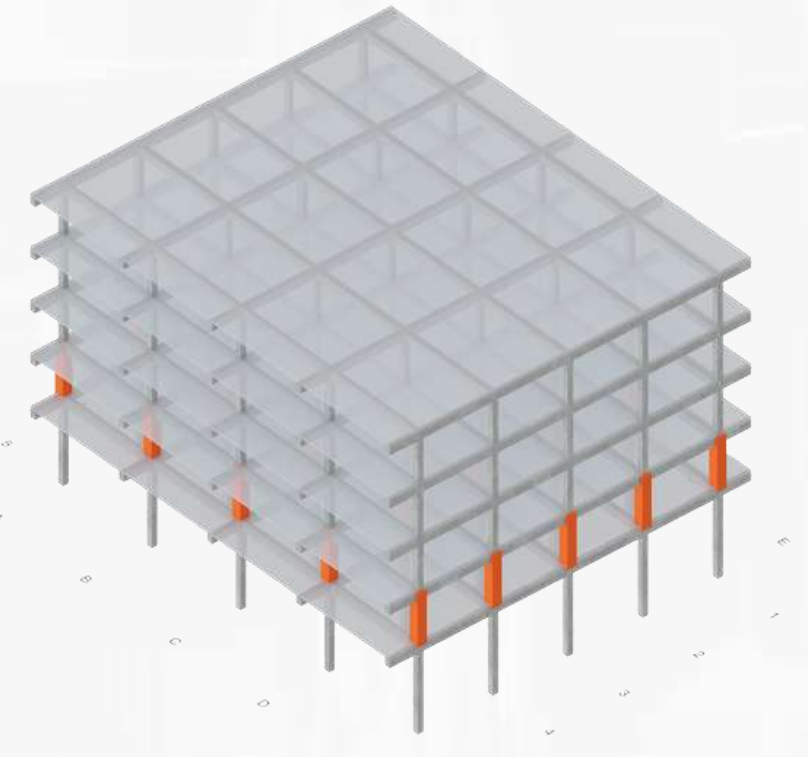
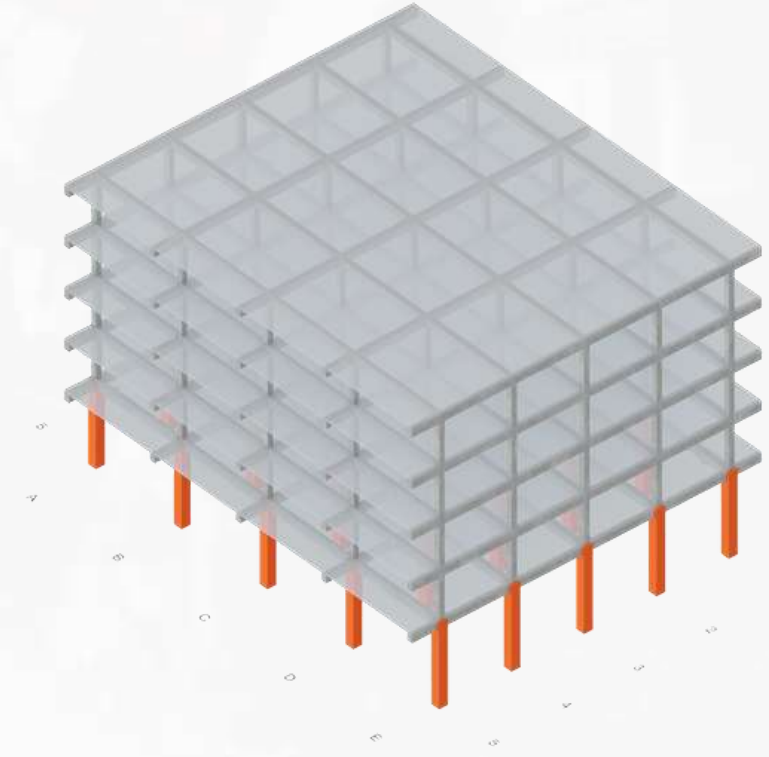


Parametric
"coding"

Application of retrofit strategy

- Column jacketing options
 - 1. Ground floor only
 - 2. Selection of one of the upper floors
 - 3. Free choice
 - The engineer can decide their own strategy

- Additionally decides
 - Block thickness
 - Reinforcement data

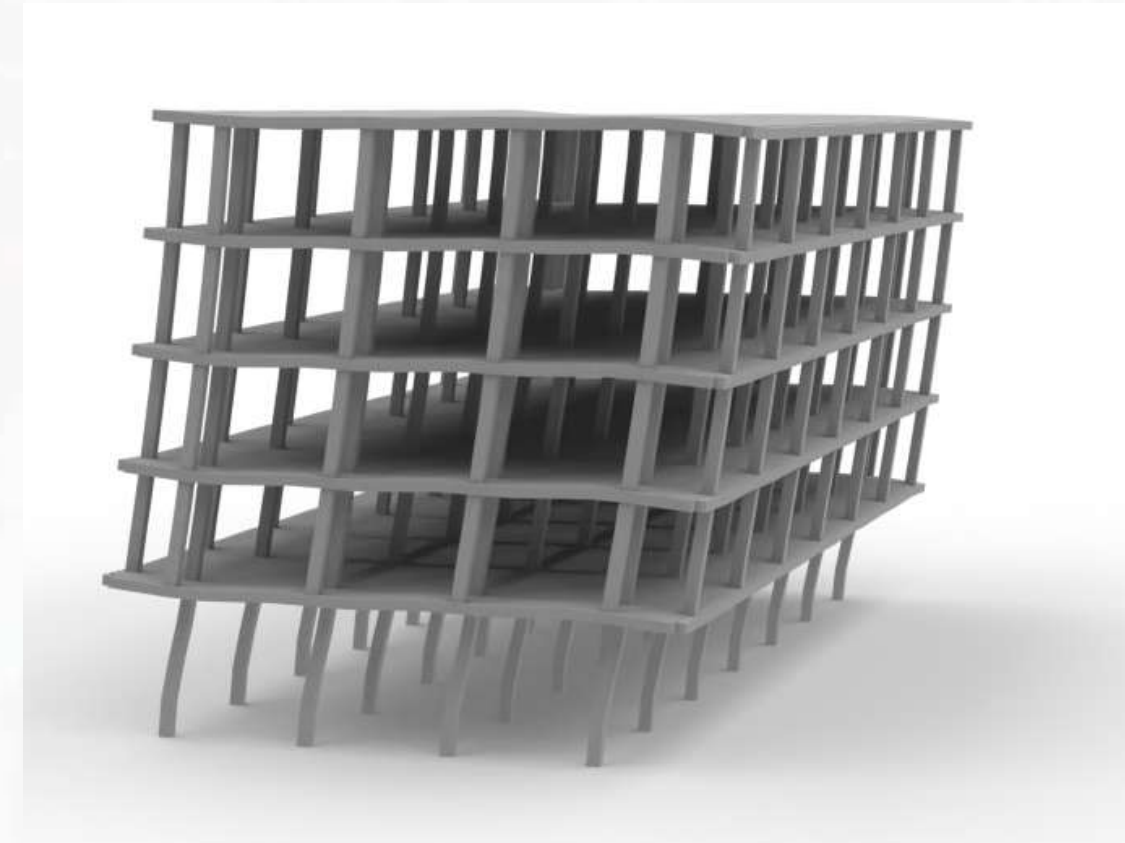


Step 5: Retrofit Strategy Selection for Case Sstudy

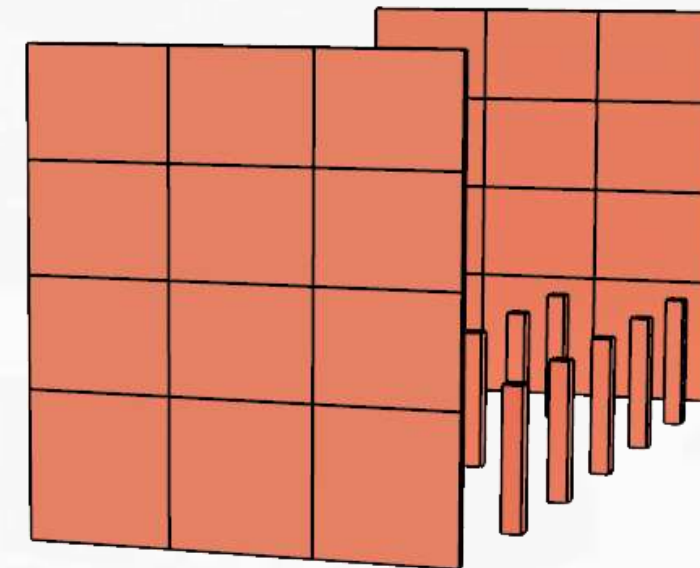
Creating Resilience

Application of retrofit strategy

- Chosen strategy
 - Column jacketing on ground floor
→ Counters soft-storey and column shear failure
 - Shear walls along X-perimeter (4 storeys high)
→ Decreases interstorey drift demand



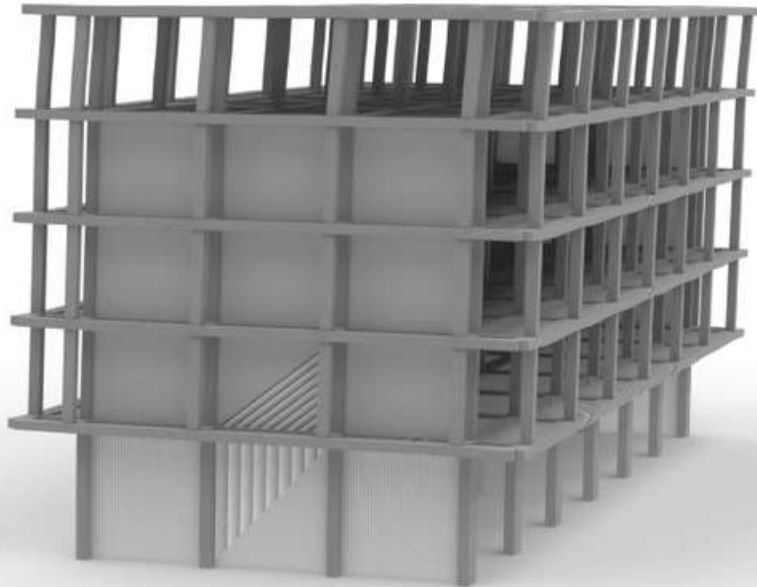
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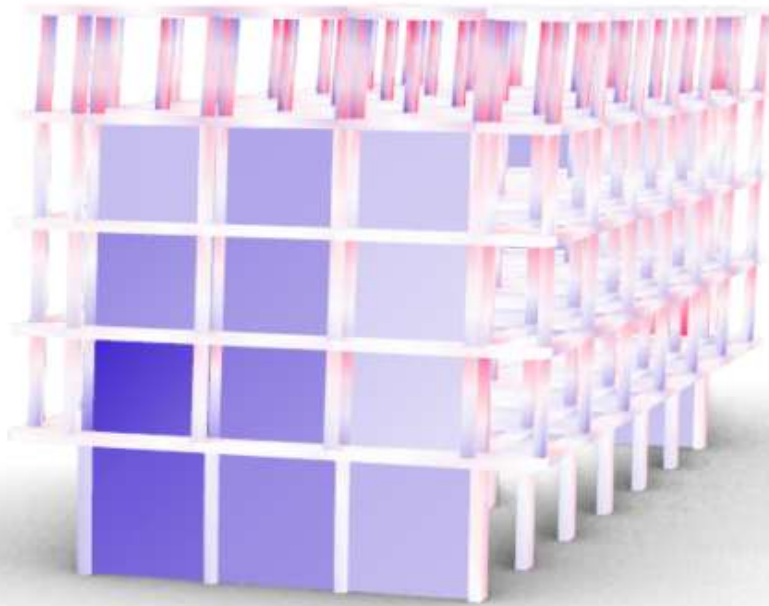
Step 6: Seismic Analysis - Retrofitted Situation

Creating Resilience

Automated!



Visualisation of the building's reaction under an earthquake

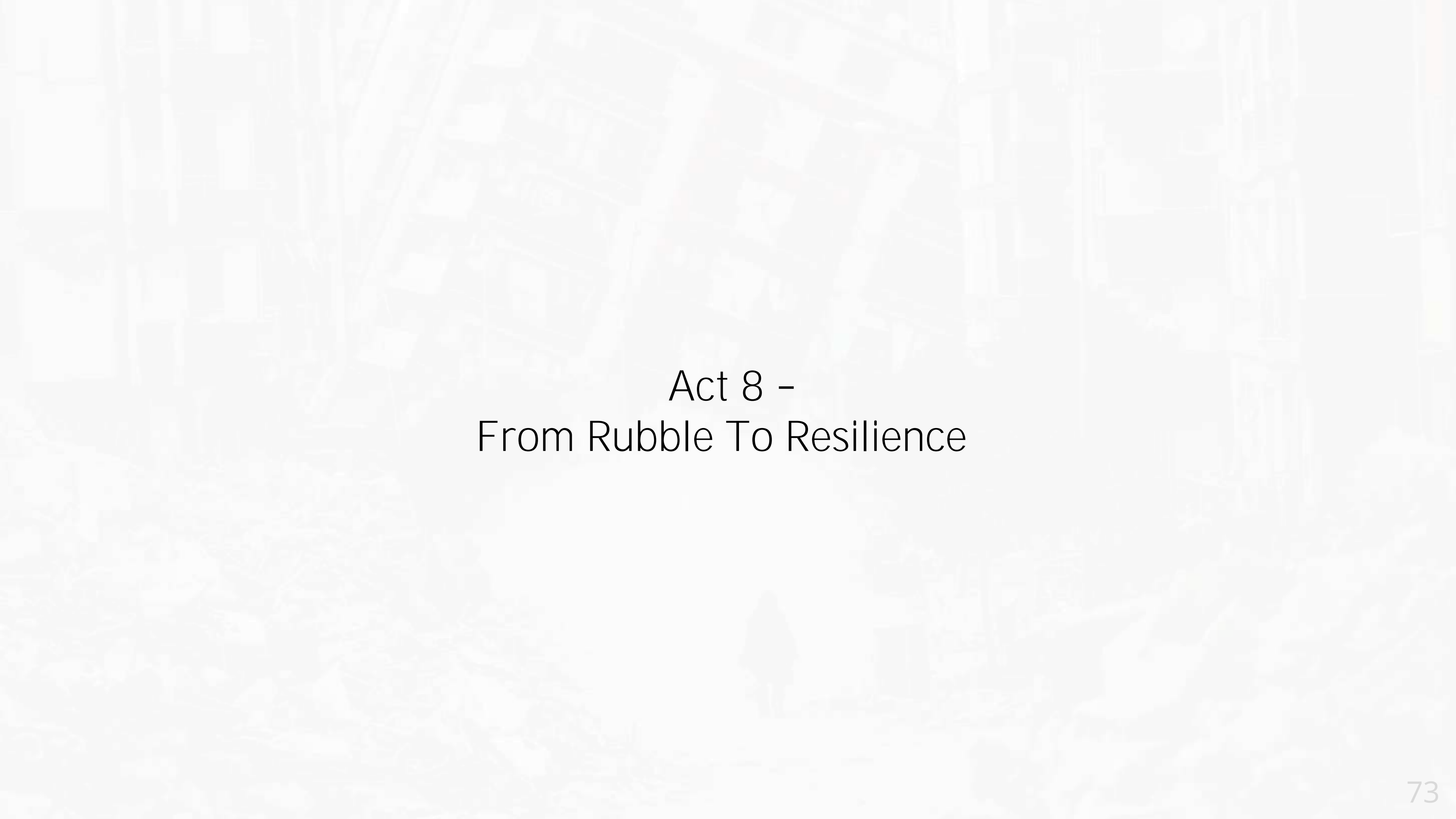


3D stress model of the building



Post-retrofit capacity check – collapse mechanism mostly resolved

Unity check values (ULS_1)		
Parameter	Unity check value	PASS/FAIL
Columns - Shear (V_z/V_y)	0.07	PASS
Columns - Moment (M_z/M_y)	0.13	PASS
Columns - Axial (compr./tens.)	0,18 / 0,467	PASS / PASS
Columns - Biaxial moment	0.15	PASS
Beams - Shear (V_z/V_y)	1,38	FAIL
Beams - Moment (M_z/M_y)	0,66	PASS
- Axial (compr./tens.)	0,10 / 0,37	PASS / PASS
Interstorey drift in X-direction	0,78	PASS
Interstorey drift in Y-direction	0,73	PASS



Act 8 -
From Rubble To Resilience

From Question to Framework:

From Rubble To Resilience

- How it started
 - Earthquake risk: urgent, but assessment is slow
 - Construction and demolition waste: abundant, but underused
 - Demand and supply: separate workflows
- What has been done?
 - Early-stage typology-based parametric workflow → Rapid vulnerability screening and retrofit design
 - Retrofit products from recycled aggregates
 - Virgin aggregate reliance: ↓ ~38% for column jacketing
↓ ~31% for shear wall implementation

Key conclusion:

A typology-based workflow can support rapid seismic vulnerability screening and resource-aware retrofit design as a streamlined process.

The background is a faded, grayscale image of a city street. It shows multi-story buildings with windows and a person walking in the distance. The overall tone is light and desaturated.

The End

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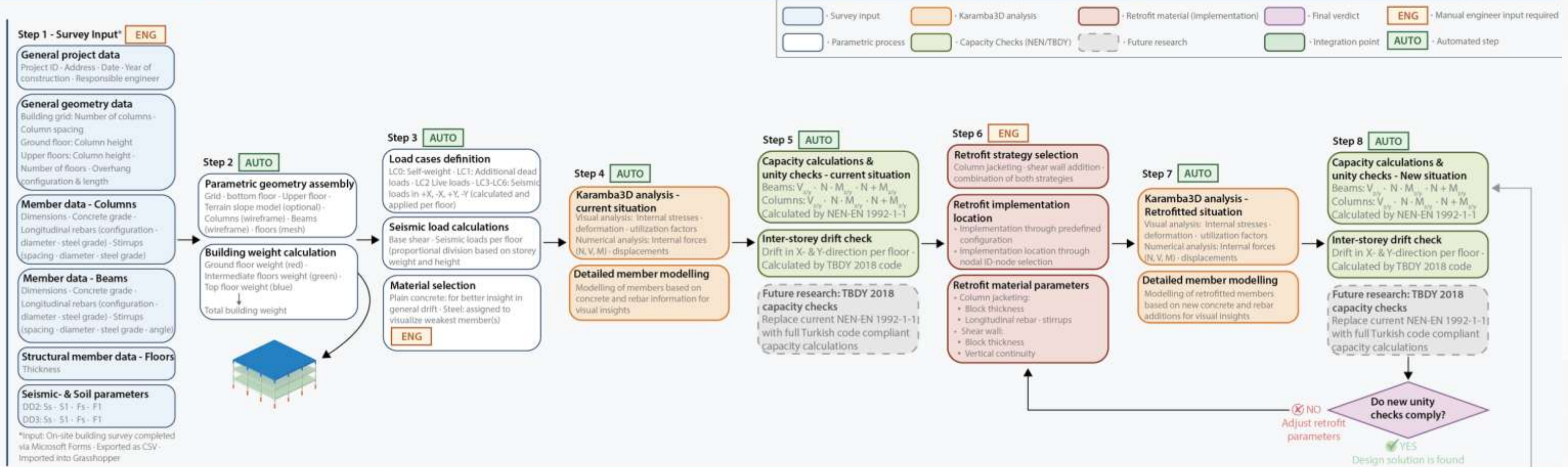
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Limitations and Future research

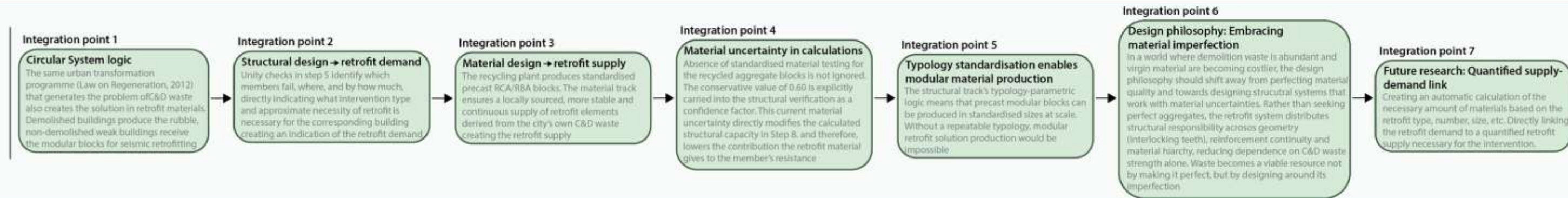
Appendix

- Limitations
 - Early-stage design tool, not final verification
 - Modular blocks need lab testing
 - Cost feasibility uncertain
- Future research
 - Full-scale testing of recycled aggregate retrofit blocks
 - Turkish-code-based capacity checks
 - Direct quantification of retrofit demand
 - Addition of new retrofit strategies (e.g. steel bracings)

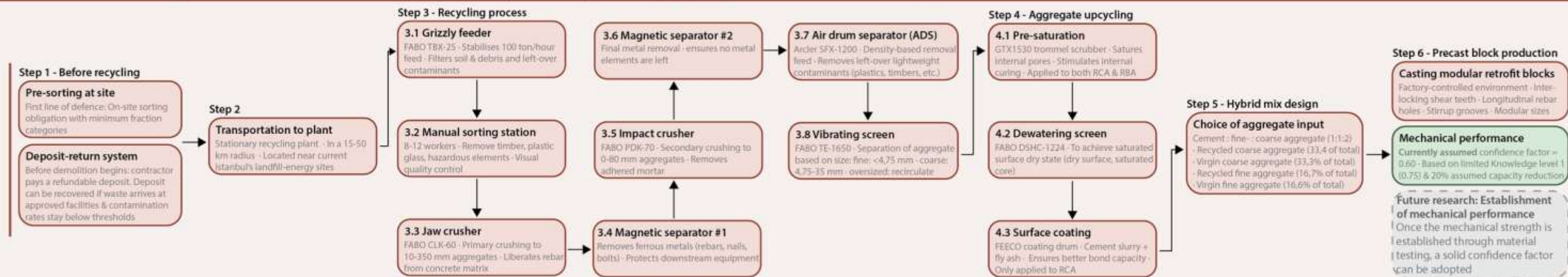
Structural Design Track - Parametric seismic assessment & retrofit workflow (Grasshopper + Karamba3D)



System integration - Demand meets supply



Material Design Track - C&D waste recovery & recycled aggregate retrofit block production



From Assessment to Retrofit: A Parametric Workflow for Seismic Evaluation

