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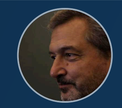
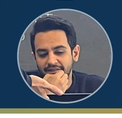
Automated Seismic Assessment and Cost-Optimal Retrofit of 2D RC Frames

An open-source OpenSeesPy framework that builds, verifies and retrofits reinforced-concrete frames end-to-end — from Eurocode load combinations to a cost-minimising search over shear-wall layouts and concrete jacketing.

Politecnico di Torino



Prof. Giuseppe Carlo Marano
Full Professor of Structural Engineering
Deputy Director, DISEG · Politecnico di Torino



Arman Hajiha, PhD
Research Assistant
DISEG · Politecnico di Torino

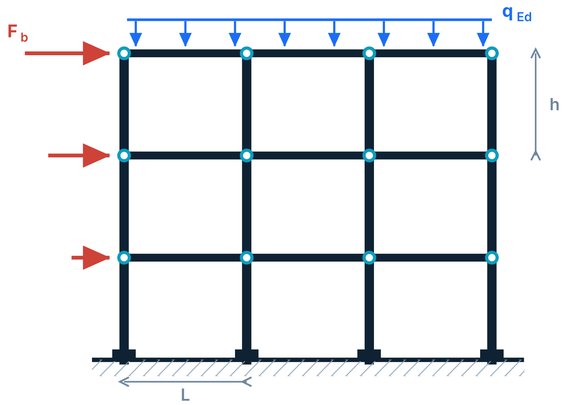
01 The problem

Much of Europe's reinforced-concrete building stock predates modern seismic codes. Assessing it is laborious; **choosing how to retrofit it is worse** — engineers compare a handful of hand-built alternatives and rarely know whether a cheaper compliant solution exists.

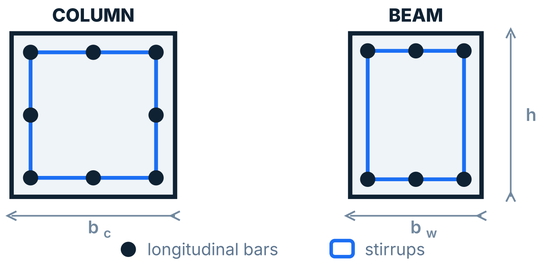
This code turns that comparison into a **reproducible, automated search**. A planar RC frame is generated, verified against Eurocode 2 and 8, then retrofitted by an optimiser that treats **total retrofit cost as the objective** and code compliance as hard constraints.

02 Model generation

Frame, sections, loads and code combinations are all built programmatically — no manual pre-processor, so an entire building stock can be swept in a loop.



Schematic. Nodes, elements, support fixity, gravity line loads and the lateral force pattern follow from bay / storey input; shear-wall panels may be declared at any bay and level.



Sections are picked from a parametric library; the same description drives the **EC2 capacity check** and, later, the jacketed cross-section used after retrofit.

03 Actions & combinations

SW	Self-weight from element geometry and concrete density
G	Permanent superimposed line loads, per storey
Q	Imposed loads with EN 1990 ψ factors
W+ / W−	Lateral actions in both signs

Combinations are assembled to **EN 1990** and **every one is solved**, so verification is driven by a full envelope rather than a single assumed governing case.

FRAMEKIT — MODULE MAP

MODEL	geometry · section_library · loads · combinations · walls · units
ANALYSIS	opensees_model · static_analysis · diagrams · dynamics · response_spectrum · time_history · planar_directions
VERIFY	ec2_checks · ec8_drift_checks · performance_summary
OPTIMISE	retrofit_recommendation · retrofit_optimizer
REPORT	retrofit_optimization_report · plotting

04 Analysis pipeline

MODEL

- **Geometry & RC sections** — Bays, storeys, beam / column section library
- **Load cases** — SW · G · Q · W+ · W−, self-weight computed
- **EN 1990 combinations** — Generated in full, each one solved

LINEAR ANALYSIS

- **OpenSeesPy static solve** — Displacements, storey drifts, N / V / M recovery
- **Mass & modal analysis** — Floor masses, eigenvalues, participation factors
- **EC8 response spectrum** — Modal combination + 100 / 30 directional rule
- **Linear time history** — Multi-record batch, Rayleigh damping, envelopes

VERIFICATION

- **EC2 member checks** — N–M interaction and shear → utilisation η
- **EC8 drift limits** — Damage-limitation check with reduction factor ν
- **Performance summary** — Failing storeys and failing members, tabulated

OPTIMISE

- **Global retrofit search** — Wall layouts × thickness × jacketing sets
- **Cost-ranked strategies** — Each re-verified to EC2 & EC8 before ranking

OUTPUT

- **Reports & dataset** — Excel workbooks, Word report, ML-ready CSV

Each stage is a separate **framekit** module and can be driven on its own — the optimiser simply calls the same verification code an engineer would run by hand.

KEEPING A FULL RUN TRACTABLE

A complete search re-analyses and re-verifies every candidate, so the user chooses how many screened wall layouts are promoted into the expensive global stage. The exhaustive sweep stays available for dataset generation; the default run finishes in a working session.

05 Eurocode verification

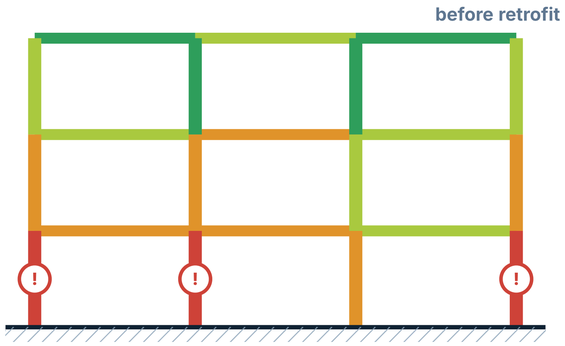
Demands recovered from OpenSeesPy are checked member by member, for **every ULS combination**, and reduced to a single worst-case utilisation table.

- **EC2 — members.** Axial–bending interaction and shear capacity, including stirrup provision, giving η per element.
- **EC8 — storeys.** Inter-storey drift against the damage-limitation limit, for both the single-direction and the 100/30 directional envelope.
- **Dynamics.** Response-spectrum and multi-record time-history drift envelopes feed the same performance tables.

Member utilisation $\eta = E_d / R_d$

0.0 — 0.25 — 0.50 — 0.75 — 1.00

Colour-coded onto the frame and into Excel — **$\eta > 1$ → member fails**



Schematic. Worst-case η mapped onto the frame; members marked **!** exceed EC2 capacity and are handed to the optimiser — ground-storey columns govern, the usual soft-storey signature.

06 Retrofit optimisation

Rather than checking one proposed intervention, the tool searches complete strategies and returns the **cheapest one that satisfies every check**.

$$\begin{aligned} &\text{minimise} \\ &\quad C_{tot}(s) = C_{wall}(s) + C_{jacket}(s) \\ &\text{subject to} \\ &\quad \theta_{max}(s) \le \theta_{lim} \quad \text{(EC8 drift)} \\ &\quad \eta_i(s) \le 1 \quad \forall i \quad \text{(EC2 members)} \\ &\quad s \in S_{constructible} \end{aligned}$$

The decision vector s holds the **bay positions and vertical continuity of new shear walls**, their **thickness**, and the **set of members receiving concrete jacketing**. Awkward-to-build layouts are down-ranked through a constructability class, and excessive jacketing is penalised.

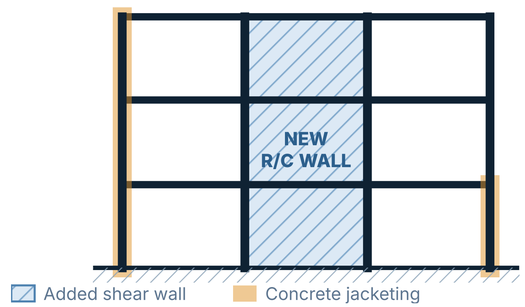
SEARCH PARAMETER	SETTING IN THE SHIPPED SCRIPT
t_w	150 / 200 / 250 / 300 mm
layout mode	hybrid vertical patterns
walls / layout	up to 2 segments
θ_{lim}	0.5 % of storey height
baseline	"no new wall" always evaluated

COST MODEL & SCOPE

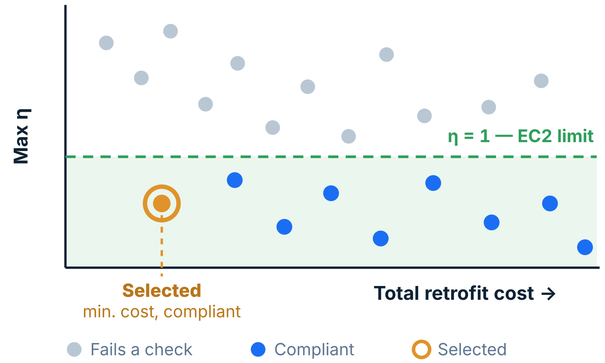
Unit rates for new walls and for jacketing are entered at run time, with documented defaults, so the ranking can be re-tuned to local prices without touching the analysis.

- Linear elastic analysis — no pushover or plastic-hinge modelling
- Planar idealisation; the orthogonal direction is covered by a cloned planar model under the EC8 100/30 rule
- Reported costs are only as good as the unit rates supplied

07 What the search returns



Schematic. A selected strategy — one new wall line, plus jacketing on the members that still fail once the wall is in place.



Schematic. Every candidate is fully re-analysed and re-verified, then ranked by cost; the top five alternatives are exported for the engineer to review.

08 Outputs

- Colour-coded **EC2 verification workbooks**, before and after retrofit
- Drift, modal, response-spectrum and time-history **result tables**
- A formatted **Word engineering report** carrying exact N/V/M diagrams recovered from the model at each retrofit stage
- A tidy **machine-learning dataset** of every evaluated strategy — groundwork for surrogate models that skip the expensive search

09 Get the code

ARCHIVED · ZENODO
doi.org/10.5281/zenodo.22812754

SOURCE · GITHUB
github.com/ArtISte-Research-Group/OpenseesPy-concrete-2D-frame-optimizer-

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