A BIM-BASED METHODOLOGY FOR THE SEISMIC PERFORMANCE ASSESSMENT OF EXISTING URM-RC BUILDINGS

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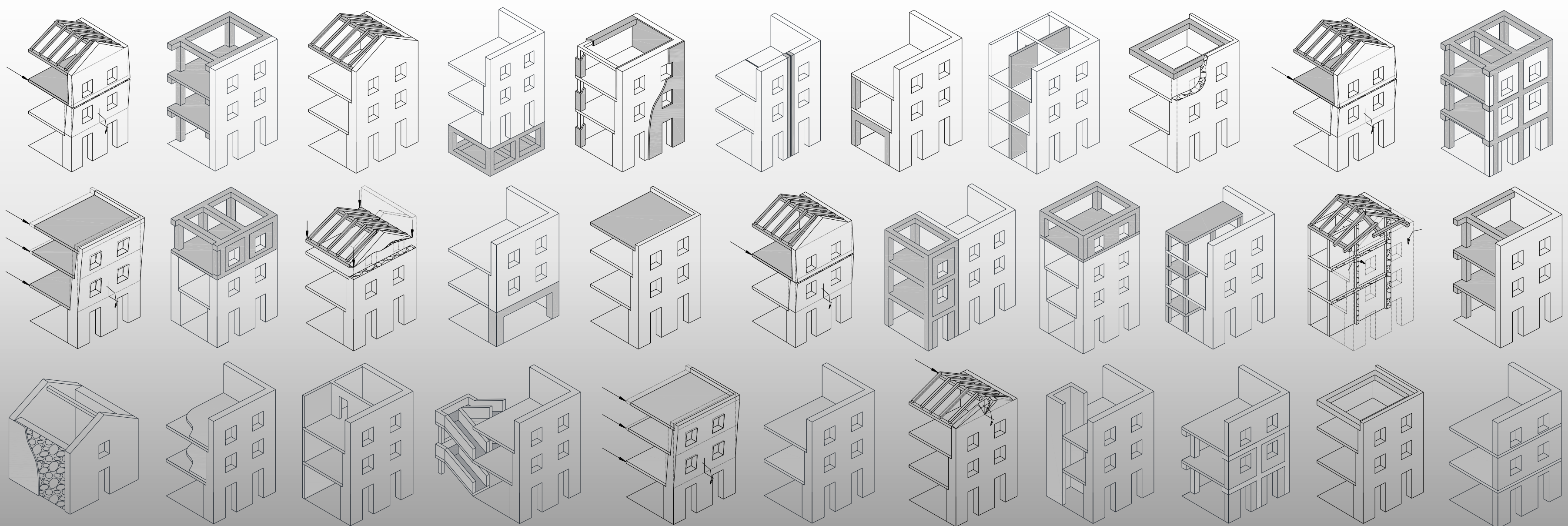
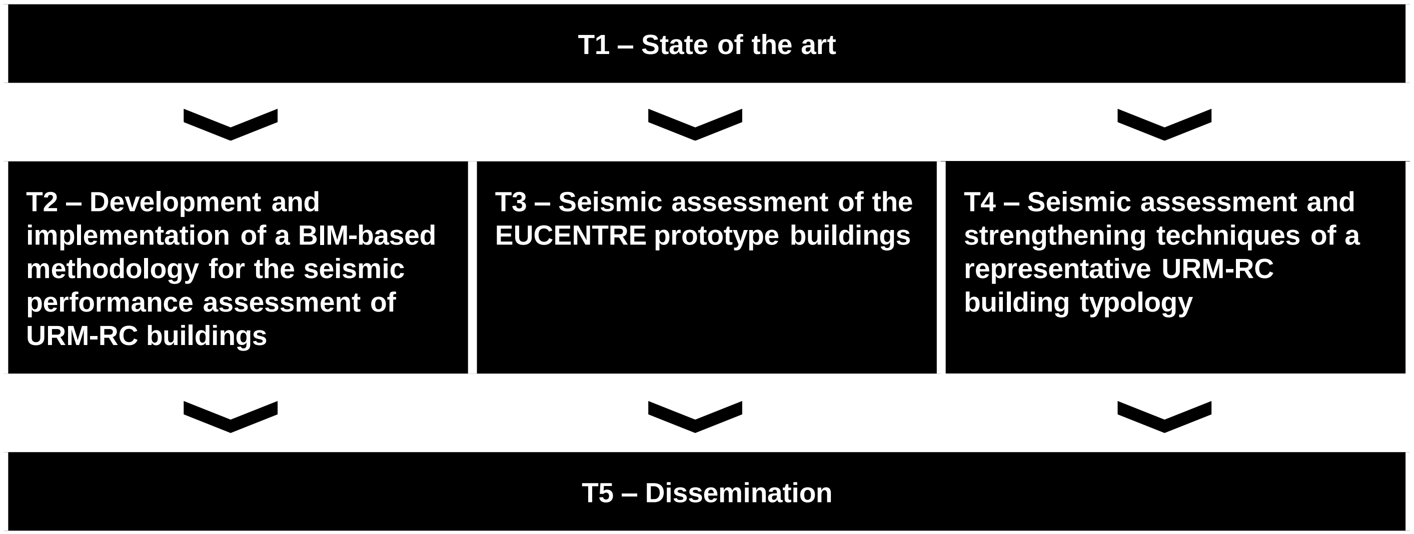


Presentation summary

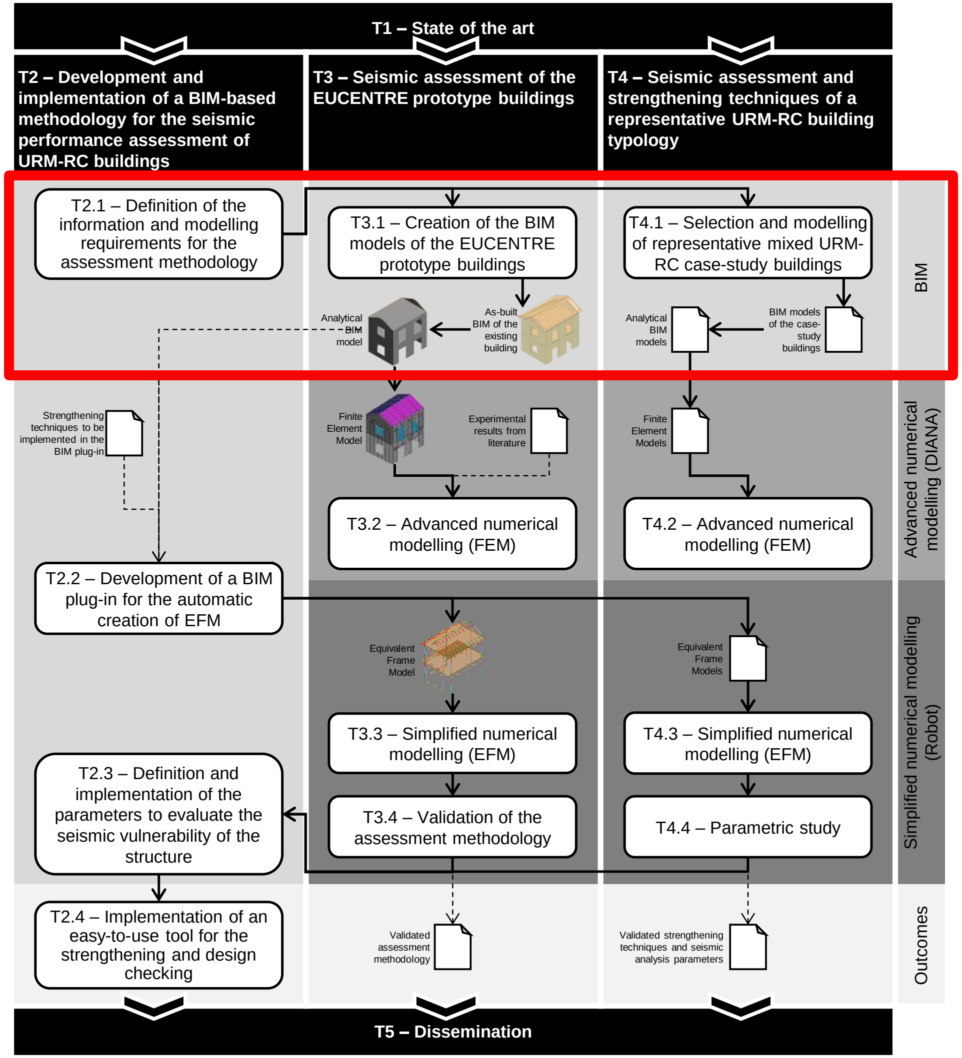
- **Planned tasks and research methodology**
  - Work done – Carried out research work
  - Work in progress – Ongoing tasks
  - Future work – Upcoming tasks

- **Thesis timeline and publications**

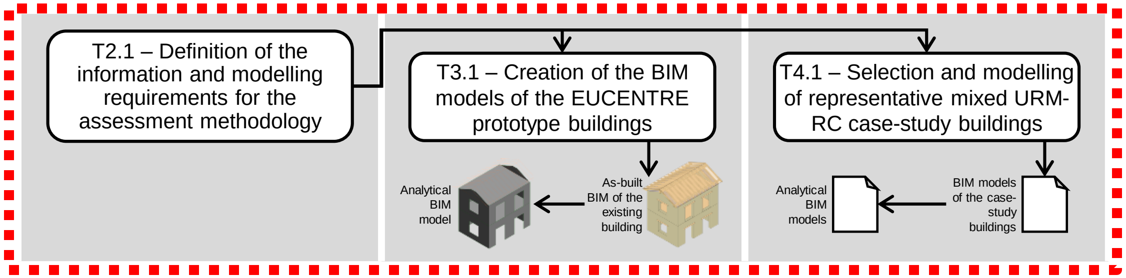
Tasks’ flowchart



Creation of the BIM models



Creation of the BIM models



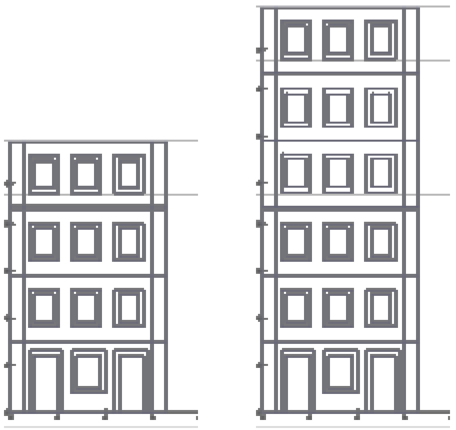
- ✓ Which building elements should be modelled (and how they should be modelled)
- ✓ Required level of detail (LOD)
- ✓ Required non-geometric attributes (material properties, boundary conditions, loads)

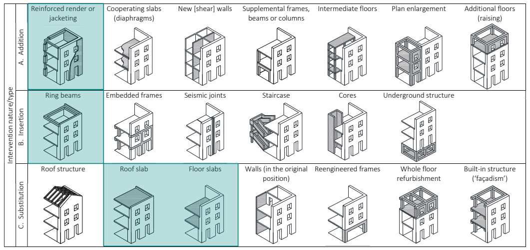
- ✓ EUCENTRE prototype buildings 1 and 3
- ✓ Software: Revit 2019
- ✓ BIM models are automatically converted to analytical 3D models (and exported to the structural analysis software)

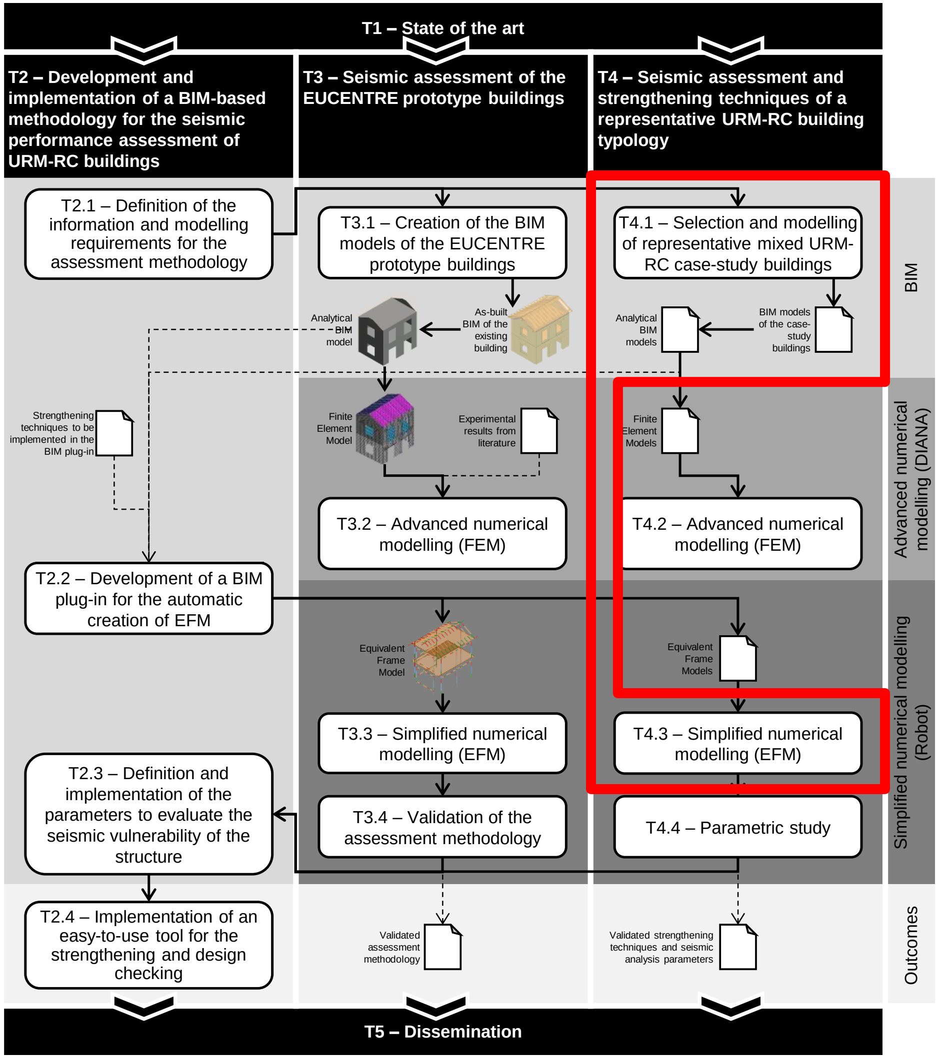
- Geometry, number of floors, openings, etc.
- Intervention typologies:
  - the **addition** of RC renders and/or jacketing;
  - the **insertion** of RC ring-beams at the top of external façade walls;
  - the **substitution** of timber floor diaphragms by RC slabs

Work done

Work in progress







Case study I – Seismic performance assessment of an existing URM-RC building

Case study I – Seismic performance assessment of an existing URM-RC building

T4.1 – Selection and modelling of representative mixed URM-RC case-study buildings

BIM models of the case-study buildings

T4.3 – Simplified numerical modelling (EFM)

- ✓ Creation of the BIM models (from point cloud)
  1. original URM building
  2. mixed URM-RC building (addition of a RC screed)
- ✓ Software: Revit 2019

- ✓ Ambient vibration testing
- ✓ Software: ARTeMIS

- ✓ Macro Element Modelling
- ✓ Software: 3DMacro
- ✓ Numerical model properties:
  - ✓ Geometry
  - ✓ Element type/class/data
  - ✓ Materials
  - ✓ Supports
  - ✓ Loads
  - ✓ Connections
  - ✓ Mesh
  - ✓ Analysis parameters

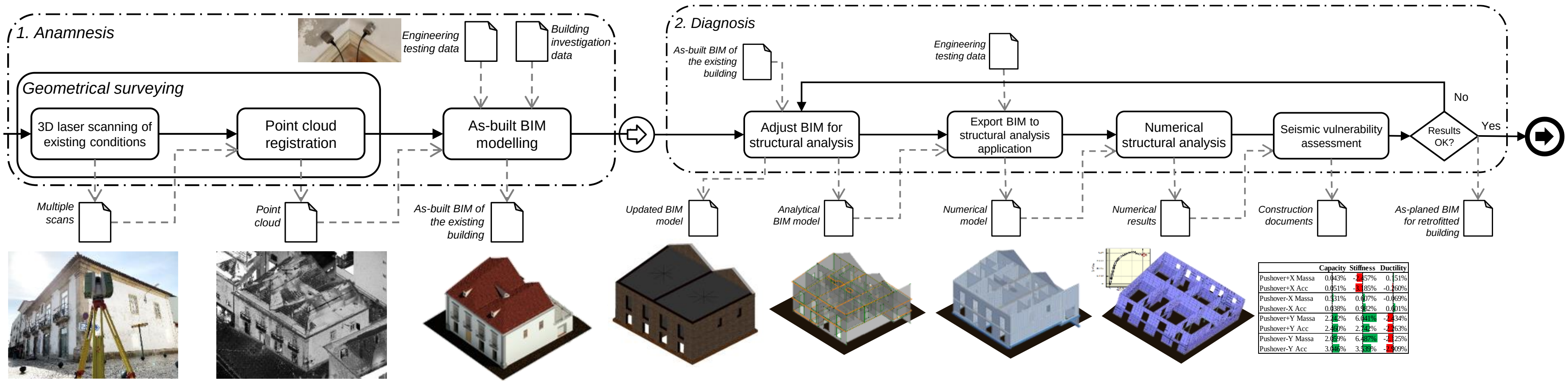
- ✓ Modal analysis
  - ✓ Calibration of the URM elastic properties (E, ν, ρ)
  - ✓ Calibration of the modal shapes and frequencies

- ✓ Pushover analysis
  - ✓ Comparisons of the results before and after the intervention

- Compare/validate the EFM
- Study the influence of other interventions with RC

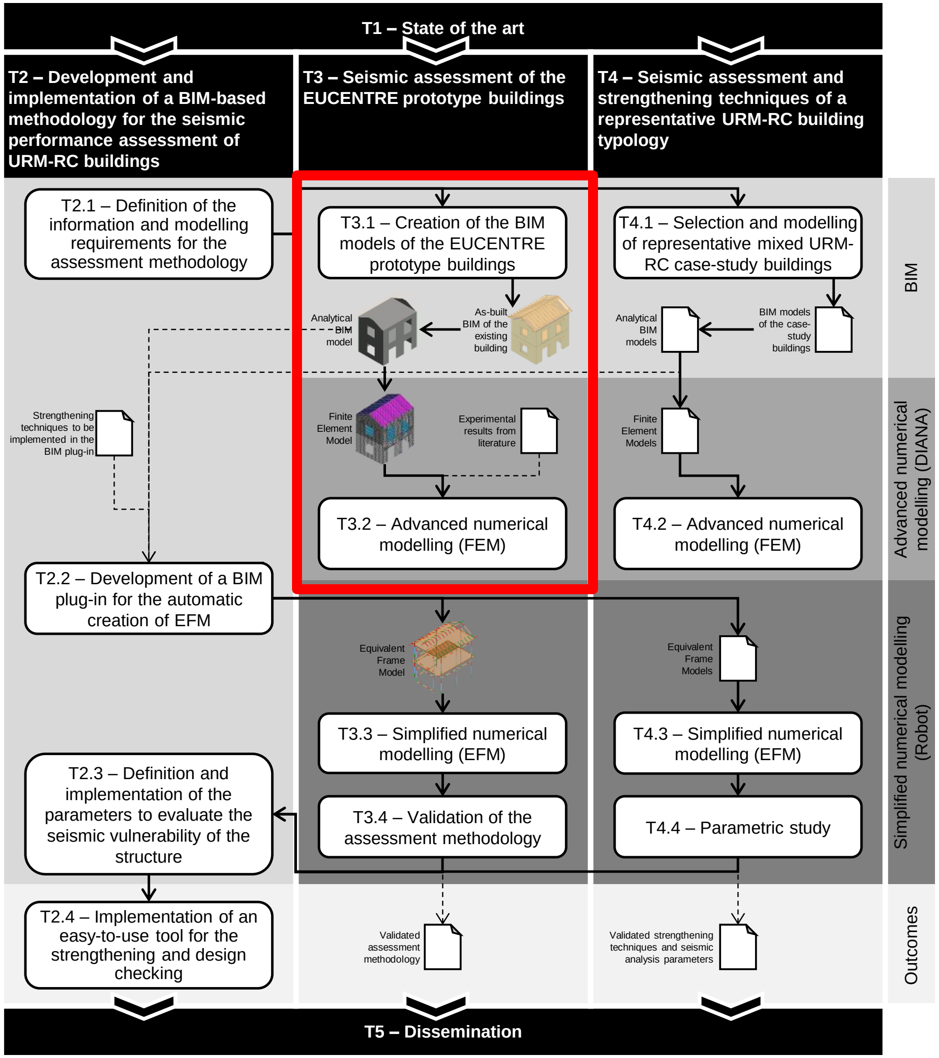
Work done

Future work

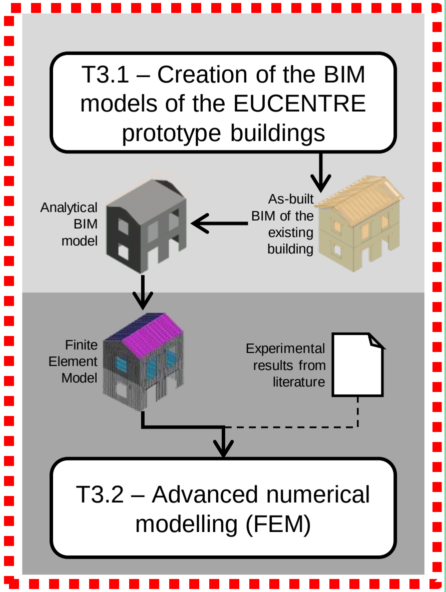


	Capacity	Stiffness	Ductility
Pushover+X Massa	0.043%	-2.457%	0.151%
Pushover+X Acc	0.051%	-3.185%	-0.260%
Pushover-X Massa	0.531%	0.607%	-0.069%
Pushover-X Acc	0.038%	0.982%	0.601%
Pushover+Y Massa	2.242%	6.041%	-2.434%
Pushover+Y Acc	2.460%	2.742%	-2.263%
Pushover-Y Massa	2.059%	6.487%	-2.125%
Pushover-Y Acc	3.046%	3.539%	-2.909%

Case study II – Validation based on EUCENTRE experimental results



Case study II – Validation based on experimental results



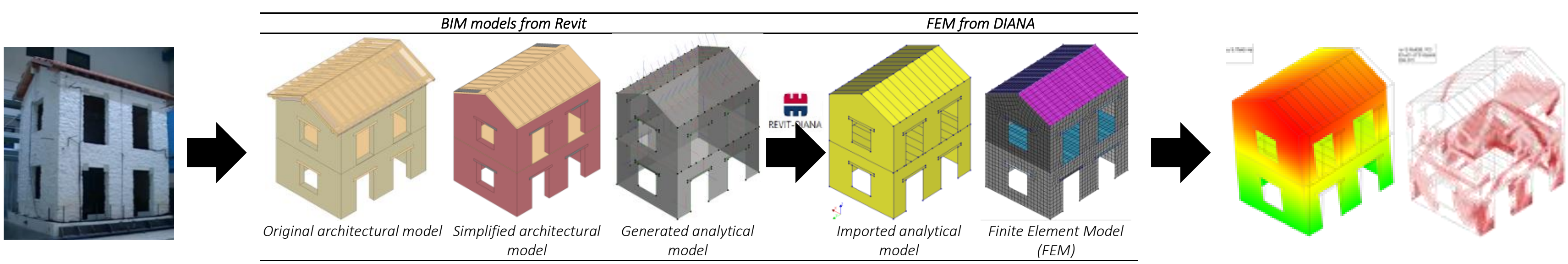
- ✓ Creation of the BIM models (from CAD)
  1. "**Building 1**" – original URM building
  2. "**Building 3**" – mixed URM-RC building (insertion of a RC ring beam and strengthened diaphragms)
- ✓ Software: Revit 2019
- ✓ Modelled information
  - ✓ Geometry
  - ✓ Material properties
  - ✓ Self-weights
- ✓ Analytical model (created automatically)

- ✓ Finite Element Modelling
- ✓ Software: DIANA v10.3
- ✓ Simplified physical model from BIM
- ✓ Numerical model properties:
  - ✓ Geometry
  - ✓ Element type/class/data
  - ✓ Materials
  - ✓ Supports
  - ✓ Loads
  - ✓ Connections
  - ✓ Mesh
  - ✓ Analysis parameters

- ✓ Modal analysis
  - ✓ Calibration of the URM elastic properties (E, ν, ρ)
  - ✓ Calibration of the modal shapes and frequencies

- ✓ Pushover analysis
  - ✓ Calibration of the pushover curves (E, ft, Gt, fc, Gc)
  - ✓ Calibration of the damage patterns

Work done

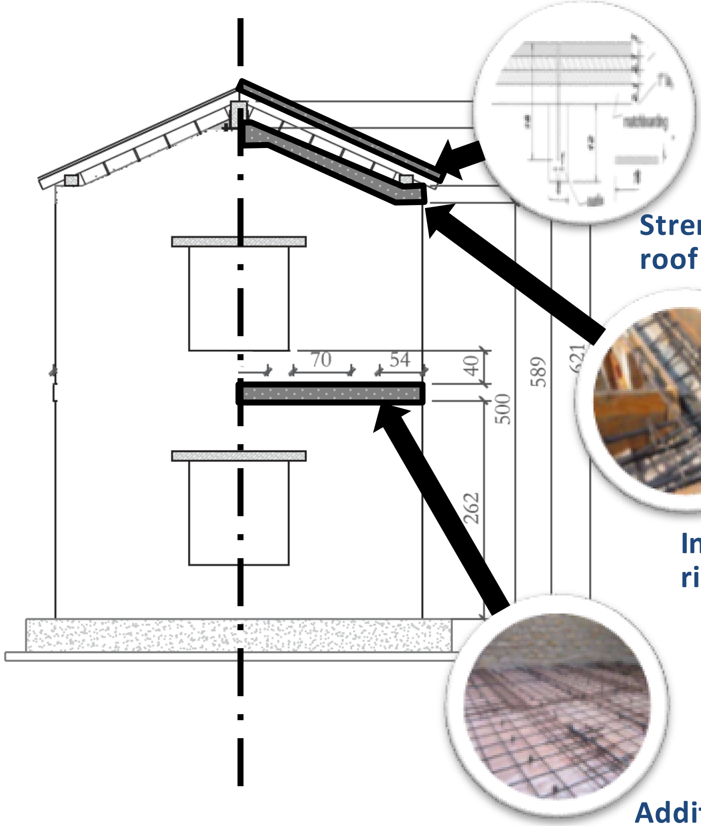


Case study II – Validation based on experimental results

"Building 1" – original URM building

Experimental setup (shaking table tests)

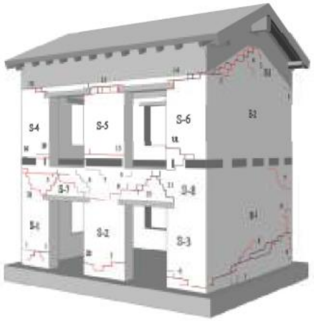
"Building 3" – mixed URM-RC building



Strengthened roof diaphragms

Insertion of RC ring beam

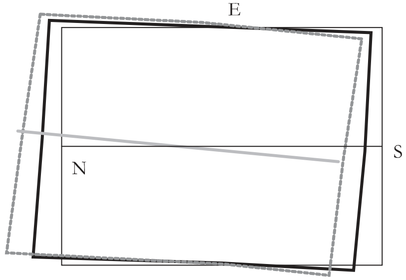
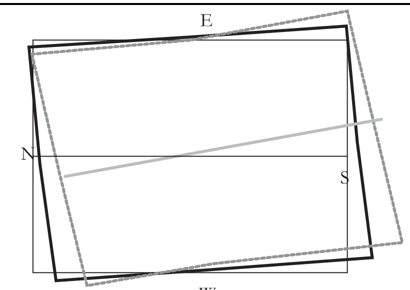
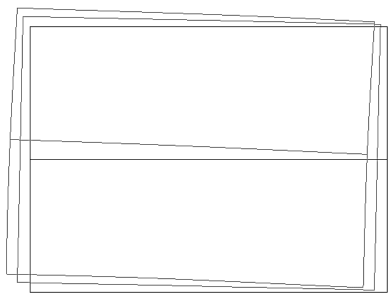
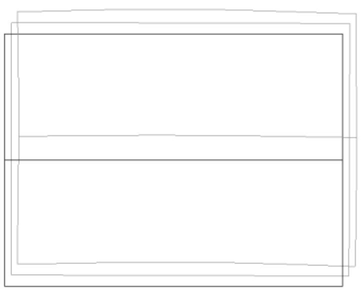
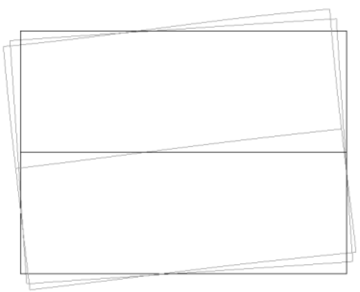
Addition of RC collaborating slab



Initial damage before experimental tests

Case study II – Calibration based on experimental results

Modal analysis

	Mode 1	Mode 2	Mode 3
Experimental analysis (dynamic test at 0.05 g) (Senaldi et al. 2014)	 $f = 7.35\ Hz$	Not available -	 $f = 14.05\ Hz$
Numerical eigenvalue analysis (DIANA) $E = 923\ MPa$	 $f = 7.41\ Hz$ $\Delta f[\%] = 0.82\%$	 $f = 7.64\ Hz$ -	 $f = 12.10\ Hz$ $\Delta f[\%] = -13.88\%$

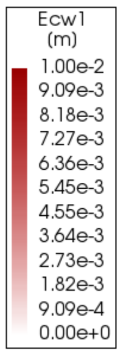
Case study II – Calibration based on experimental results

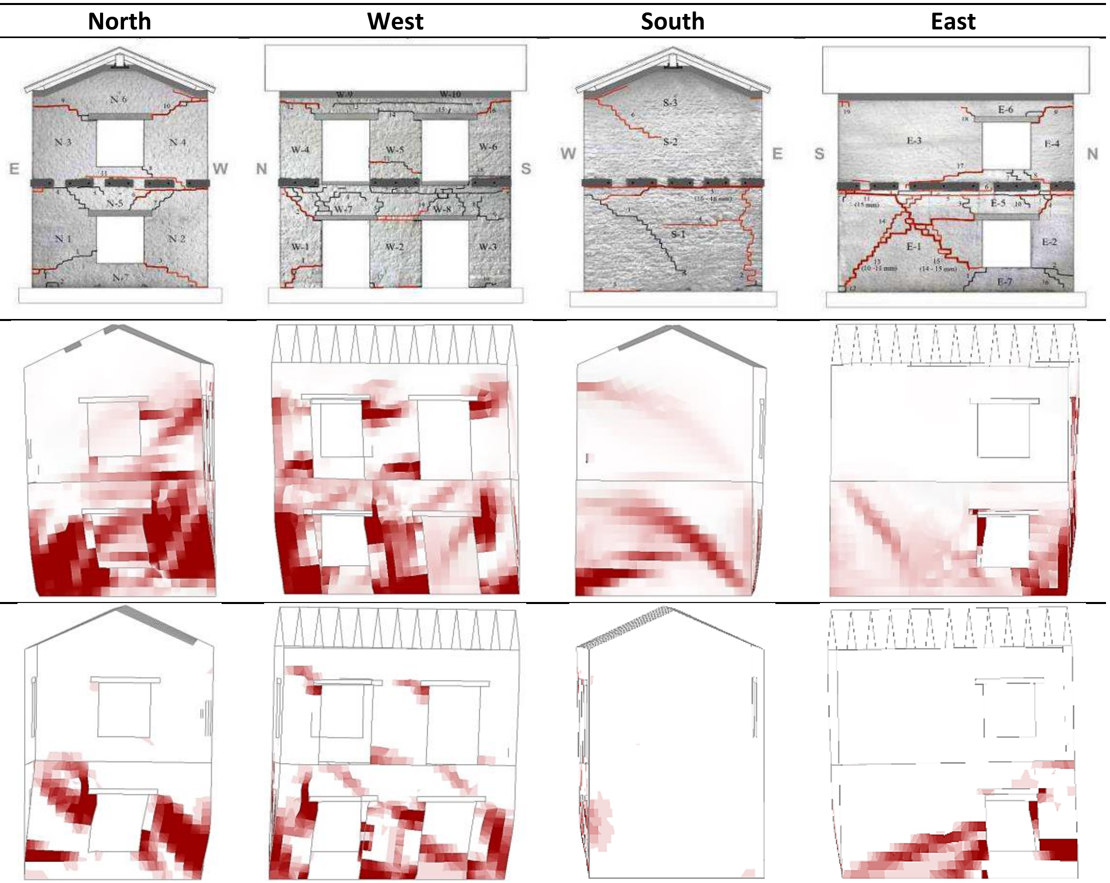
Damage patterns

Cracks induced after transportation to the shaking table (in black).
Cracks induced after the experimental test at nominal PGA of 0.6 g (in red) (Magenes and Penna 2011; Magenes et al. 2012).

Crack-widths obtained from DIANA (Ecw1, max of 5 layers) – Positive Y direction.

Crack-widths obtained from DIANA (Ecw1, max of 5 layers) – Negative Y direction.

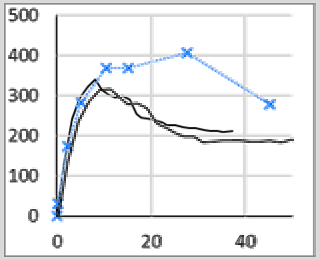




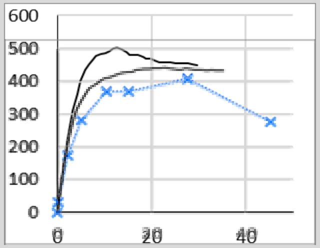
Case study II – Calibration based on experimental results

Influence of material properties

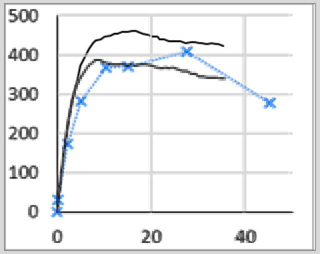
E =700000 kN/m2
500000 kN/m2
ft = 180 kN/m2
Gt = 0.05 kN/m
fc = 1000 kN/m2
Gc = 1 kN/m



E =700000 kN/m2
ft = 200 kN/m2
100 kN/m2
Gt = 0.35 kN/m
fc = 1000 kN/m2
Gc = 6 kN/m

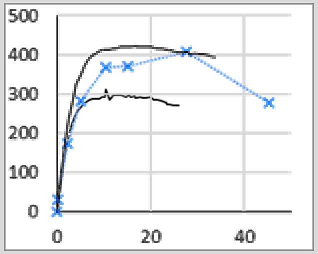


E =700000 kN/m2
ft = 138 kN/m2
Gt = 0.35 kN/m
0.1 kN/m
fc = 1000 kN/m2
Gc = 6 kN/m



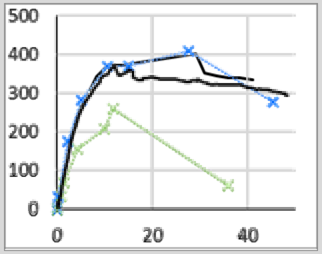
Influence of the load distribution and analysis parameters

E =700000 kN/m2
ft = 138 kN/m2
Gt = 0.35 kN/m
fc = 700 kN/m2
Gc = 6 kN/m
"PUSHOV", "Y"
"PUSHOV", "ALLDIR"

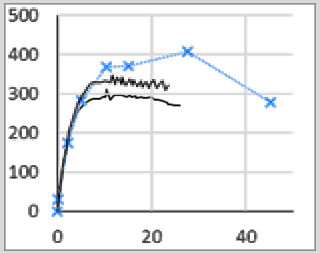


E =700000 kN/m2
ft = 138 kN/m2
Gt = 0.35 kN/m
fc = 700 kN/m2
Gc = 6 kN/m
Time steps: 0.1(10) 0.5(5) 2(5)
Conv. tolerance: 0.01

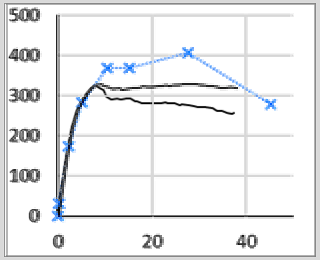
0.1(15) 0.2(5) 0.3(5) 0.4(5) 0.5(10)
0.001



E =700000 kN/m2
ft = 138 kN/m2
Gt = 0.35 kN/m
fc = 2000 kN/m2
700 kN/m2
Gc = 6 kN/m

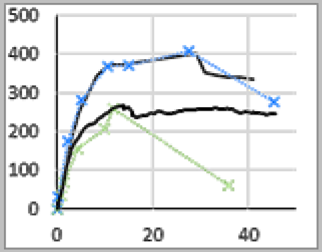


E =700000 kN/m2
ft = 100 kN/m2
Gt = 0.05 kN/m
fc = 1000 kN/m2
Gc = 4 kN/m
1 kN/m



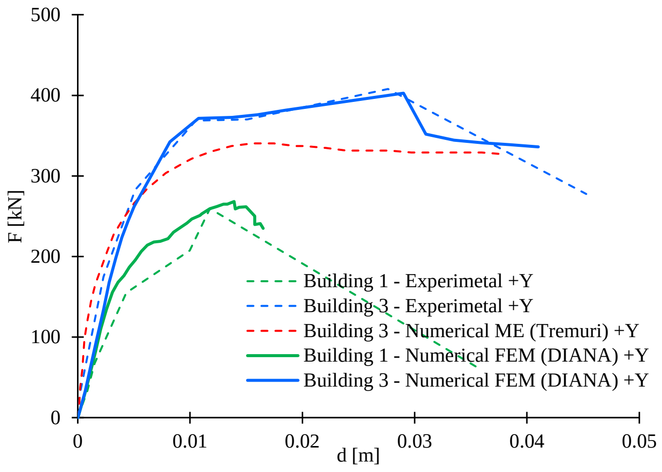
Influence of the building typology

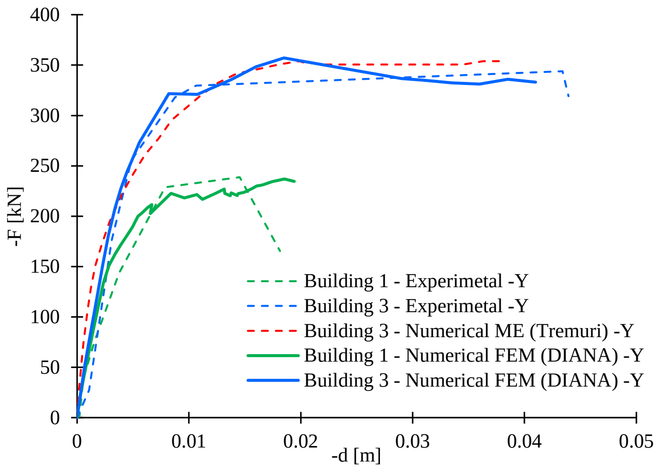
E =500000 kN/m2
ft = 180 kN/m2
Gt = 0.05 kN/m
fc = 1000 kN/m2
Gc = 6 kN/m
Mixed URM-RC
Original URM



Case study II – Pushover results

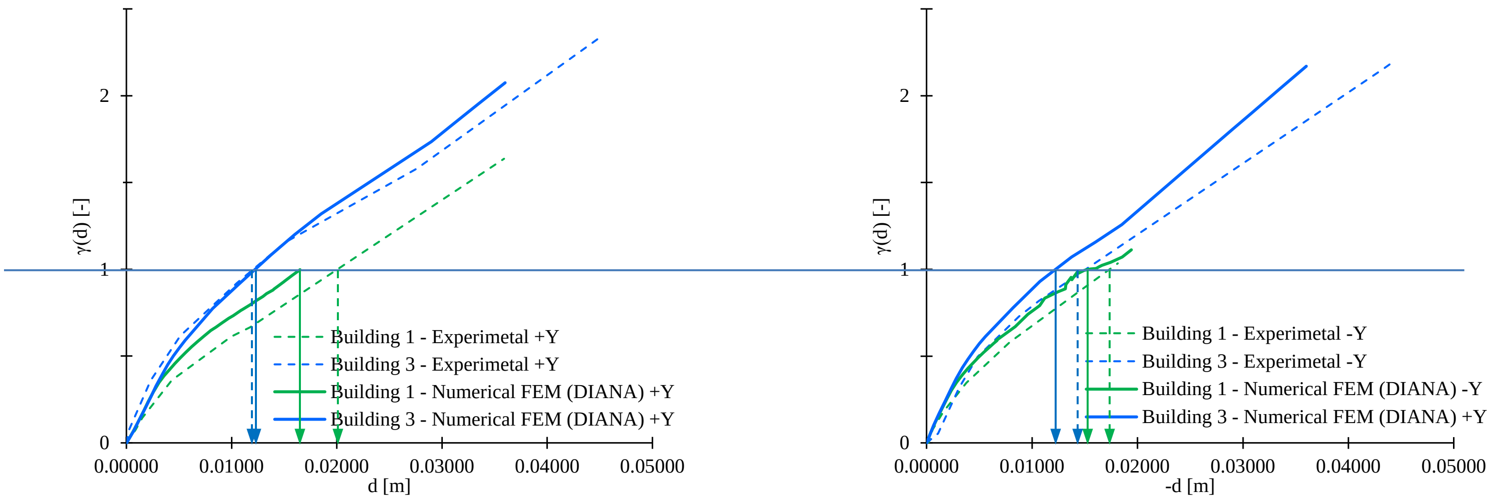
Pushover curves





Case study II – Pushover results

Target displacement of the SDoF system *versus* the percentage of the seismic action (γ(d))



Scale factor for the initial seismic demand, γ(d)

$T^*(d^*) < T_C$

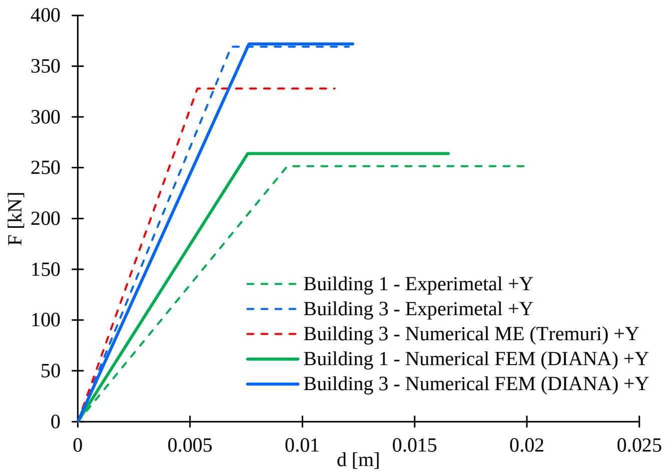
$$\gamma(d^*) = \frac{S_a(d^*) \cdot T^*(d^*) \cdot \ T_C - S_a(d^*) \cdot \left(T^*(d^*)\right)^2 + d^* \cdot 4\pi^2}{S_{ae}(d^*) \cdot T^*(d^*) \cdot T_C}$$

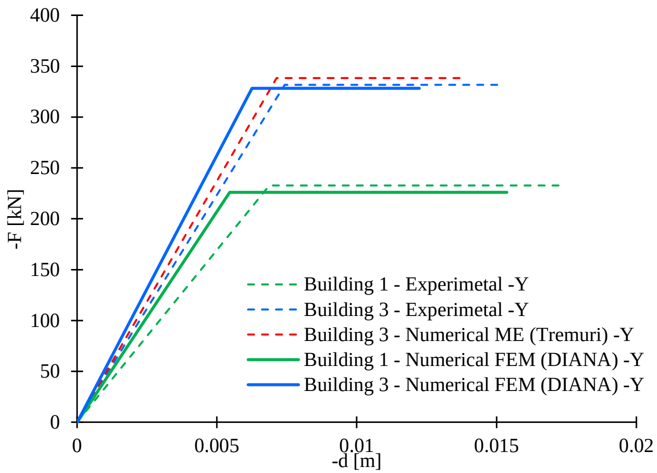
$T^*(d^*) \geq T_C$

$$\gamma(d^*) = \frac{d^* \cdot 4\pi^2}{S_{ae}(d^*) \cdot \left(T^*(d^*)\right)^2}$$

Case study II – Pushover results

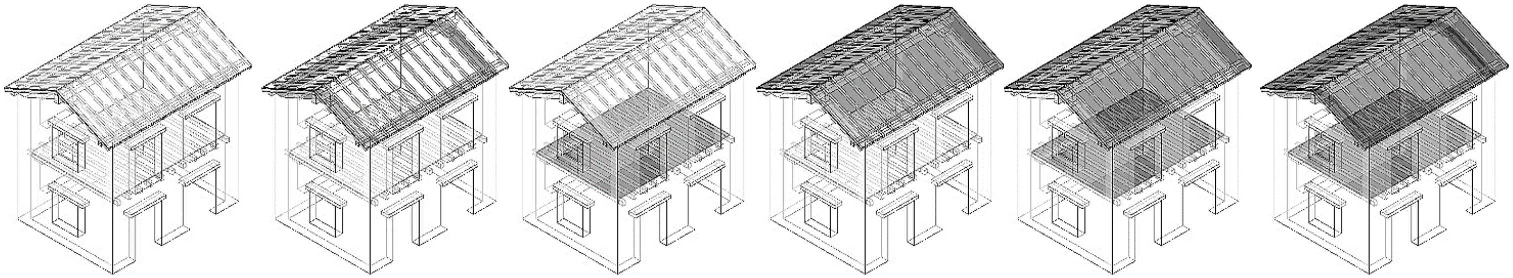
Idealised elasto-perfectly plastic force displacement relationships (N2 method)





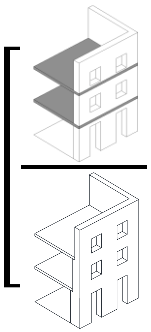
Case study II – Pushover results

Comparison of the results obtained from the models with and without the strengthening elements

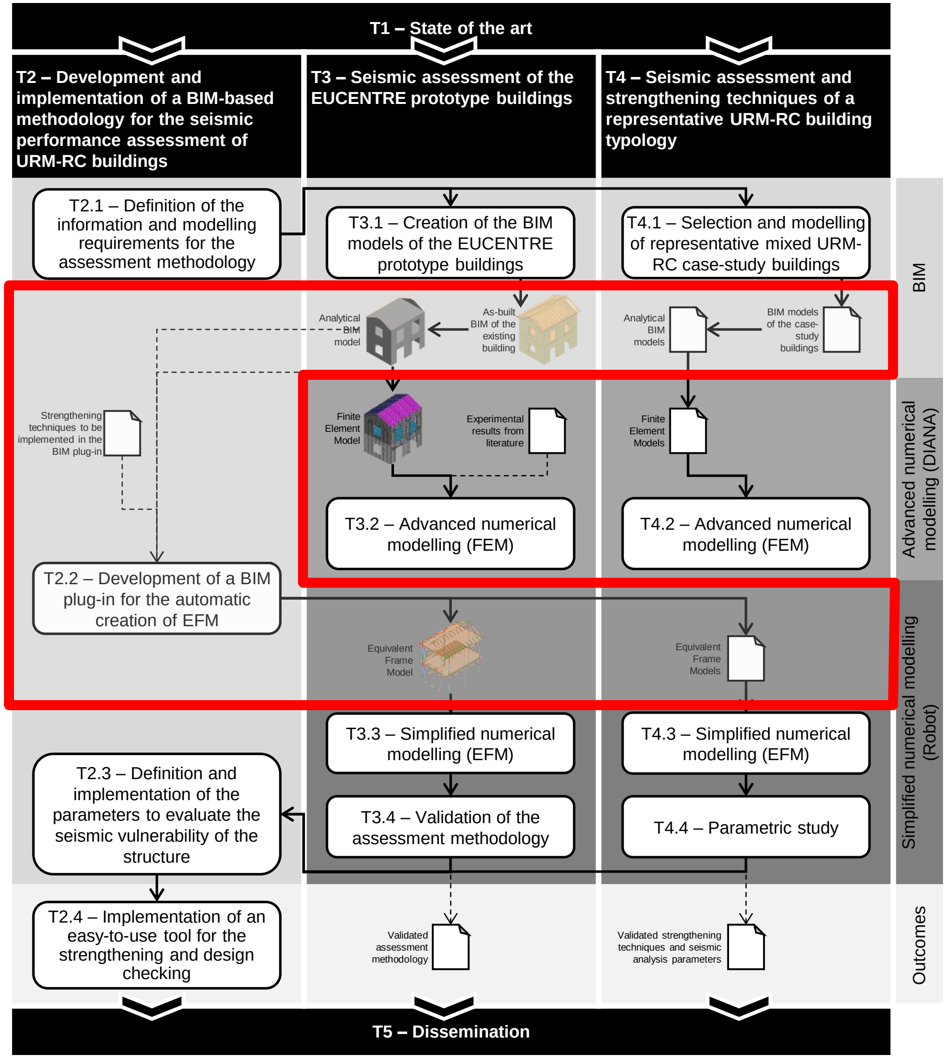


OB	**SB1**	**SB2**	**SB3**	**SB4**	**SB5**
Original building (EUCENTRE Building 1)	RC ring beam	Strengthened floor diaphragm	Strengthened roof diaphragm	Strengthened floor and roof diaphragms	RC ring beam and strengthened floor and roof diaphragms (EUCENTRE Building 3)

			Capacity (Fy)	Stiffness (Fy/dy)	Ductility ratio (du/dy)
(+Y)	Numerical (DIANA)	(SB1)/(OB)-1	18.5%	9.3%	123.8%
		(SB2)/(OB)-1	32.5%	30.5%	118.8%
		(SB3)/(OB)-1	16.8%	17.9%	132.6%
		(SB4)/(OB)-1	43.9%	40.1%	107.3%
	Numerical (DIANA)	(SB5)/(OB)-1	43.6%	35.9%	144.4%
	Experimental	(SB5)/(OB)-1	46.8%	100.5%	203.9%
(-Y)	Numerical (DIANA)	(SB1)/(OB)-1	40.9%	-8.8%	98.3%
		(SB2)/(OB)-1	45.4%	19.5%	241.7%
		(SB3)/(OB)-1	27.9%	-10.4%	313.4%
		(SB4)/(OB)-1	52.1%	30.4%	245.9%
	Numerical (DIANA)	(SB5)/(OB)-1	51.8%	28.5%	321.1%
	Experimental	(SB5)/(OB)-1	42.5%	31.9%	160.1%

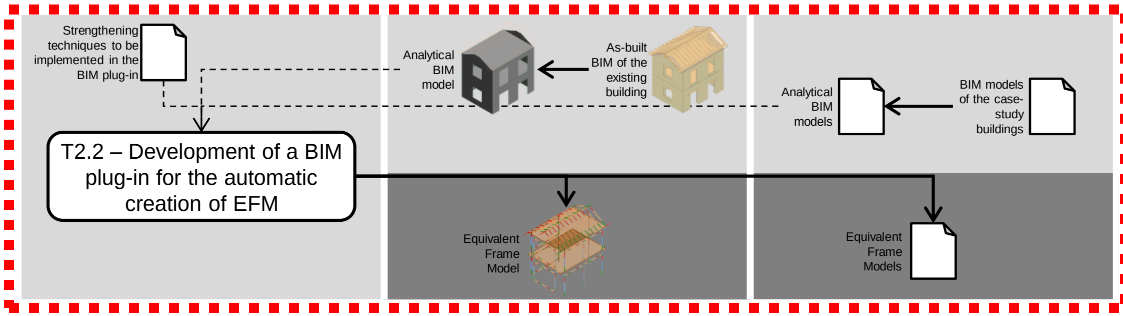


$$\Delta\% = \left[\frac{\quad}{\quad} - 1\right] \times 100$$



Creation of the Equivalent Frame Models

Creation of the Equivalent Frame Models



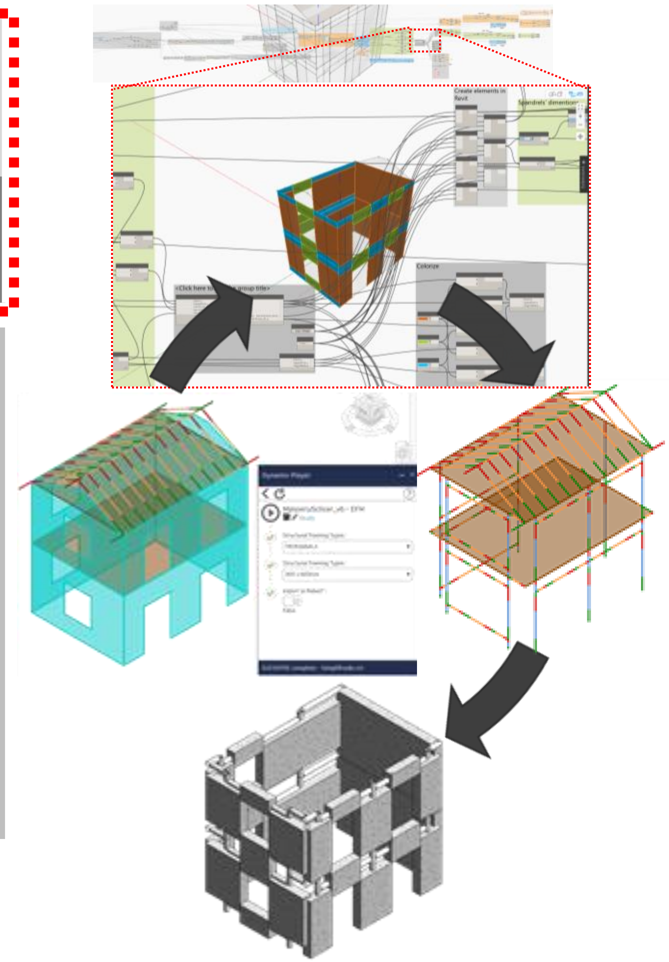
- ✓ Revit plug-in based on a python script written in the Revit API
- ✓ Implemented workflow
  1. Selection of elements
  2. Wall discretization (piers, spandrels, rigid nodes)
  3. Element identification
  4. EF idealization
  5. Properties assignment
  6. Export to the analysis software

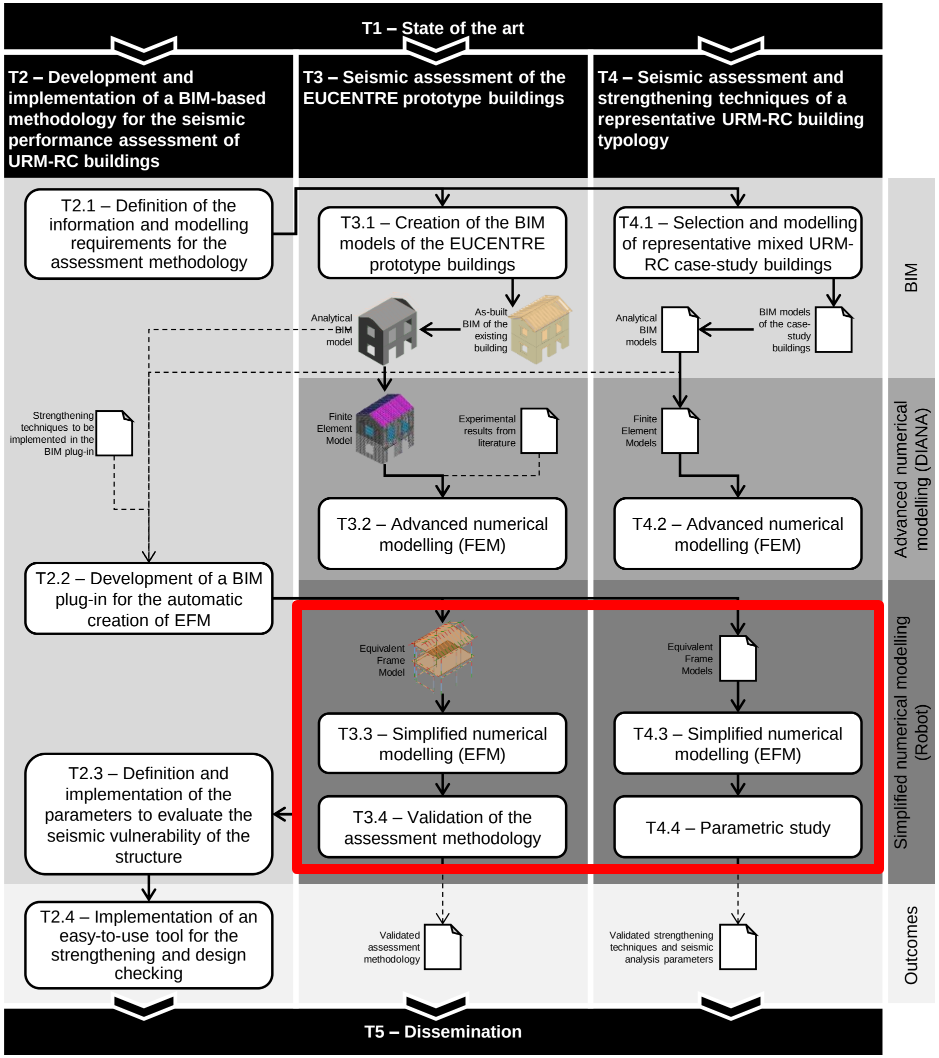
- ✓ Input: Analytical BIM models
- ✓ Output: EFM

- Input: Analytical BIM models (and material properties)
- Output: EFM

Work done

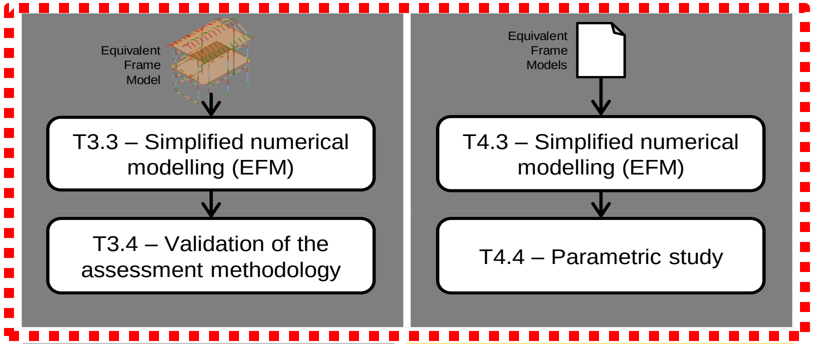
Work in progess





Analysis of the EFM and validation based on numerical results

Analysis of the EFM and validation based on numerical results



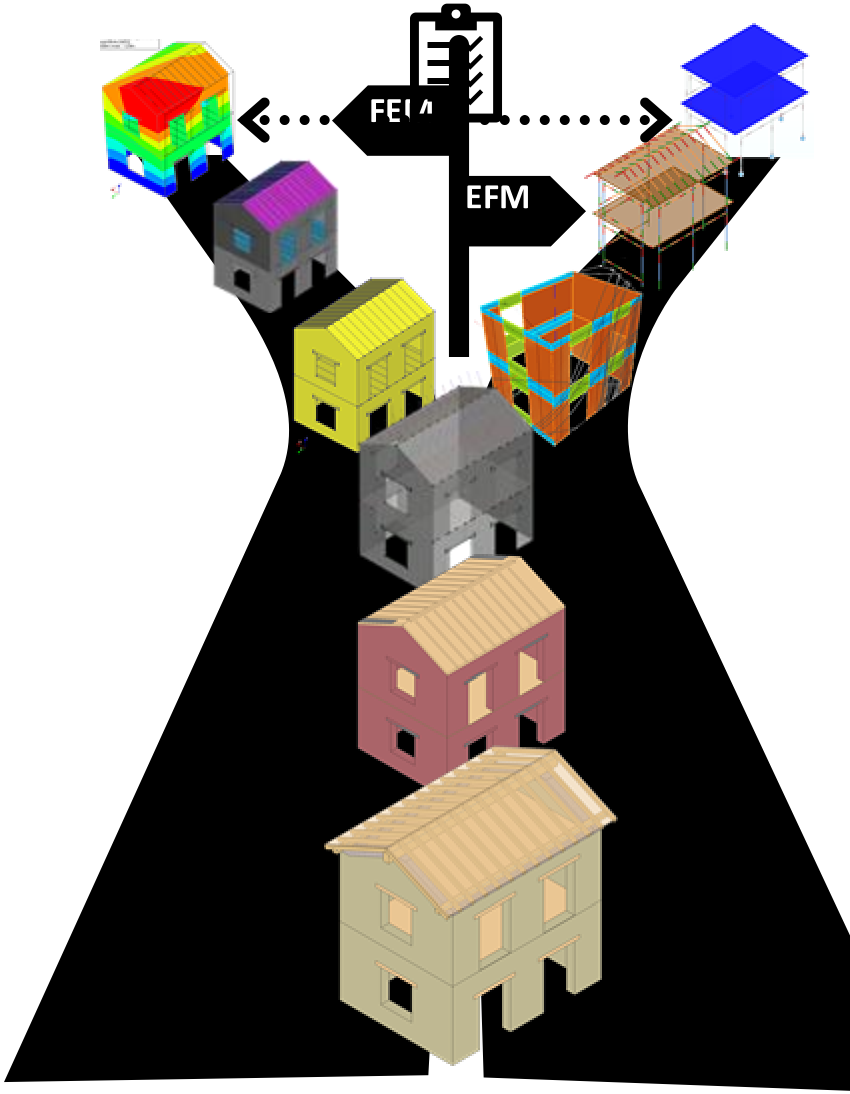
- Simplified numerical analysis (EFM)
- Software: Robot

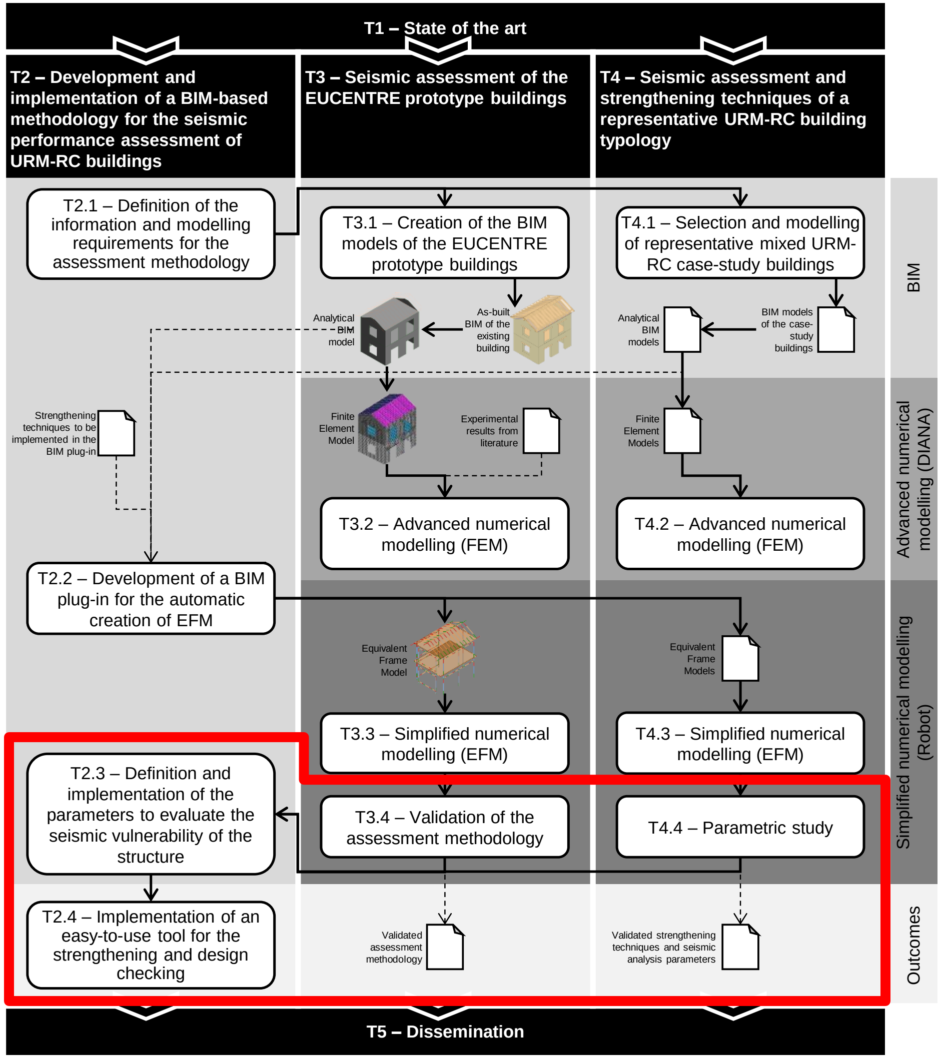
Work in progress

- Analysis of representative URM-RC buildings

- Calibration and validation of the numerical models based on the comparison of the obtained results (pushovers, modal analysis)
- Parametric analysis (compare the structural response before and after the intervention with RC)

Future work





Development and implementation of the assessment methodology

Development and implementation of the assessment methodology

T2.3 – Definition and implementation of the parameters to evaluate the seismic vulnerability of the structure

T2.4 – Implementation of an easy-to-use tool for the strengthening and design checking

T3.4 – Validation of the assessment methodology

Validated assessment methodology

T4.4 – Parametric study

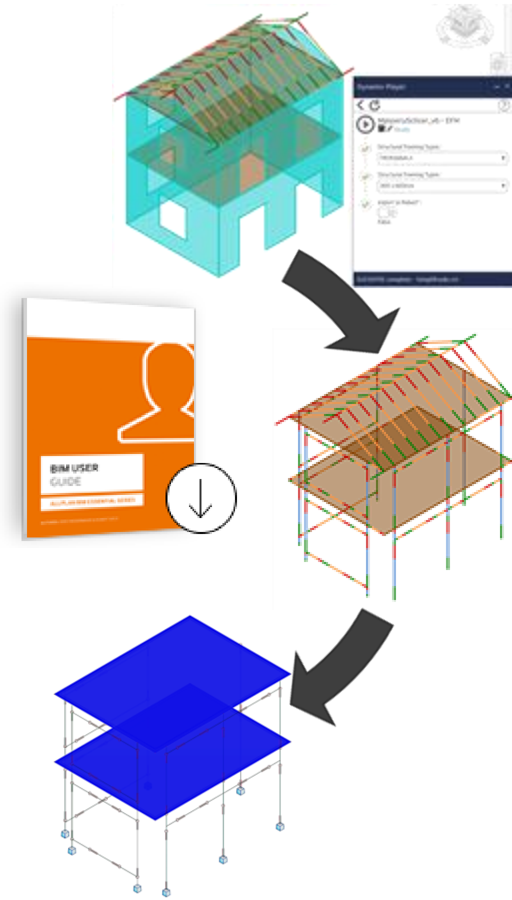
Validated strengthening techniques and seismic analysis parameters

- Analysis tool (implemented in Revit) for the seismic assessment (based on Eurocode 8 - Part 3)
- Expeditious assessment of the building without the need of using analysis software (report)
- Decision on the strengthening strategy
- BIM user guide for seismic retrofit projects

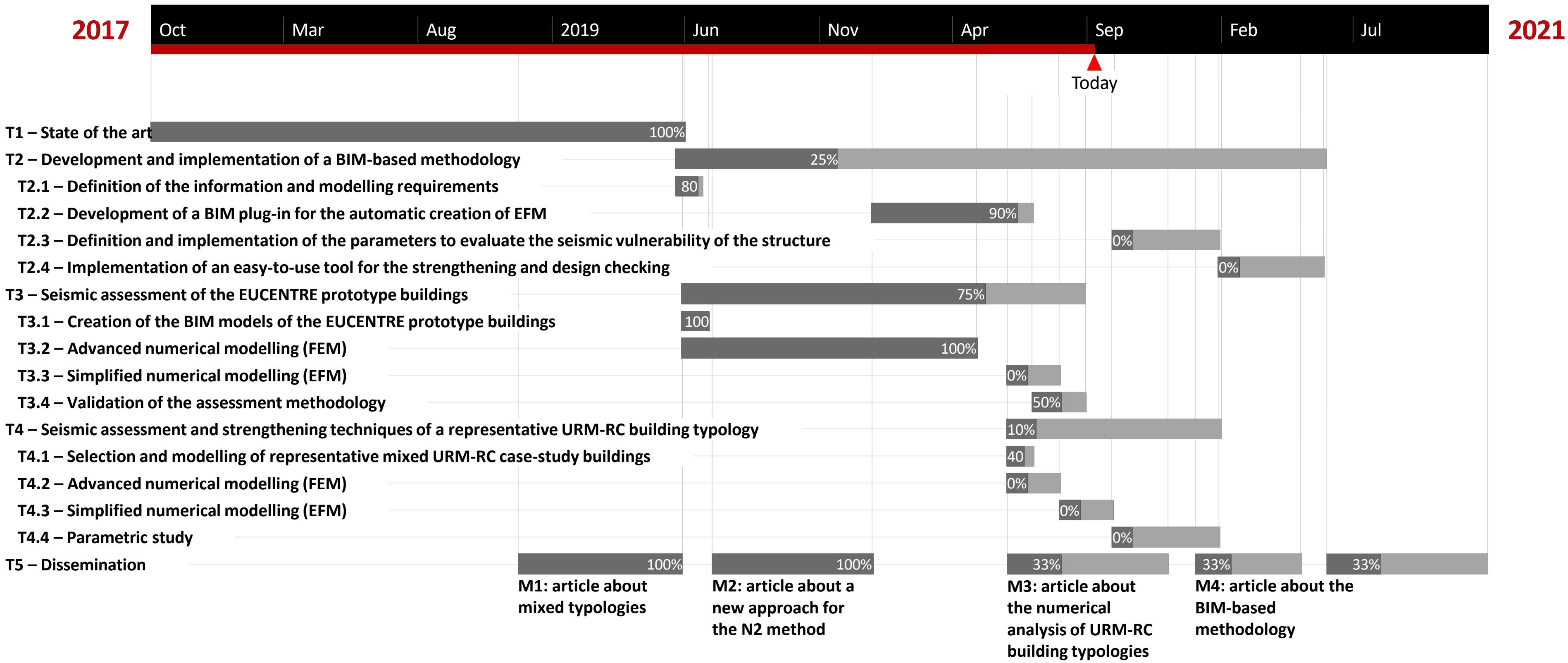
- Establishment of validated parameters to estimate the damage and assess losses (vulnerability function)

- Definition of the necessary parameters to evaluate the response of URM-RC structures
  - How to model and evaluate RC strengthening interventions?
  - Material properties, vulnerability curves, inter-storey drifts, damage state parameters, repair costs/times, etc.
  - Displacement-based?

Future work



Thesis timeline



Current impact

- Articles in International Journals

Published

Intervened URM buildings with RC elements: typological characterisation and associated challenges
Lopes, G. C., Vicente, R., Ferreira, T. M., & Azenha, M. (2019).
Bulletin of Earthquake Engineering, 1-33.

Displacement-based seismic performance evaluation and vulnerability assessment of buildings: The N2 method revisited
Lopes, G. C., Vicente, R., Ferreira, T. M., Azenha, M., & Estêvão, J. (2020).
Structures (24), 41-49.

Submitted

Numerical simulations of derived URM-RC buildings: assessment of strengthening interventions with RC
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BIM-based methodology for the seismic performance assessment of existing buildings
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Thank you for your attention!

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