The NIKER Catalogue

PROF. FRANCESCA DA PORTO

francesca.daporto@unipd.it

DIPARTIMENTO ICEA
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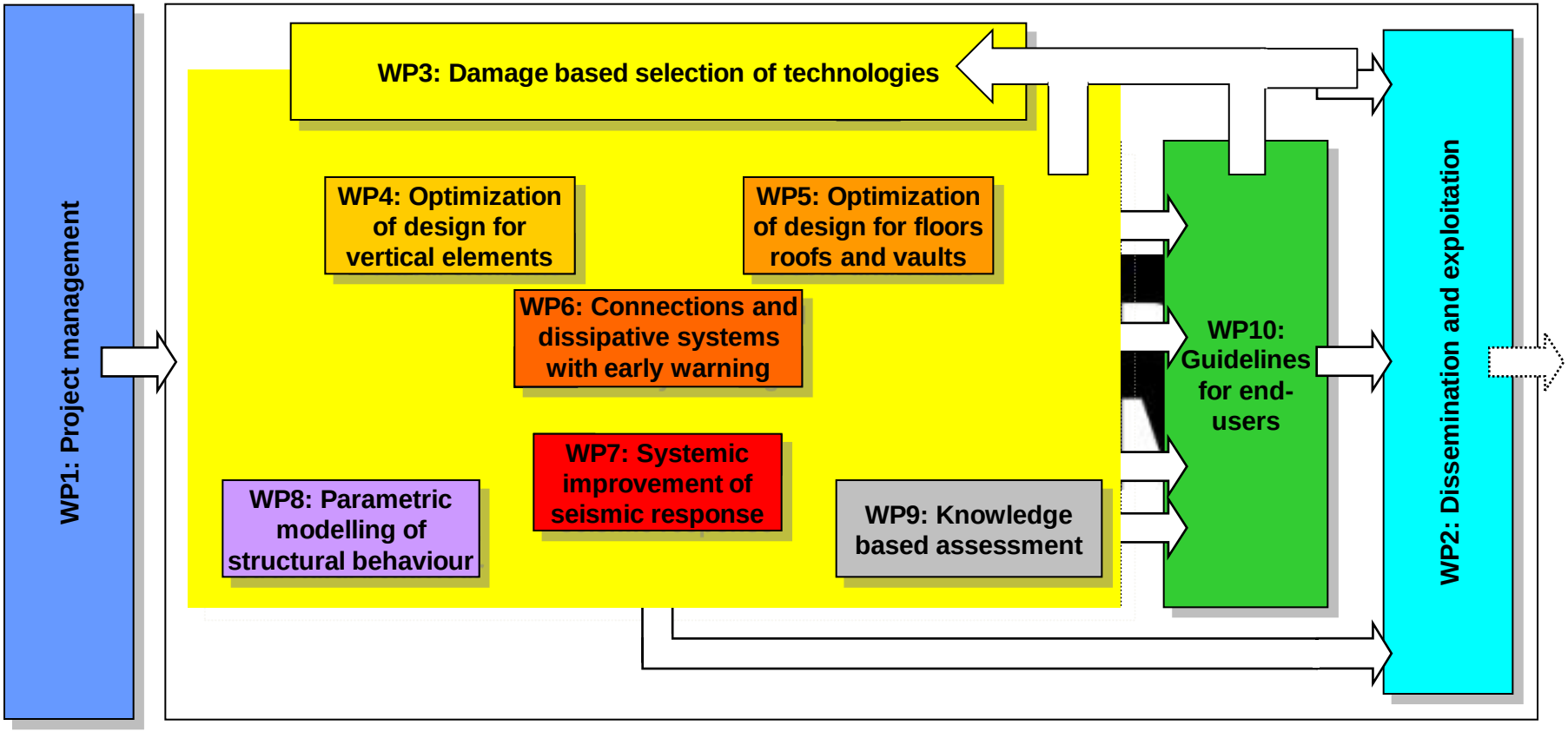
WORKPACKAGE 3
DELIVERABLE 3.6



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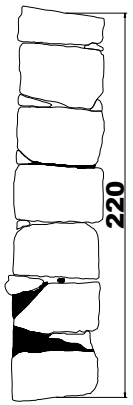
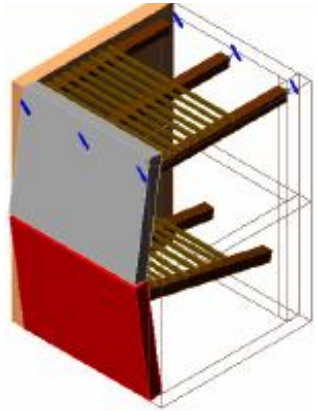
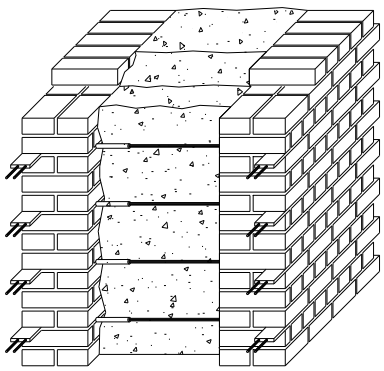
CATALOGUE

- Construction typologies
- Construction materials
- Failure mechanisms
- Intervention techinques







BACKGROUND OF THE CATALOGUE

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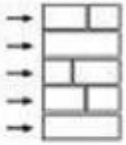
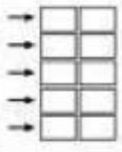
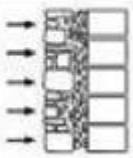
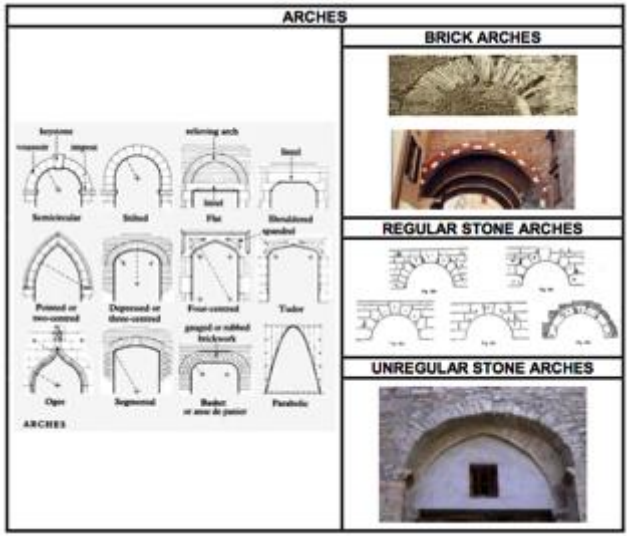
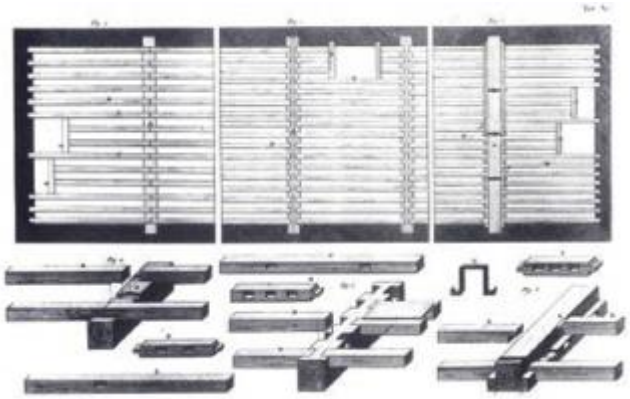
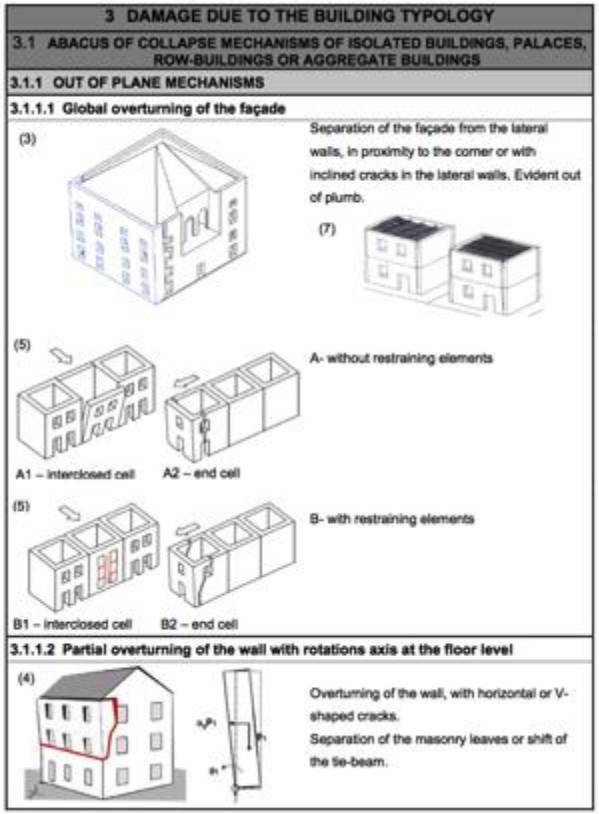
Picture	Survey	Model	Structural Behaviour
			
			
			
			







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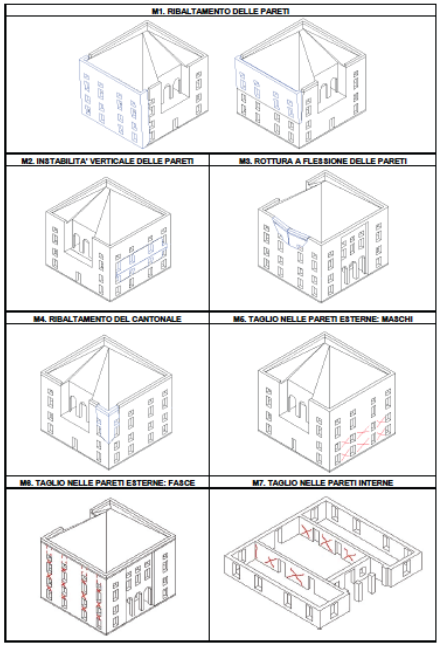

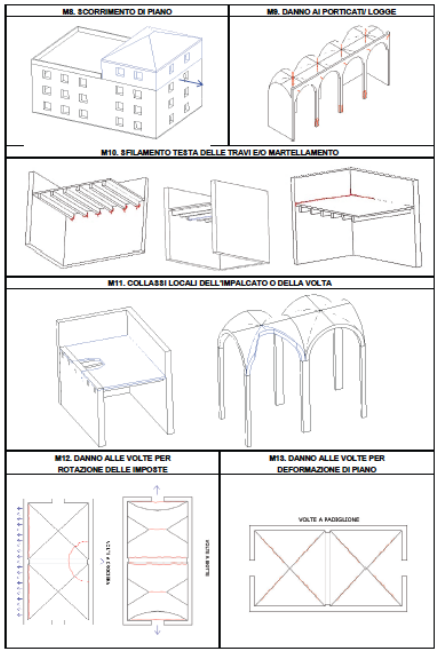

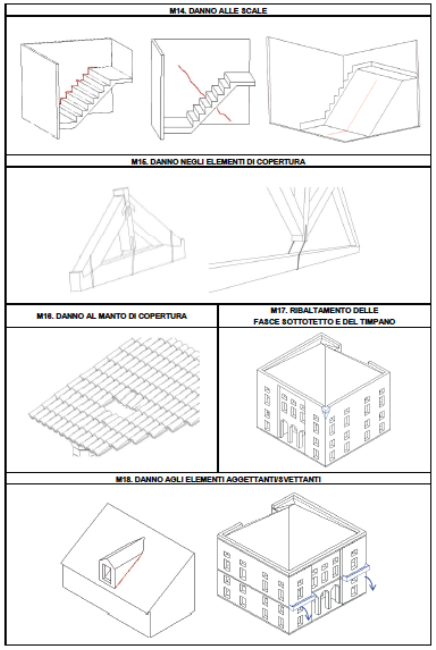

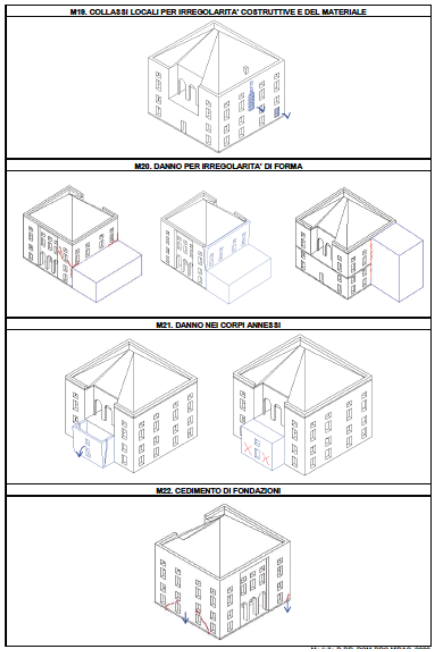

Form B-DP PCM-DPC MiBAC [2006] Scheda per il rilievo del danno ai beni culturali – Palazzi Available at: (www.beniculturali.it/mibac/multimedia/MiBAC/documents/1338454343145_allegato3.pdf).

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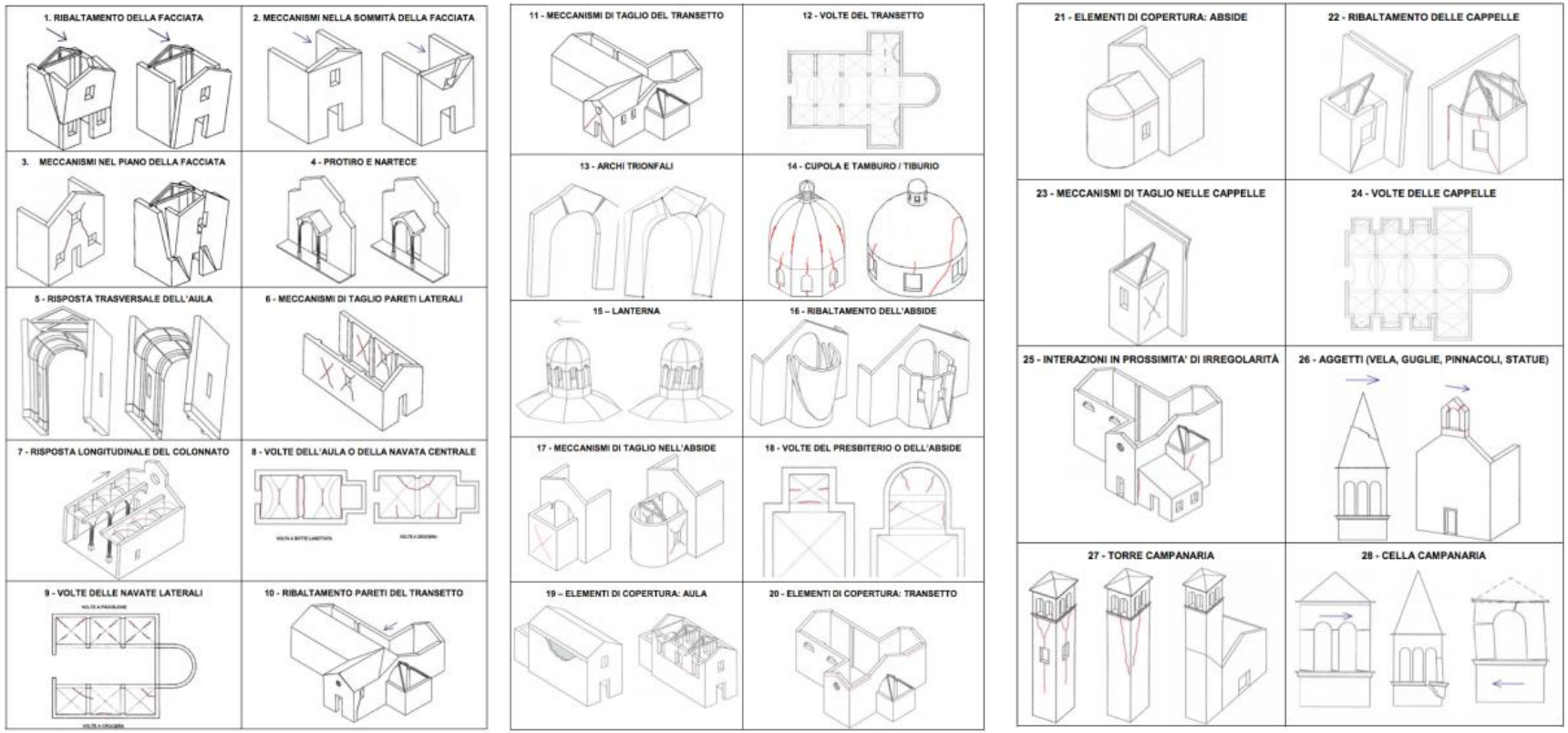

Form A-DC PCM-DPC MiBAC [2006] “Scheda per il rilievo del danno ai beni culturali – Chiese” (www.beniculturali.it/mibac/multimedia/MiBAC/documents/1338454237471_allegato4.pdf).

BACKGROUND OF THE CATALOGUE

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NEW STRUCTURED CATALOGUE

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https://niker.isqweb.it/

NEW STRUCTURED CATALOGUE

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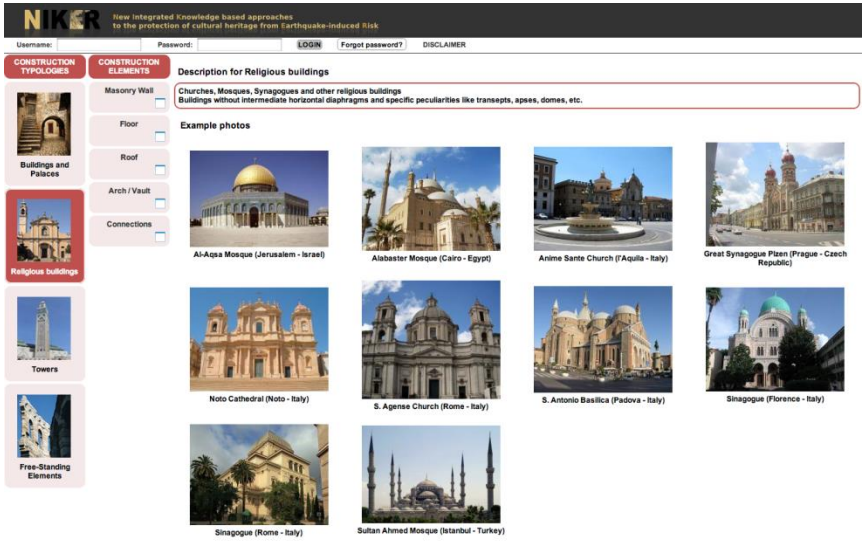
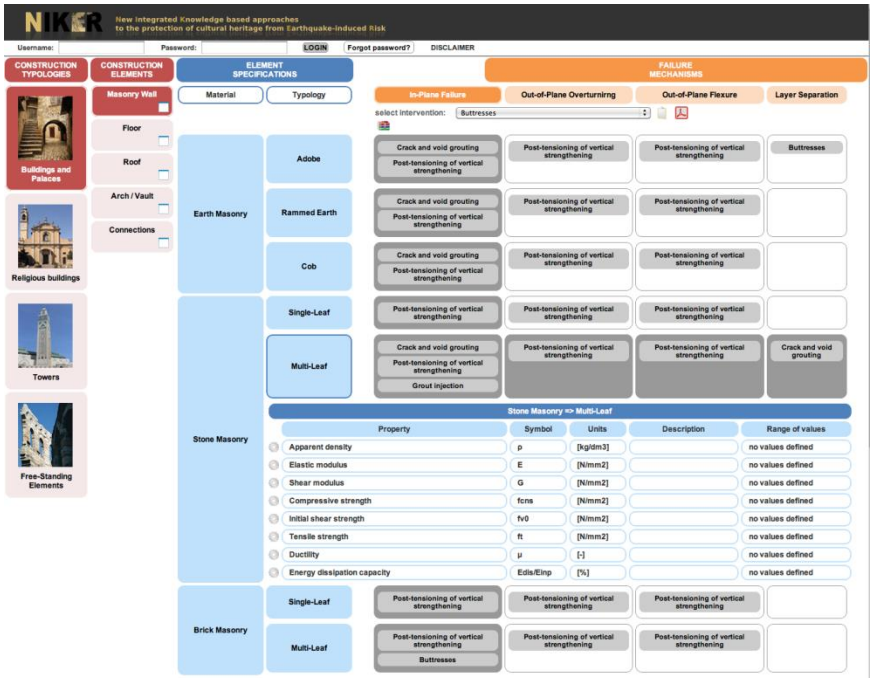
The structured catalogue links earthquake induced failure mechanisms, construction typologies and materials, interventions and assessment techniques.

This aims at knowledge-based optimization of interventions and definition of main design parameters and requirements for materials and intervention techniques

The in-depth properties (such as ductility, energy dissipation capacity, etc) of some materials and interventions used so far, evaluated mainly by laboratory testing, have been defined by previous projects, and can be found dispersed in literature.





THE IDEA OF THE CATALOGUE:

INTERVENTIONS MATRIX

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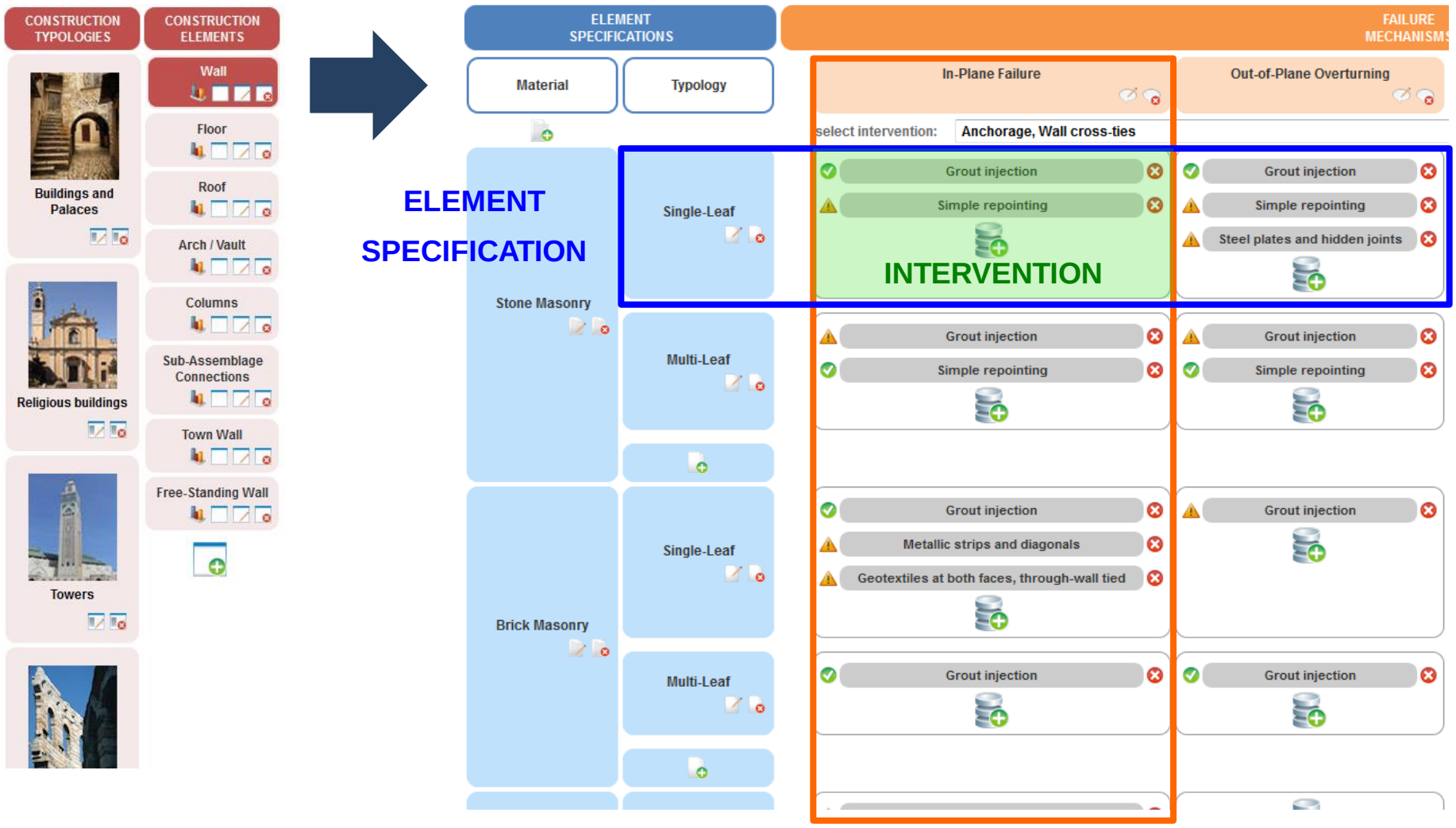

DETAILS OF THE CATALOGUE

CONSTRUCTION TYPES IN THE CATALOGUE

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CONSTRUCTION TYPOLOGIES

Buildings and Palaces

Religious buildings

Towers

Description for Religious buildings

Churches, Mosques, Synagogues and other religious buildings
Buildings without intermediate horizontal diaphragms and specific peculiarities like transepts, apses, domes, etc.
This category includes buildings realized for the reunion of believers of the same cult. It includes churches, mosques, synagogues and all the temples used for religious purposes. These buildings present specific peculiarities in the organization of the space like transepts, apses, domes, etc. The absence of intermediate horizontal diaphragms in the vertical development of the interior walls in a common characteristic of the most diffused religious buildings. The monumental effect of the religious buildings is obtained by developing peculiar building technologies: bi-dimensional structures like vertical walls or horizontal floors and three-dimensional elements like vaults, realized by specific technologies (stones, bricks, woods, etc.).

Application suggestions

Example photos

Alabaster Citadel (Cairo - Egypt)

Anime Sante Church (l'Aquila - Italy)

Great Synagogue Plzen (Prague - Czech Republic)

Noto Cathedral (Noto - Italy)

S. Agense Church (Rome - Italy)

S. Antonio Basilica (Padova - Italy)

Sinagogue (Florence - Italy)

Sinagogue (Rome - Italy)

Sultan Ahmed Mosque (Istanbul - Turkey)

CONSTRUCTION TYPES IN THE CATALOGUE

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CONSTRUCTION TYPOLOGIES

Buildings and Palaces

Religious buildings

Towers

Free-Standing Elements

Description for Buildings and Palaces

Ordinary or monumental buildings, palaces and castles, isolated or in aggregates.
This category includes diffused and monumental historical buildings. The diffused buildings are ordinary habitations and rural constructions, or buildings for productive and working activities, organized as isolated units or into complex aggregates. The term "palace" (from "palatium", an area in Rome where the emperors developed their residence) is used for noble habitations of different ages: villas, castles and representative buildings. These buildings were designed for the specific needs requested by human activities and present different organization of the spaces: private rooms; stores, archives and places of worship. Due to this variety of functions, the buildings could be realized with different elements (walls, columns, floors, arches, vaults, etc.) formed by specific technologies (stones, bricks, woods, etc.).

Application suggestions

Example photos

Ordinary building - Italy

Palazzo Ducale (Urbino - Italy)

Reggia Venaria Reale (Turin - Italy)

S. Stefano di Sessanio (Abruzzo - Italy)

Thun Castel (Trento - Italy)

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CONSTRUCTION TYPOLOGIES

Buildings and Palaces

Religious buildings

Towers

Free-Standing Elements

Description for Towers

Clock towers, bell towers, minarets; constructions with a high height-to-base ratio.
This category includes clock towers, bell towers, minarets and more in general constructions with a high height-to-base ratio. The structure is designed for facing very high stress at the base. Vertical connection systems can be organized into the section of the walls or into the interior of the tower. Horizontal floors can connect the load bearing walls. Each construction element is formed by specific technologies (stones, bricks, woods, etc.).

Application suggestions

Example photos

Clérigos bell tower (Porto - Portugal)

Leaning Tower (Pisa - Italy)

Minaret of the Al Muhdhar mosque (Tarim - Yemen)

Minaret of the Mosque of Uqba (Kairouan - Tunisia)

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CONSTRUCTION TYPOLOGIES

Buildings and Palaces

Religious buildings

Towers

Free-Standing Elements

Description for Free-Standing Elements

Freestanding elements without horizontal diaphragms.
This category takes into account the ruins of ancient buildings. The rests of ancient buildings are usually constituted by parts of vertical walls or columns without horizontal diaphragms.
These elements, survived to misuse, are formed by specific technologies (stones, bricks, etc.).

Application suggestions

Example photos

Ala of the Verona Arena (Verona - Italy)

Ancient columns (Beit She'an - Israel)

Defensive wall of the Moorish Castle (Sintra - Portugal)

Fori Romani (Rome - Italy)

The Palmyrene Gate, city of Dura Europos (Syria)

MATERIAL PROPERTIES

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CONSTRUCTION TYPOLOGIES

Buildings and Palaces

Religious buildings

Towers

CONSTRUCTION ELEMENT

- WALL
- FLOOR
- ROOF
- ARCH/VAULT
- CONNECTION
- SUB-ASSEMBLY

MATERIAL	TYPOLOGY
EARTH MASONRY	ADOBE
	RAMMED
	COB
STONE MASONRY	SINGLE-LEAF
	MULTI-LEAF
BRICK MASONRY	SINGLE-LEAF
	MULTI-LEAF

FAILURE MECHANISMS

IN-PLANE FAILURE	OUT OF PLANE OVERTURNING	OUT-OF-PLANE FLEXURE	LAYER SEPARATION
INTERVENTION 1 INTERVENTION 2	INTERVENTION 1 INTERVENTION 2	INTERVENTION 1 INTERVENTION 2	
INTERVENTION 1	INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	
INTERVENTION 1	INTERVENTION 1	INTERVENTION 1	
INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	INTERVENTION 1	INTERVENTION 1 INTERVENTION 2
INTERVENTION 1	INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	INTERVENTION 1 INTERVENTION 2
INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	INTERVENTION 1	INTERVENTION 1
INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	INTERVENTION 1 INTERVENTION 2	INTERVENTION 1

PRE-INTERVENTION PARAMETERS

Property	Symbol [Units]	Description	Range of values
Apparent density	ρ [kg/m3]		
Elastic Modulus	E [N/mm^2]		
Shear modulus	G [N/mm^2]		
Compressive strength	f_c [N/mm^2]		
Initial shear strength	f_{v0} [N/mm^2]		
Tensile strength	f_t [N/mm^2]		
….	…		

MATERIAL PROPERTIES

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Stone Masonry

Multi-Leaf				
	Post-tensioning of vertical strengthening	Post-tensioning of vertical strengthening	Post-tensioning of vertical strengthening	Grout injection
	Grout injection	Grout injection	Simple repointing	Transversal ties
	Simple repointing	Transversal ties		
		Simple repointing		
		Dowelling to anchor internal walls to perpendicular external walls		

Stone Masonry => Multi-Leaf

Pre-intervention parameters

Property	Symbol	Units	Description	Range of values
Displacement capacity	ψ	[%]		0.40 - 0.45 (view)
Equivalent viscous damping	ζ	[%]		19.10 - 19.10 (view)
Max. Horizontal Force	Fhmax	[kN]		55.70 - 93.50 (view)
Apparent density	ρ	[kg/m3]		no values defined
onset of cracking	σcr	[MPa]		0.15 - 2.90 (view)
Peak Strain	ε	[x 10(-3)]		4.40 - 5.10 (view)
Elastic modulus	E	[N/mm2]		167.00 - 5,200.00 (view)
Shear modulus	G	[N/mm2]		8.00 - 837.00 (view)
Compressive strength	fcns	[N/mm2]		0.21 - 15.32 (view)
Shear Strength	fv	[N/mm²]		0.57 - 4.37 (view)
Initial shear strength	fv0	[N/mm2]		0.029 - 0.37 (view)
Tensile strength	ft	[N/mm2]		0.055 - 0.055 (view)
Ductility	μ	[-]		no values defined
Energy dissipation capacity	Edis/Einp	[%]		46.00 - 46.00 (view)

Component parameters

Component	Property	Symbol	Units	Description	Range of values
Stone	Apparent density	ρ	[kg/m3]		2,642.00 - 2,665.00 (view)
Mortar	Compressive strength	fcns	[N/mm2]		3.80 - 3.80 (view)
Stone	Compressive strength	fcns	[N/mm2]		93.40 - 189.90 (view)
Mortar	Elastic modulus	E	[N/mm2]		4,700.00 - 4,700.00 (view)
Stone	Elastic modulus	E	[N/mm2]		54,500.00 - 80,100.00 (view)
Stone	Open porosity	po	[%]		1.20 - 1.40 (view)
Mortar	Poisson´s Ratio	v	[-]		0.27 - 0.27 (view)
Stone	Porosity	ϕ	[%]		8.30 - 15.00 (view)
Stone	Real density	ρr	[kg/m3]		2,405.00 - 3,104.00 (view)
Mortar	Tensile strength	ft	[N/mm2]		1.40 - 1.40 (view)
Stone	Tensile strength	ft	[N/mm2]		16.10 - 29.60 (view)

NIKER Catalogue – ELEMENT SPECIFICATION PARAMETER VALUES

https://niker.isqweb.it/get.element_specification_parameter_values.php?es=7&id=410&action=view

Buildings and Palaces => Wall => Stone Masonry => Multi-Leaf

Peak Strain • ε [x 10(-3)]

Value	Description	Publication
4.4	Masonry prism made by two external regular Noto stone layers and an internal rubble infill without offsets	Binda, L., Anzani, A., Fontana, A. (2003b). "Mechanical behaviour of multiple-leaf stone masonry: experimental research". 3-Day Int. Conf. Structural Faults & Repair - 2003, CD-ROM. In English. (LAB TESTS)
5.1	Masonry prism made by two external regular Noto stone layers and an internal rubble infill with offsets	Binda, L., Anzani, A., Fontana, A. (2003b). "Mechanical behaviour of multiple-leaf stone masonry: experimental research". 3-Day Int. Conf. Structural Faults & Repair - 2003, CD-ROM. In English. (LAB TESTS)
6.2		Vintzileou, E. (2008a). "Effect of timber ties on the behavior of historic masonry". ASCE, Journal of Structural Engineering, 134, 961-972. In English. (LAB TESTS)

CLOSE

MATERIAL PROPERTIES

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Stone Masonry

Multi-Leaf	Post-tensioning of vertical strengthening Grout injection Simple repointing	Post-tensioning of vertical strengthening Grout injection Transversal ties Simple repointing Dowelling to anchor internal walls to perpendicular external walls	Post-tensioning of vertical strengthening Simple repointing	Grout injection Transversal ties

Stone Masonry => Multi-Leaf

Pre-intervention parameters

Property	Symbol	Units	Description	Range of values
Displacement capacity	ψ	[%]		0.40 - 0.45 (view)
Equivalent viscous damping	ζ	[%]		19.10 - 19.10 (view)
Max. Horizontal Force	Fhmax	[kN]		55.70 - 93.50 (view)
Apparent density	ρ	[kg/m3]		no values defined
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Initial shear strength	fv0	[N/mm2]		0.029 - 0.37 (view)
Tensile strength	ft	[N/mm2]		0.055 - 0.055 (view)
Ductility	μ	[-]		no values defined
Energy dissipation capacity	Edis/Einp	[%]		46.00 - 46.00 (view)

Component parameters

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Mortar	Compressive strength	fcns	[N/mm2]		3.80 - 3.80 (view)
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Mortar	Elastic modulus	E	[N/mm2]		4,700.00 - 4,700.00 (view)
Stone	Elastic modulus	E	[N/mm2]		54,500.00 - 80,100.00 (view)
Stone	Open porosity	po	[%]		1.20 - 1.40 (view)
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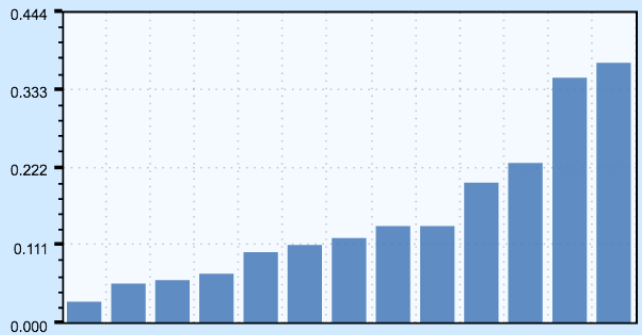
Stone	Porosity	ϕ	[%]		8.30 - 15.00 (view)
Stone	Real density	ρr	[kg/m3]		2,405.00 - 3,104.00 (view)
Mortar	Tensile strength	ft	[N/mm2]		1.40 - 1.40 (view)
Stone	Tensile strength	ft	[N/mm2]		16.10 - 29.60 (view)

NIKER Catalogue – ELEMENT SPEC… …ALUES

https://niker.isqweb.it/get.element_specification_parameter_chart.p…

Buildings and Palaces => Wall => Stone Ma… …lti-Leaf

Initial shear strength • fv0 [N/mm2]



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FAILURE MECHANISM DETAILS

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CONSTRUCTION TYPOLOGIES

Buildings and Palaces

Religious buildings

Towers

CONSTRUCTION ELEMENT

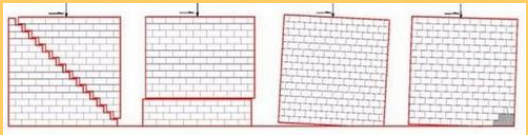
- **WALL**
- FLOOR
- ROOF
- ARCH/VAULT
- CONNECTION
- SUB-ASSEMBLY

MATERIAL	TYPOLOGY
EARTH	ADOBE
	RAMMED
	COB
STONE	SINGLE-LEAF
	MULTI-LEAF
BRICK	SINGLE-LEAF
	MULTI-LEAF

FAILURE MECHANISM

IN-PLANE FAILURE	**OUT OF PLANE OVERTURNING**	OUT-OF-PLANE FLEXURE	LAYER SEPARATION
INTERVENTION 1 INTERVENTION 2	INTERVENTION 1 INTERVENTION 2	INTERVENTION 1 INTERVENTION 2	
INTERVENTION 1	INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	
INTERVENTION 1	INTERVENTION 1	INTERVENTION 1	
INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	INTERVENTION 1	INTERVENTION 1 INTERVENTION 2
INTERVENTION 1	INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	INTERVENTION 1 INTERVENTION 2
INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	INTERVENTION 1	INTERVENTION 1
INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	INTERVENTION 1 INTERVENTION 2	INTERVENTION 1

In-plane failure

Performance Indicators	Symbol	Units	Description	Failure Scheme
Apparent density				
Elastic modulus				
Shear modulus				
Compressive strength				
…				

Descriptive performance indicator	Description
Section monolithism	

FAILURE MECHANISM DETAILS

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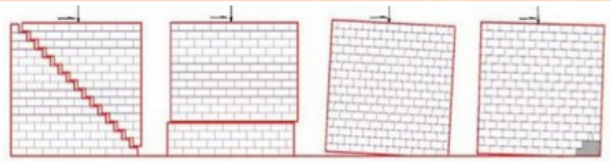
In-Plane Failure

Failure scheme



Property (performance indicator)	Symbol	Units	Description
Bond strength, tensile	ftb	[MPa]	test...
Equivalent viscous damping	ζ	[%]	
In-plane global stiffness (elastic)	Ky	[kN/mm]	
In-plane global stiffness (plastic)	Ku	[kN/mm]	
Apparent density	ρ	[kg/m3]	
Elastic modulus	E	[N/mm2]	
Shear modulus	G	[N/mm2]	
Compressive strength	fcns	[N/mm2]	
Initial shear strength	fv0	[N/mm2]	
Tensile strength	ft	[N/mm2]	
Ductility	μ	[-]	
Energy dissipation capacity	Edis/Einp	[%]	
Displacement capacity	ψ	[%]	
Shear Strength	fv	[N/mm²]	
Shear Strain	γ	[-]	Angular Distortion, d/H...
Shear strength recovery	fv(recovered)	[%]	Thus failure = 0% Total recovery of initial shear...

Descriptive performance indicator	Description
Boundary Confinement	Masonry with disconnected leaves is extremely vuln...
Section Monolithism	The non-monolithic in-thickness behaviour of mason...
Geometry of masonry texture	

The accurate description of materials and failure mechanisms is the key point for a friendly use of the catalogue, allowing an easy recognising of the typologies.

SELECTION OF THE OPTIMUM INTERVENTION

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CONSTRUCTION TYPOLOGIES

Buildings and Palaces

Religious buildings

Towers

CONSTRUCTION ELEMENT

- WALL
- FLOOR
- ROOF
- ARCH/VAULT
- CONNECTION
- SUB-ASSEMBLY

MATERIAL	TYPOLOGY
EARTH	ADOBE
	RAMMED
	COB
STONE	SINGLE-LEAF
	MULTI-LEAF
BRICK	SINGLE-LEA
	MULTI-LEA

FAILURE MECHANISM

IN-PLANE FAILURE	OUT OF PLANE OVERTURNING	OUT-OF-PLANE FLEXURE	LAYER SEPARATION
INTERVENTION 1 INTERVENTION 2	INTERVENTION 1 INTERVENTION 2	INTERVENTION 1 INTERVENTION 2	
INTERVENTION 1	INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	
INTERVENTION 1	**INTERVENTION 1**	INTERVENTION 1	
INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	INTERVENTION 1	INTERVENTION 1 INTERVENTION 2
INTERVENTION 1	INTERVENTION 1 INTERVENTION 2	INTERVENTION 1	INTERVENTION 1 INTERVENTION 2

POST-INTERVENTION PARAMETERS

INTERVENTION 1

Property	Symbol [Units]	Description	Range of values
Apparent density	ρ [kg/m3]		
Elastic Modulus	E [N/mm^2]		
Shear modulus	G [N/mm^2]		
Compressive strength	f_c [N/mm^2]		
Initial shear strength	f_{v0} [N/mm^2]		
Tensile strength	f_t [N/mm^2]		
…			

Performance indicator	Description
Section monolithism	
…	

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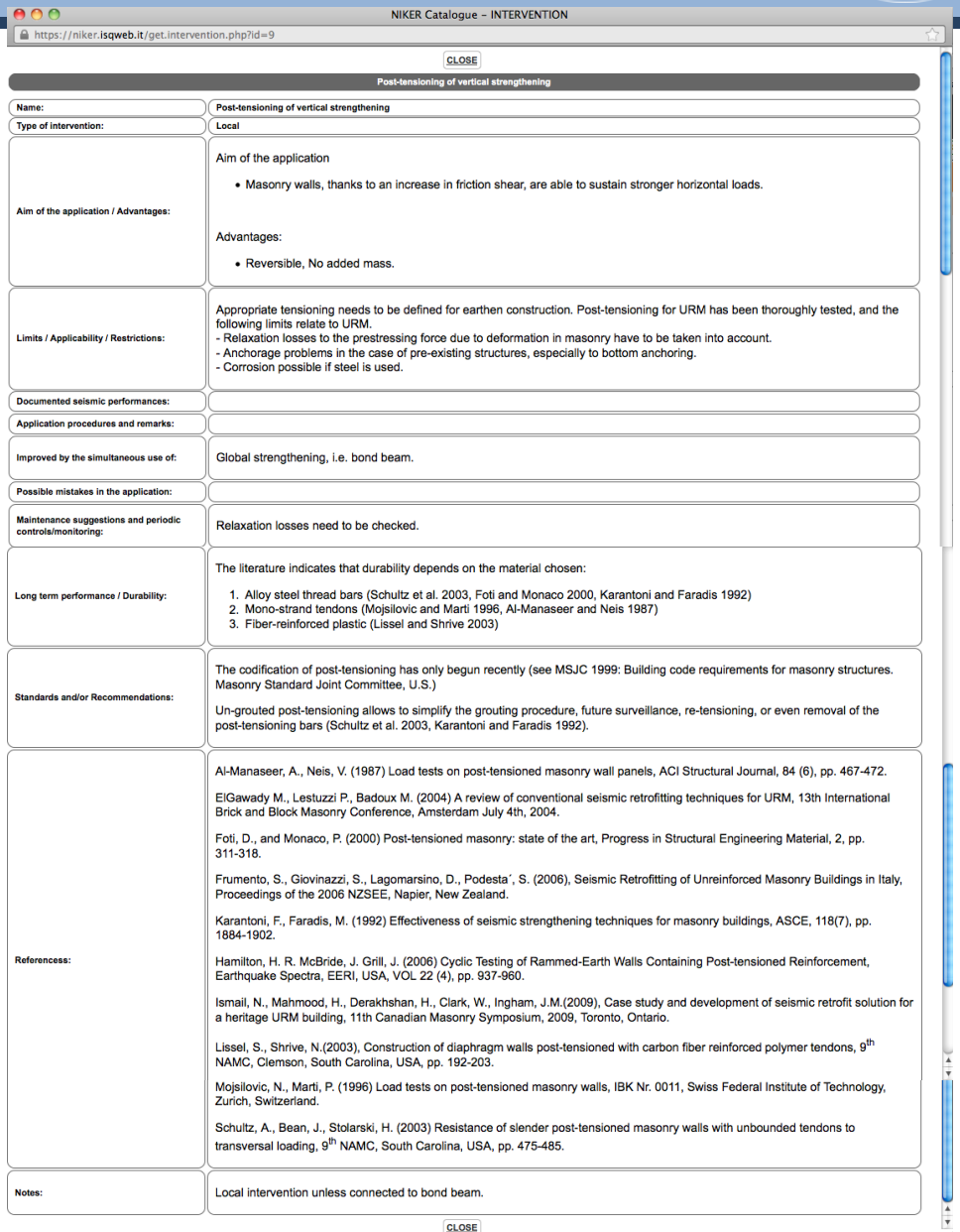
The interventions are reported linking damages to element typologies.
For each intervention, information includes: limits and advantages, possible restrictions, documented seismic performance, preliminary tests, on site and in laboratory, maintenance observation and monitoring issues and references.



NIKER Catalogue – INTERVENTION

https://niker.isqweb.it/get.intervention.php?id=9

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Post-tensioning of vertical strengthening

Name:	**Post-tensioning of vertical strengthening**
Type of intervention:	**Local**
Aim of the application / Advantages:	Aim of the application • Masonry walls, thanks to an increase in friction shear, are able to sustain stronger horizontal loads. Advantages: • Reversible, No added mass.
Limits / Applicability / Restrictions:	Appropriate tensioning needs to be defined for earthen construction. Post-tensioning for URM has been thoroughly tested, and the following limits relate to URM. - Relaxation losses to the prestressing force due to deformation in masonry have to be taken into account. - Anchorage problems in the case of pre-existing structures, especially to bottom anchoring. - Corrosion possible if steel is used.
Documented seismic performances:	
Application procedures and remarks:	
Improved by the simultaneous use of:	Global strengthening, i.e. bond beam.
Possible mistakes in the application:	
Maintenance suggestions and periodic controls/monitoring:	Relaxation losses need to be checked.
Long term performance / Durability:	The literature indicates that durability depends on the material chosen: 1. Alloy steel thread bars (Schultz et al. 2003, Foti and Monaco 2000, Karantoni and Faradis 1992) 2. Mono-strand tendons (Mojsilovic and Marti 1996, Al-Manaseer and Neis 1987) 3. Fiber-reinforced plastic (Lissel and Shrive 2003)
Standards and/or Recommendations:	The codification of post-tensioning has only begun recently (see MSJC 1999: Building code requirements for masonry structures. Masonry Standard Joint Committee, U.S.) Un-grouted post-tensioning allows to simplify the grouting procedure, future surveillance, re-tensioning, or even removal of the post-tensioning bars (Schultz et al. 2003, Karantoni and Faradis 1992).
References:	Al-Manaseer, A., Neis, V. (1987) Load tests on post-tensioned masonry wall panels, ACI Structural Journal, 84 (6), pp. 467-472. ElGawady M., Lestuzzi P., Badoux M. (2004) A review of conventional seismic retrofitting techniques for URM, 13th International Brick and Block Masonry Conference, Amsterdam July 4th, 2004. Foti, D., and Monaco, P. (2000) Post-tensioned masonry: state of the art, Progress in Structural Engineering Material, 2, pp. 311-318. Frumento, S., Giovinazzi, S., Lagomarsino, D., Podesta´, S. (2006), Seismic Retrofitting of Unreinforced Masonry Buildings in Italy, Proceedings of the 2006 NZSEE, Napier, New Zealand. Karantoni, F., Faradis, M. (1992) Effectiveness of seismic strengthening techniques for masonry buildings, ASCE, 118(7), pp. 1884-1902. Hamilton, H. R. McBride, J. Grill, J. (2006) Cyclic Testing of Rammed-Earth Walls Containing Post-tensioned Reinforcement, Earthquake Spectra, EERI, USA, VOL 22 (4), pp. 937-960. Ismail, N., Mahmood, H., Derakhshan, H., Clark, W., Ingham, J.M.(2009), Case study and development of seismic retrofit solution for a heritage URM building, 11th Canadian Masonry Symposium, 2009, Toronto, Ontario. Lissel, S., Shrive, N.(2003), Construction of diaphragm walls post-tensioned with carbon fiber reinforced polymer tendons, 9th NAMC, Clemson, South Carolina, USA, pp. 192-203. Mojsilovic, N., Marti, P. (1996) Load tests on post-tensioned masonry walls, IBK Nr. 0011, Swiss Federal Institute of Technology, Zurich, Switzerland. Schultz, A., Bean, J., Stolarski, H. (2003) Resistance of slender post-tensioned masonry walls with unbounded tendons to transversal loading, 9th NAMC, South Carolina, USA, pp. 475-485.
Notes:	Local intervention unless connected to bond beam.

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SELECTION OF THE OPTIMUM INTERVENTION

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Buildings and Palaces => Wall => Brick Masonry => Multi-Leaf • In-Plane Failure

Grout injection

Post-intervention parameters

Property	Symbol	Units	Description	Range of values
Apparent density	ρ	[kg/m3]		no values defined
Elastic modulus	E	[N/mm2]		1,040.00 - 3,350.00 (view)
Shear modulus	G	[N/mm2]		no values defined
Compressive strength	fcns	[N/mm2]		2.40 - 16.94 (view)
Initial shear strength	fv0	[N/mm2]		12.76 - 12.76 (view)
Tensile strength	ft	[N/mm2]		0.60 - 0.73 (view)
Ductility	μ	[-]		no values defined
Energy dissipation capacity	Edis/Einp	[%]		no values defined

Performance indicators

Performance indicator	Description
Boundary Confinement	Masonry with disconnected leaves is extremely vuln...
Section Monolithism	The non-monolithic in-thickness behaviour of mason...
Geometry of masonry texture	

Parameters are obtained by the state-of-art references and directly from the experimental research of the NIKER project.

BASE OF DATA FOR THE CATALOGUE

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PUBLICATIONS

2013	Poletti, E., Vasconcelos, G., Oliveira, D.V. (2013). "Influence of infill on the cyclic behaviour of traditional half-timbered walls". *International Conference on Rehabilitation and Restoration of Structures, Chennai, India*. In English. (ON SITE TESTS)
2012	Miccoli, L., Müller, U., Perrone, C., Ziegert, C. (2012). "Structural performance of earthen structural components of different construction techniques". *Terra 2012, XI International Conference on the Study and Conservation of Earthen Architectural Heritage*. In German. (LAB TESTS)
2012	Müller, U., Ziegert, C., Kaiser, C., Röhlen, U. (2012). "Eigenschaften industrieller Lehmbauprodukte für den Mauerwerksbau und Verhalten von Lehmsteinmauerwerk". *Mauerwerk, Ernst und Sohn Verlag für Architektur und technische Wissenschaften GmbH & Co. KG, Berlin*, 16, 17-28. In German. (LAB TESTS)
2012	Miccoli, L., Müller, U. (2012). "Characterisation of Earthen Materials. A comparison between earth block masonry, rammed earth and cob". *Structural Analysis of Historical Constructions, Wroclaw, Poland 2012 (SAHC 2012)*. In English. (LAB TESTS)
2012	Müller, U., Miccoli, L., Malaga, K. (2012). "A New Grouting Material for the Repair of Cracks in Earthen Structures". *Terra 2012, XI International Conference on the Study and Conservation of Earthen Architectural Heritage*. In English. (LAB TESTS)
2012	Miccoli, L., Müller, U., Silva, B., Da Porto, F., Hracov, S., Adami, C.E., Vintzileou, E., Vasconcelos, G., Poletti, E. (2012). "Overview of Different Strengthening Techniques Applied on Walls Used in Historical Structures". *Structural Analysis of Historical Constructions, Wroclaw, Poland 2012 (SAHC 2012)*. In English. (LAB TESTS)
2012	Wünsche, M., Pospíšil, S., Hračov, S., Urushadze, S. (2012). "Cyclic loading of masonry walls and its anti seismic strengthening". *Engineering Mechanics 2012*. In English. (LAB TESTS)
2012	(2012a). "Parametric assessment and optimized design procedures for floors and vaults". *University of Padova*. Extradoss SRG width 240 mm (2 strips x 120 mm, with 18 steel cord each) + 4 Steel spikes. In English. (LAB TESTS)
2012	(2012b). "Parametric assessment and optimized design procedures for floors and vaults". *University of Padova*. Extradoss SRG width 240 mm (2 strips x 120 mm, with 18 steel cord each) + 4 Steel spikes. In English. (LAB TESTS)
2012	(2012c). "Parametric assessment and optimized design procedures for floors and vaults". *University of Padova*. Extrados BTRM (Basalt Textile Reinforced Mortar) all the surface + 8 Basalt spikes. In English. (LAB TESTS)
2012	(2012d). "Parametric assessment and optimized design procedures for floors and vaults". *University of Padova*. Extradoss SRP width 220 mm (2 strips x 110 mm, with 94 steel cord each) + 4 Steel spikes. In English. (LAB TESTS)
2012	(2012e). "Parametric assessment and optimized design procedures for floors and vaults". *University of Padova*. Extradoss CFRP width 240 mm (2 strips x 120 mm) + 4 Basalt spikes. In English. (ON SITE TESTS)

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WALLS (1): STONE AND BRICK MASONRY

ELEMENT SPECIFICATIONS		FAILURE MECHANISMS			
Material	Typology	In-Plane Failure	Out-of-Plane Overturning	Out-of-Plane Flexure	Layer Separation
		select intervention: Additional connection elements			
Stone Masonry	Single-Leaf	Post-tensioning of vertical strengthening Grout injection Simple repointing	Post-tensioning of vertical strengthening Grout injection Simple repointing Dowelling to anchor internal walls to perpendicular external walls Steel plates and hidden joints	Post-tensioning of vertical strengthening Grout injection Simple repointing	
	Multi-Leaf	Post-tensioning of vertical strengthening Grout injection Simple repointing Steel rods and additional nails and bolts	Post-tensioning of vertical strengthening Grout injection Transversal ties Simple repointing Dowelling to anchor internal walls to perpendicular external walls	Post-tensioning of vertical strengthening Grout injection Simple repointing	Grout injection Transversal ties Simple repointing
Brick Masonry	Single-Leaf	Post-tensioning of vertical strengthening Grout injection Simple repointing Reinforced repointing Metallic strips and diagonals Geotextiles at both faces, through-wall tied	Post-tensioning of vertical strengthening Grout injection Reinforced repointing Dowelling to anchor internal walls to perpendicular external walls	Post-tensioning of vertical strengthening Grout injection Reinforced repointing	wooden horizontal chaining
	Multi-Leaf	Post-tensioning of vertical strengthening Grout injection Simple repointing Reinforced repointing Reinforced concrete cooperating slab Reinforced openings with vertical and horizontal stiffeners	Post-tensioning of vertical strengthening Grout injection Reinforced repointing Dowelling to anchor internal walls to perpendicular external walls	Post-tensioning of vertical strengthening Grout injection Reinforced repointing	Grout injection Transversal ties Artificial headers wooden horizontal chaining

WALLS (2): EARTH MASONRY

Earthen Masonry	Adobe	Crack and void grouting Grout injection Metallic strips and diagonals Geotextiles at both faces, through-wall tied Cables and straps Reinforced openings with vertical and horizontal stiffeners		Crack and void grouting Grout injection Geotextiles at both faces, through-wall tied Cables and straps	wooden horizontal chaining
Monolithic Earth Materials	Rammed Earth	Crack and void grouting Post-tensioning of vertical strengthening Grout injection Reinforced repointing Crack Stitching Steel mesh with cement plaster Geotextiles at both faces, through-wall tied Cables and straps Reinforced openings with vertical and horizontal stiffeners	Post-tensioning of vertical strengthening Buttresses Grout injection Reinforced repointing Anchorage, Wall cross-ties Dowelling to anchor internal walls to perpendicular external walls Bond-beam (stiff, i.e. concrete or steel) Bond-beam (flexible, i.e. timber) Diaphragm Steel connection elements	Crack and void grouting Post-tensioning of vertical strengthening Buttresses Grout injection Reinforced repointing Anchorage, Wall cross-ties Bond-beam (stiff, i.e. concrete or steel) Bond-beam (flexible, i.e. timber) Steel mesh with cement plaster Geotextiles at both faces, through-wall tied Diaphragm Cables and straps Steel connection elements	Steel connection elements wooden horizontal chaining
	Cob	Crack and void grouting Post-tensioning of vertical strengthening Grout injection Reinforced repointing Steel mesh with cement plaster Geotextiles at both faces, through-wall tied Cables and straps Reinforced openings with vertical and horizontal stiffeners	Post-tensioning of vertical strengthening Buttresses Grout injection Reinforced repointing Anchorage, Wall cross-ties Dowelling to anchor internal walls to perpendicular external walls Bond-beam (stiff, i.e. concrete or steel) Bond-beam (flexible, i.e. timber) Diaphragm Steel connection elements	Crack and void grouting Post-tensioning of vertical strengthening Buttresses Grout injection Reinforced repointing Anchorage, Wall cross-ties Bond-beam (stiff, i.e. concrete or steel) Bond-beam (flexible, i.e. timber) Steel mesh with cement plaster Geotextiles at both faces, through-wall tied Diaphragm Cables and straps Steel connection elements	Steel connection elements wooden horizontal chaining

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WALLS (3): TIMBER REINFORCED MASONRY

Timber Reinforced Masonry	Timber framed masonry	Steel rods and additional nails and bolts Textile-reinforced mortar Steel plates and hidden joints Bolts Steel plates Steel flat bars (NSM)	Steel rods and additional nails and bolts Textile-reinforced mortar Steel plates and hidden joints	Timber flange connected by dowels to main beams Steel rods and additional nails and bolts Textile-reinforced mortar Steel plates and hidden joints	Steel rods and additional nails and bolts Textile-reinforced mortar Steel plates and hidden joints
	Timber tied stone masonry	Steel rods and additional nails and bolts Textile-reinforced mortar Steel plates and hidden joints	Steel rods and additional nails and bolts Textile-reinforced mortar Steel plates and hidden joints	Timber flange connected by dowels to main beams Steel rods and additional nails and bolts Textile-reinforced mortar Steel plates and hidden joints	Steel rods and additional nails and bolts Textile-reinforced mortar Steel plates and hidden joints

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FLOORS: TIMBER AND STEEL

ELEMENT SPECIFICATIONS		FAILURE MECHANISMS			
Material	Typology	Inadequate out-of-plane bending strength and stiffness	Inadequate in-plane stiffness	Slipping at supports	Beam-vault separation
		select intervention: Additional connection elements			
Timber	Simple unidirectional floor	Composite materials Timber flange connected by dowels to main beams Orthogonal or diagonal planking Reinforced concrete cooperating slab Cross beam built from the intrados of the existing wooden floor	Composite materials Metallic strips and diagonals Timber flange connected by dowels to main beams Orthogonal or diagonal planking Reinforced concrete cooperating slab Anchor bolts for semi-rigid connection	Additional connection elements	
	Bidirectional floor	Timber flange connected by dowels to main beams Orthogonal or diagonal planking Reinforced concrete cooperating slab Strengthening of laminated wooden joints and increase of ductility	Composite materials Metallic diagonals Metallic plates Metallic strips and diagonals Orthogonal or diagonal planking Reinforced concrete cooperating slab Anchor bolts for semi-rigid connection	Additional connection elements	
Steel	Steel beams and brick vaults	Enlargement Load Reduction and control Steel I Beam Replacement	Anchorage, Wall cross-ties Bond-beam (stiff, i.e. concrete or steel) Load Reduction and control Stoppers/restriction braces insertion Steel plates welding	Additional connection elements Supporting wall stabilization	Void filling

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ROOFS: TIMBER

ELEMENT SPECIFICATIONS		FAILURE MECHANISMS			
Material	Typology	Inadequate bending strength and stiffness	Inadequate in-plane stiffness	Slipping at supports	Material degradation
Timber	Non thrusting structure - truss (rafter under flexure)	Bond-beam (flexible, i.e. timber) Application of FRP composite strips glued to the surface Cables and straps			Bond-beam (flexible, i.e. timber)
	Non thrusting structure - truss (rafter without flexure)		Additional connection elements		
	Thrusting structure		Ties beams or Ties rods	Ties beams or Ties rods	

select intervention: Additional connection elements

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ARCH/VAULT: BRICK AND STONE

ELEMENT SPECIFICATIONS		FAILURE MECHANISMS			
Material	Typology	Displacement of the supports	Differential settlement of the piers	Longitudinal sliding	Load variation
		select intervention: Additional connection elements			
Brick - Stone	Arch and barrel vault	Buttresses Extrados r.c. jacketing FRP/SRP/SRG application on vaults Ties beams or Ties rods Extrados stiffening elements (frenelli) Extrados stiffening elements (frenelli) + FRP/SRP/SRG	Buttresses Extrados r.c. jacketing FRP/SRP/SRG application on vaults Ties beams or Ties rods Extrados stiffening elements (frenelli) Extrados stiffening elements (frenelli) + FRP/SRP/SRG	Extrados r.c. jacketing Extrados stiffening elements (frenelli) Extrados stiffening elements (frenelli) + FRP/SRP/SRG	Extrados r.c. jacketing Reducing the loads from extrados infilling Extrados stiffening elements (frenelli) Extrados stiffening elements (frenelli) + FRP/SRP/SRG
	Groin vault	Extrados r.c. jacketing FRP/SRP/SRG application on vaults Ties beams or Ties rods	Extrados r.c. jacketing FRP/SRP/SRG application on vaults Ties beams or Ties rods	Extrados r.c. jacketing FRP/SRP/SRG application on vaults	Extrados r.c. jacketing FRP/SRP/SRG application on vaults Reducing the loads from extrados infilling
	Cloister vault	Buttresses Extrados r.c. jacketing FRP/SRP/SRG application on vaults Ties beams or Ties rods	Buttresses Extrados r.c. jacketing FRP/SRP/SRG application on vaults Ties beams or Ties rods	Extrados r.c. jacketing FRP/SRP/SRG application on vaults	Buttresses Extrados r.c. jacketing FRP/SRP/SRG application on vaults Reducing the loads from extrados infilling
	Ribbed vault and dome				

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COLUMNS: BRICK AND STONE

select intervention: Additional connection elements

ELEMENT SPECIFICATIONS		FAILURE MECHANISMS			
Typology	Specification	Compression	Compression & Creep	Buckling	Crumbling and loss of symmetry
Brick - Stone	Monolithic columns	Confinement with Steel or FRP/SRP/SRG	Confinement with Steel or FRP/SRP/SRG	Vertical prestressing	Confinement with Steel or FRP/SRP/SRG Vertical core stainless steel rod Titanium/Stainless steel reinforcement bars with epoxy/cement glue External support system
	Drum columns	Confinement with Steel or FRP/SRP/SRG	Vertical centre-core rods (steel of fibreglass) or equivalent (polypropylene strapping outside the walls)	Vertical centre-core rods (steel of fibreglass) or equivalent (polypropylene strapping outside the walls) Vertical prestressing	Confinement with Steel or FRP/SRP/SRG Vertical core stainless steel rod Titanium/Stainless steel reinforcement bars with epoxy/cement glue External support system
	Masonry Pillars	Grout injection Scuci-Cuci Steel rods and additional nails and bolts Confinement with Steel or FRP/SRP/SRG	Grout injection Scuci-Cuci Reinforced repointing Metallic strips and diagonals	Grout injection Scuci-Cuci Vertical prestressing	

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SUB-ASSAMBLAGES/CONNECTIONS (1): HORIZONTAL-TO-VERTICAL STRUCTURE

ELEMENT SPECIFICATIONS		FAILURE MECHANISMS
Elements	Typology	Separation of structural elements
		select intervention: Additional connection elements
Connection horizontal to vertical structure	Connection between (stone/brick) masonry walls and floor/roof structures	Reinforced masonry ring beam LATLAM Steel ring beam Metallic connectors timber joists to wall Cross-ties/anchors with end plate Cross ties/anchors without end plate Shock Transmission Units (STUs) Shape Memory Alloy Devices (SMADs)
	Connection between stonework wall and timber floor	Metallic anchor with end plate and steel angle
	Timber laced connections in rubble infill stonework building	
	Connection between earthen walls and floor/roof structures	Metallic connectors timber joists to wall Wall plates External wall plates/Timber bands Continuous ledger and lag screws Perimeter horizontal cable Viscous dampers

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SUB-ASSAMBLAGES/CONNECTIONS (2): HORIZONTAL-TO-HORIZONTAL STRUCTURE AND ROOF CARPENTERY

Connection vertical to vertical structure	Connection between orthogonal (brick/stone) masonry walls	Scuci-Cuci Cross-ties/anchors with end plate Cross ties/anchors without end plate Column-ties Corner confinement by composite materials RAG energy absorbers Rotation amplifying energy absorber RETE energy absorber
	Connection between orthogonal stonework walls	Ductile anchor plates
	Corner connection between orthogonal brickwork walls	Cross ties/anchors without end plate Hysteretic anchor dissipative device Frictional anchor dissipative device
	Connection between stonework wall and vertical timber frame	Cross ties/anchors without end plate
	Timber laced connections in rubble infill stonework building	
	Connection between orthogonal earthen walls	Scuci-Cuci Cross ties/anchors without end plate Corner confinement by Geomesh Corner confinement by steel mesh Corner confinement by Polypropylene (PP) mesh
Roof carpentery connections	Halved dove tail connections	Composite materials Timber flange connected by nails to main beams Timber flange connected by bolt to main beams Oak plate inserted between wooden elements Plate of carbon fibres and adhesive glued to contact surfaces of both wooden beams

POST-PROCESSING OF THE INSERTED DATA

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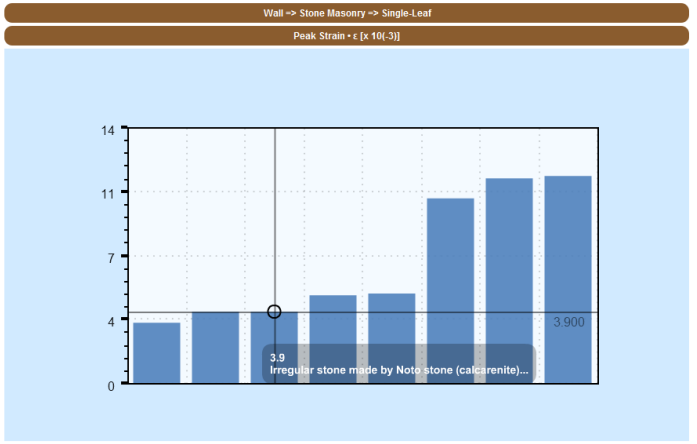
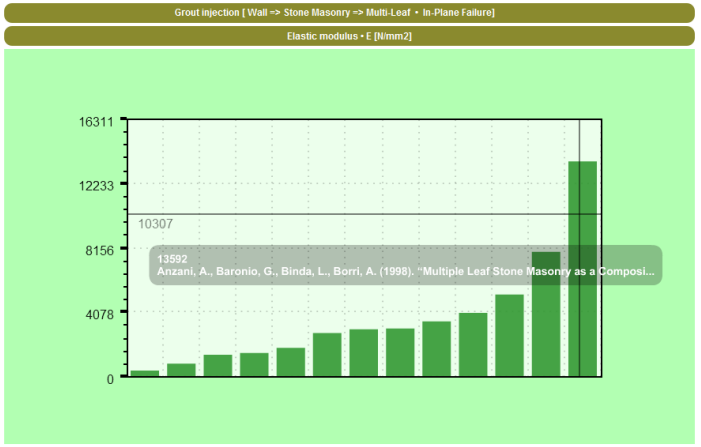
Statistical analysis of data, visualizing the most significant results in a quick way by trends and graphs are implemented.

STATISTICAL DISTRIBUTION OF MATERIALS AND FAILURE MECHANISMS

PRE-INTERVENTION PARAMETERS COMPONENT PARAMETERS



POST-INTERVENTION PARAMETERS REINFORCEMENT PARAMETERS



CONCLUSIVE REMARKS

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- The research led to the construction of an integrated process which could reorganise information necessary to an appropriate strategy of intervention, starting from addressed preliminary investigation on the original structure.
- The catalogue created within the NIKER project provides the technical data to define the behaviour of the structure, and to design the minimum required intervention, in relation to the target performance.
- Information concerning the material and building typologies are cross-linked to damages and repair intervention.
- Each intervention can be linked to one or more combinations of damage mechanisms and element typologies. For each intervention, information includes: limits and advantages, possible restrictions, documented seismic performance, preliminary tests, on site and in laboratory, maintenance observation and monitoring issues and references.
- The catalogue could be considered a friend-user tool able to addressed within a virtuous updated process, the selection of the intervention strategies, including maintenance and sustainable issue.

THANK YOU!

SPEAKER: ING. FRANCESCA DA PORTO

DEPARTMENT OF CIVIL, ENVIRONMENTAL &
ARCHITECTURAL ENGINEERING
UNIVERSITY OF PADOVA, ITALY