Risk analysis in natural disasters

Built heritage & earthquakes

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Introduction

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Natural and made-made hazards

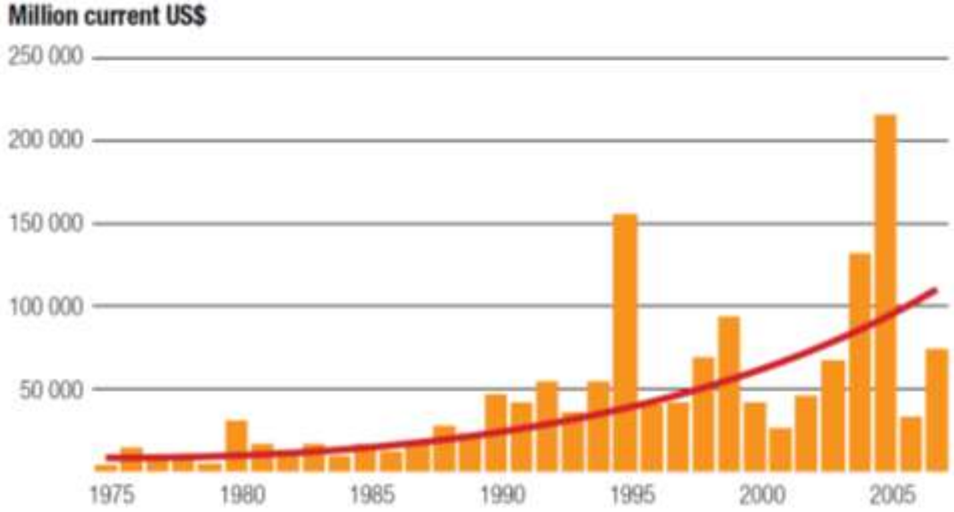
- ❑ **Climate change (and non-deliberate human action)**
- ❑ **Deliberate human action**

Growing value at risk

- The U.S. National Academy of Sciences projected for the next 50 years the human population to increase in ±50% with ±40% more life expectancy. This means >100% the demand for housing
- Half of the global population lives in cities, and by 2050 two-thirds is expected to live in urban areas (UN, World Urbanization Prospects)

Risk Management, Technical Experts and Society

- ❑ **Perception and communication**
- ❑ **Assessment and diagnosis**
- ❑ **Solutions, costs and implementation**



Since 1950, yearly costs increased more than 10x

- ❑ ***How to solve the mathematical indeterminacy of huge consequences and low probabilities?***

Natural Hazards Losses: Huge and Spread Worldwide (2011)

http://usatoday30.usatoday.com/weather/news/extremes/story/2012-01-04/world-disasters-costliest-earthquake-tsunami/52377642/1

$380 billion is the annual wealth produced by 15 million European

Community resilience

- Sustained ability of a community to utilize available resources (energy, communication, transportation, food, etc.) to respond to, withstand, and recover from adverse situations (e.g. economic collapse to global catastrophic risks)

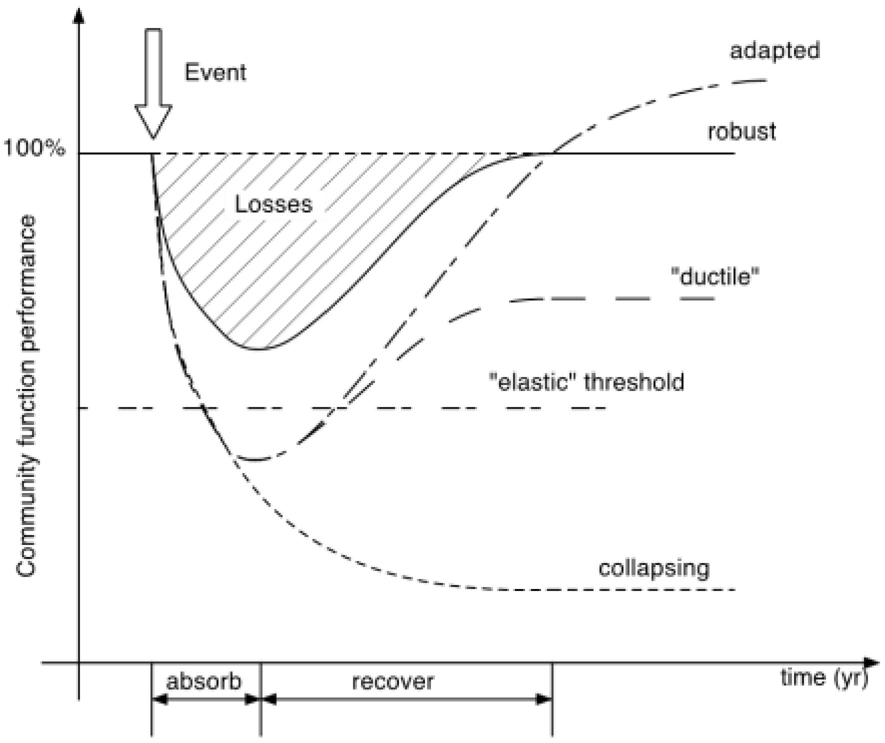
Wikipedia text

- Allows for the adaptation and growth of a community after disaster strikes
- Able to minimize any disaster, making the return to normal life as effortless as possible, while rebuilding physically and economically

- **Not giving up**
- **Continuity of community existence thorough the survival of its inhabitants and the continuity of its social and economic functions**
- **Community resilience depends on the resilience of its built infrastructure**

Built infrastructure

- **Built environment: Housing is only a part**
- **Civil infrastructure systems: Complex & Interconnected**
- **Vulnerability in one system easily affects others: Cascading failures**
- **Reducing the risk in one system is not enough**



Performance measured in terms of casualties and loss of function

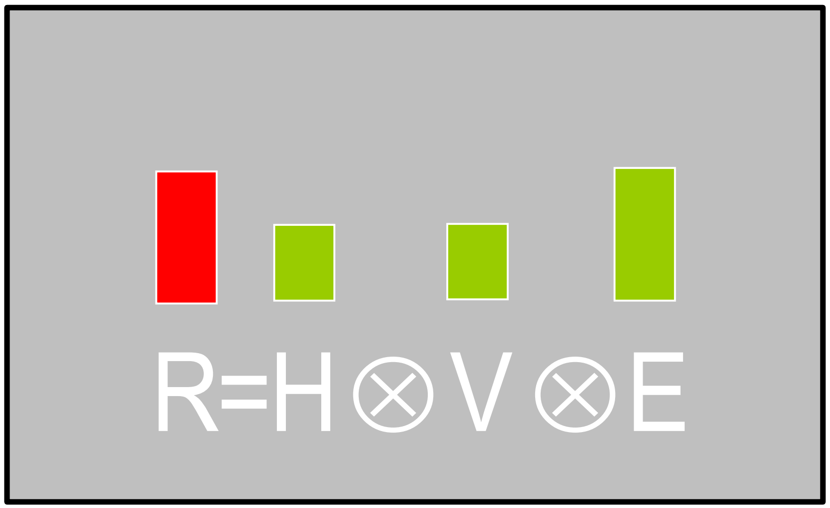
Risk assessment

- **Risk evaluation for the built environment is associated with the level of hazard, building vulnerability and level of exposure**

- Within this holistic approach, building vulnerability is the most important, not only because of the physical consequences in a disaster, but because it is where engineering can intervene, reducing the level of vulnerability and consequently the level of physical damage, life loss and economical loss

Risk assessment

- **Risk evaluation for the built environment is associated with the level of hazard, building vulnerability and level of exposure**



- Within this holistic approach, building vulnerability is the most important, not only because of the physical consequences in a disaster, but because it is where engineering can intervene, reducing the level of vulnerability and consequently the level of physical damage, life loss and economical loss

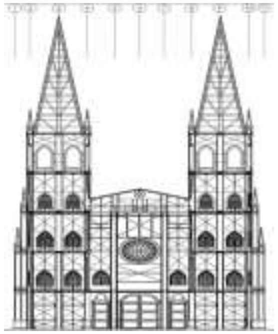
Tools and methodology

Evaluation scales


World


Country


City


Building

Earthquakes

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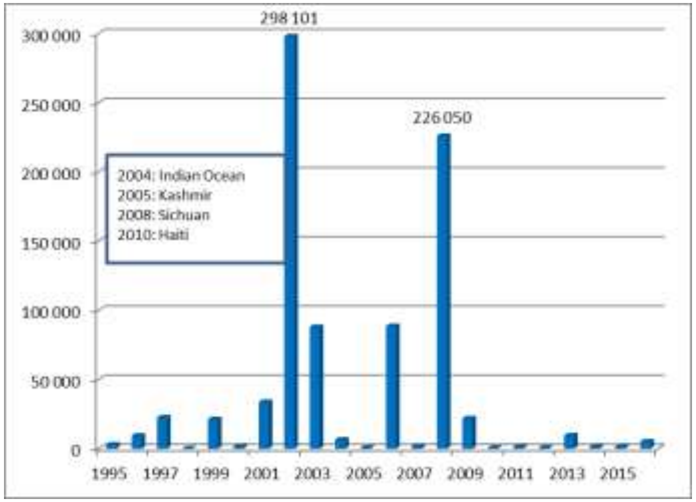
Earthquakes

- Since 1960, 40% of natural disaster deaths occurred as a result of earthquake events
- 60% of these are due to masonry buildings (stone, clay, earth, lime,…)
- More than half of the built heritage is unreinforced masonry

Lisbon, 1755 earthquake



Eqs since 1995, 40.000 people/yr

Earthquakes. Perception and communication

- **Perception and communication (WHO)**

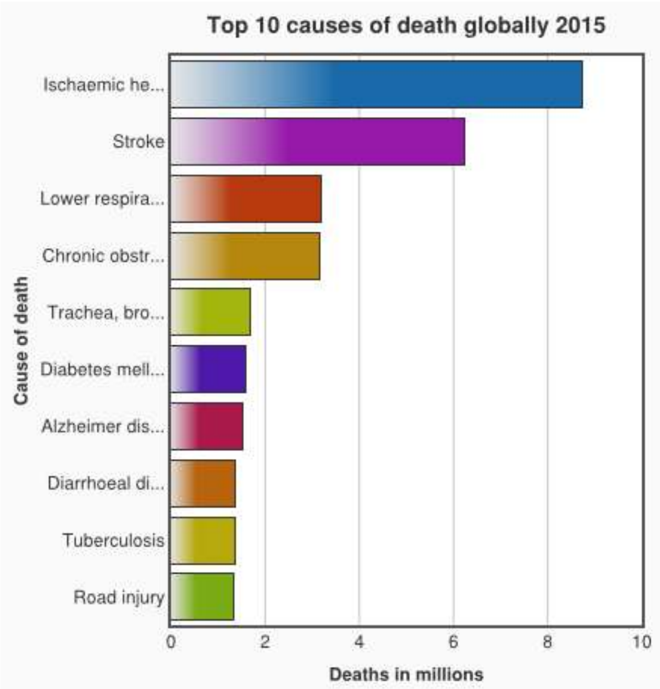
Ischemic heart disease

Lower respiratory infections

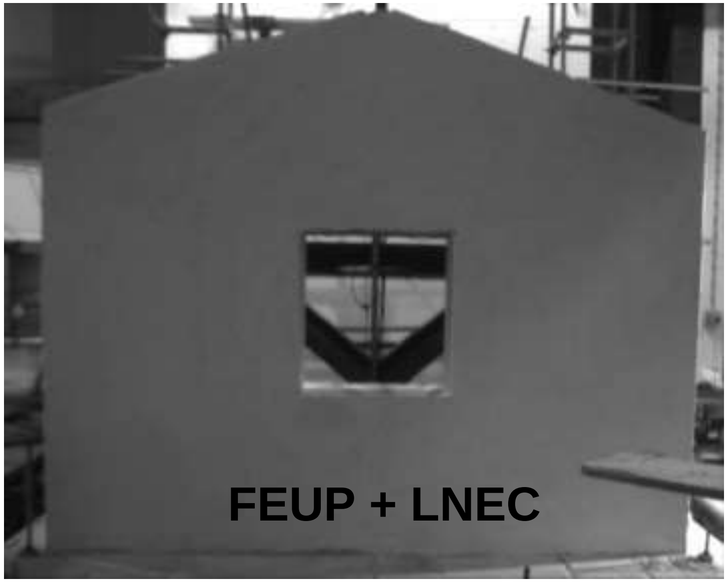
Chronic obstructive pulmonary disease

90 to 95% is type II. 0.5% GDP

1.3 million people!



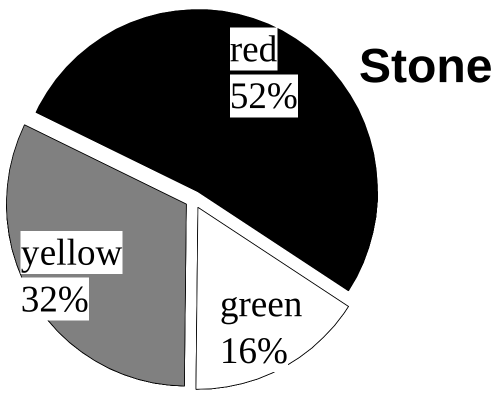
Earthquakes: Acceptable vs. Unacceptable

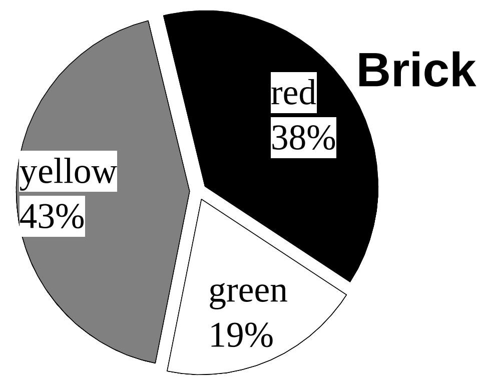


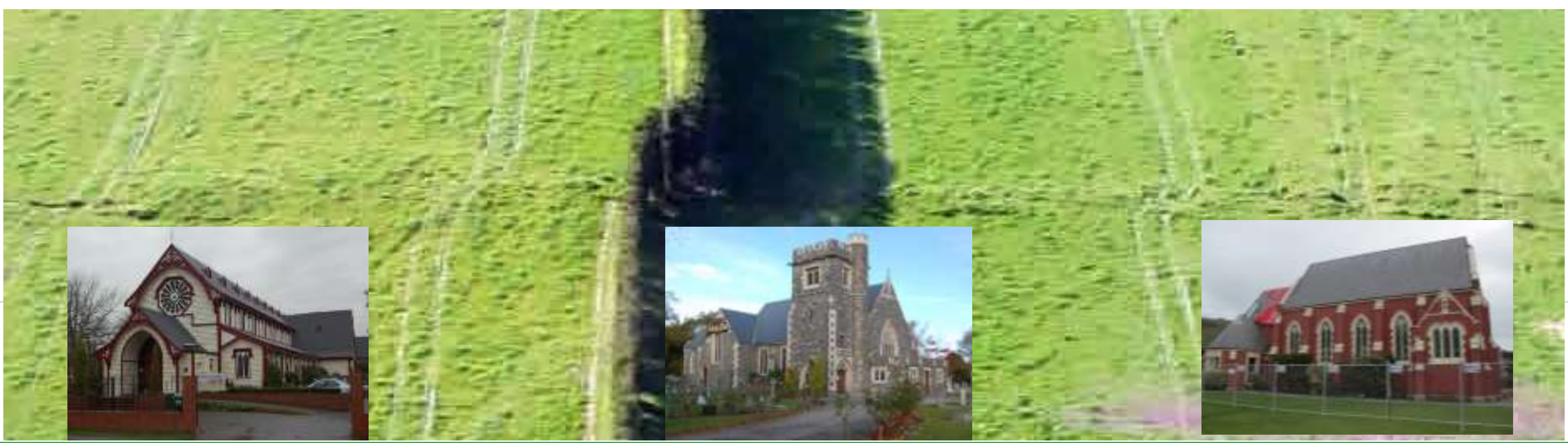
- **Cultural heritage buildings are usually rather vulnerable: (a) fragile materials; (b) heavy construction; (c) inadequate connections.**
- **Simple and moderate cost measures can make drastically change the situation**

Existing masonry: Churches in New Zealand (EQs 2010-11)

- Red: unsafe building with access forbidden
- Yellow: safety compromised but urgent access allowed
- Green: no restrictions







Importance

Identity

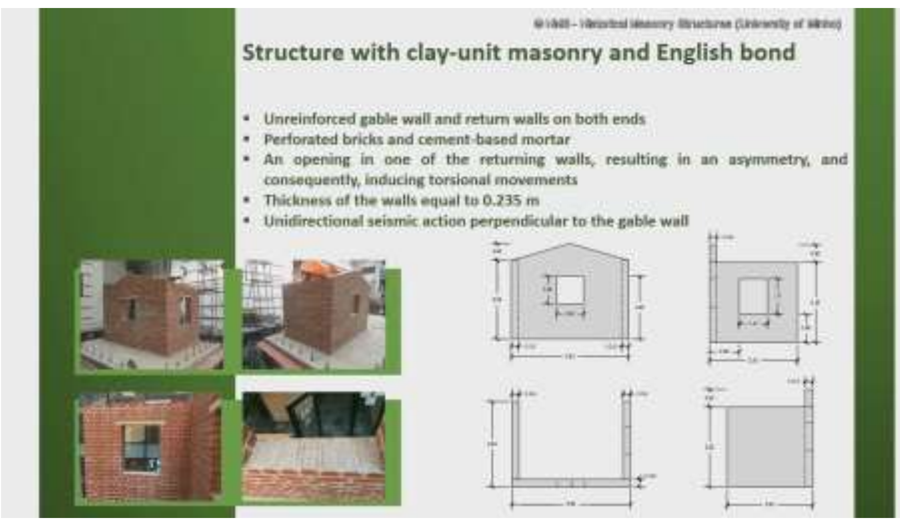
- ❑ Conservation of cultural heritage buildings is a demand from society
- ❑ No memory, no identity; no identity, no nation, A.D. Smith, LSE, 1995
- ❑ We shape our buildings; thereafter they shape us, W. Churchill, 1943

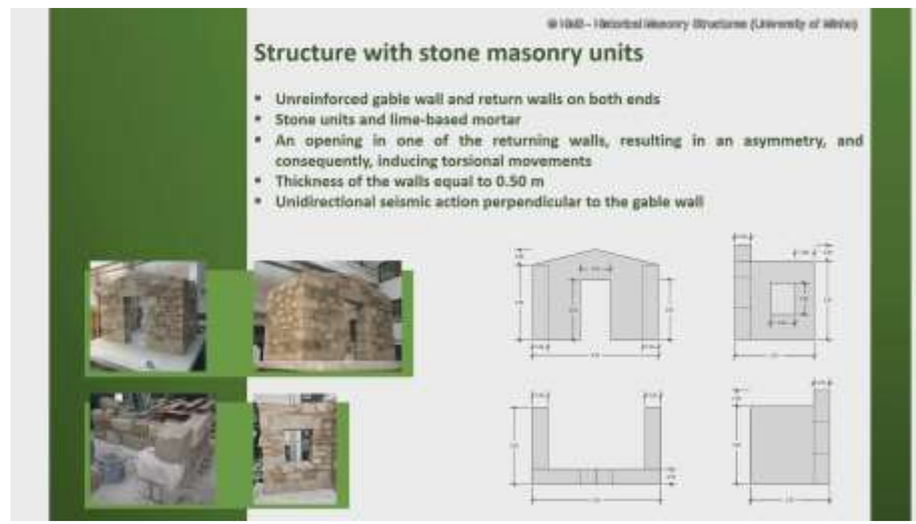
Economy. Follow the money

- ❑ Europe: tourism is 10% of the GDP and 12% of the employment
- ❑ Europe is the world's no. 1 tourist destination (50% of tourist arrivals)
- ❑ 45% of the UNESCO World Heritage sites are within Europe

Existing Masonry Buildings: Blind test prediction

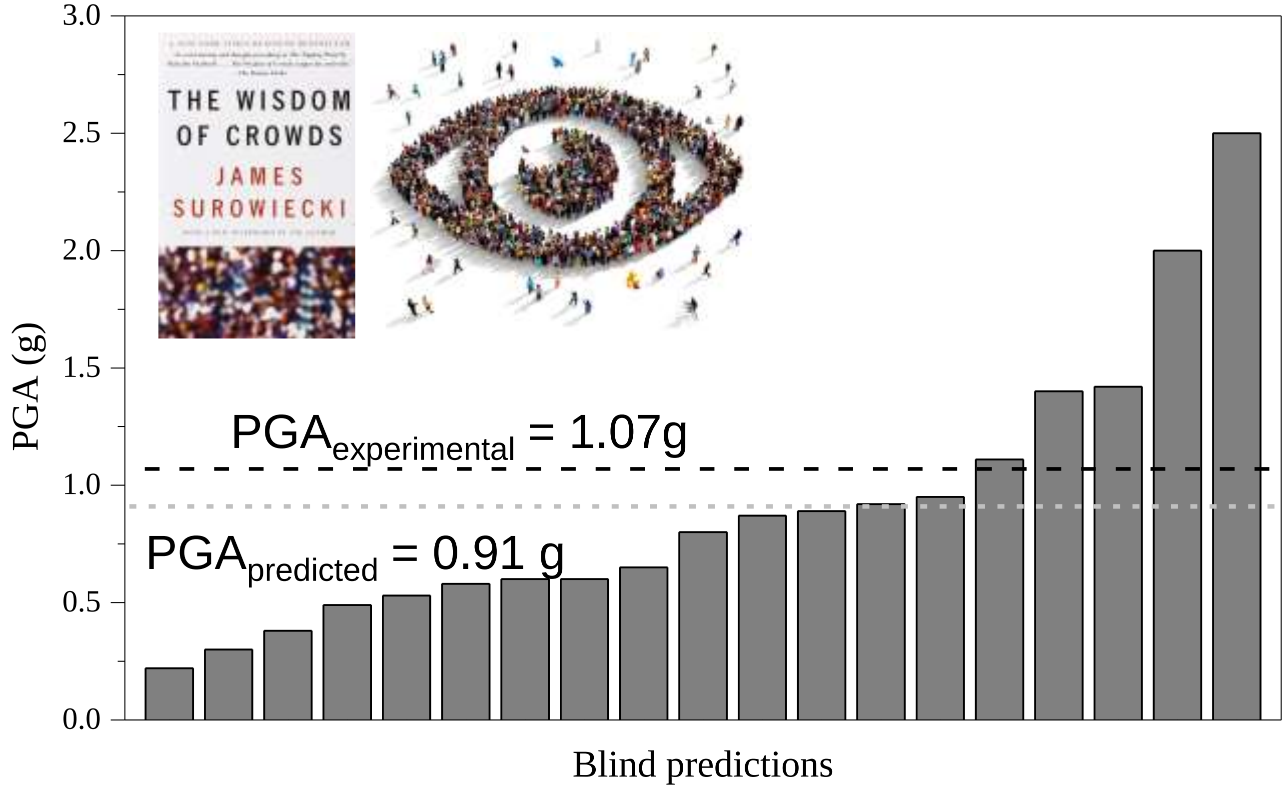
- ❑ Recent benchmark test
- ❑ 25 international masonry experts
- ❑ 18 blind predictions
- ❑ 2 masonry types





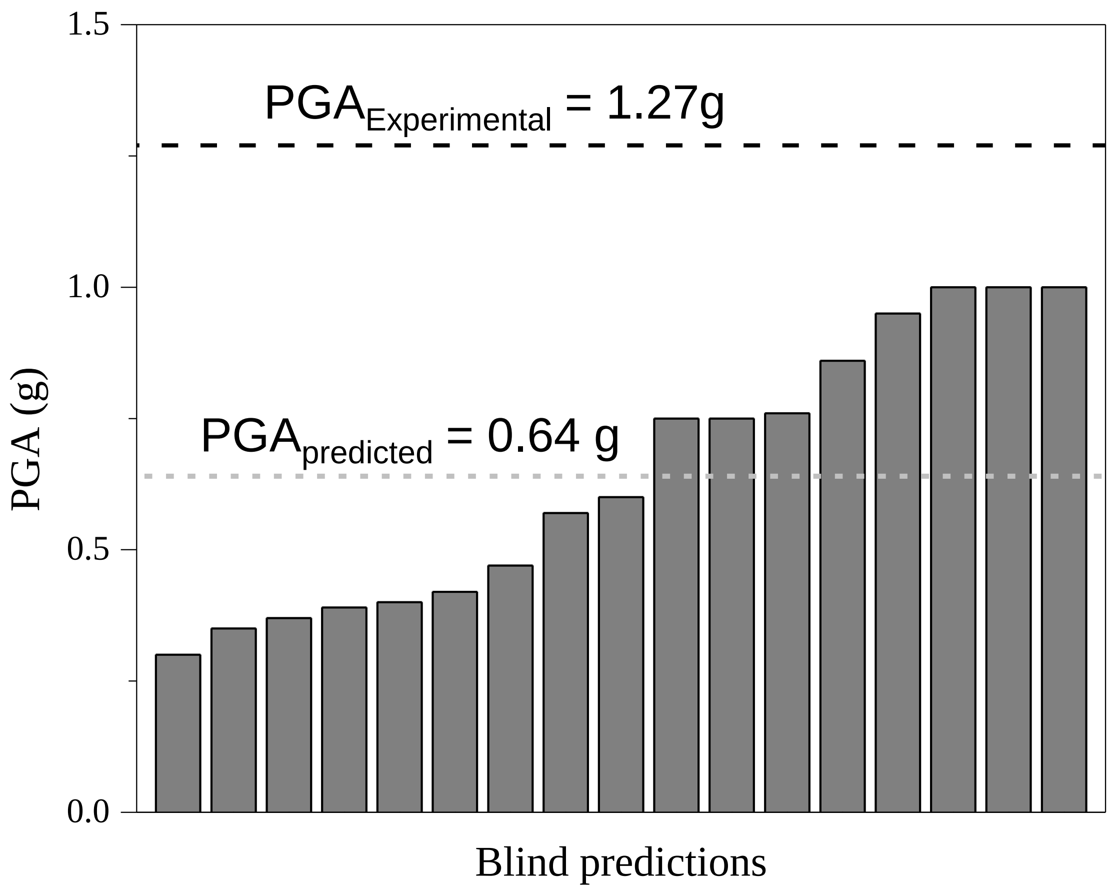
Stone building: 13 idealized collapse mechanism proposed (II)

- Average error between test and predicted PGA for good mech. was 28%
- 80% presented a predicted PGA lower than or equal to test
- Within good mech., two results presented collapse displacement at top (0.16 and 0.25 m).Test provided 0.22 m (about half of the wall thickness).



Brick building

- 17 predictions. Estimated PGA at collapse: 0.30-1.00 g (COV=39%)
- Experimental result (1.27 g). Average PGA of predictions: 0.64 g. All predictions lower than experimental results
- Problems: slenderness of the structure, torsional effects, material properties?



Examples (i): Building level and earthquakes

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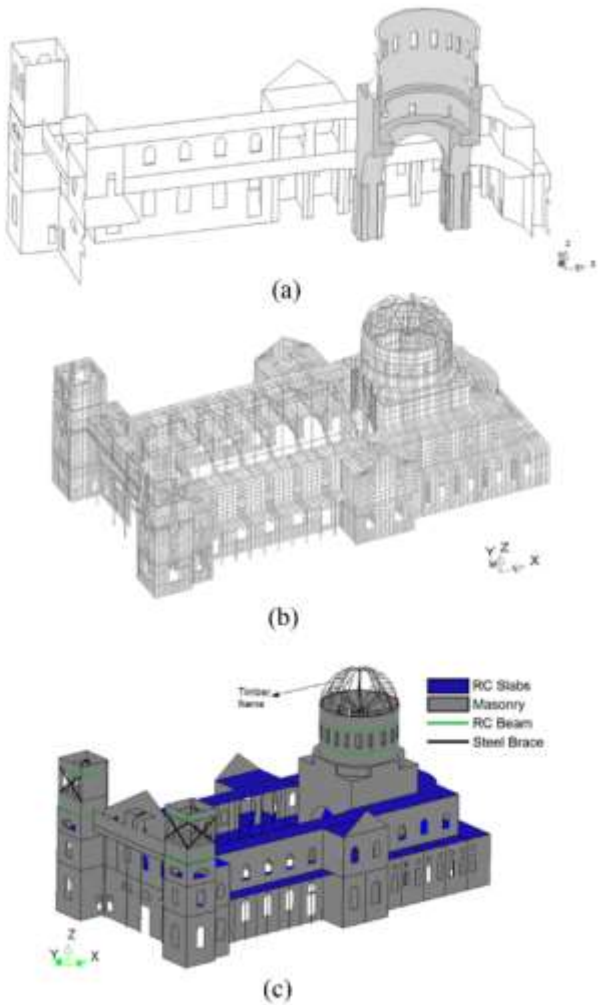
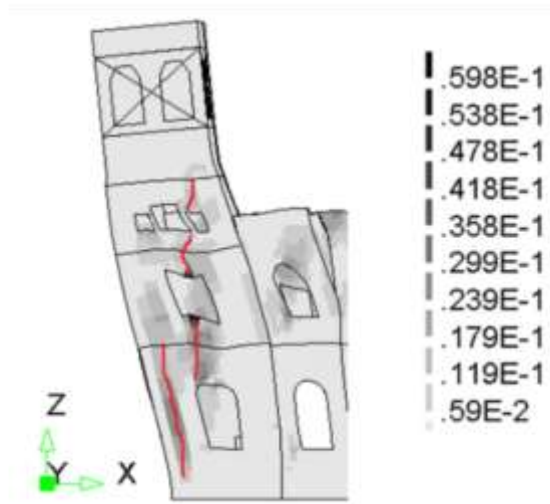
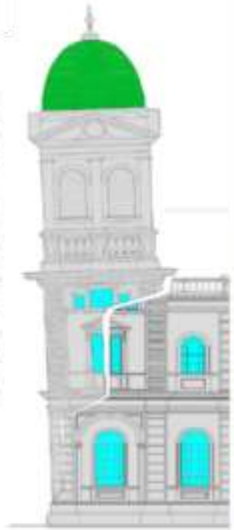
Blessed Sacrament Cathedral, Christchurch, NZ

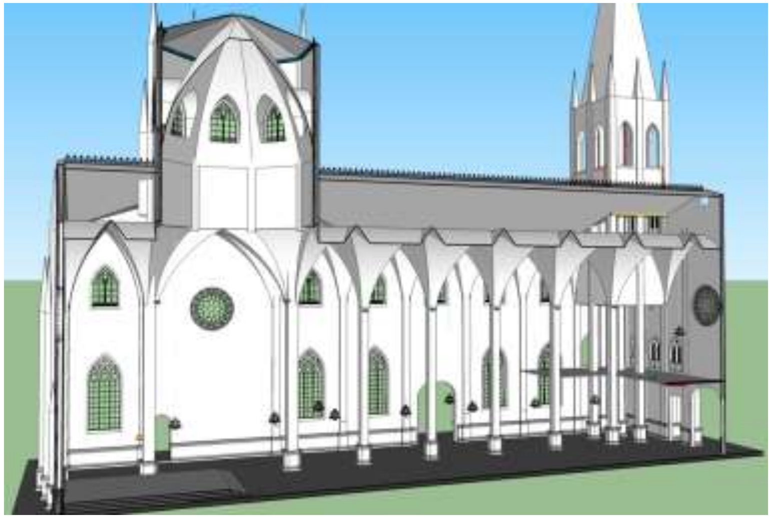
- ❑ **Construction 1901-1905**
- ❑ **Seismic strengthening: 2004**
- ❑ **Major damage in EQs 2010-11**


(a)
(b)
RC Slabs
Masonry
RC Beam
Steel Brace
(c)

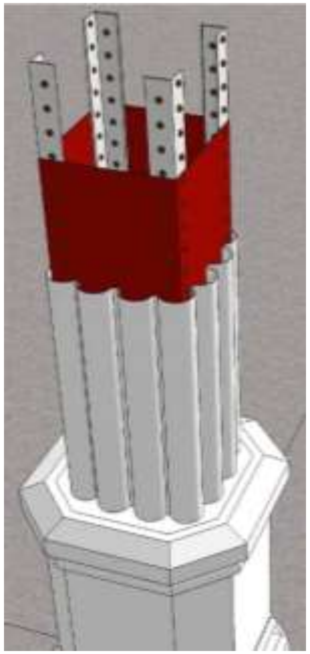

Z
Y
X
.598E-1
.538E-1
.478E-1
.418E-1
.358E-1
.299E-1
.239E-1
.179E-1
.119E-1
.59E-2

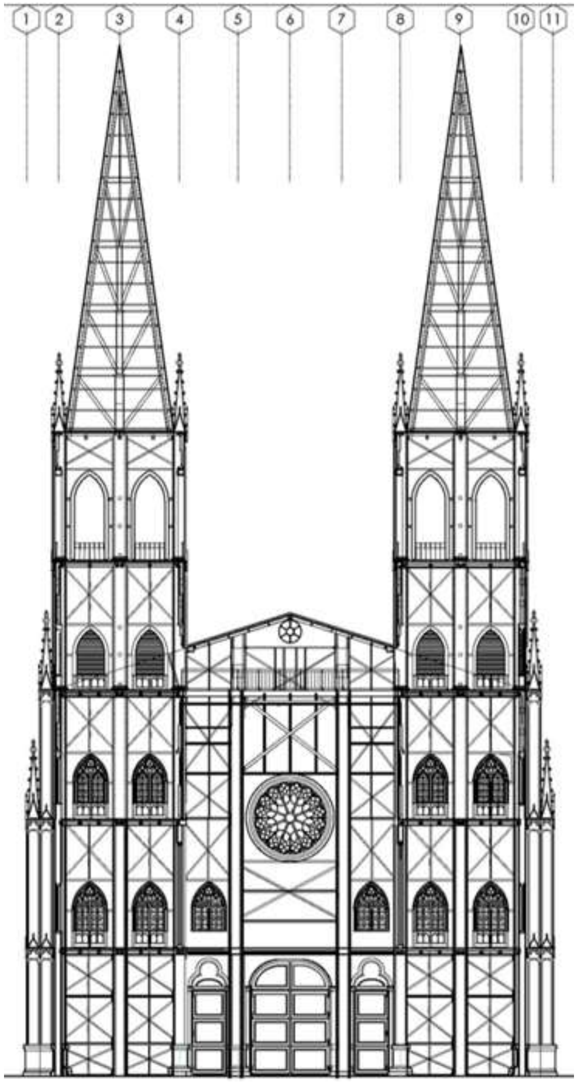


San Sebastian Basilica, Manila, Philippines

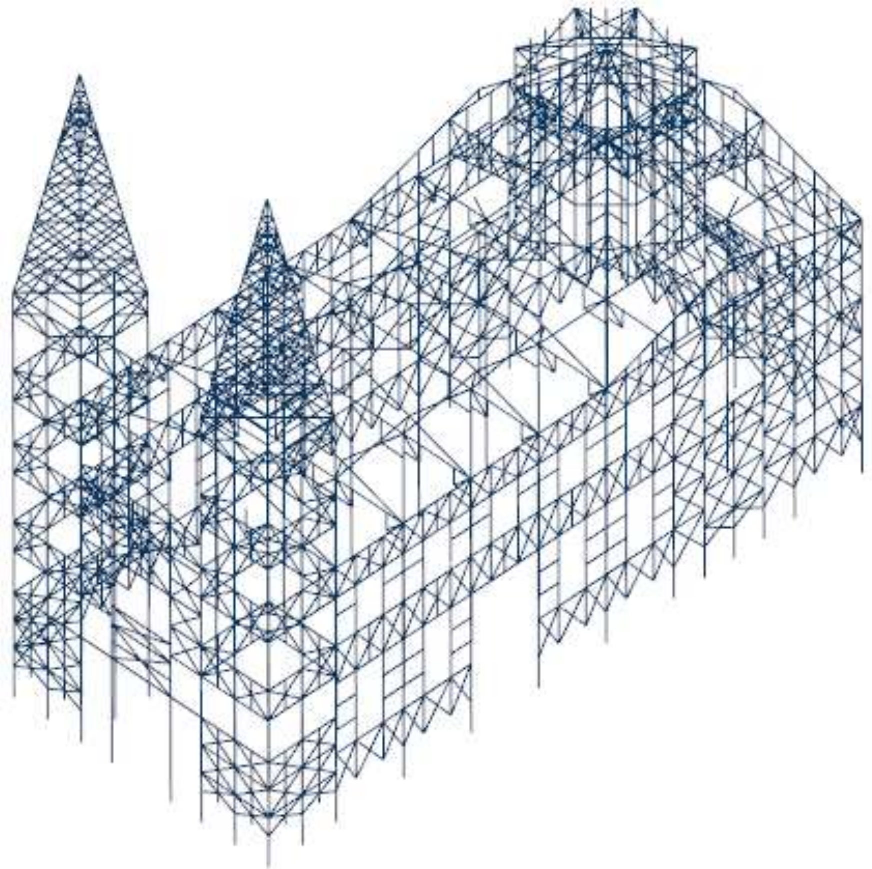


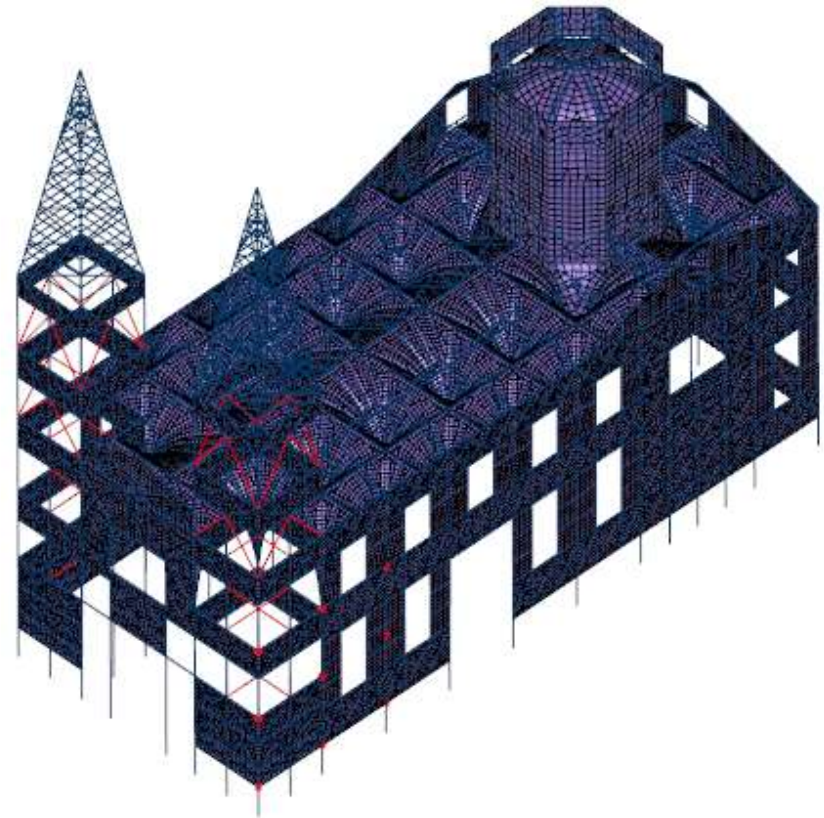
- Construction: 1890-1891
- Unique gothic metallic church. 9 steam boats from Belgium and 1500 ton
- 3 previous buildings (1639, masonry, fire and revolution), 1645 (earthquake), 1863 (masonry, earthquake), 1880 (timber, earthquake)





Complex structure. Important corrosion



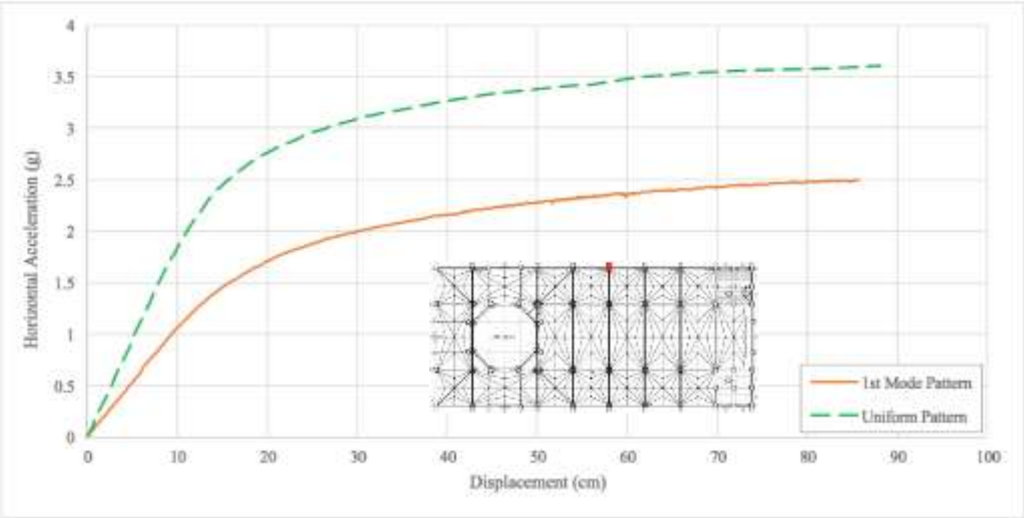


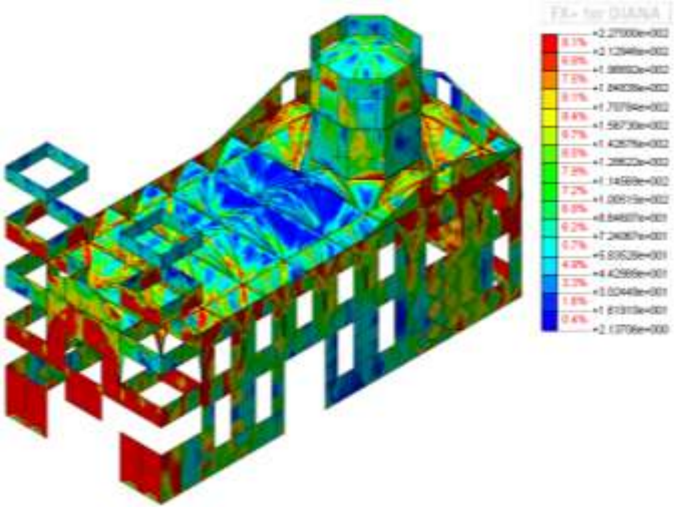
Beam elements: 56 452
Shell elements: 50 555
Springs elements: 9
Total DOF: > 1 000 000

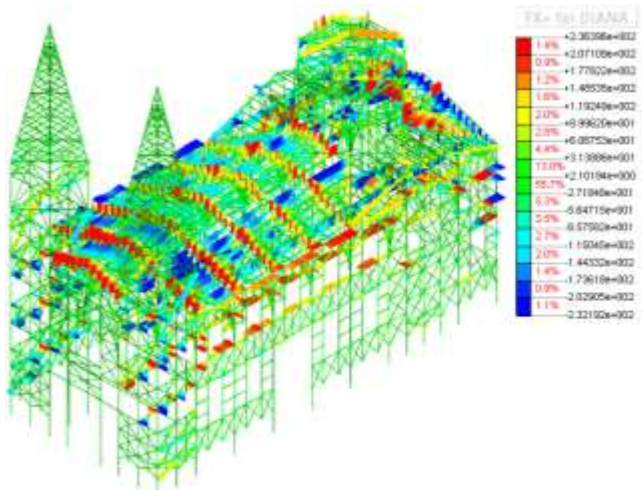
Beam elements: 54 905
Total DOF: 645 198

Model 1…

…Model 5



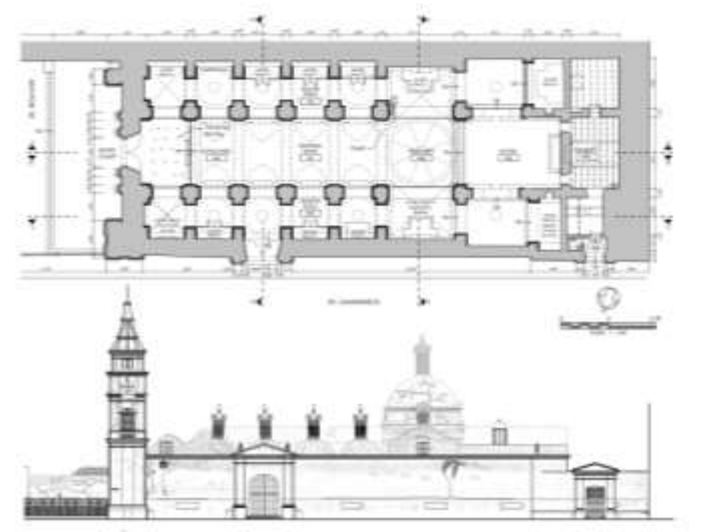


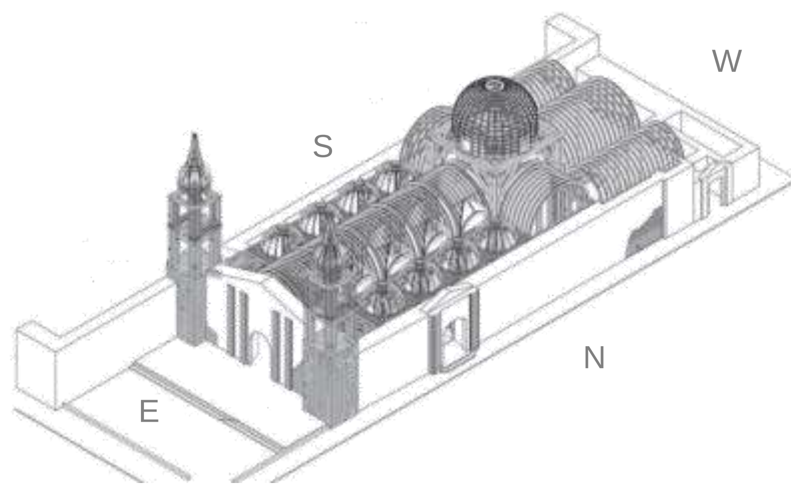


Damaged model. Safety still acceptable

Ica Cathedral

- Built in **18th century**, national monument since 1982
- **Structure**
  - External masonry envelope (rubble stone, fired brick, rubble stone)
  - Internal timber frame (*quincha* technique)



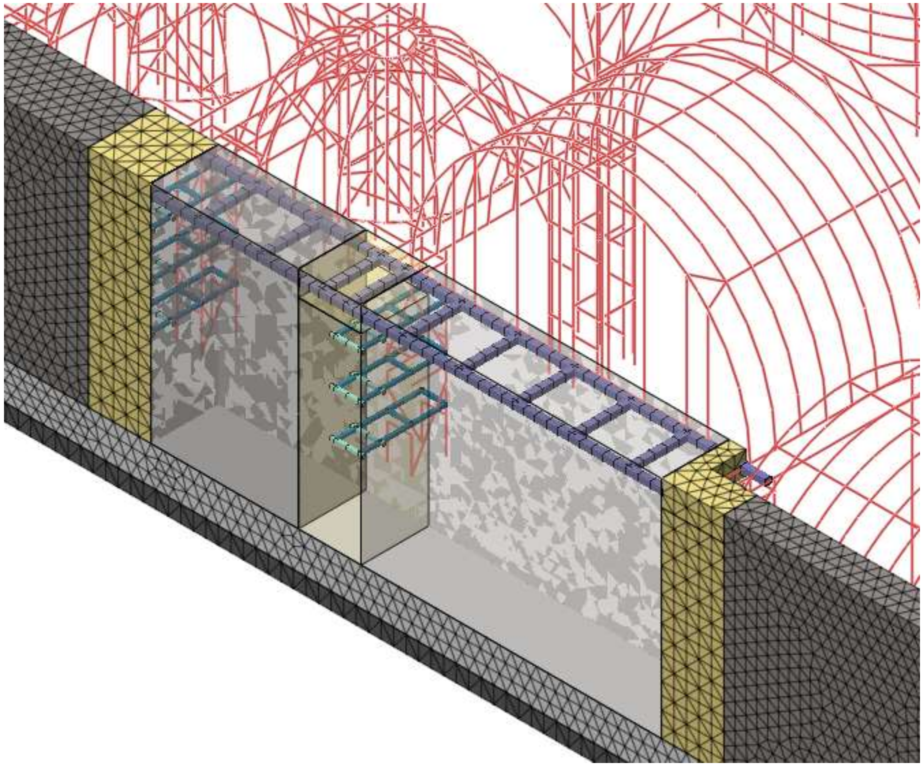


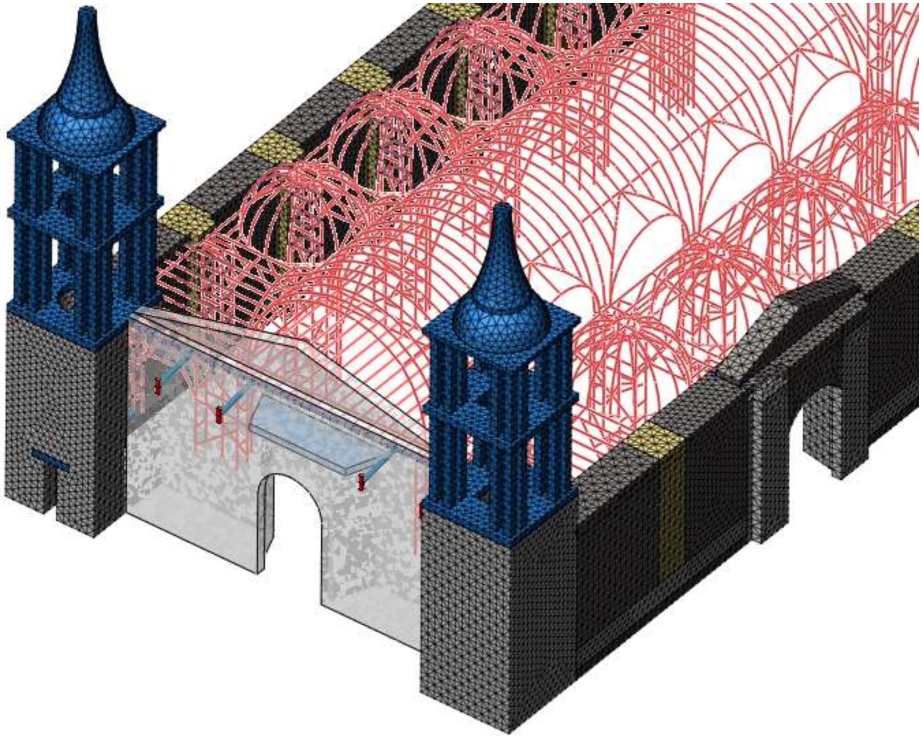
Ica Cathedral (IC)

- **Damage**
  - Collapse of the roof system
  - Vertical cracks
  - Loss of material
  - Deterioration

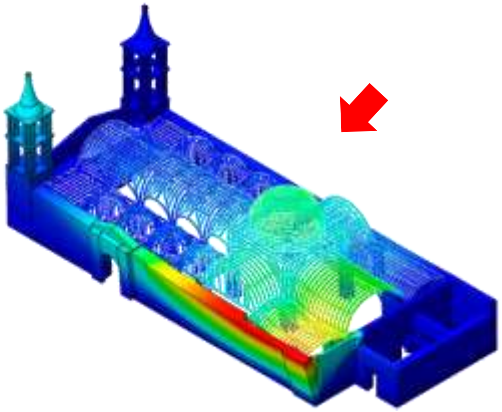
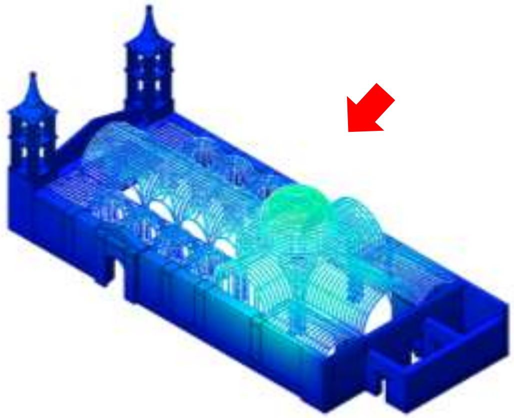
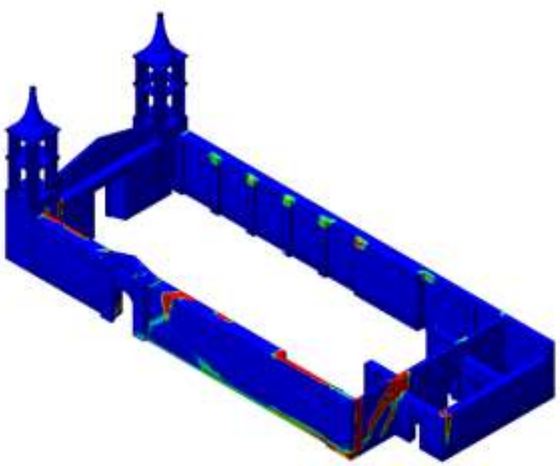
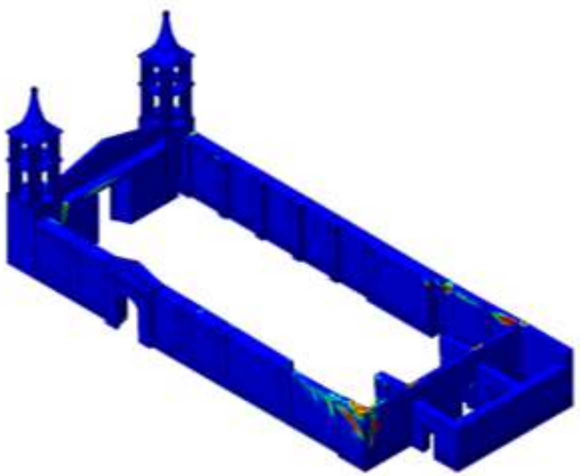
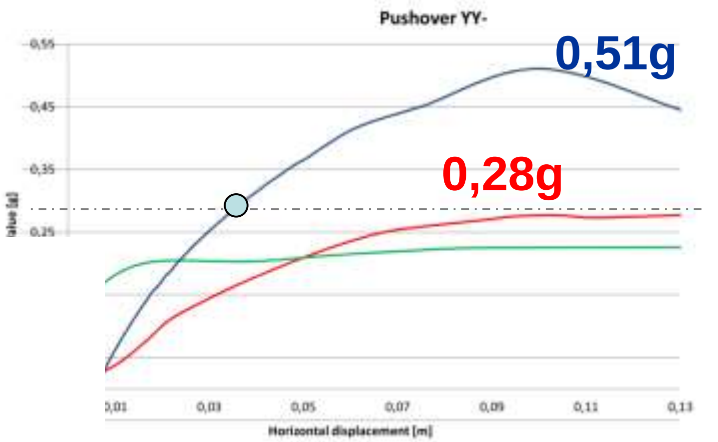
- **Diagnosis**
  - Earthquakes in 2007 (MW 7.9-8.0) and in 2009 (MW 5.8)
  - Lack of maintenance

Model with strengthening





Unstrengthened vs. strengthened model

Examples (ii): Territorial level and earthquakes: Horta – Azores & Coimbra

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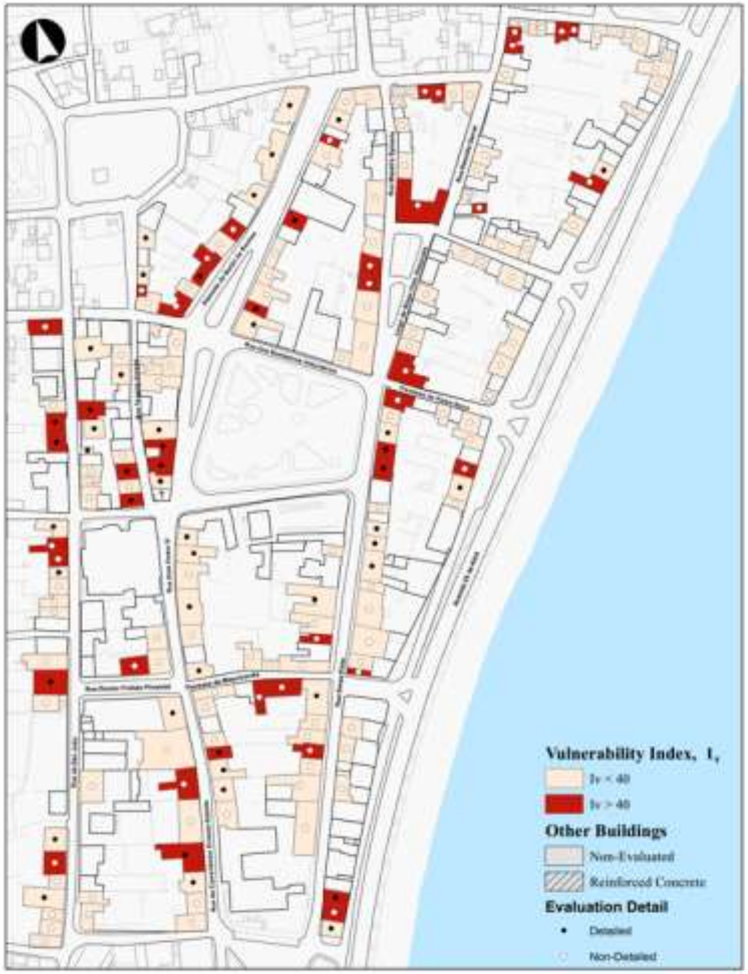
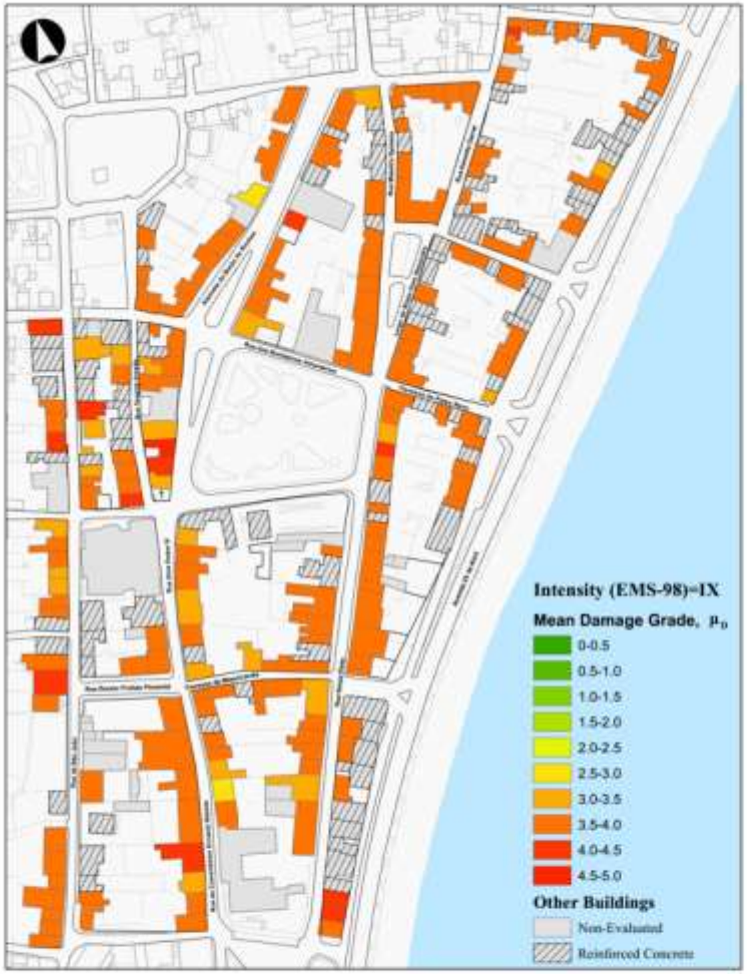
Seismic vulnerability assessment and scenarios



Global vulnerability distribution and identification of the buildings with I_v values over 45



Damage scenarios for macroseismic intensities I_{EMS-98}= IX.

Seismic vulnerability assessment and scenarios

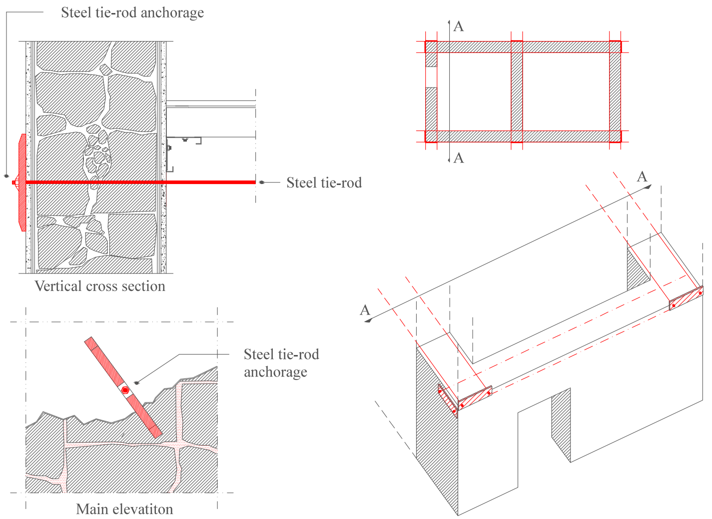
Total number of buildings: 192	Macroseismic intensity, $I_{EMS\text{-}98}$			
	VII	VIII	IX	X
Collapsed	0	0	15 (7.7%)	101 (52.7%)
Unusable	3 (1.8%)	33 (17.3%)	93 (48.2%)	72 (37.3%)

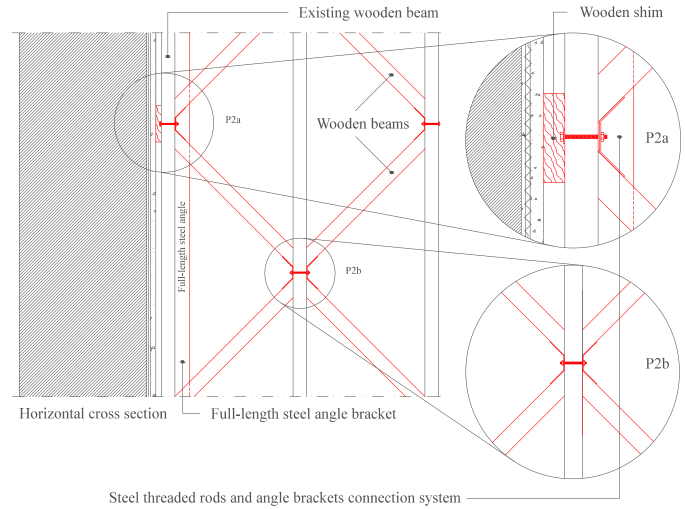
Total number of inhabitants: 1596	Macroseismic intensity, $I_{EMS\text{-}98}$			
	VII	VIII	IX	X
Dead and severely injured	0	0	37 (2.3%)	252 (15.8%)
Homeless	29 (1.8%)	278 (17.4%)	856 (53.7%)	1184 (74.2%)

Example of seismic retrofitting

RP1

Retrofitting Package 1 (RP1): Improvement of the connections and floor stiffening (35€/m^2)

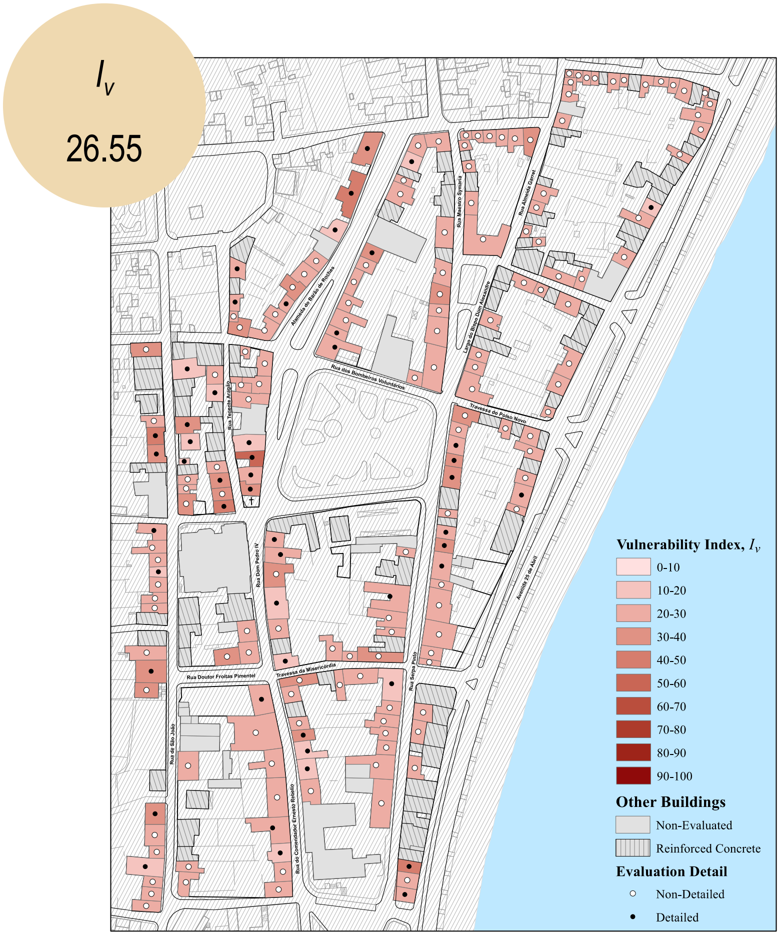


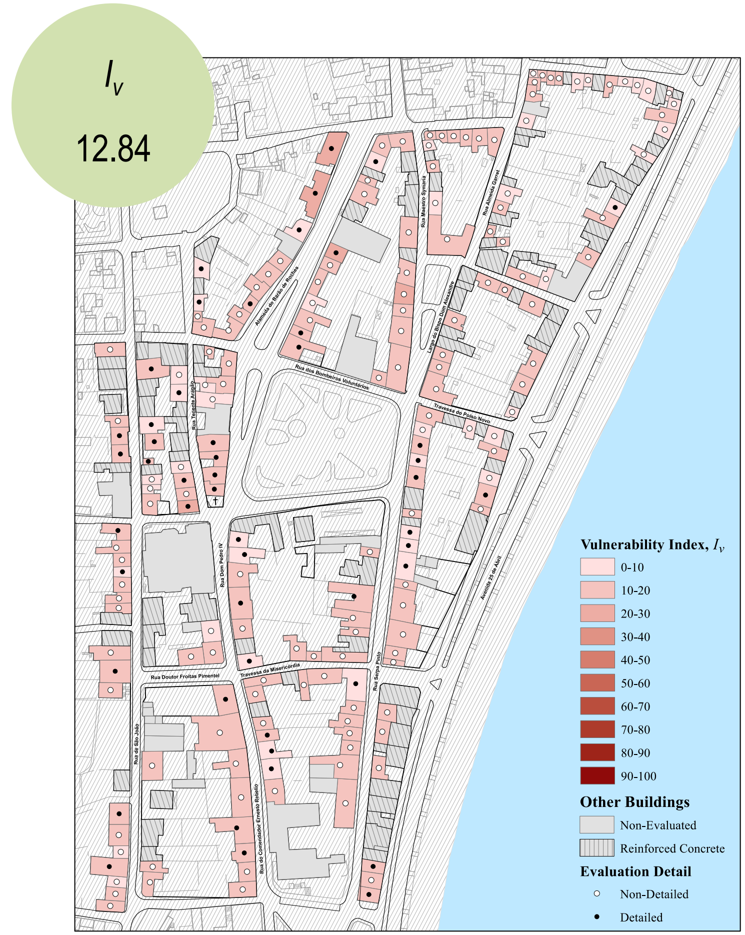



WALL-TO-WALL CONNECTION IMPROVEMENT THROUGH TIE-RODS


FLOOR STIFFENING WITH DIAGONAL BRACING AND TIMBER PLANKS

Impact of seismic retrofitting (vulnerability results)



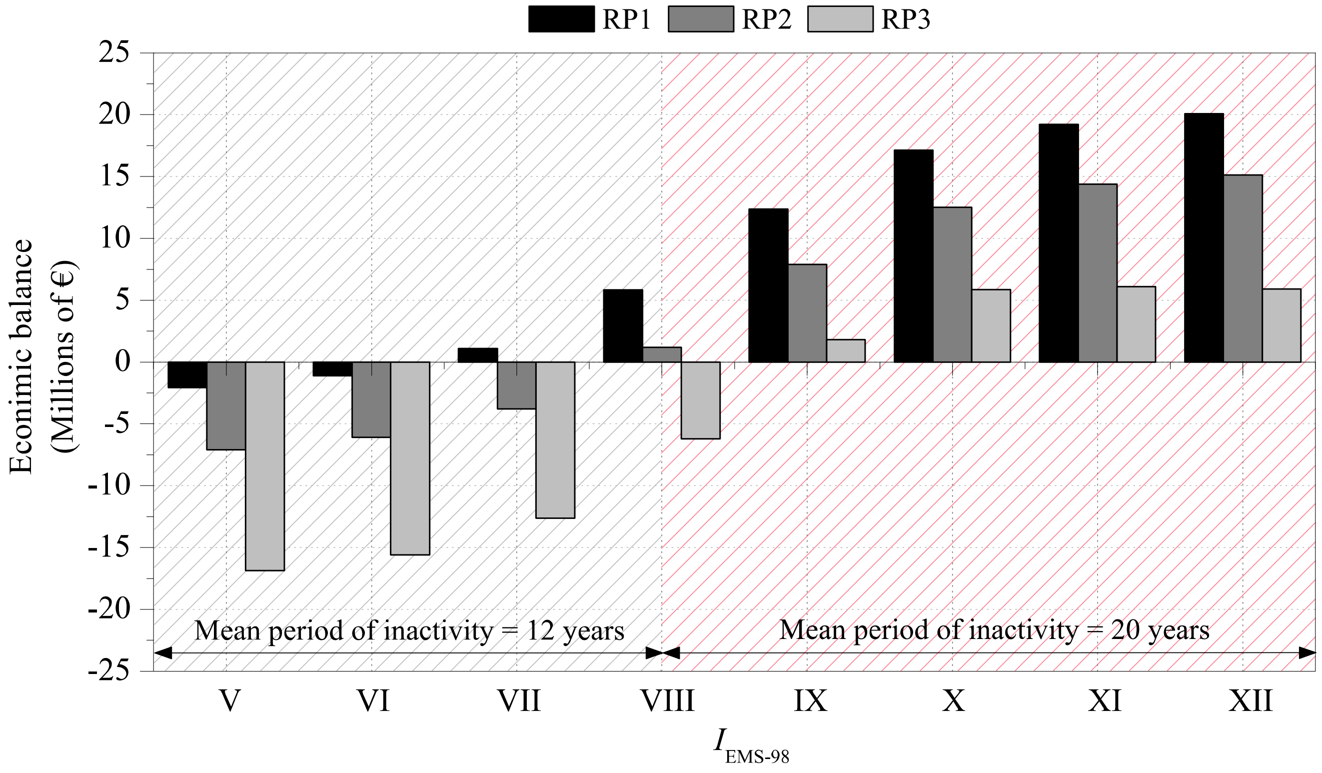


Impact of seismic retrofitting (loss estimation)

Intensity I_{EMS-98}	Collapsed buildings				Unusable buildings			
	BR	RP1	RP2	RP3	BR	RP1	RP2	RP3
VIII	0	0	0	0	9 (4.5%)	6 (3.1%)	5 (2.8%)	3 (1.5%)
IX	1 (0.3%)	0	0	0	43 (22.4%)	35 (18.1%)	33 (17.1%)	22 (11.5%)
X	14 (7.2%)	9 (4.7%)	8 (4.2%)	4 (2.0%)	92 (47.7%)	85 (44.1%)	83 (43.2%)	70 (36.4%)
XI	67 (34.9%)	55 (28.6%)	52 (27.3%)	36 (18.8%)	91 (47.3%)	96 (49.8%)	96 (50.2%)	100 (51.8%)
XII	129 (67.3%)	120 (62.4%)	118 (61.2%)	101 (52.7%)	52 (27.1%)	59 (30.7%)	60 (31.5%)	72 (37.3%)

Intensity I_{EMS-98}	Deaths and severely injured				Homeless			
	BR	RP1	RP2	RP3	BR	RP1	RP2	RP3
VIII	0	0	0	0	73 (4.5%)	49 (3.1%)	45 (2.8%)	24 (1.5%)
IX	2 (0.1%)	1 (0.1%)	1 (0.1%)	0	363 (22.7%)	290 (18.2%)	275 (17.2%)	185 (11.6%)
X	34 (2.2%)	22 (1.4%)	20 (1.3%)	9 (0.6%)	841 (52.7%)	756 (47.4%)	737 (46.2%)	603 (37.8%)
XI	167 (10.5%)	137 (8.6%)	131 (8.2%)	90 (5.6%)	1144 (71.7%)	1114 (69.8%)	1106 (69.3%)	1037 (65.0%)
XII	322 (20.2%)	299 (18.7%)	293 (18.4%)	253 (15.8%)	1184 (74.2%)	1186 (74.3%)	1187 (74.4%)	1184 (74.2%)

Impact of seismic retrofitting (cost-benefit analysis)



Retrofitting package	Intensity, I_{EMS-98}							
	V	VI	VII	VIII	IX	X	XI	XII
RP1	-	-	1.08 M€	5.85 M€	12.24 M€	17.15 M€	19.23 M€	20.10 M€
RP2	-	-	-	1.20 M€	7.89 M€	12.53 M€	14.39 M€	15.13 M€
RP3	-	-	-	-	1.80 M€	5.86 M€	6.12 M€	5.91 M€

Support of emergency planning

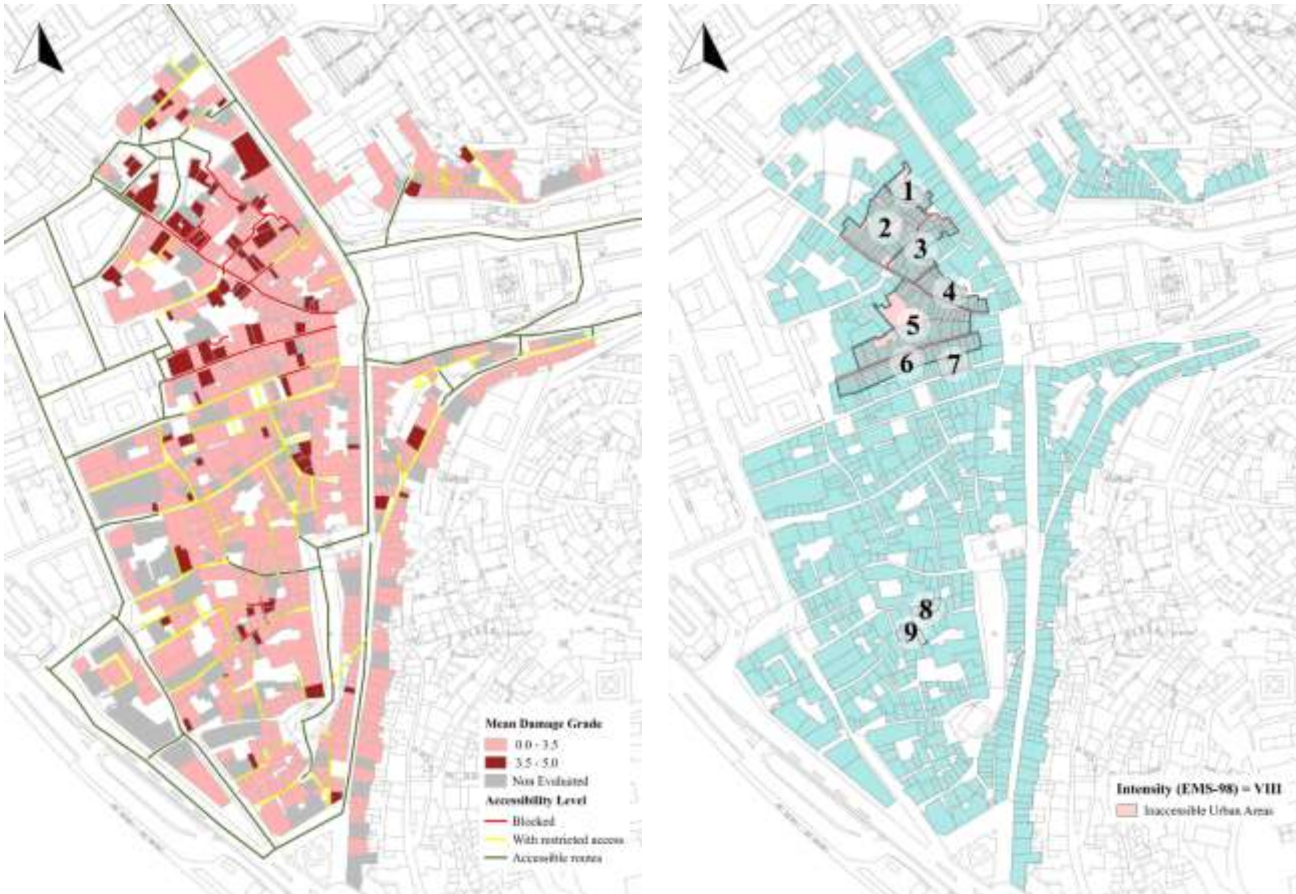
Using the damage scenarios, buildings that present a damage grade equal or higher than a threshold are identified and the **routes passing at least one of these buildings (and that do not have alternative accesses) will be obstructed.**

The unobstructed routes are further categorized according to the following criteria:

If the free width of the route is **higher than 4 meters**
The route is considered unobstructed
(accessible to rescue vehicles)

If the free width of the route is **lower than 4 meters**
The route is considered partially obstructed
(only pedestrian access is guaranteed)

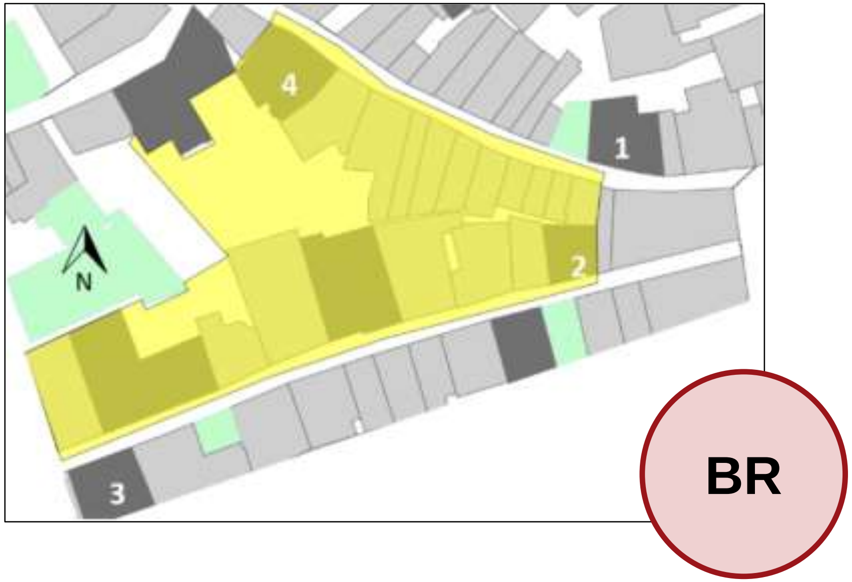
Evacuation routes and inaccessible areas



EVACUATION ROUTES

Definition of evacuation routes for a scenario of $I_{EMS\text{-}98}$=VIII and possible inaccessible areas

Impact of retrofitting



Situation	Population	Macroseismic Intensity, I_{EMS-98}							
		V	VI	VII	VIII	IX	X	XI	XII
Before retrofitting	98	0	0	1 (1%)	33 (34%)	88 (90%)	97 (99%)	98 (100%)	98 (100%)
After retrofitting	50	0	0	0	25 (50%)	47 (94%)	50 (100%)	50 (100%)	50 (100%)

25%
reduction

Others

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Natural and made-made hazards


Chiado, Lisbon, 1988


Funchal, Madeira, 2016


Rio de Janeiro

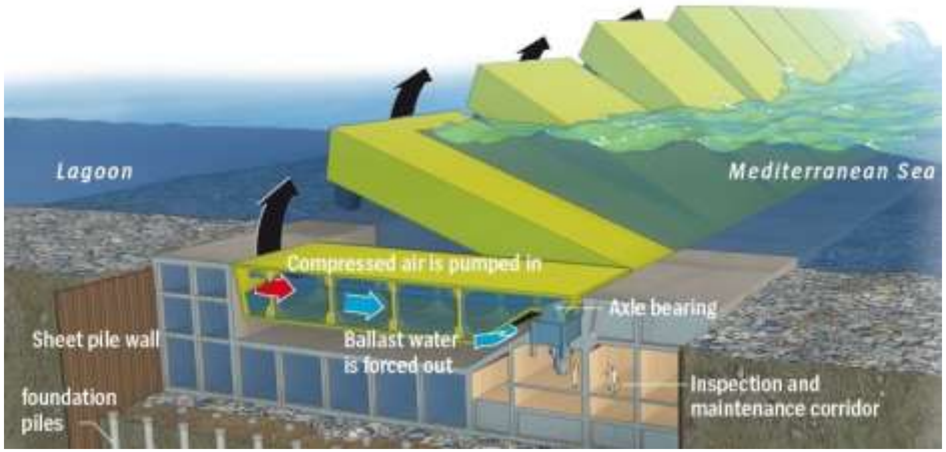

Windsor Castle


Wangduephodrang dzong

- ❑ **84% of wildfires caused be humans (Boulder’s Earth Lab, UColorado)**

Natural and made-made hazards

Floods


Lagoon
Mediterranean Sea
Compressed air is pumped in
Axle bearing
Sheet pile wall
Ballast water
is forced out
foundation
piles
Inspection and
maintenance corridor


Venice 2018


Reno floods


Porto Fino 2018

Conclusions

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Conclusions

- Our Built Cultural Heritage is at increasing risk (climate change and human actions). Extreme events pose a major challenge and disasters will continue to occur. Risk management is the key.
- Earthquake engineering community is quite strong and disseminated. But other hazards must be considered: Multi-hazard analysis is the key.
- If the society defines built cultural heritage as invaluable, there is a mathematical indetermination, but there is no alternative to risk mitigation. How to assess economic value?
- Studies from National Institute of Building Sciences (US) show that the investment in mitigation saves six times the amount for damage repair ("prevention pays"). How to convince society and politicians?
- Engineers have the tools and methodology to assess vulnerability, produce scenarios, reduce vulnerability, carry out cost-benefit analysis and help emergency planning. What is the next step?

Risk analysis in natural disasters

Built heritage & earthquakes

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