DEVELOPMENT OF MULTI-HAZARD RISK INDICATORS FOR IMMOVABLE CULTURAL HERITAGE

Project Research

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Content

Fire Risk Assessment for CH

- **Definition of Indicators**
- **Development of Vulnerability Indicators**

Seismic Risk Assessment for CH

Indicators

Objective

Framework

1 2 3 4 5 6 7

Flood Risk Assessment for CH

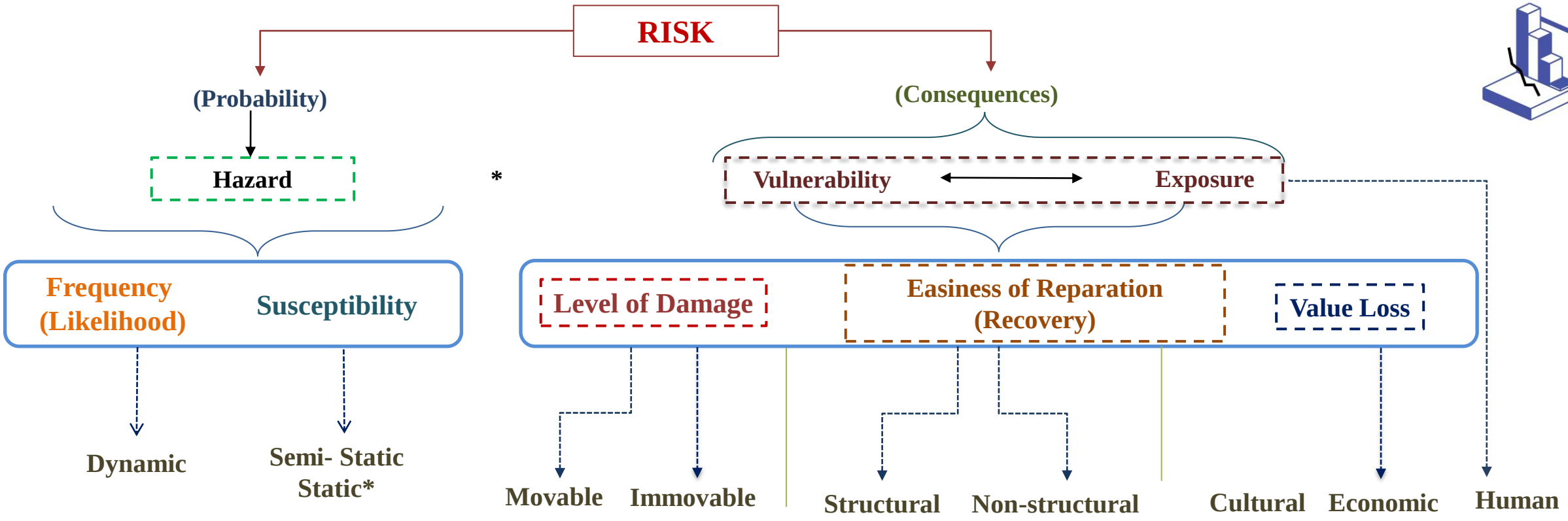
Indicators

Multi-hazard Risk Assessment for Cultural Heritage

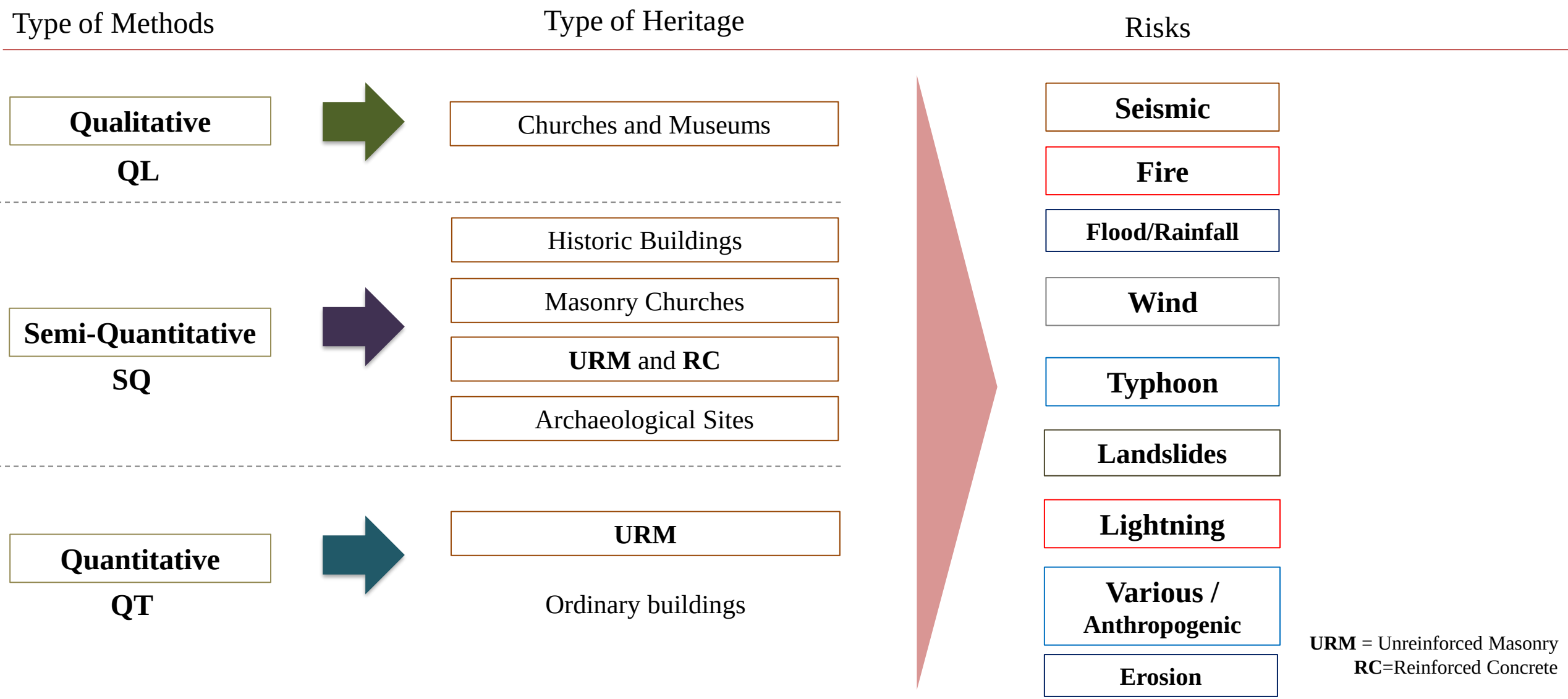
Future Tasks

Multi-hazard **Risk** Assessment for Cultural Heritage

Objective: **Create a simplified multi-hazard risk assessment method (Tool) for decision making management in Cultural Heritage :** This method aims to safeguard the structure, with some considerations to the protection of movable assets, and life safety.



Multi-hazard Risk **Assessment** for Cultural Heritage

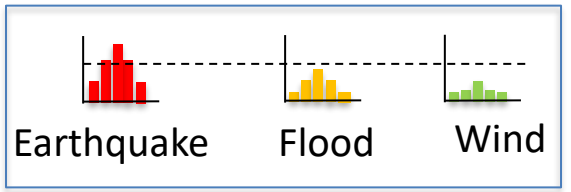


URM = Unreinforced Masonry
RC=Reinforced Concrete

Multi-hazard Risk **Assessment** for Cultural Heritage

Type of approaches – Provide by Literature (Up to now)

Exceeds a threshold of potential losses



1

Multi-hazard Risk Assessments from Single Risk to identify the **Significant Risk**

- Heterogeneity of Procedures → FaMIVE / HAZUS-MH modified / PARNASSUS V1.0
- Homogeneity of Procedures → Mechanical-based Procedures
- Common indicators of Vulnerability

2

From Single-Hazard Risk Assessment to Multi-Risk **Vulnerability** Assessment (Domino) → e.g. Earthquake → Landslide, Tsunami, Fire

→ **Cumulative** Multi-Risk **Vulnerability** Assessment → Flood → Erosion → Earthquake

3

From Single Hazard indexes to **Multi-Hazard Index**

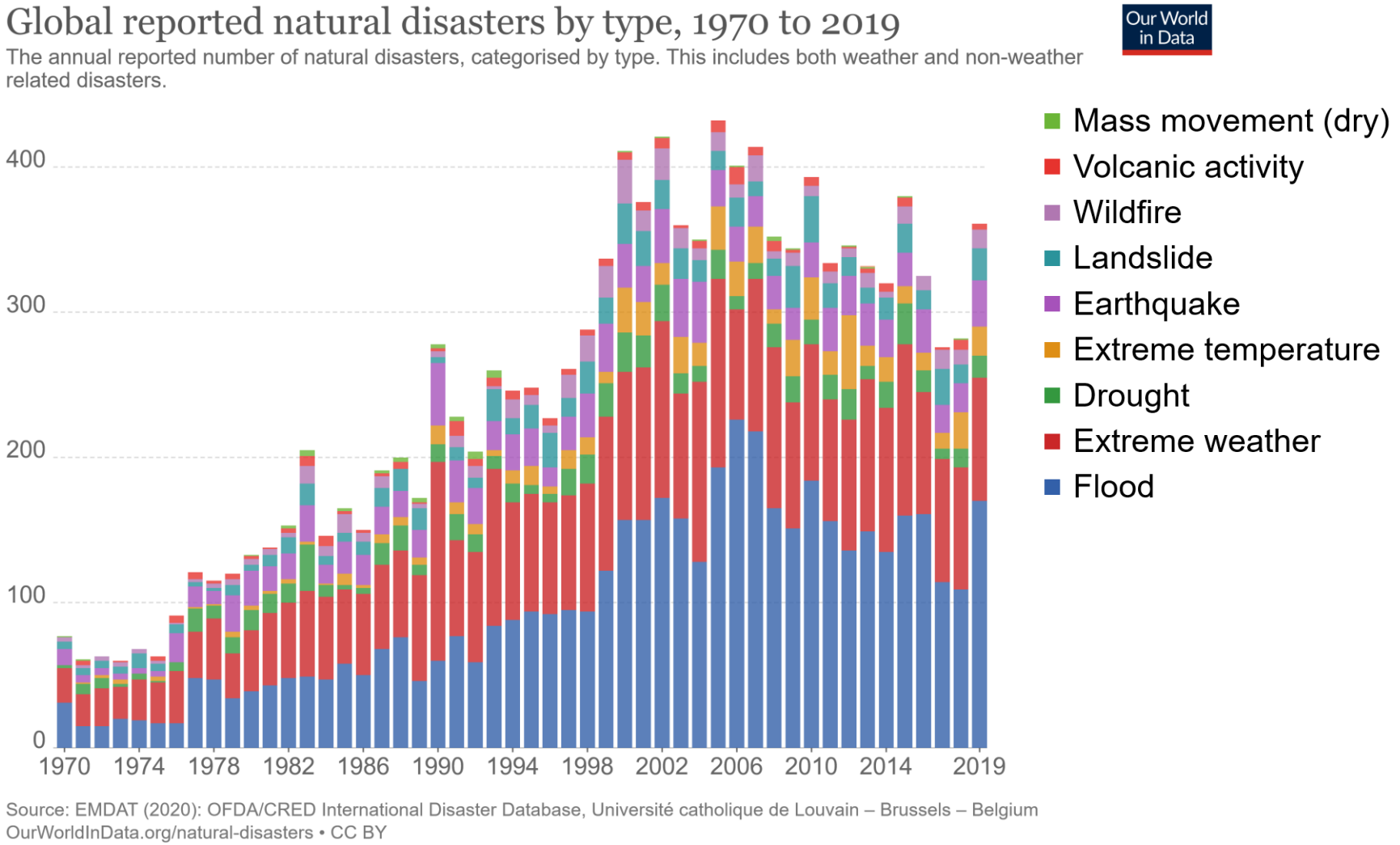
Multi-Hazard Assessments from **Hazard Maps** **over the Cultural Heritage Properties**

Highlighting factor
Cultural Value

GIS Maps
Remote Sensing
} **Hazard** ← Criteria to be used **INDICATORS** → **Vulnerability** { Literature Review of Selected Indicators

Multi-hazard Risk **Assessment** for Cultural Heritage

Which Hazards to be chosen for the Multi-hazard Risk Assessment in Cultural Heritage?



2011 floods in Thailand: 2156 damaged buildings and 135 M€ for recovery

2010 earthquake in Chile: 437 damaged churches (collapsed **19%**, severe damages **24%**, significant recoverable damages **25%**, minor damages **32%**)

2011 Lorca earthquake: 74 damaged buildings and 64.3 M€ for recovery

2015 fire in Basilica of Saint Donatien (Nantes): 8 M€ for recovery

Multi-hazard Risk **Assessment** for Cultural Heritage

|Multi-Hazard Risk Assessment| vs |Diagnosis|

Everything starts from here

BUILDING SURVEY

Survey form

- Historic Survey
- Photographic Survey
- Material Survey
- Damage Survey
- Content Survey
- Context Survey
- Theoretical Framework

Hazard

(Vulnerability)

Exposure

Loss Value

DIAGNOSIS - RISK

Simplified Large-Scale – Urban Planning

Simplified Single Buildings – Priority Intervention Actions

Indicators for **Seismic** Risk Assessment in Cultural Heritage

Mixed Systems (e.g. Main material+ timber)

Heritage / Main Material	Towers or Fortresses	Bridges	Non-monumental Buildings / Vernacular	Churches / Castles / Museums	Ruins in Archaeological Sites	Movable Assets	Historic Buildings
Masonry walls (Clay brick/Stone)	**B**	**Q**	**B**	**B**	**Q**	**Q**	**B**
Masonry and RC			**SSQ**				
Earth Construction	**SSQ**		**B**				
Timber							
Iron or Steel							

...Loading

31 References Consulted

None

Few

Some

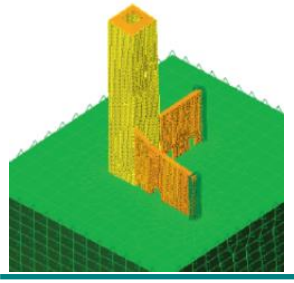
Several

Many

Legends → **Q** ← Type of Method

SSQ - Simplified Semi-quantitative | **Q** – Quantitative | **B** - Both

Indicators for **Seismic** Risk Assessment in Cultural Heritage



Components \ References	Romão et al., 2015	Bartoli, et al., 2019	Basaglia et al., 2018	Briceño et al., 2018	Cattari et al., 2013	Coisson et al., 2017	D'ayala et el., 2008	Despotaki et al., 2018	Díaz, 2017	Delinikola et al. 2015	Fabbrocino et al., 2019	Fiore et al., 2017	Galassi et al., 2018	Limoge. et al., 2015	D'Amato et al., 2018	Novelli et al., 2014	Ortega et al., 2015	Ortega et al., 2019	Palazzi et al., 2019/20	Parisi et al., 2013	Quagliarini et al., 2019	Ripepe et al., 2015	Sarno et al., 2018	Shakya et al., 2018	Silva et al., 2018	Torelli et al., 2018	Uva et al., 2014	Zampieri et al., 2016
Structural building system																												
Type of resisting system	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X	X
Maximum distance between walls / span	X			X	X				X		X				X		X	X	X			X	X	X				X
Macroelements							X			X				X	X				X				X	X	X	X		X
Building materials and antiseismic devices		X	X		X	X		X		X		X		X		X		X	X		X		X			X	X	
Structural geometry of the building	X			X	X		X		X	X	X				X	X	X	X	X			X	X	X	X	X	X	X
Quality of the resisting system	X	X	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X
Slenderness		X			X	X				X				X			X	X	X				X	X		X		
Joints and connections		X			X	X	X						X			X	X	X					X	X	X		X	
Classes of resisting systems	X	X	X	X		X			X	X	X		X	X	X	X	X	X	X			X	X	X	X	X	X	
Deformation and cracking													X	X	X	X			X				X					
Mechanical Properties		X	X	X	X	X	X		X				X	X	X	X	X		X	X		X	X	X	X	X	X	X
Number of floors	X		X	X		X	X		X		X	X		X	X		X	X				X				X	X	
Location and soil conditions	X		X	X		X		X	X	X	X			X	X	X	X				X	X	X	X		X	X	
Floor slabs and roofs																												
Horizontal diaphragms effectiveness	X		X	X		X	X		X	X	X				X		X	X				X		X			X	
Interaction with the vertical systems						X											X	X						X				

Indicators for **Seismic** Risk Assessment in Cultural Heritage

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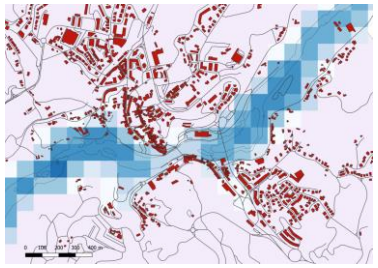
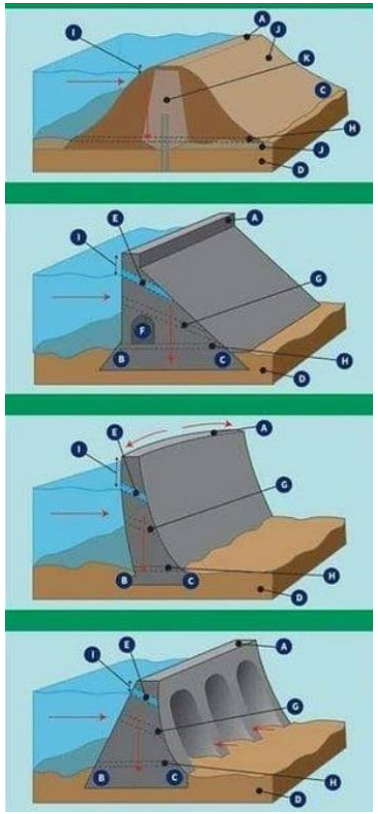
Irregularities and global interaction																												
Aggregate position and interaction	X	X	X	X		X	X	X		X		X		X		X					X	X		X		X	X	
Regularity in height	X		X	X					X	X	X			X	X	X			X		X	X		X			X	
Wall façade openings and alignments	X	X	X	X	X	X				X						X	X	X	X			X		X			X	
Planar symmetry	X		X	X			X		X		X			X	X	X	X				X	X		X			X	
Conservation status and other elements																												
Fragilities and conservation state	X		X	X		X	X	X	X		X				X	X	X				X	X	X	X		X	X	
General Maintenance conditions			X			X	X	X	X	X	X				X	X	X	X			X		X					
Structural alterations							X	X	X	X	X				X	X	X						X	X			X	
Non-structural elements	X		X	X		X			X		X				X		X					X		X			X	
Special program to artwork									X	X	X				X					X								
Social, economic, politic or institutional indicators									X			X			X												X	
Hazard Indicators																												
Intensities (e.g. Macro-seimic, Mercalli)	X		X				X		X		X	X		X	X	X		X			X			X			X	
PGA	X	X	X	X	X	X	X	X						X		X			X			X	X		X			X
Spectral displacement or Spectral acceleration			X				X						X	X		X	X	X		X			X			X	X	X
Velocity of shear wave (Type of soil)	X							X																				

Indicators for **Flood** Risk Assessment in Cultural Heritage

Components \ References	Dottori et al. (2016)	Wang (2015)	Figueiredo et al. (2020; 2020)	Arrighi et al. (2018)	Boinas et al. (2016:2018)	Drdácký (2010)	Holický (2010)	Li et al (2017)	Masgrau et al. (2002)	Miranda & Ferreira (2019)	Nedvědová (2013)	Ortiz et al. (2016)	Stephenson et al. (2014)	Vojinovic et al. (2014)	Vojinovic et al. (2016)	Garrote, J., 2019	Gandini et al. (2018)
Geometrical characteristics	X	X	X	X	X		X	X	X	X		X	X	X	X	X	X
Footprint, Internal and Basement Area	X		X									X	X				
Interstorey and Basement Height	X		X	X	X		X								X		X
Number of Floors	X									X			X				
Ground Level	X				X												
Building Type	X	X	X	X	X			X	X			X	X	X	X	X	X
Plan distribution	X																
Material properties	X	X	X		X	X	X		X	X	X	X	X	X	X	X	X
Building Structure	X	X	X			X				X		X	X	X	X	X	X
External and Internal walls	X	X	X		X					X		X	X		X	X	X
Basement walls	X		X	X	X		X			X		X	X		X	X	X
Last Finishing	X		X							X		X	X		X	X	
Utilities	X				X	X											X
Heating system type	X																
Electrical installations	X		X														
Hydro sytems	X				X												X
Foundations and soil conditions		X				X	X		X			X		X	X		

Indicators for **Flood** Risk Assessment in Cultural Heritage





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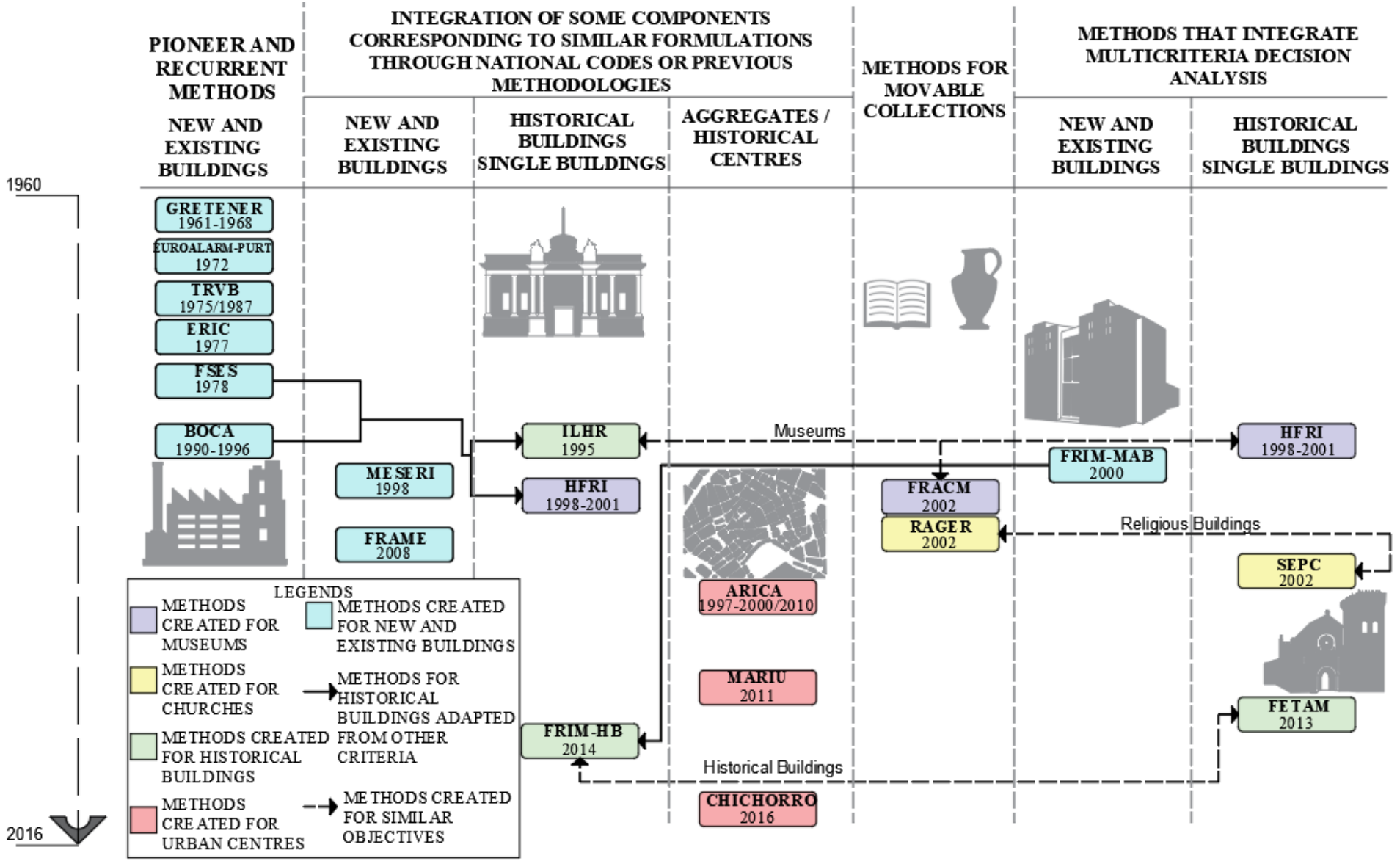
Conservation status and other elements	X	X	X	X		X	X		X	X		X	X	X			X
Level of maintenance of materials	X	X	X			X	X		X	X		X	X				X
Non-structural elements			X														
Year of construction / Age	X									X		X					
Movable assets / relics		X	X	X						X	X					X	X
Mitigation Preventive Local Actions							X	X	X		X			X	X		
Obstacle existence / Policies / Social					X	X						X					
Hazard Indicators																	
Water Depth	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Duration of flood or rainfall	X	X						X									
Rain patterns (i.e. Intensity or mean [mm])		X						X								X	
Flow Velocity	X					X	X	X				X	X			X	X
Sediments / Polutants	X					X	X										
Location of the Monument					X			X			X	X			X	X	
Other Hydrogeological conditions					X	X		X			X					X	
Dams		X															
Geotechnical properties							X				X	X				X	

Indicators for **Fire** Risk Assessment in Cultural Heritage

- Literature Review
- Recommendation for Archaeological Zones
- Manuals for Historic Urban Districts
- Guidelines and Checklists for Single Buildings
- Standards
- Scientific papers



Proposed methodology - indicators for **Fire** Risk Assessment in Cultural Heritage

Selected Vulnerability Indicators

Building Properties (BP)
- Fire Load Density
- Fire Resistance
- Compartmentalisation
- Adjacent Buildings
- Urban Configuration
- Vertical and Horizontal Propagation
- Conservation Status
- Fire breaks/Buffer zones

Utilities: Electric Power, Gas and Telecommunications (UEPGT)
- Electrical Installations
- Gas Installations
- HVAC Installations
- Telecommunications and CCTV
- Technical Room

Firefighting measures (FM)
- Alarm and Detection System
- Smoke Control System
- Active Suppression System
- Water Supply
- Fire Rescue Services

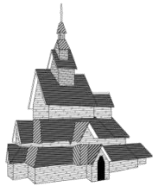
Emergency Preparedness Planning for Cultural Assets (EPP)
- Cultural value: Movable and immovable
- Emergency preparedness and response plan
  - During routine activities
  - During Hot works
- Evacuation and escape routes
- Signage and emergency lights

Groups of Vulnerability Indicators	Final weight based on diverse studies
Building Properties (BP)	35
Utilities (UEPGT)	20
Firefighting measures (FM)	30
Emergency preparedness planning (EPP)	15
	100

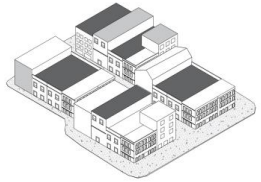
Determination of 4 Architectural Heritage Classes (AHC)

AHC 1

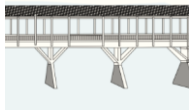
AHC 2



AHC 3



AHC 4



Hazard Indicators

FWI
Burned areas
Fuel Vegetation
Slope-Aspect
Elevation
Land cover
Density of population

Proposed methodology - indicators for **Fire** Risk Assessment in Cultural Heritage

Damage Classes

A	**0**
B	**25**
C	**50**
D	**75**
E	**100**

Level of Damage

$D_V = Damage\ Level\ associated\ with\ possible\ Fire$

$$\boldsymbol{D_V = G_1 + G_2 + G_3 + G_4}$$

$$G_1 = BP = [Max(P_{i,i=1:7})] \times 0.35$$

$$G_2 = UEPGT = [Max(P_{i,i=8:12})] \times 0.20$$

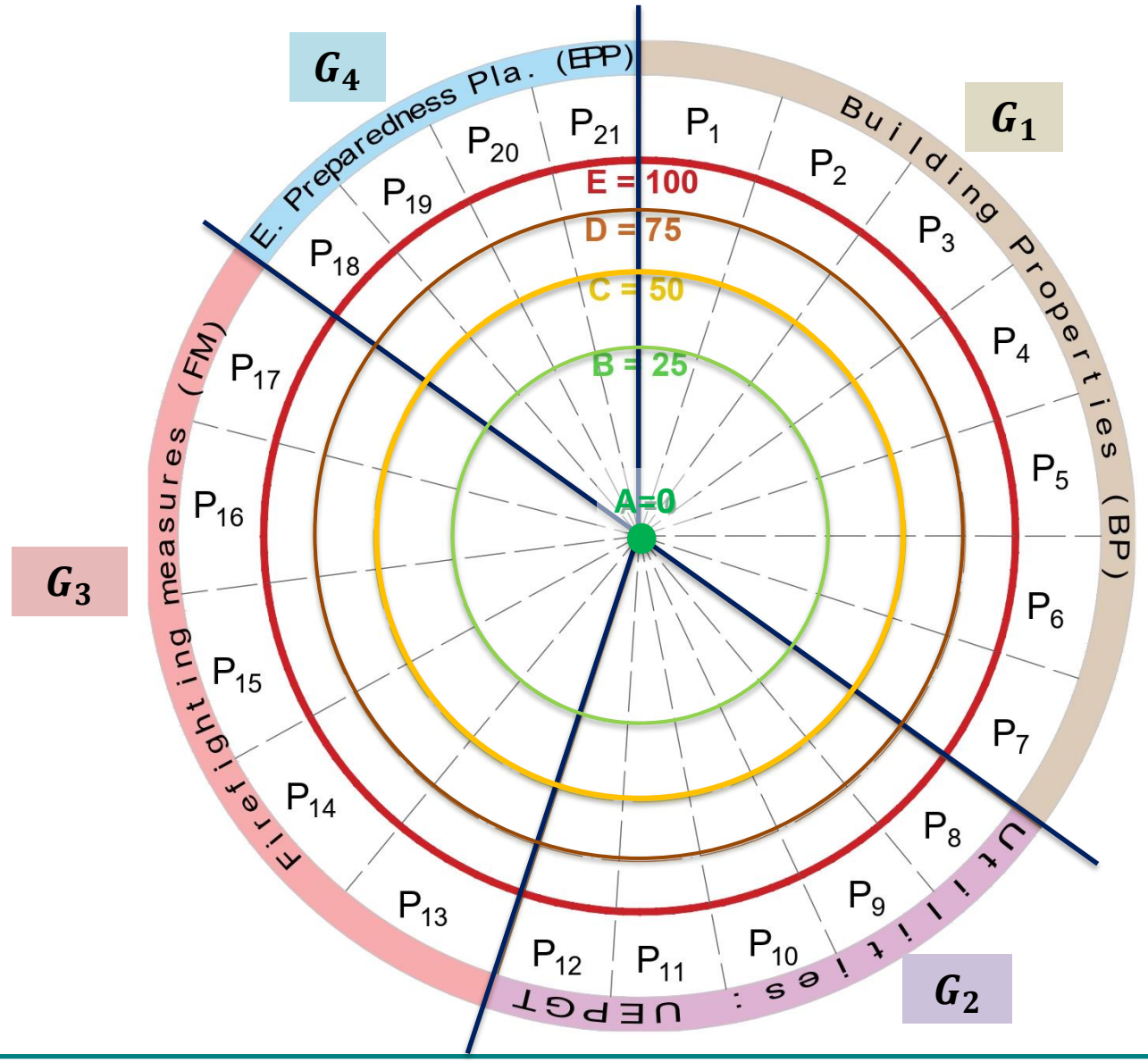
$$G_3 = FM = [Max(P_{i,i=13:17})] \times 0.30$$

$$G_4 = EPP = [Max(P_{i,i=18:21})] \times 0.15$$

Heavy D_V = <70-100

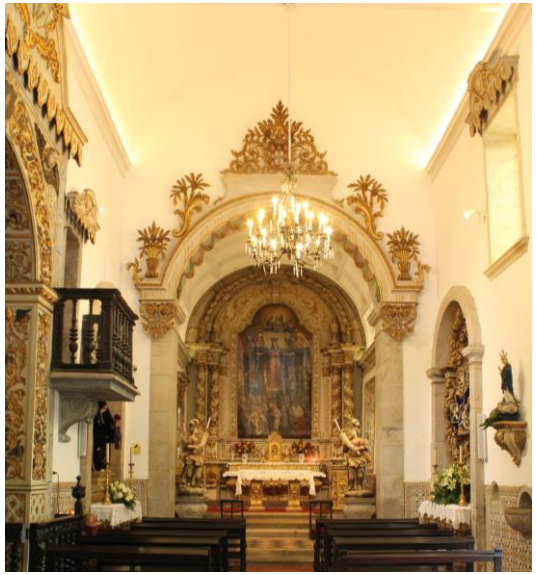
Medium D_V = <35-70

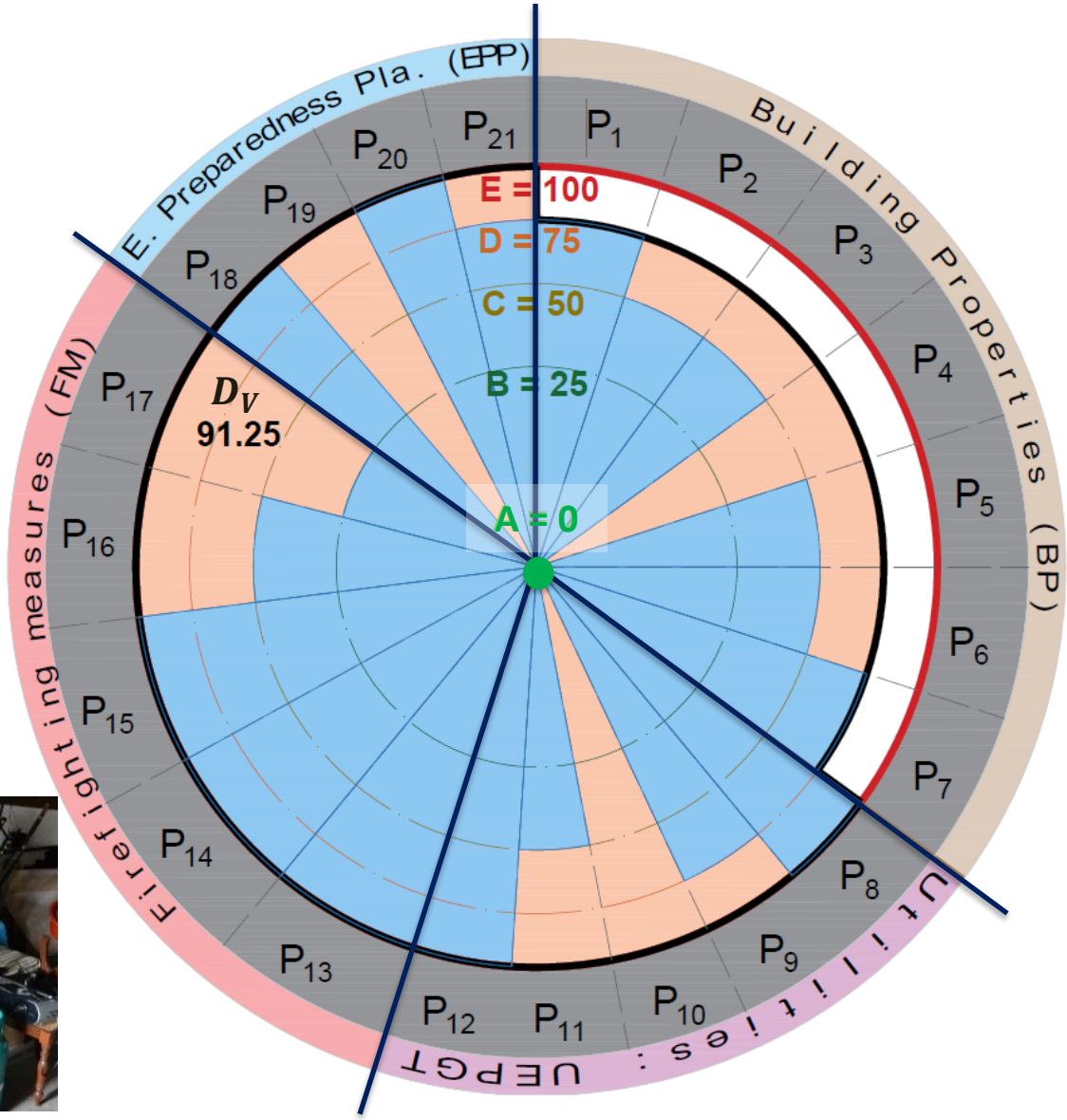
Light D_V = 0-35



Proposed methodology - indicators for **Fire** Risk Assessment in Cultural Heritage

16th Church of Misericordia, Esposende (Portugal)





Proposed methodology - indicators for **Fire** Risk Assessment in Cultural Heritage

	Indicator	**Damage** Class A **0**	B **25**	C **50**	D **75**	E **100**	Class	Weight	Gi
BP	P_1 - **Fire Load** (MJ/m2)	q_{CH}<500	500≤ q_{CH} < 750	750≤ q_{CH} < 1500	1500≤ q_{CH} < 3000	q_{CH} >3000	D = 75	0.35	26.25
BP	P_2 - **Fire Resistance**	A1	A2	B	C, D	E, F			
BP	P_3 - **Compartmentalisation** (m2)	<50	50-100	100-200	200-400	>400			
BP	P_4 - **Adjacent Buildings**	IS or AN	IC	ACN	AC	ACA			
BP	P_5 - **Aligned Openings**	NAI	r≥1	r≥1 and r<1	r<1 and nl≤2	r≤1 and nl>2			
BP	P_6- **Conservation of Fire Load**	Very Good	Good	Medium	Bad	Very Bad			
BP	P_7 - **Fire Breaks** (m)	SV>50 or I	(50 ≥ SV > 30) or II	(30 ≥ SV > 5) or III	(5 ≥ SV > 1.5) or IV	(SV ≤ 1.5) or V			
UEPGT	P_8 - **Electrical Installation**	EX	G	M	BA	VB	E=100	0.20	20
UEPGT	P_9 - **Gas Installation**	P	GR	EGC	IGCV	IGCNV			
UEPGT	P_{10} - **HVAC Installation**	NH	DE or CE	DCF	CCF or LMD	LMC			
UEPGT	P_{11} - **CCTV system**	TT1	TT2	TT3	TT4	TT5			
UEPGT	P_{12} - **Technical Control Room**	Out≥5 m	Out<5 m	IMC	IMM	IB			
FM	P_{13} - **Alarm and Detection**	AF	AM	AMN	AAN	NAD	E = 100	0.30	30
FM	P_{14} - **Smoke Control**	SC1	SC2	SC3	SC4	SC5			
FM	P_{15} - **Active Suppression**	AS1	AS2	AS3	AS4	AS5			
FM	P_{16} - **Water Supply**	W1	W2	W3	W4	W5			
FM	P_{17} - **Proximity of Fire Brigade**	0-10 min	10-20 min	20-30 min	30-40 min	>40 min			
EPP	P_{18} -**Emergency Planning**	EA	EB	EC	ED	EE	E = 100	0.15	15
EPP	P_{19} - **Elevation of compartments**	HS ≤ 9 m and EA	HS ≤ 9 m	HS >9 m and AS2 and EA	HS >9 m and EA	HS >9 m			
EPP	P_{20} - **Evacuation Routes**	d≤15 m and w≥3 m	(d≤20 m and W<3 m) and EA	d≤20 m and W<3 m	(d>20 m and w<3 m) and EA	d>20 m and w<3m			
EPP	P_{21} - **Emergency Signage**	SP and EL	SPM	SP and (EA or EB)	SP	N			

$$D_V = 26.25 + 20 + 30 + 15 = 91.25$$

$$\therefore \textit{Heavy Level of Damage}$$

Future Tasks

Development of vulnerability Indicators V_{ML}

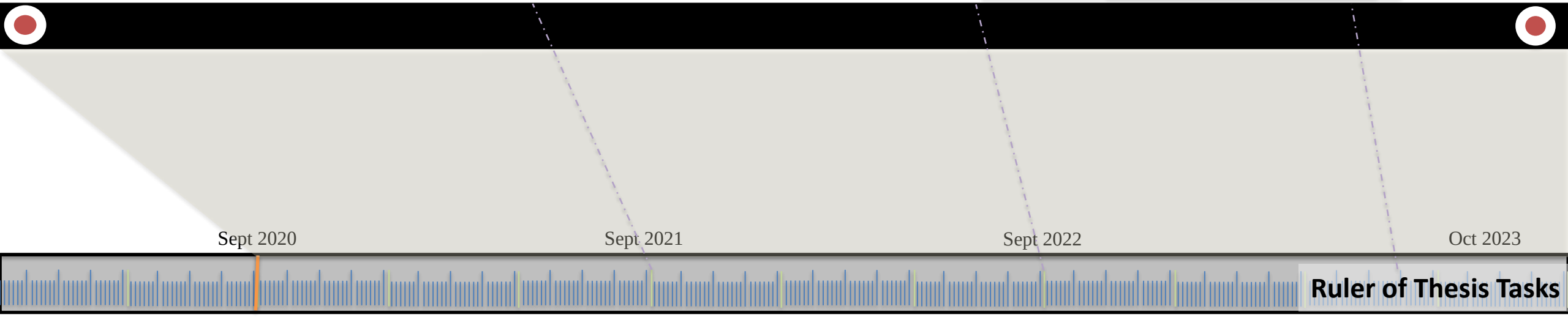
- Fire
- Earthquake
- Flood

Integration of Hazard Criteria H

- Fire
- Earthquake
- Flood

Integration and Relation between the indicators – Multi-risk Assessment for CH R_{MH}

- Recovery Factor
- Building Value
- Application and Validation
- Sensitivity Analysis
- Plug-in or Code in GIS
- Conclusions



THANK YOU FOR YOUR ATTENTION

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