

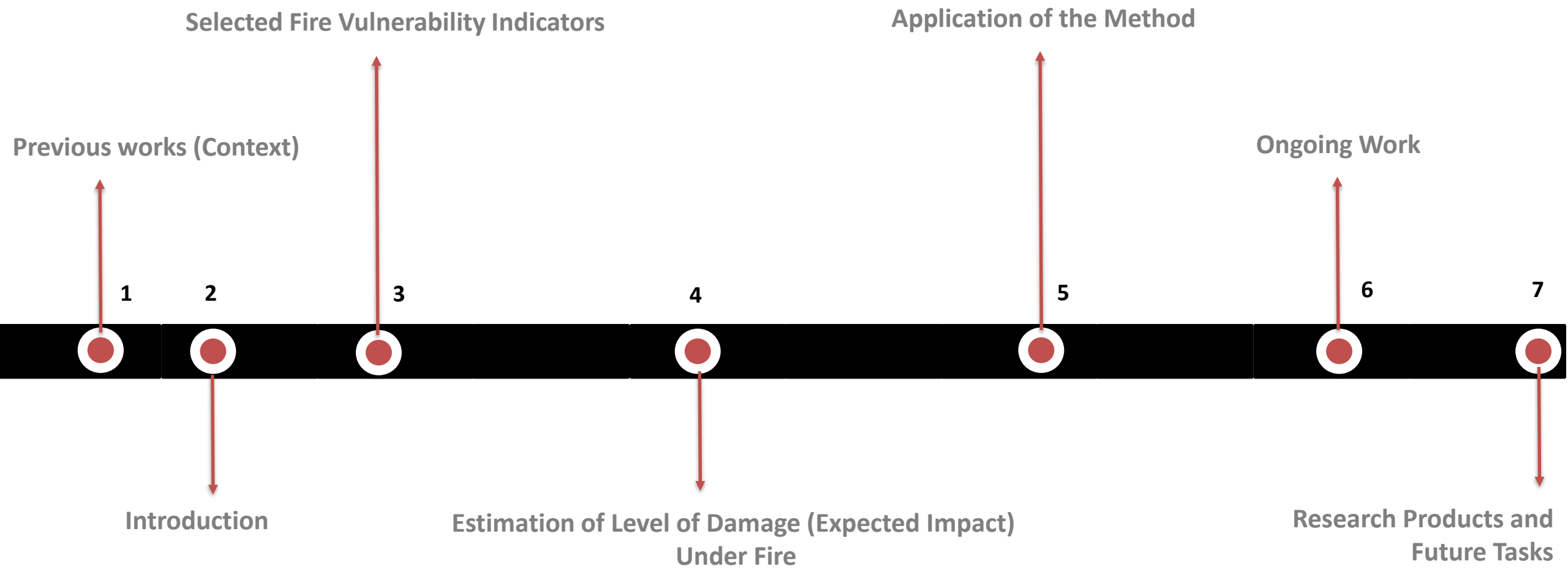
DEVELOPMENT OF MULTI-HAZARD RISK INDICATORS FOR IMMOVABLE CULTURAL HERITAGE (Fire Vulnerability Assessment)

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Content



Previous Presentation Infrarisk- Workshop 2020

Multi-hazard → Different hazardous events threatening the same exposed elements (with or without temporal coincidence)

Multi-vulnerability → A variety of exposed sensitive targets (e.g. population, infrastructure, cultural heritage, etc.) with possible different vulnerability degrees against the various hazards.

Source: Gallina et al. (2016)

Fire

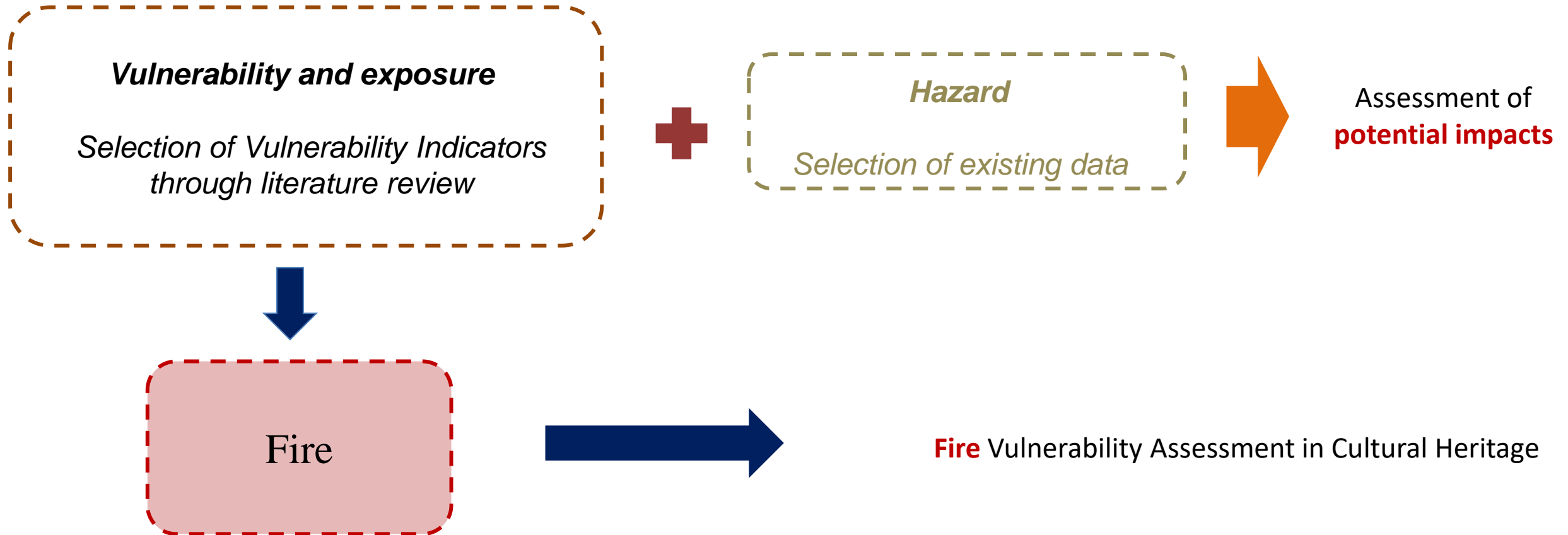
Earthquake

Flood

Previous Presentation Infrarisk- Workshop 2020


Indicator-based methods for risk in cultural heritage

Large groups of cultural heritage assets can be assessed with limited resources through the use of **simple and reliable indicators**



Introduction


- Methods for the fire risk assessment of cultural heritage are scarcer and have limitations, such as **only being applicable to a single type of heritage, to specific countries or not considering specific characteristics that heritage buildings present.**
- The proposed index is the result of an in-depth literature review of existing Fire Vulnerability Indicators (FVIs) (Salazar et al., 2021). This index comprises **twenty-one FVIs**, selected to measure **the level of damage due to fire** in built heritage assets, that are organized in four categories:
 - (1) the properties of the built elements (*PBE*),
 - (2) the utilities (*U*),
 - (3) the firefighting measures (*FM*) and
 - (4) the emergency preparedness planning (*EPP*).
- The method was designed such that **it may be applied to different types of heritage buildings** in different contexts and countries, and used autonomously (i.e. independently of specific codes).



In Salazar et al. (2021), the **cultural value** is a FVI but is **not considered (in this index)** to assess expected level of damage

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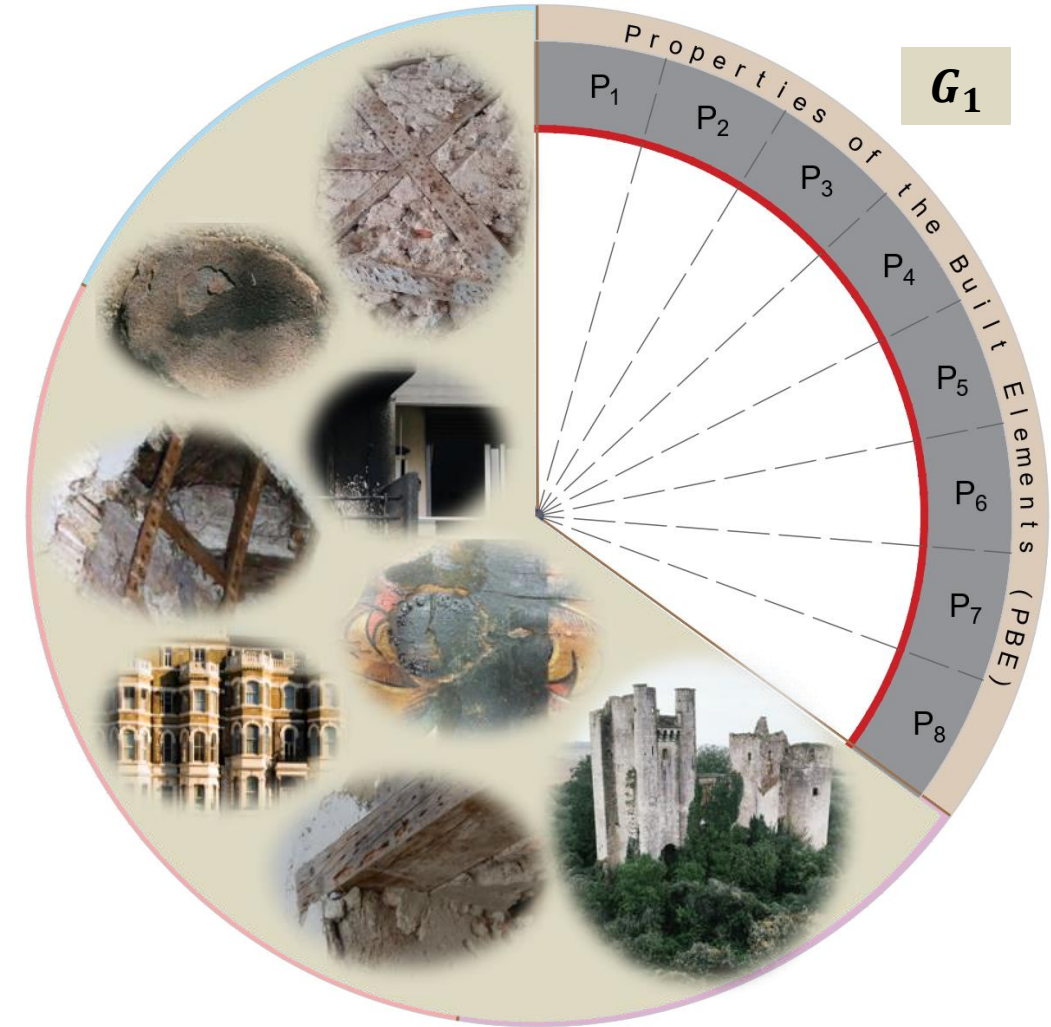
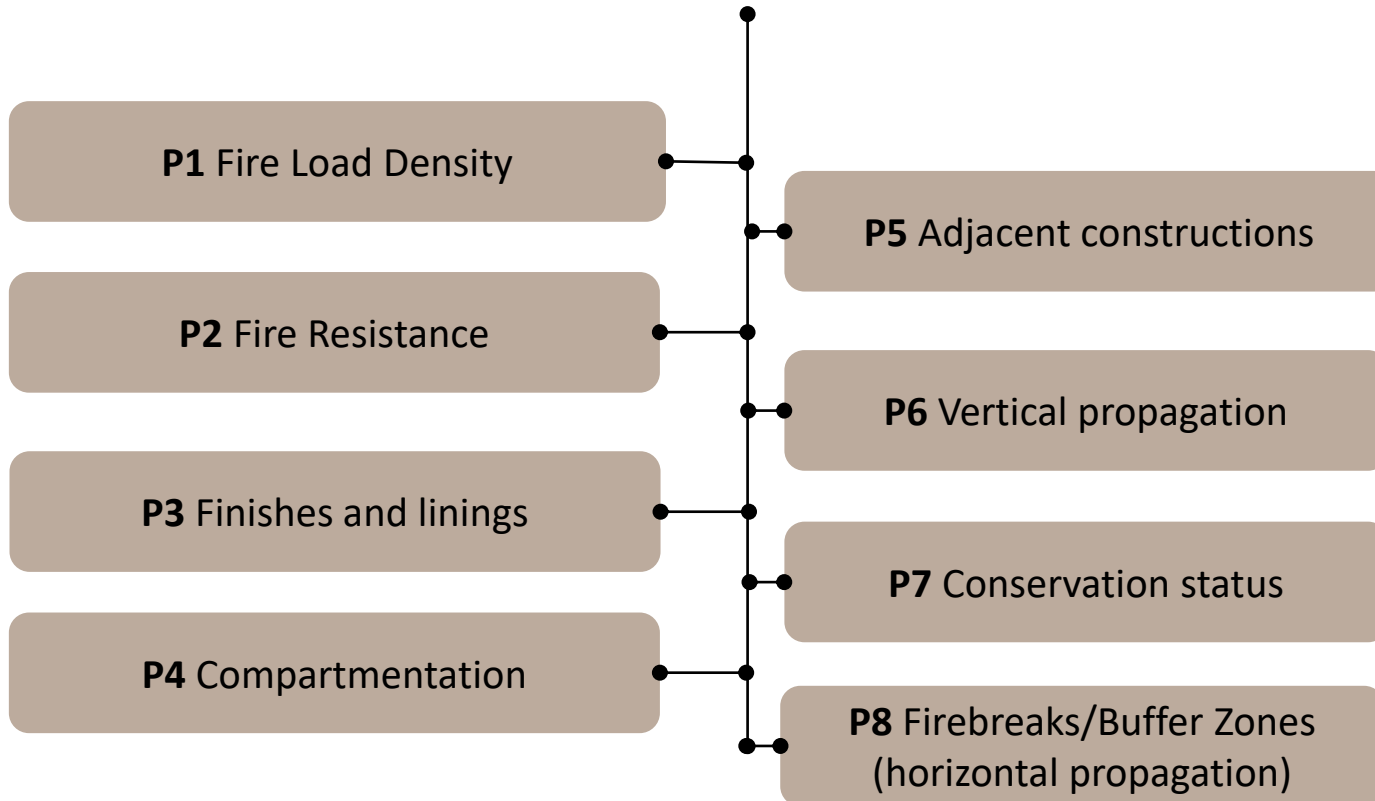


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Fire Vulnerability Assessment in Cultural Heritage

G₁ – Properties of the Built Elements (PBE)

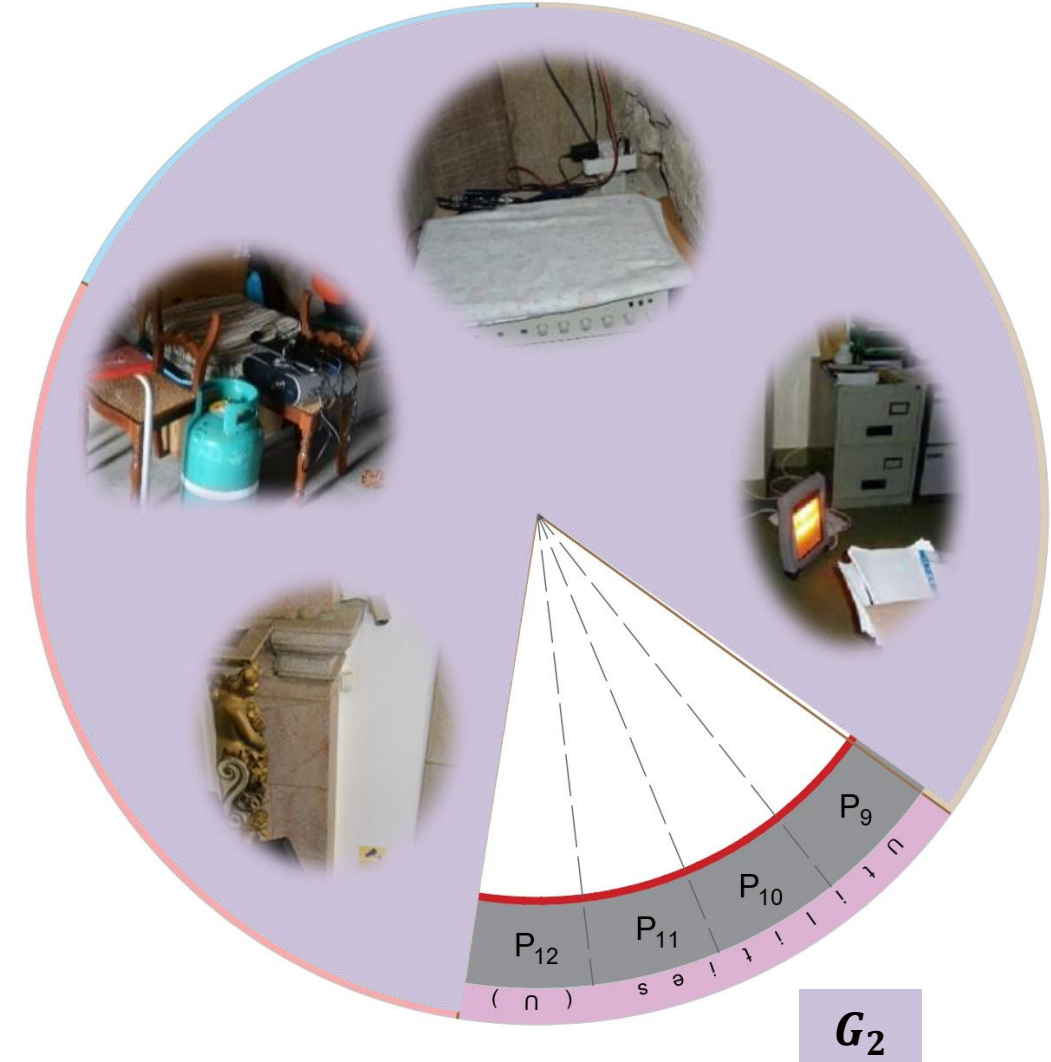
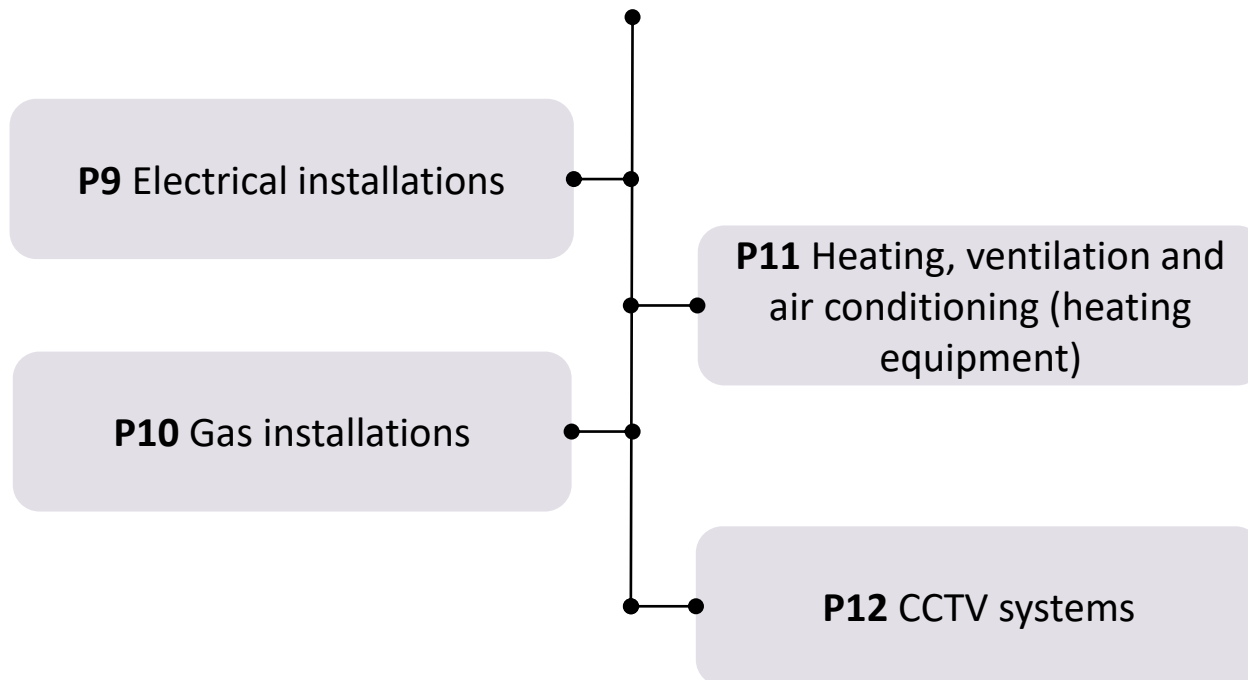
The first category refers to indicators related to the physical properties of the building and immediate surroundings **that influence the impact of a fire to its cultural value.**



Fire Vulnerability Assessment in Cultural Heritage

G₂ – Utilities (U)

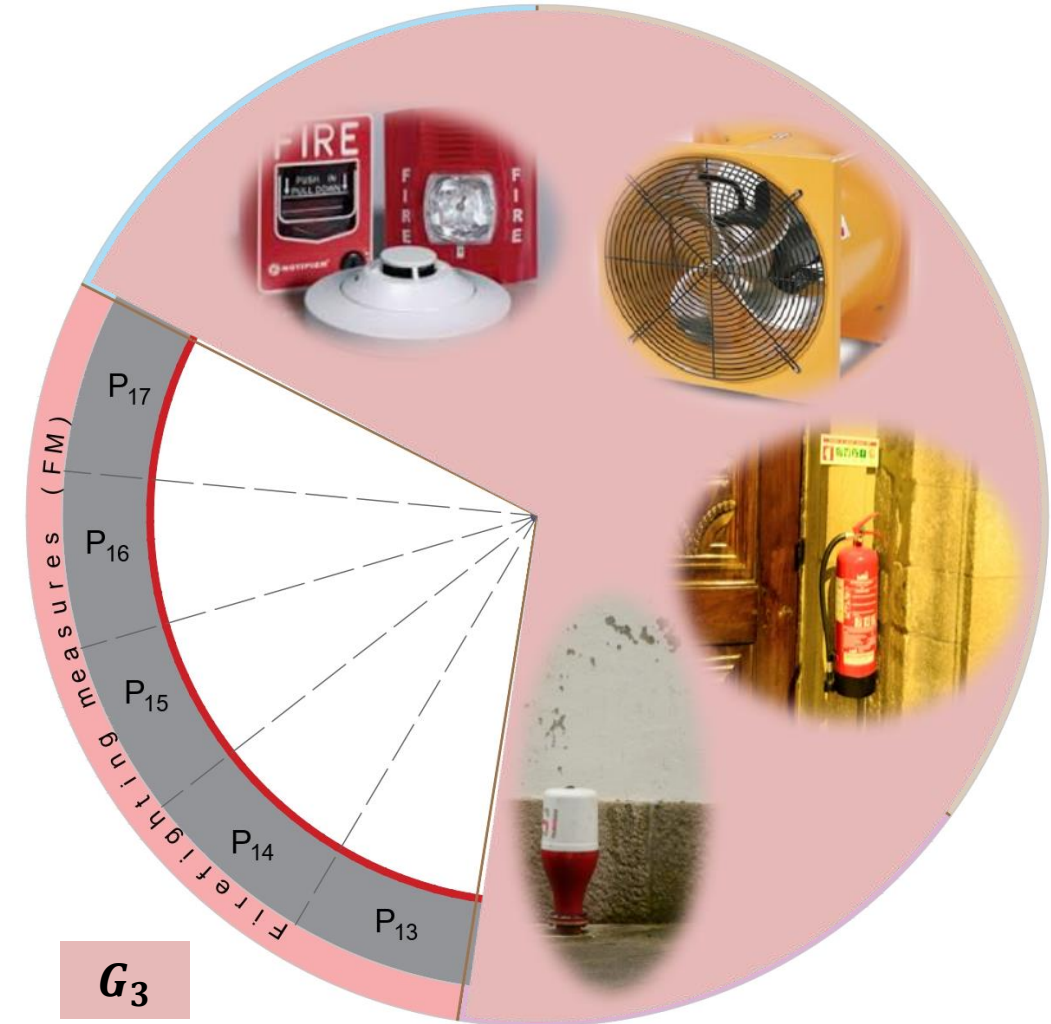
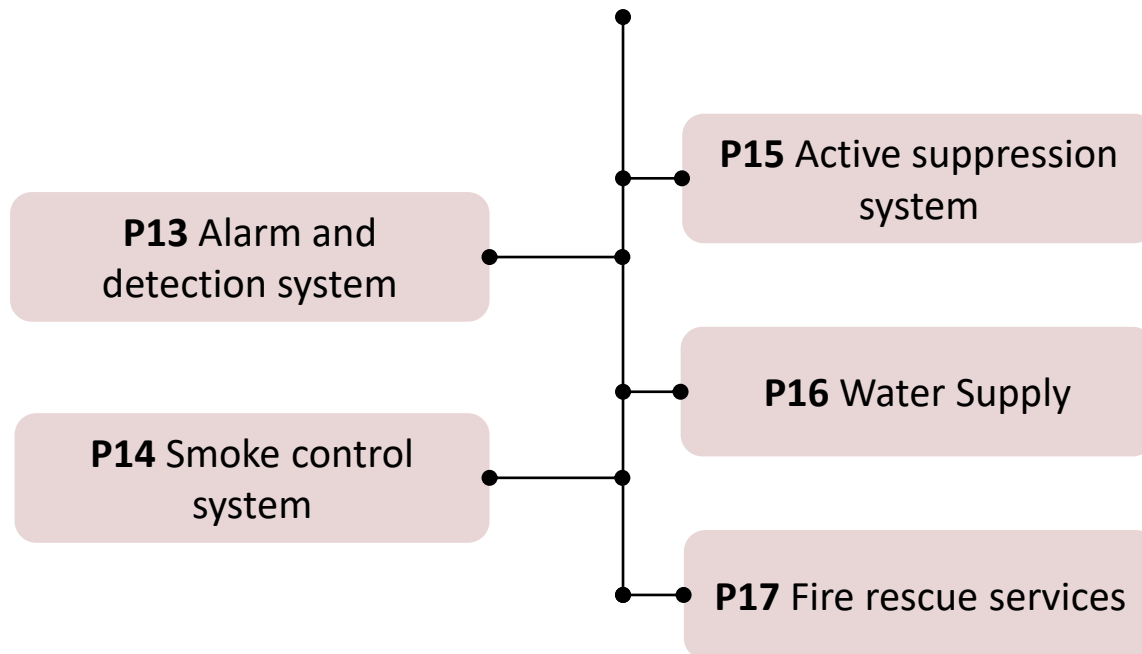
The second group of indicators is based on the characteristics and components of the existing **utilities that can facilitate the occurrence or propagation of a fire due to their maintenance conditions, or contribute to increasing the overall fire safety.**



Fire Vulnerability Assessment in Cultural Heritage

G₃ - Firefighting Measures (FM)

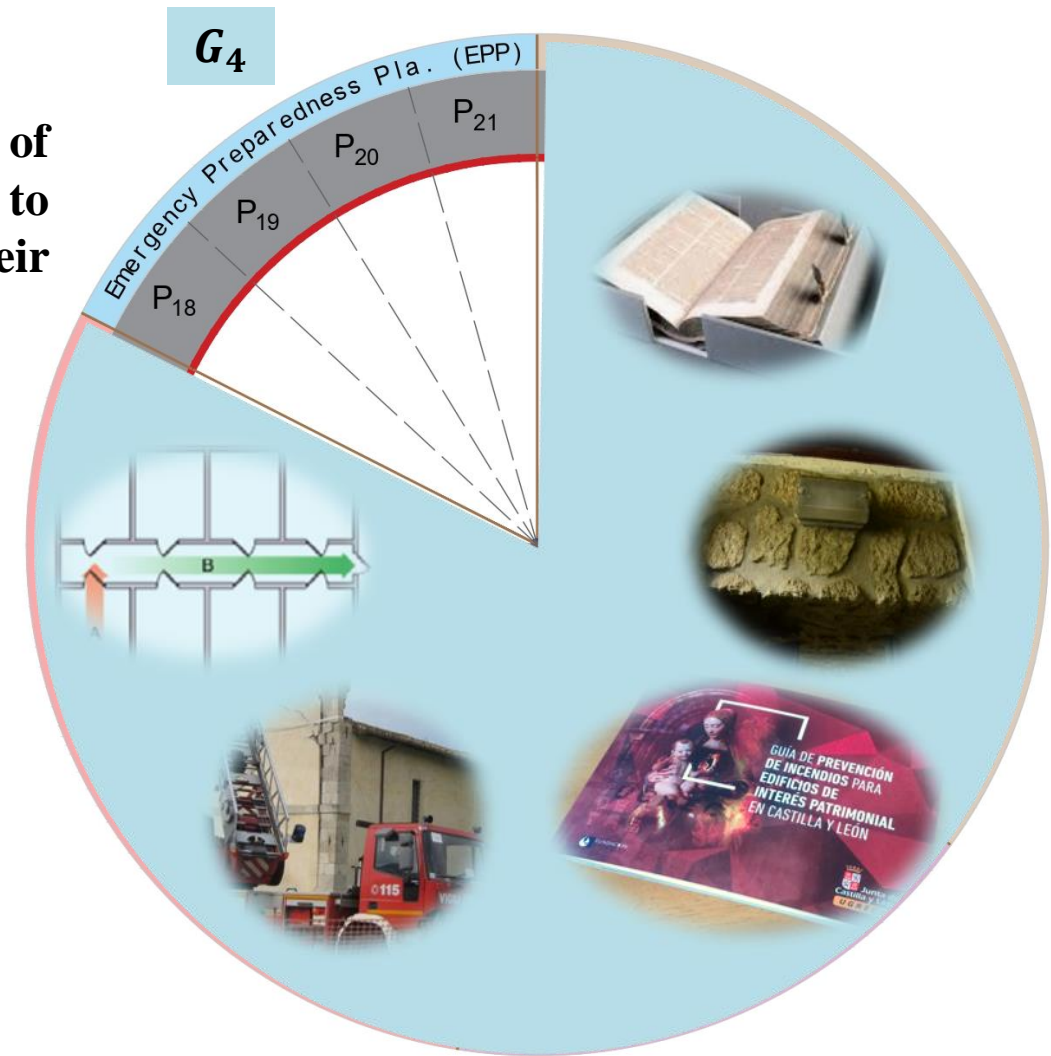
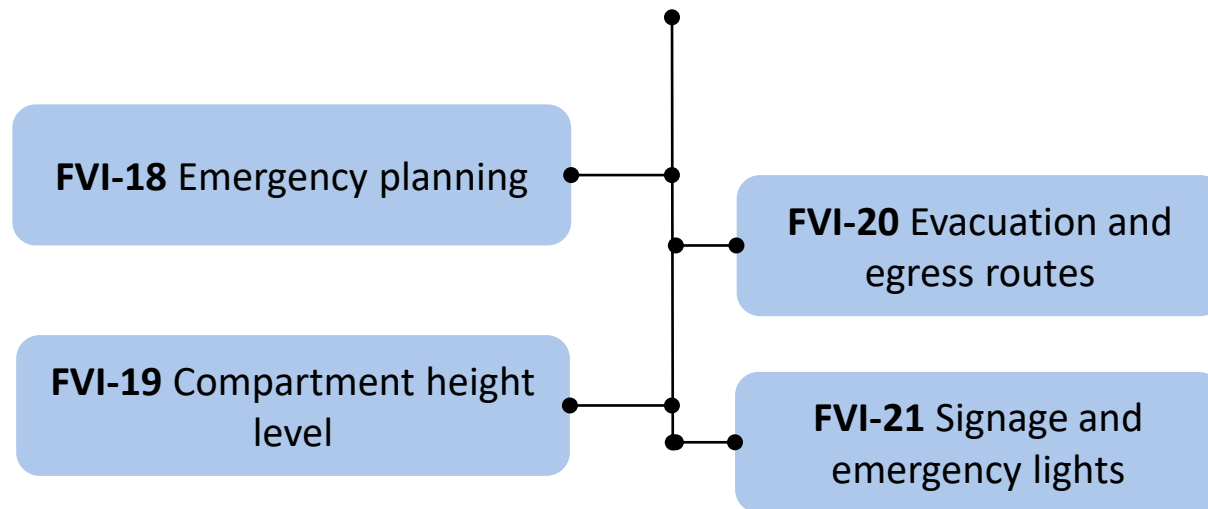
The third group involves indicators that account for **fire mitigation measures once it starts**.



Fire Vulnerability Assessment in Cultural Heritage

G4 - Emergency Preparedness Planning (EPP)

The fourth group reflects indicators that account for the **availability of evacuation measures and emergency strategies implemented to safeguard the construction and its movable heritage assets given their cultural value.**



Fire Vulnerability Assessment in Cultural Heritage

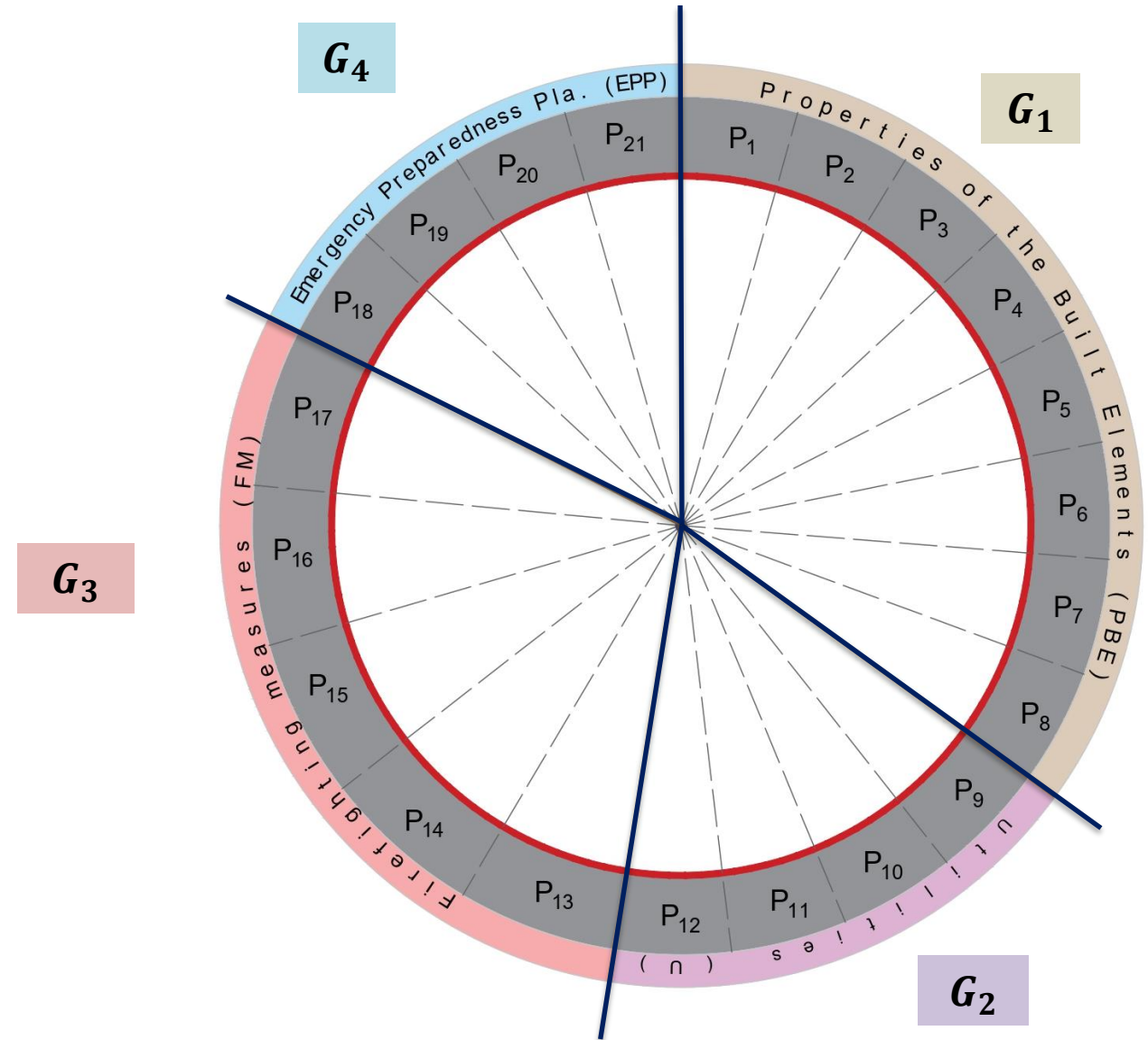
Level of Damage under fire effects

- The estimation of the level of damage under fire (D_f) considers the interconnectedness between dependent or similar fire vulnerability indicators through the sum of the product between the score of each category (G_i) and its corresponding weight (W_i) according to:

$$D_f = \sum_{i=1}^{n=4} G_i \times W_i$$

- The score of each category is obtained by the worst FVI performance, which is defined by the higher indicator score, (each indicator is scored among 5 Damage Potential Classes (DPC)).

$$G_i = [Max(P_{i,i})]$$



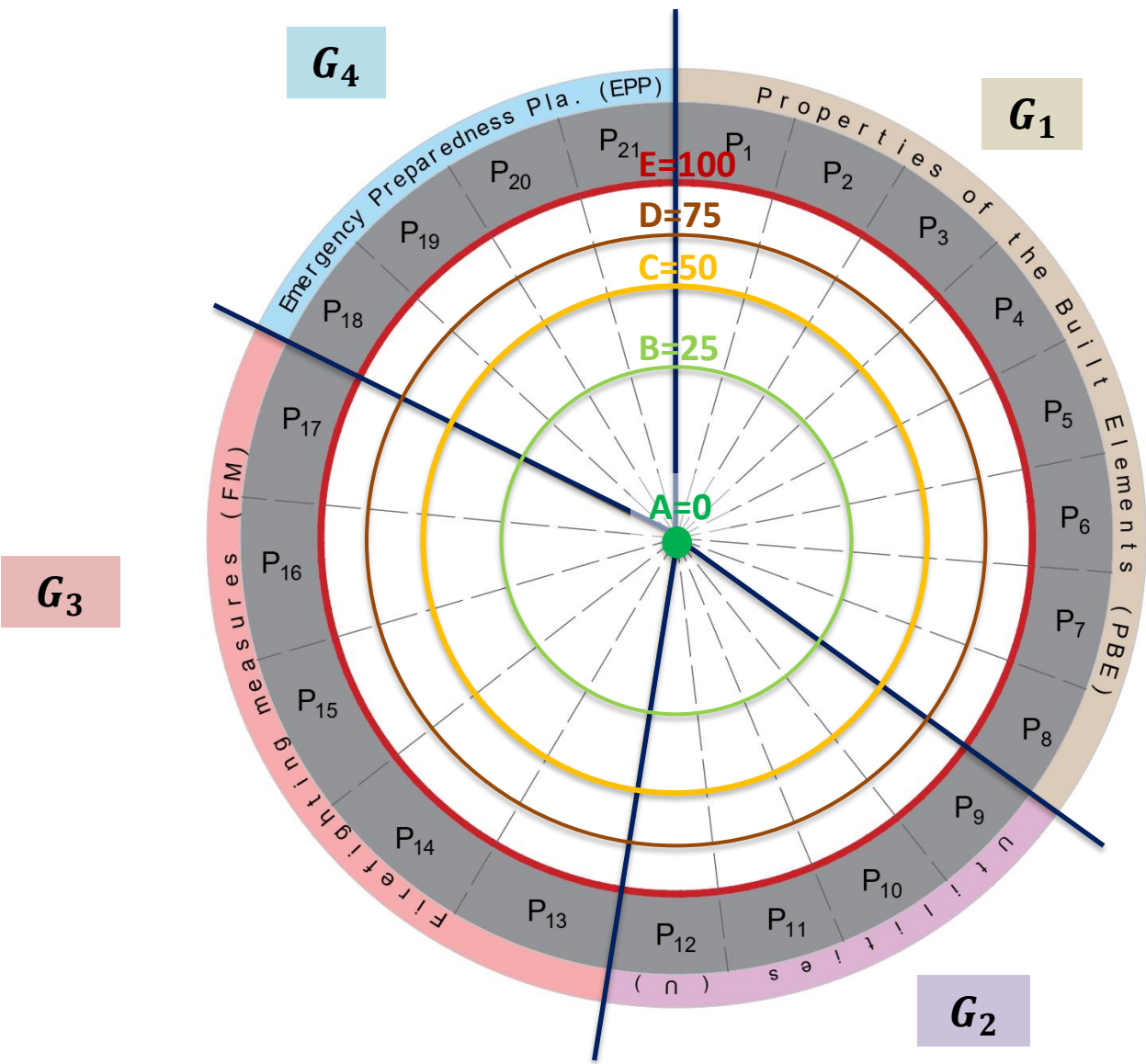
Fire Vulnerability Assessment in Cultural Heritage

Damage Potential Class

The Damage Potential Class (DPC) expresses the expected impact (from A to E) to the immovable asset under assessment, also accounting for some aspects that can contribute to the damage of movable assets by considering specificities that could increase the susceptibility in a fire.

Damage Potential Class (DPC) code and corresponding value

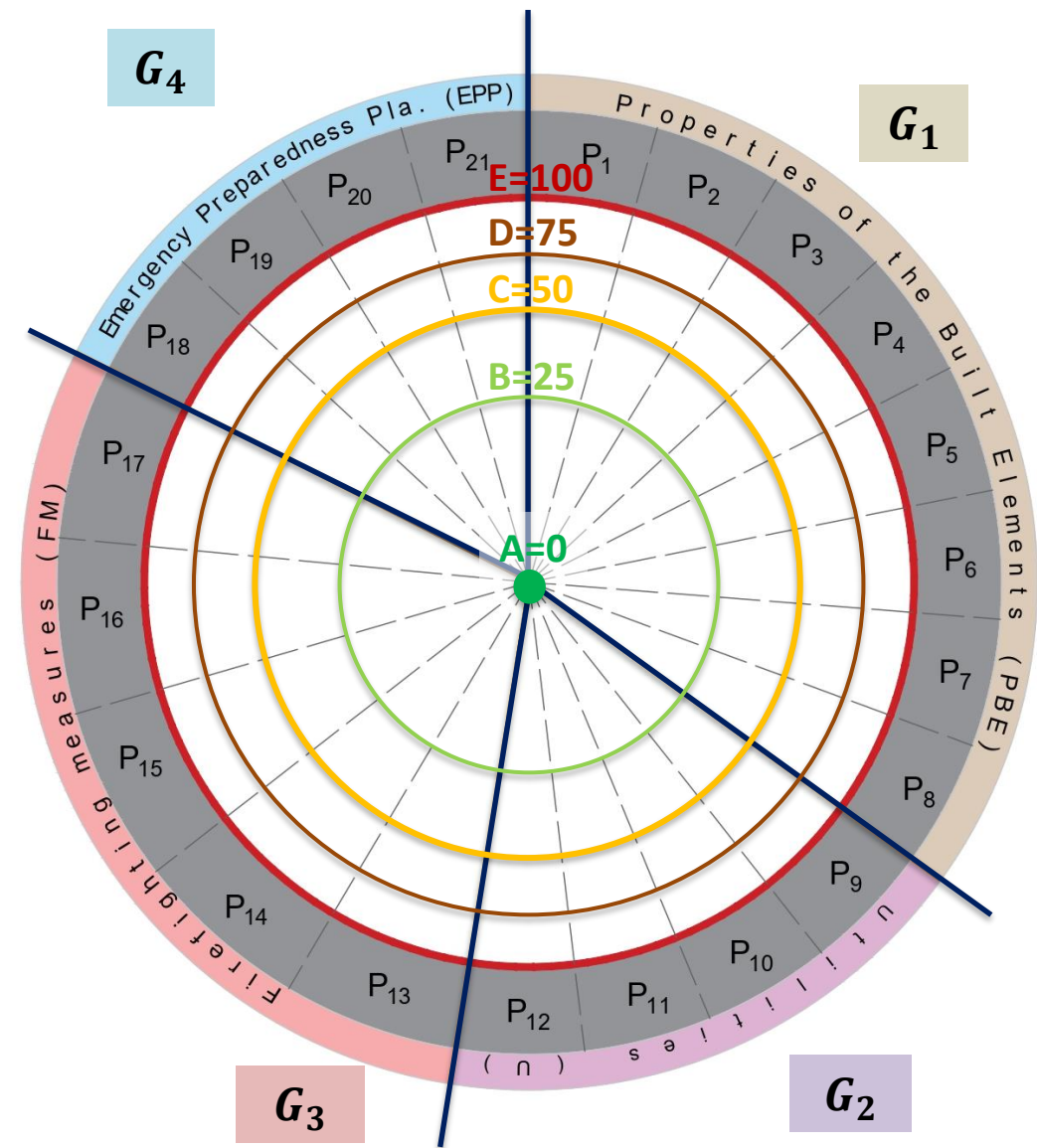
A	B	C	D	E
0	25	50	75	100



Fire Vulnerability Assessment in Cultural Heritage

Multi-Attribute Scoring Criteria (Level of Damage)

Group	Copping (2002)	Lopes et al. (2011)	Wen et al.(2012)	Arborea et al. (2015)	NFPA 914 (2015)	μ	Final Proposed
PBE	37	21.1	45.69	40.6	28	34.48	35
U	-	22.2	5.15	7.5	-	11.62	17.5
FM	35	34.2	21.36	22.1	33	29.13	30
EPP	28	22.5	27.8	19.8	26	24.82	17.5
	100	100	100	90	87	-	100

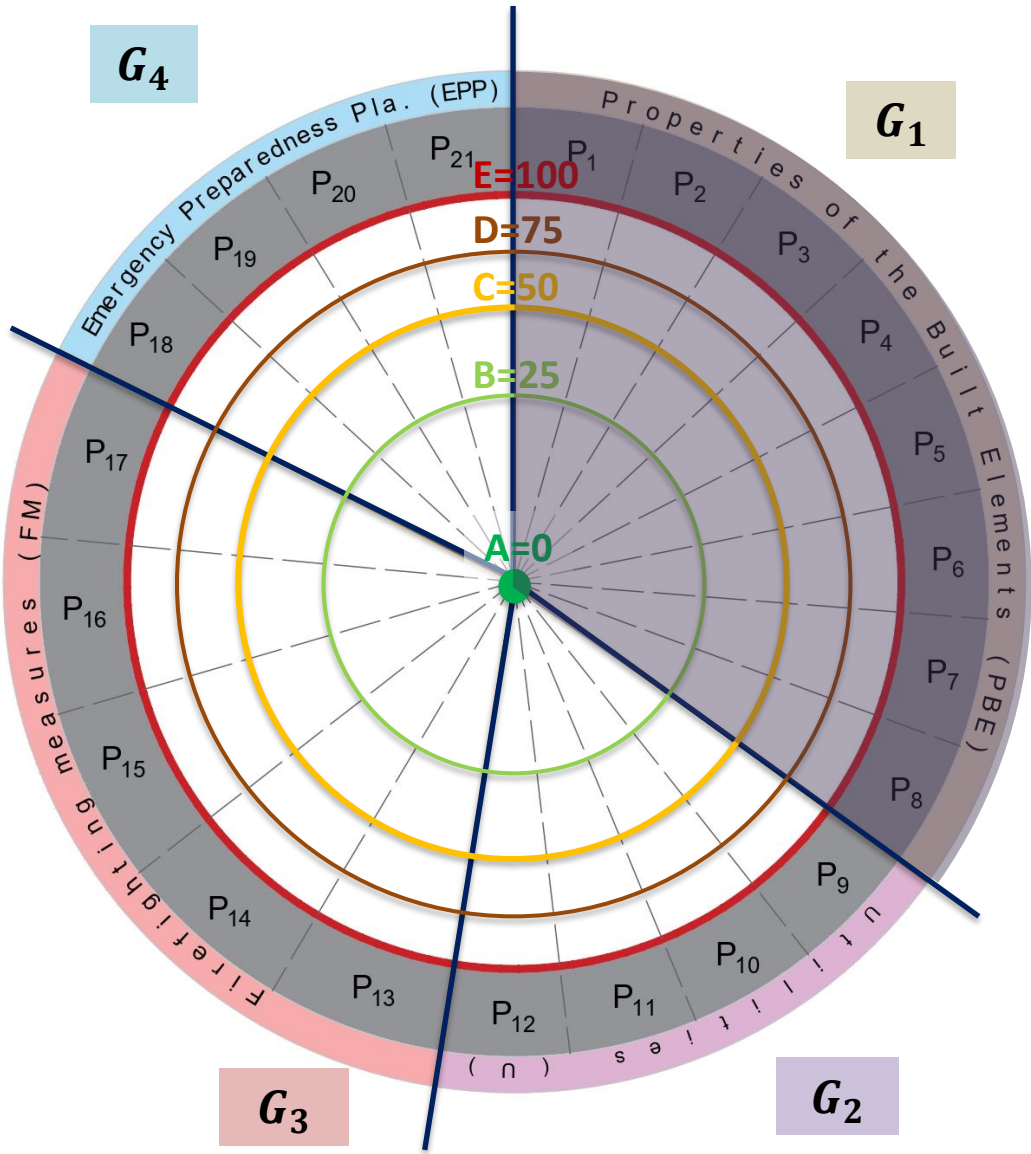


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$$G_1 = PBE = [Max(P_{i,i=1:8})] \times 0.35$$

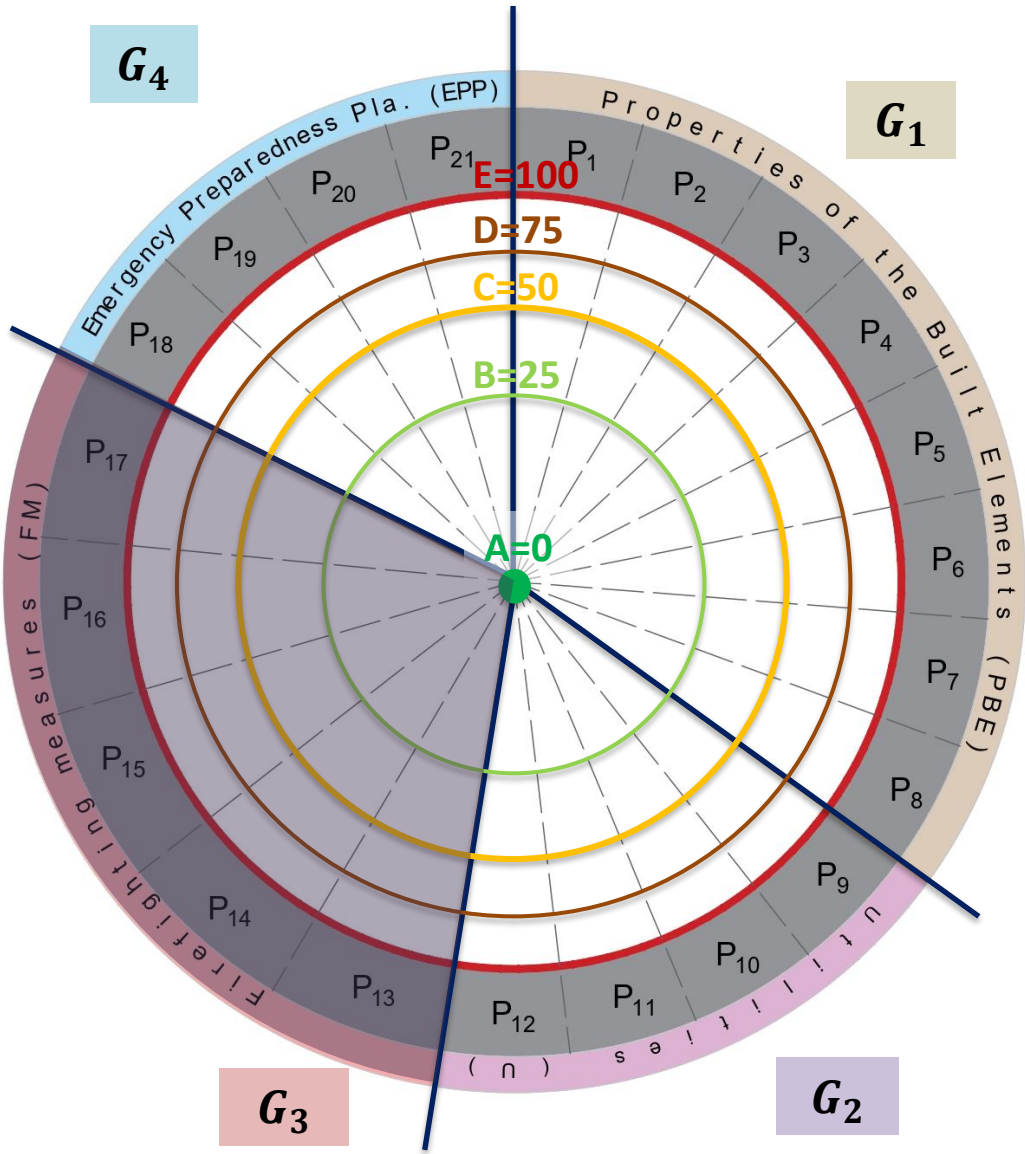


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$$G_3 = FM = \left[Max\left(P_{i,i=13:17}\right)\right] \times 0.30$$

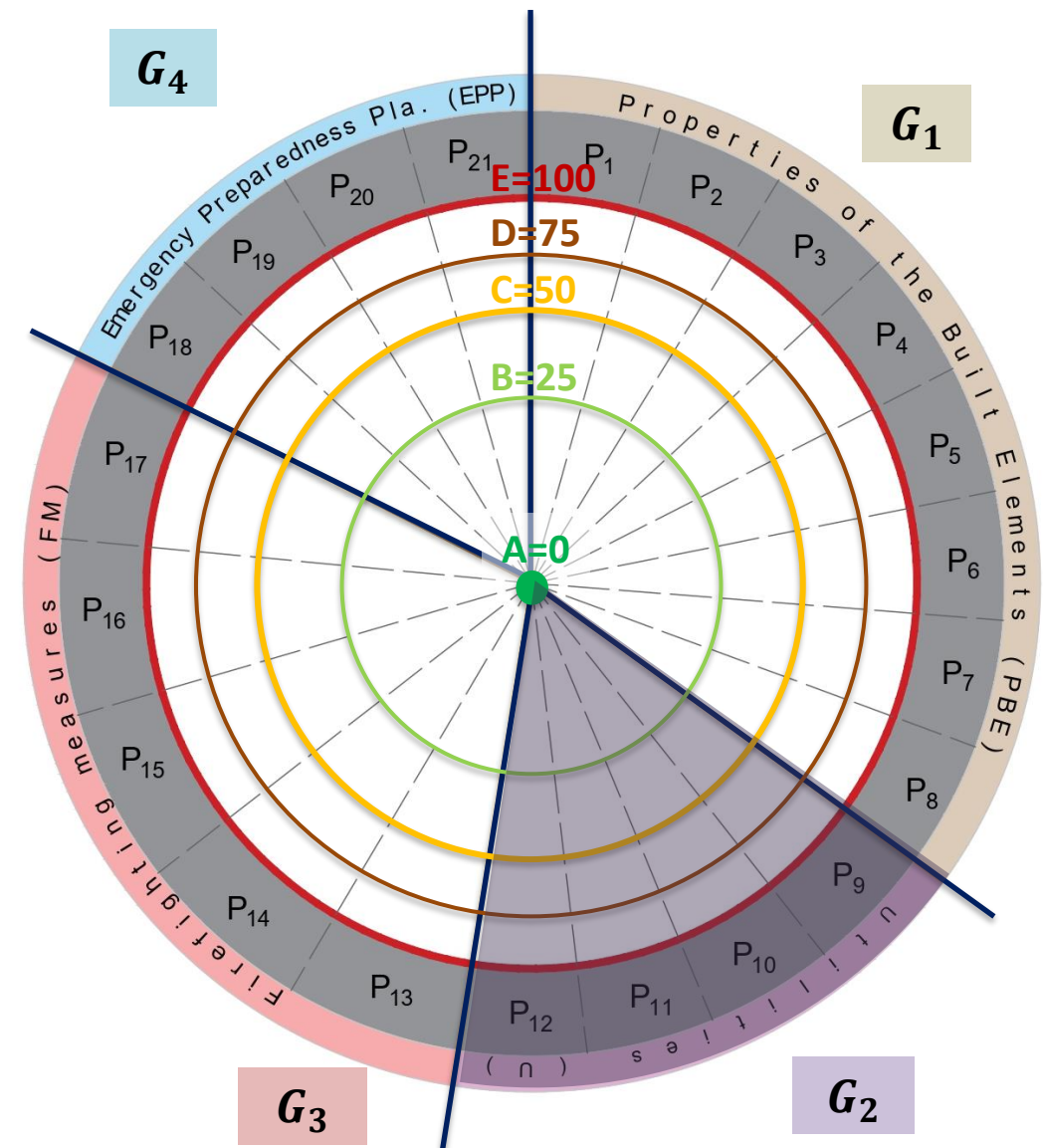


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EPP	28	22.5	27.8	19.8	26	24.82	17.5
	100	100	100	90	87	-	100

$$G_2 = U = \left[\text{Max}(P_{i,i=9:12}) \right] \times 0.175$$

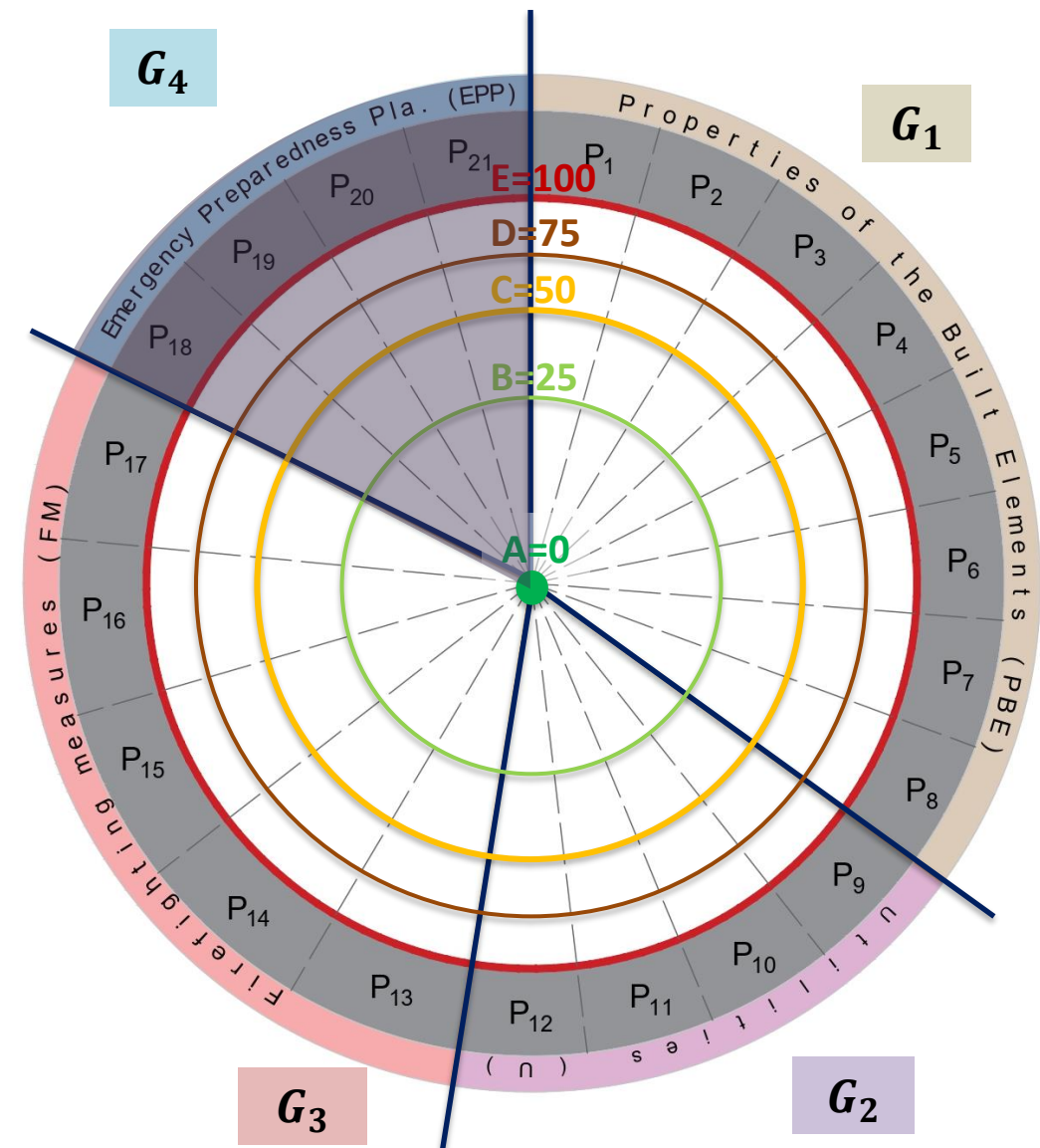


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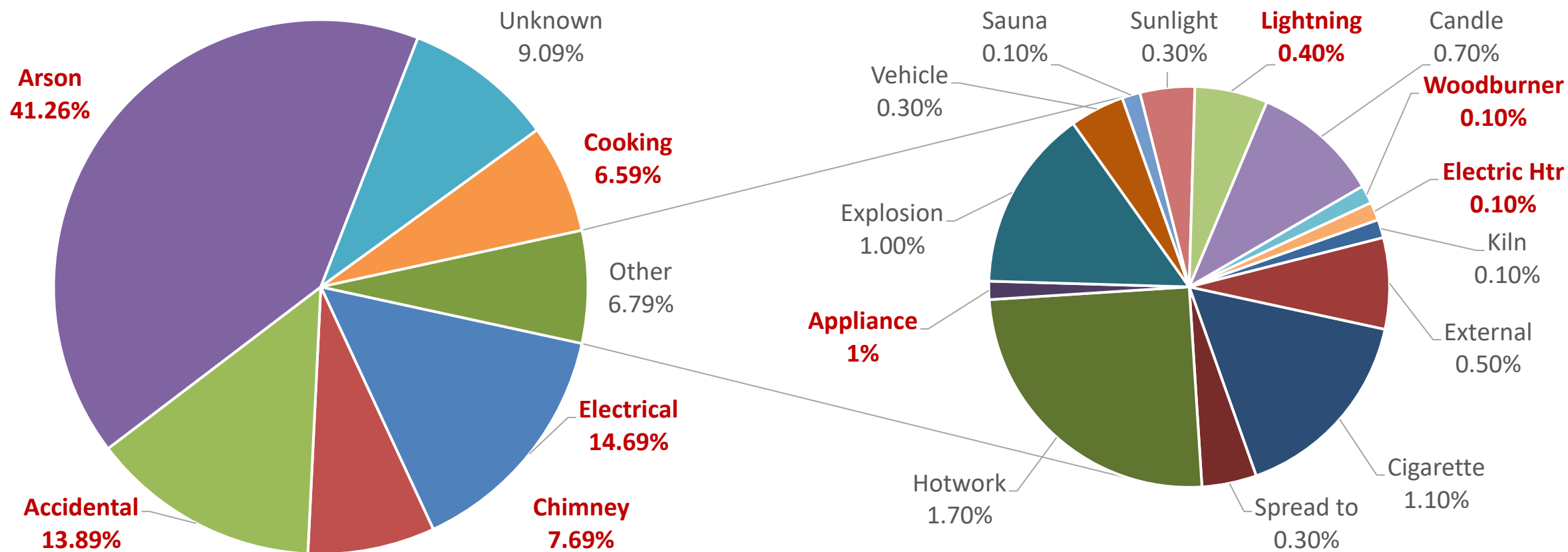
$$G_4 = EPP = \left[\text{Max}(P_{i,i=18:21}) \right] \times 0.175$$



Fire Vulnerability Assessment in Cultural Heritage

Multi-Attribute Scoring Criteria (Level of Damage)

Database of Fire in Historic Buildings January 2017 – June 2020 (<https://www.fireprotect.me.uk/fires.html>)



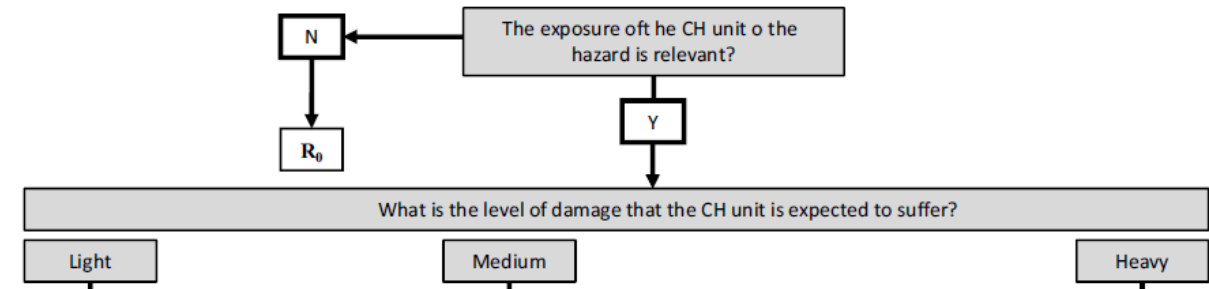
Associated causes (in red) involved in group U (Utilities) ≈ 85%

Fire Vulnerability Assessment in Cultural Heritage

Level of Damage Score

Following the qualitative approach of Romão et al. (2016), three levels of damages were proposed

- Light damage refers to cases where the cultural asset is expected to sustain negligible damage and safety is ensured, but a regular monitoring of the situation is recommended.
- Medium damage refers to situations where the cultural asset can suffer damage that may be partially recovered in case of fire.
- Heavy damage refers to cases that may involve irreparable damage or the total loss of the cultural asset.

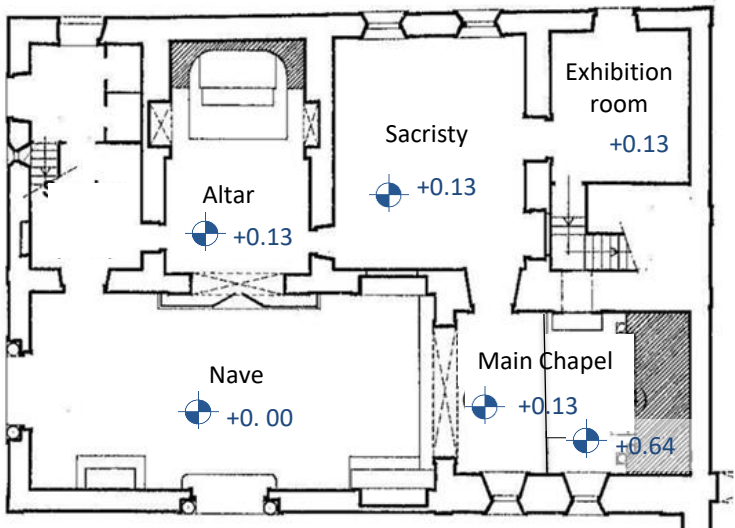


➡ **Light** $D_f = 0-35$

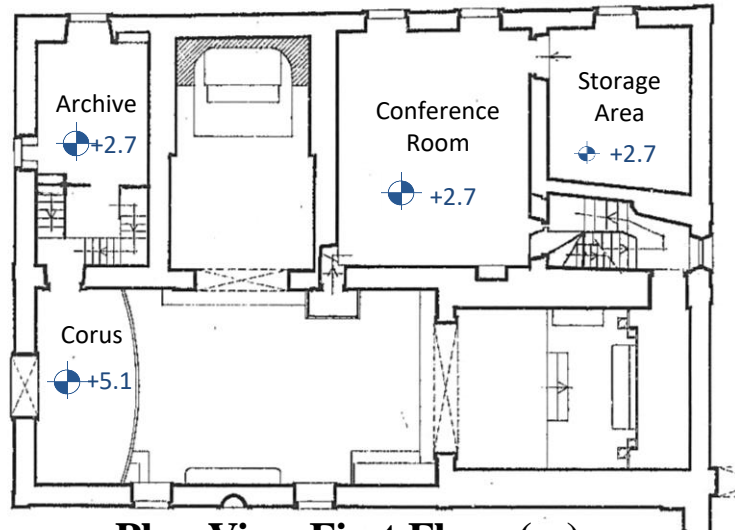
➡ **Medium** $D_f = <35-70$

➡ **Heavy** $D_f = <70-100$

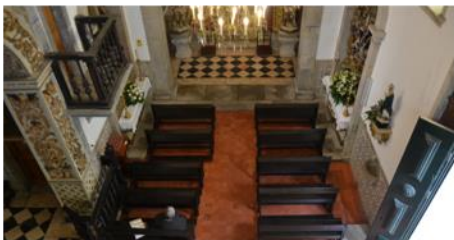
Case Study - Misericórdia de Esposende - Church



Ground Floor plan (m)

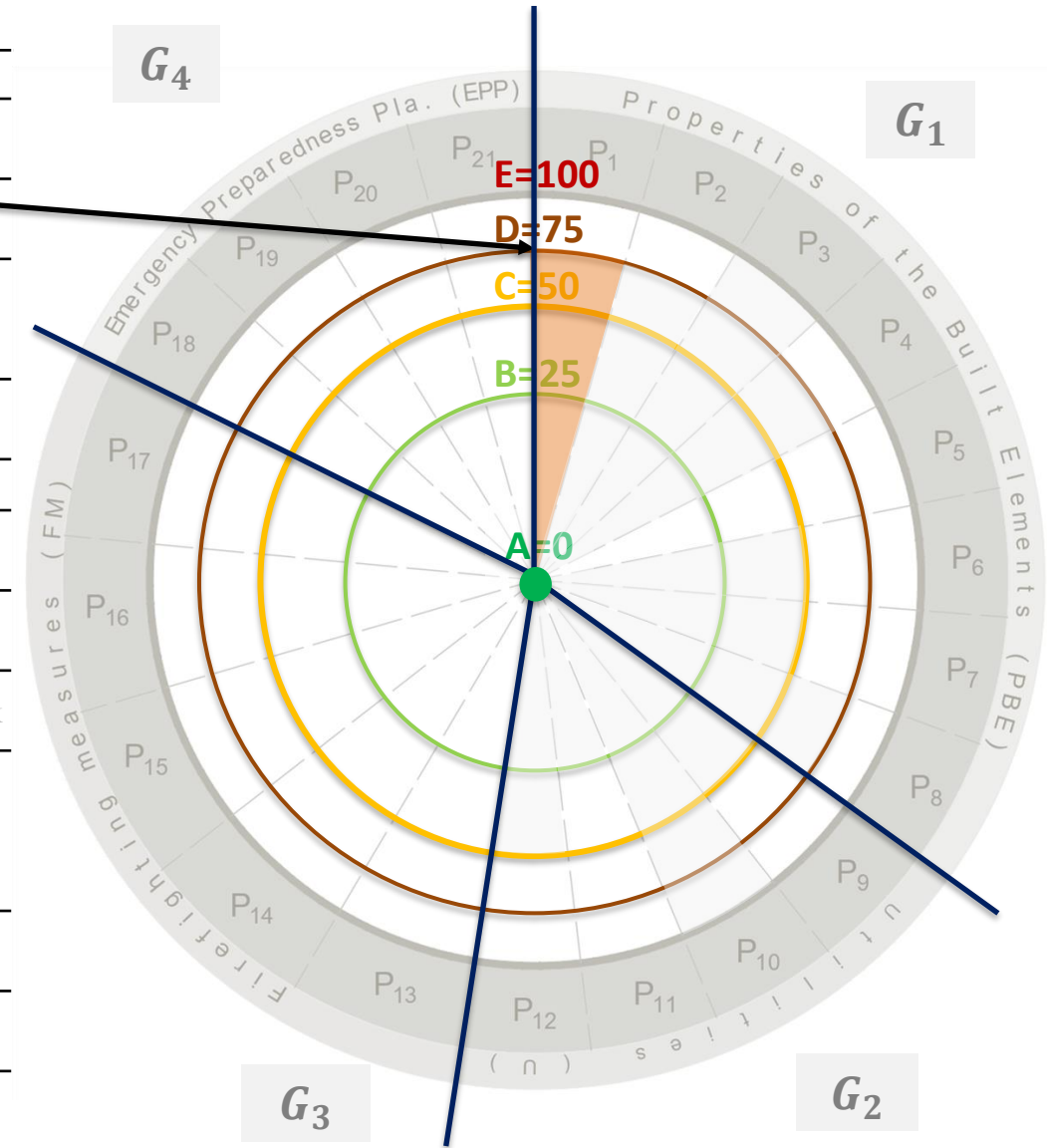


Plan View First Floor (m)



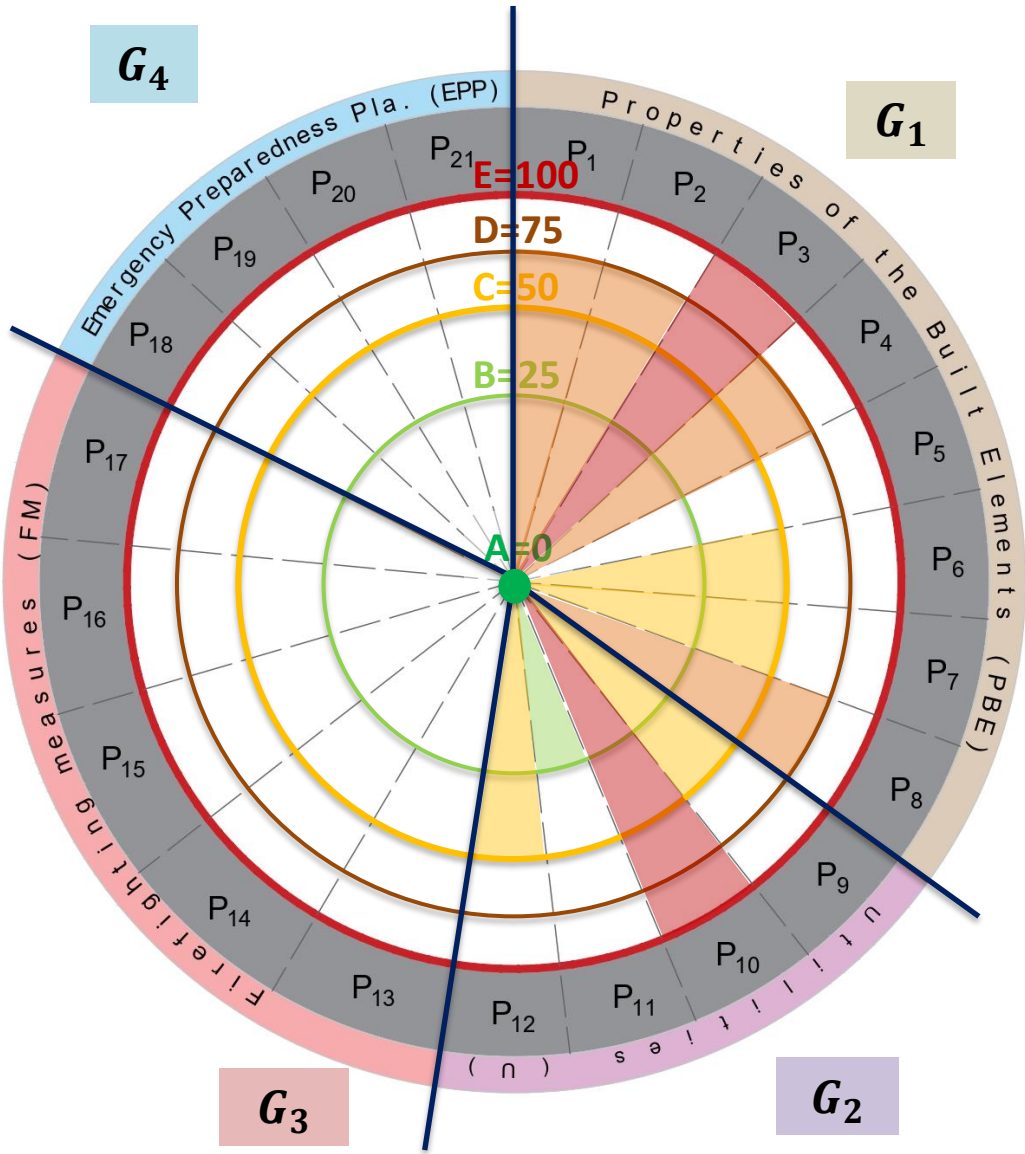
Case Study

Indicator		Assessment	
		DPC	Justification
PBE	P_1 - Fire Load (MJ/m ²)	D	Estimation of Fire load: Immovable (around 1,100 MJ/m ²) and Movable of 525 MJ/m ² (in Bernardini, 2017) \approx 1,625 MJ/m ²
	P_2 - Fire Resistance (°C)	D	Susceptible material to ignite of the structure is wood (around 300 °C) in the roof
	P_3 - Finishes and linings	E	Abundant combustible material in the building is timber in vertical linings (flash point \geq 230°C) and horizontal finishes (floors and ceilings)
	P_4 - Compartmentation (m ²)	D	The largest compartment size is approximately 103 m ² , and the height of the compartment is more than 4 m
	P_5 - Adjacent Constructions	A	The church is an isolated construction
	P_6 - Vertical Propagation	C	The worst-case aligned openings are less than 1.5 m without façade protruding elements
	P_7 - Conservation Status	C	There are combustible materials in good conservation condition
	P_8 - Fire Breaks	D	Surrounding vegetation located at 3.13 m at one side (right flank
D	P_9 - Electrical Installation	C	Four vulnerable characteristics: electrical outlets present overloading; poor implementation of cable organizers and excessive dust; short-circuits are known, electric room used as storage room.
	P_{10} - Gas Installation	E	Gas containers stored in a poorly-ventilated area inside the building (see Figure 4d) located near combustible materials.
	P_{11} - HVAC Installation	B	Decentralized system/good level of maintenance/ near to combustible or flammable materials.
	P_{12} - CCTV system	C	The building has cameras in some relevant areas and the zone is considered as moderate criminality (Verified in Numbeo, 2019)



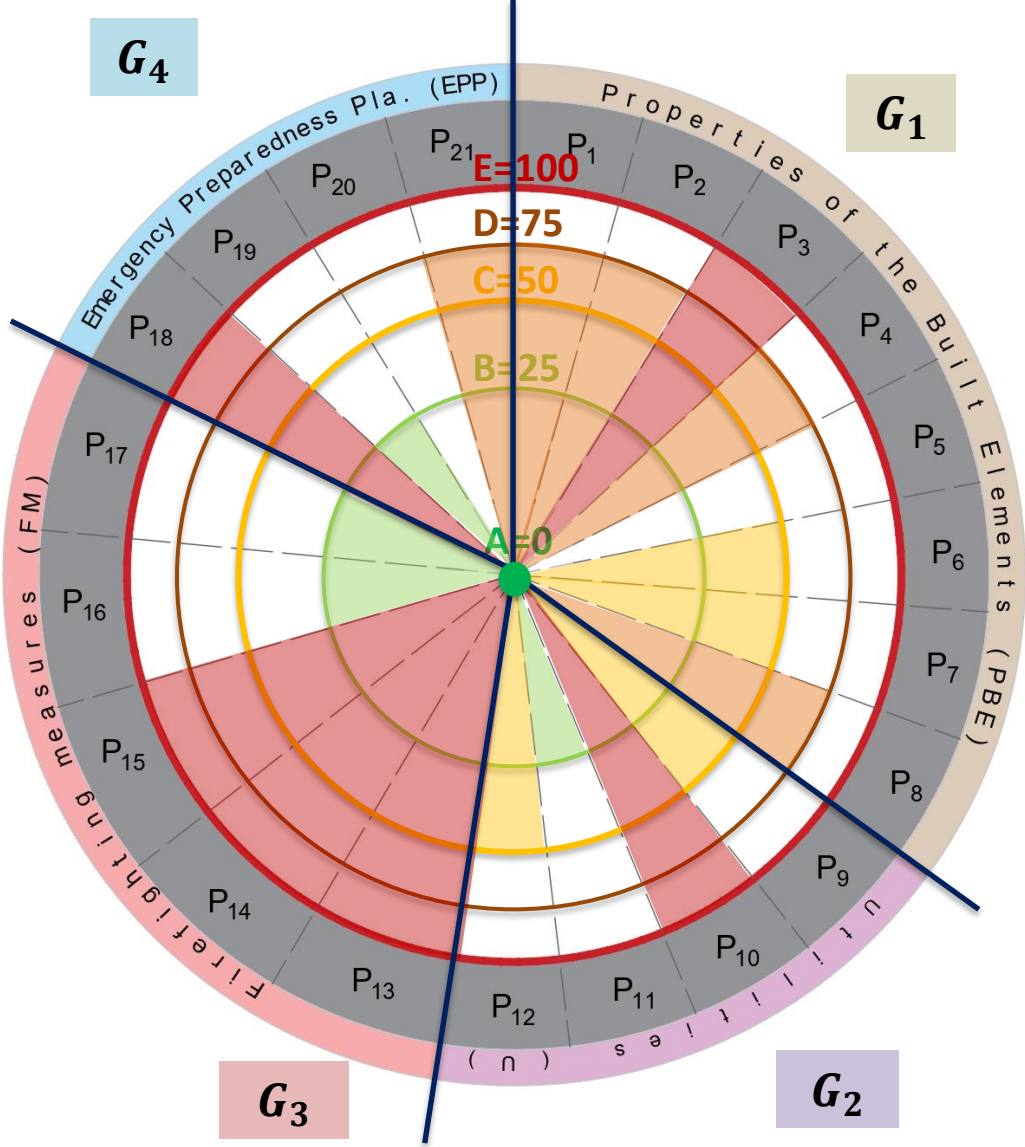
Case Study with the selected DPC for each Fire Indicator

		Assessment	
Indicator		DPC	Justification
PBE	P ₁ - Fire Load (MJ/m2)	D	Estimation of Fire load: Immovable (around 1,100 MJ/m2) and Movable of 525 MJ/m2 (in Bernardini, 2017) ≈1,625 MJ/m2
	P ₂ - Fire Resistance (°C)	D	Susceptible material to ignite of the structure is wood (around 300 °C) in the roof
	P ₃ - Finishes and linings	E	Abundant combustible material in the building is timber in vertical linings (flash point ≥230°C) and horizontal finishes (floors and ceilings)
	P ₄ - Compartmentation (m2)	D	The largest compartment size is approximately 103 m2, and the height of the compartment is more than 4 m
	P ₅ - Adjacent Constructions	A	The church is an isolated construction
	P ₆ - Vertical Propagation	C	The worst-case aligned openings are less than 1.5 m without façade protruding elements
	P ₇ - Conservation Status	C	There are combustible materials in good conservation condition
	P ₈ - Fire Breaks	D	Surrounding vegetation located at 3.13 m at one side (right flank
D	P ₉ - Electrical Installation	C	Four vulnerable characteristics: electrical outlets present overloading; poor implementation of cable organizers and excessive dust; short-circuits are known, electric room used as storage room.
	P ₁₀ - Gas Installation	E	Gas containers stored in a poorly-ventilated area inside the building located near combustible materials.
	P ₁₁ - HVAC Installation	B	There is a decentralized system with good level of maintenance and near to combustible or flammable materials.
	P ₁₂ - CCTV system	C	The building has cameras in some relevant areas and the zone is considered as moderate criminality (Verified in Numbeo, 2019)



Case Study

Indicator		Assessment	
		DPC	Justification
FM	P ₁₃ - Alarm and Detection System	E	There is no human surveillance and the warning system does not exist
	P ₁₄ - Smoke Control	E	There is no smoke system (neither passive nor active system) that prevent damages to the cultural heritage
	P ₁₅ - Active Suppression System	E	There is no active suppression system
	P ₁₆ - Water Supply	B	There is a public hydrant at approximately 45 m
	P ₁₇ - Fire Rescue Services	B	The firefighter services take approximately 15 minutes to arrive (Verified in Google Maps)
EPP	P ₁₈ -Emergency Planning	E	No emergency planning
	P ₁₉ - Compartment Height Level	B	Height of the upper level (habitable space) is 5.10 m
	P ₂₀ - Evacuation and Egress Routes	A	Travel distance was 44.1 m with more than 2 evacuation exits
	P ₂₁ - Emergency Signage	D	There are emergency lights but as an incomplete system (not all the relevant areas of evacuation) without evacuation signage



Worst cases per category

G1 – Properties of the Built Elements (PBE)

P ₃ - Finishes and linings	E	Abundant combustible material in the building is timber in vertical linings (flash point $\geq 230^{\circ}\text{C}$) and horizontal finishes (floors and ceilings)
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G2 – Utilities (U)

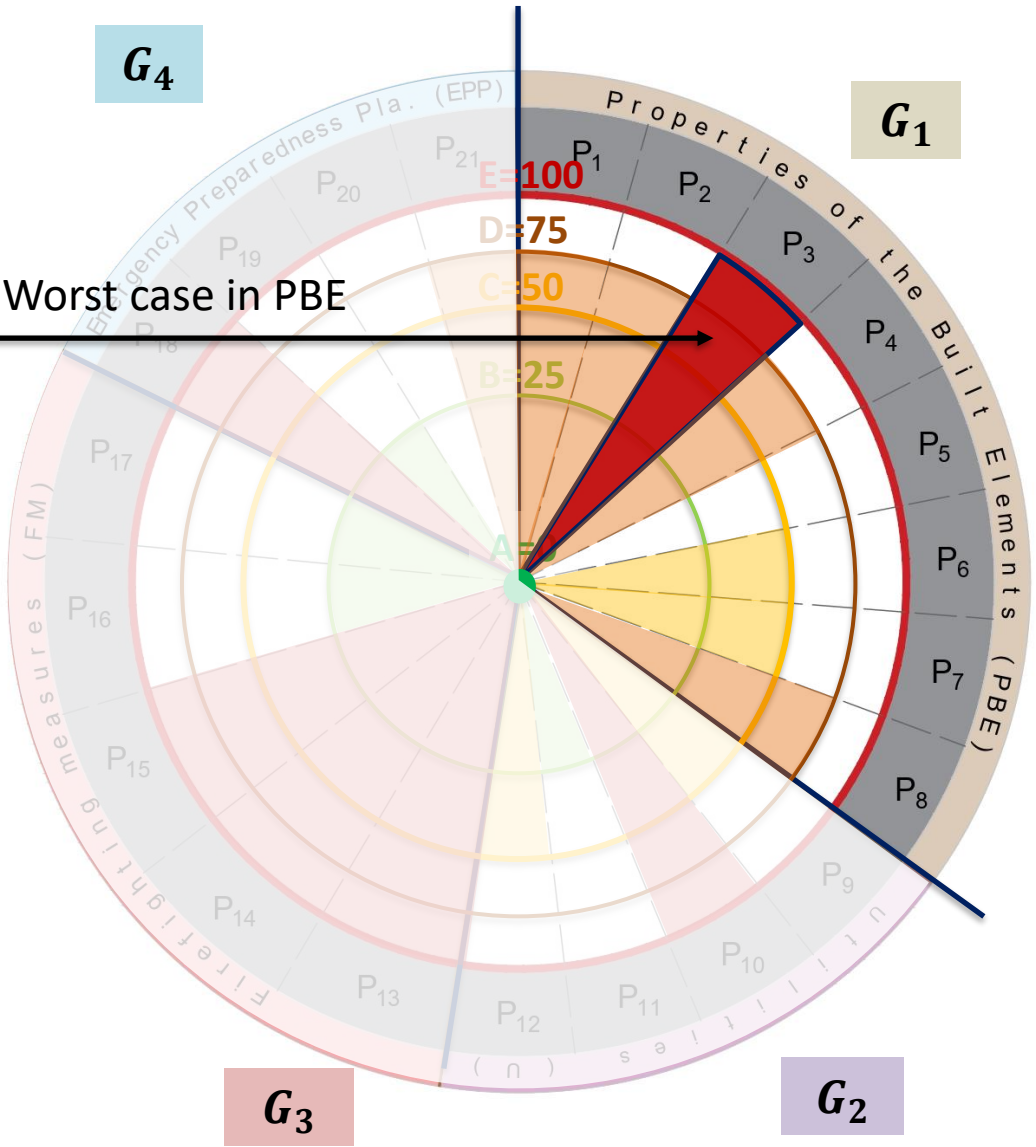
P ₁₀ - Gas Installation	E	Gas containers stored in a poorly-ventilated area inside the building located near combustible materials.
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G3 - Firefighting Measures (FM)

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P ₁₅ - Active Suppression	E	There is no active suppression system

G4 - Emergency Preparedness Planning (EPP)

P ₁₈ -Emergency Planning	E	No emergency planning
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Worst cases per category

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<i>P</i> ₃ - Finishes and linings	E	Abundant combustible material in the building is timber in vertical linings (flash point ≥230°C) and horizontal finishes (floors and ceilings)
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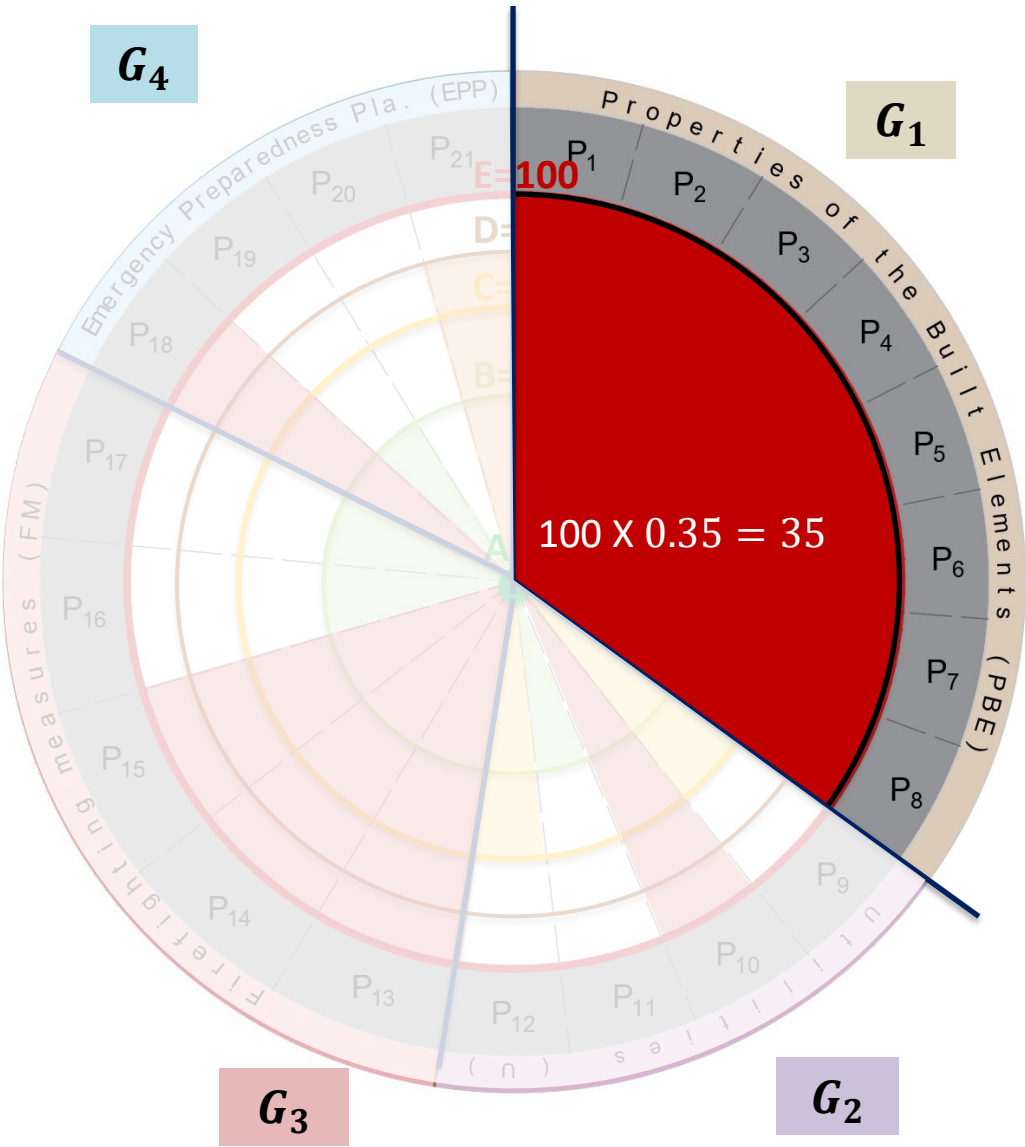
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G4 - Emergency Preparedness Planning (EPP)

<i>P</i> ₁₈ -Emergency Planning	E	No emergency planning
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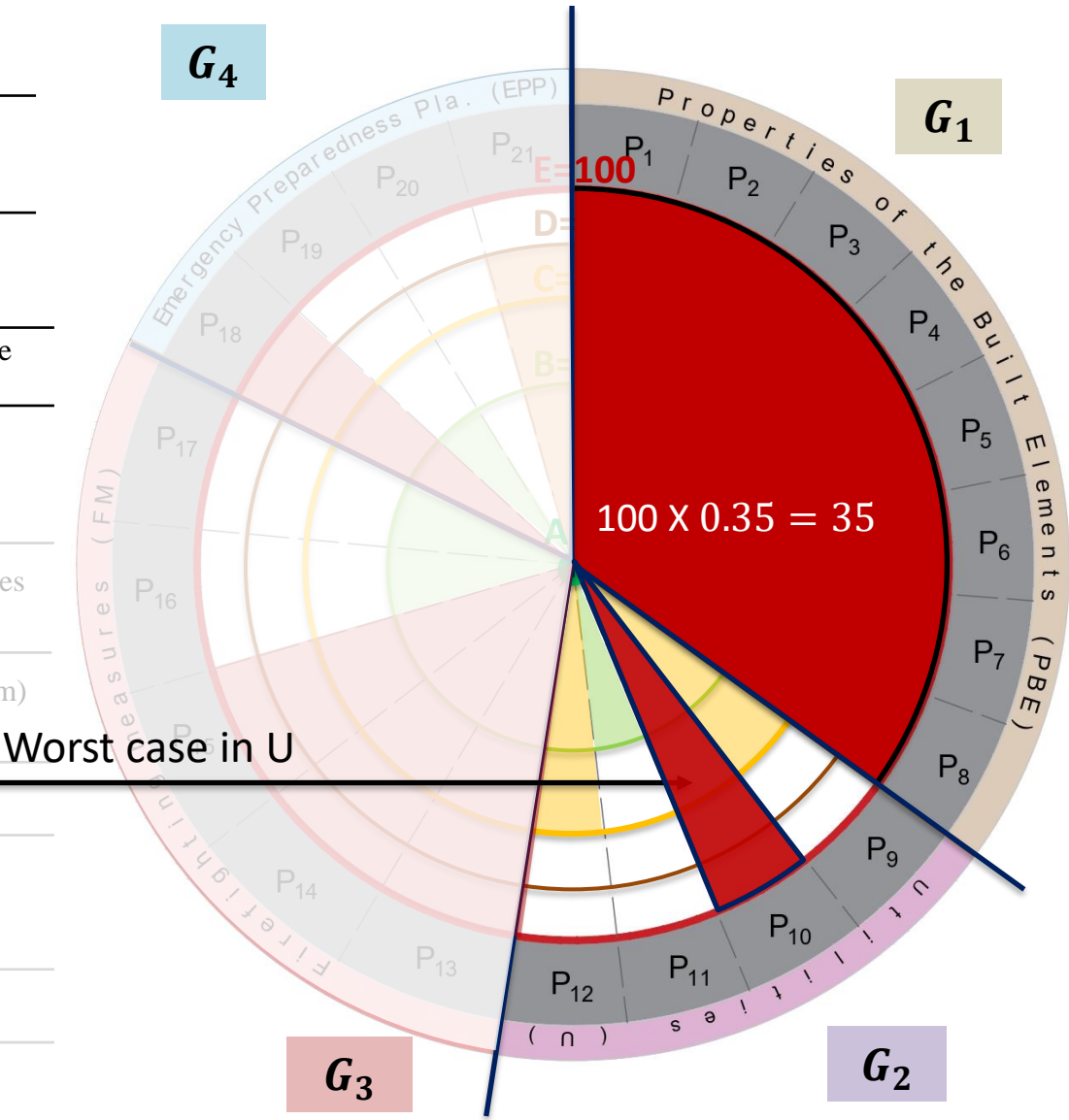
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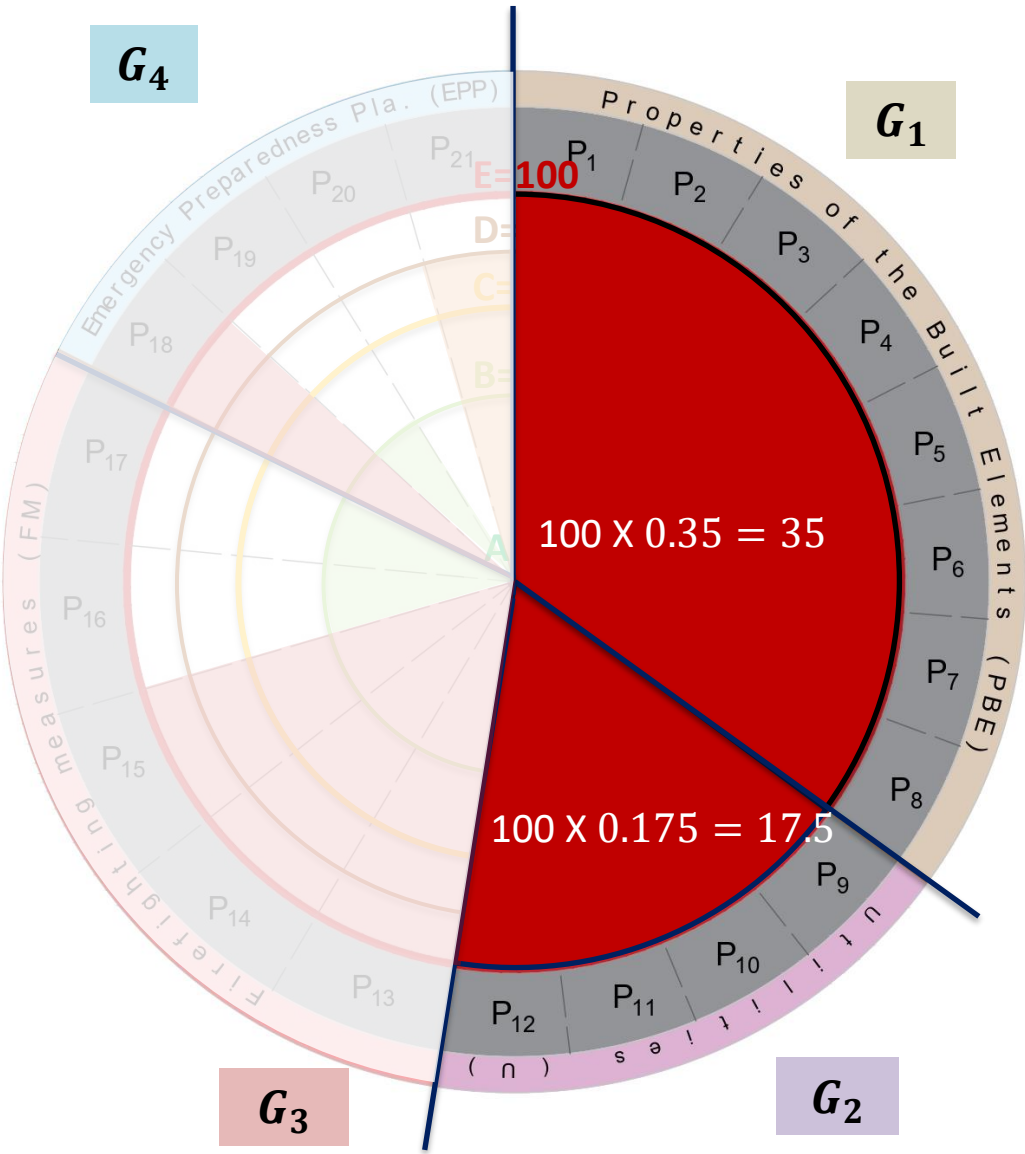
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Worst cases per category

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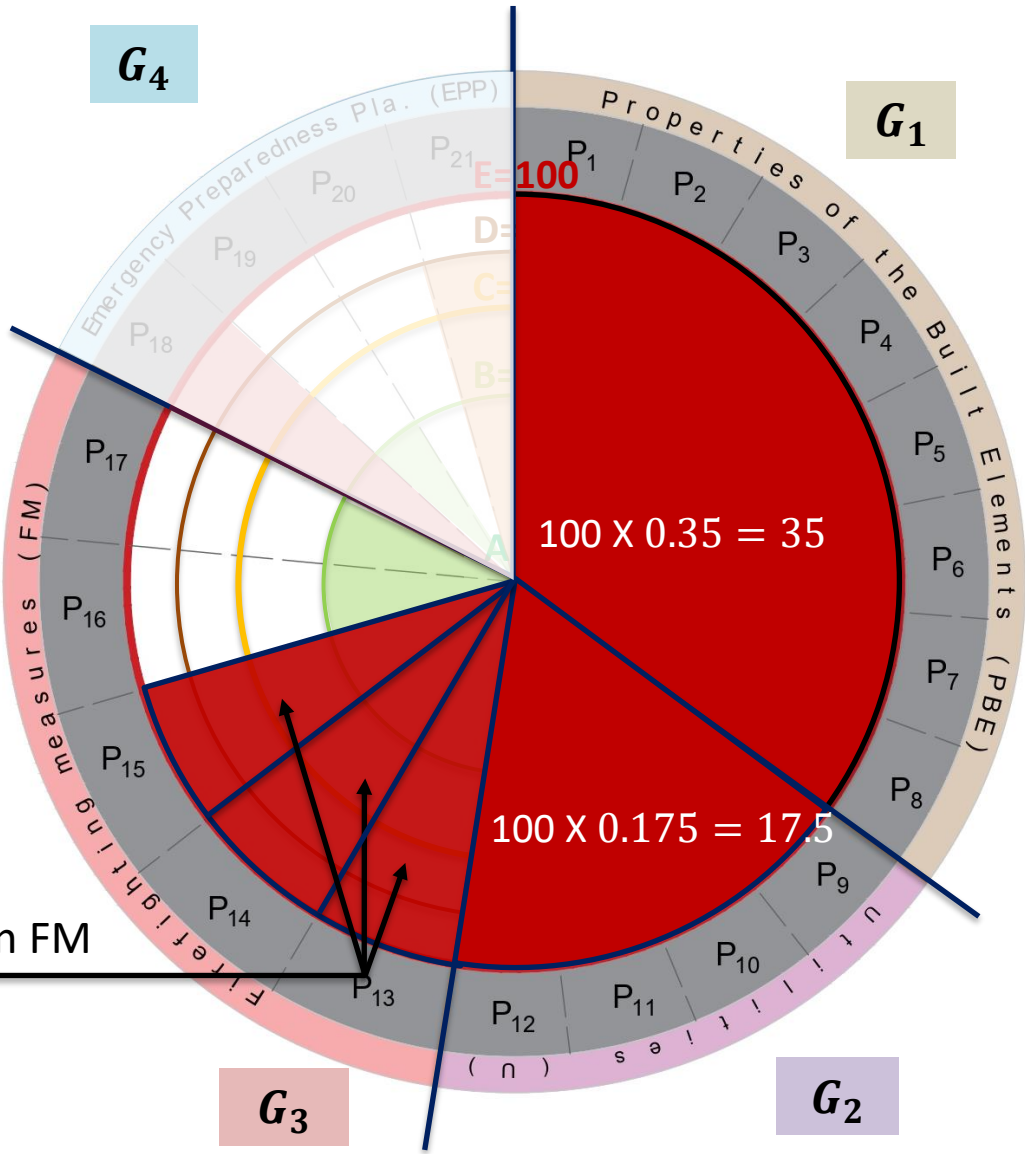
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G4 - Emergency Preparedness Planning (EPP)

<i>P</i> ₁₈ -Emergency Planning	E	No emergency planning
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Three worst cases in FM



Worst cases per category

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G2 – Utilities (U)

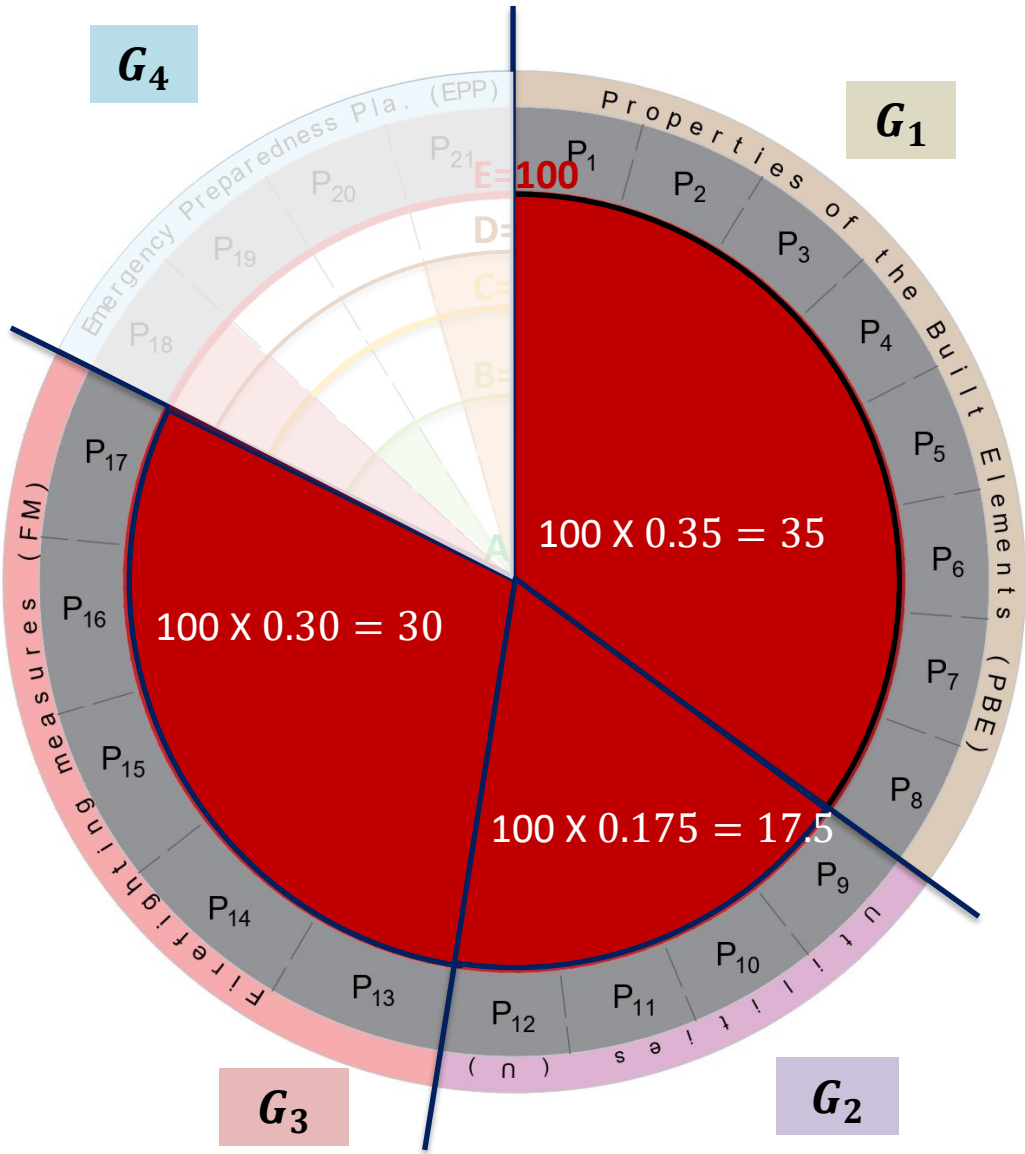
<i>P</i> ₁₀ - Gas Installation	E	Gas containers stored in a poorly-ventilated area inside the building located near combustible materials.
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G3 - Firefighting Measures (FM)

<i>P</i> ₁₃ - Alarm and Detection	E	There is no human surveillance and the warning system does not exist
<i>P</i> ₁₄ - Smoke Control	E	There is no smoke system (neither passive nor active system) that prevent damages to the cultural heritage
<i>P</i> ₁₅ - Active Suppression	E	There is no active suppression system

G4 - Emergency Preparedness Planning (EPP)

<i>P</i> ₁₈ -Emergency Planning	E	No emergency planning
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Worst cases per category

G1 – Properties of the Built Elements (PBE)

<i>P</i> ₃ - Finishes and linings	E	Abundant combustible material in the building is timber in vertical linings (flash point ≥230°C) and horizontal finishes (floors and ceilings)
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G2 – Utilities (U)

<i>P</i> ₁₀ - Gas Installation	E	Gas containers stored in a poorly-ventilated area inside the building located near combustible materials.
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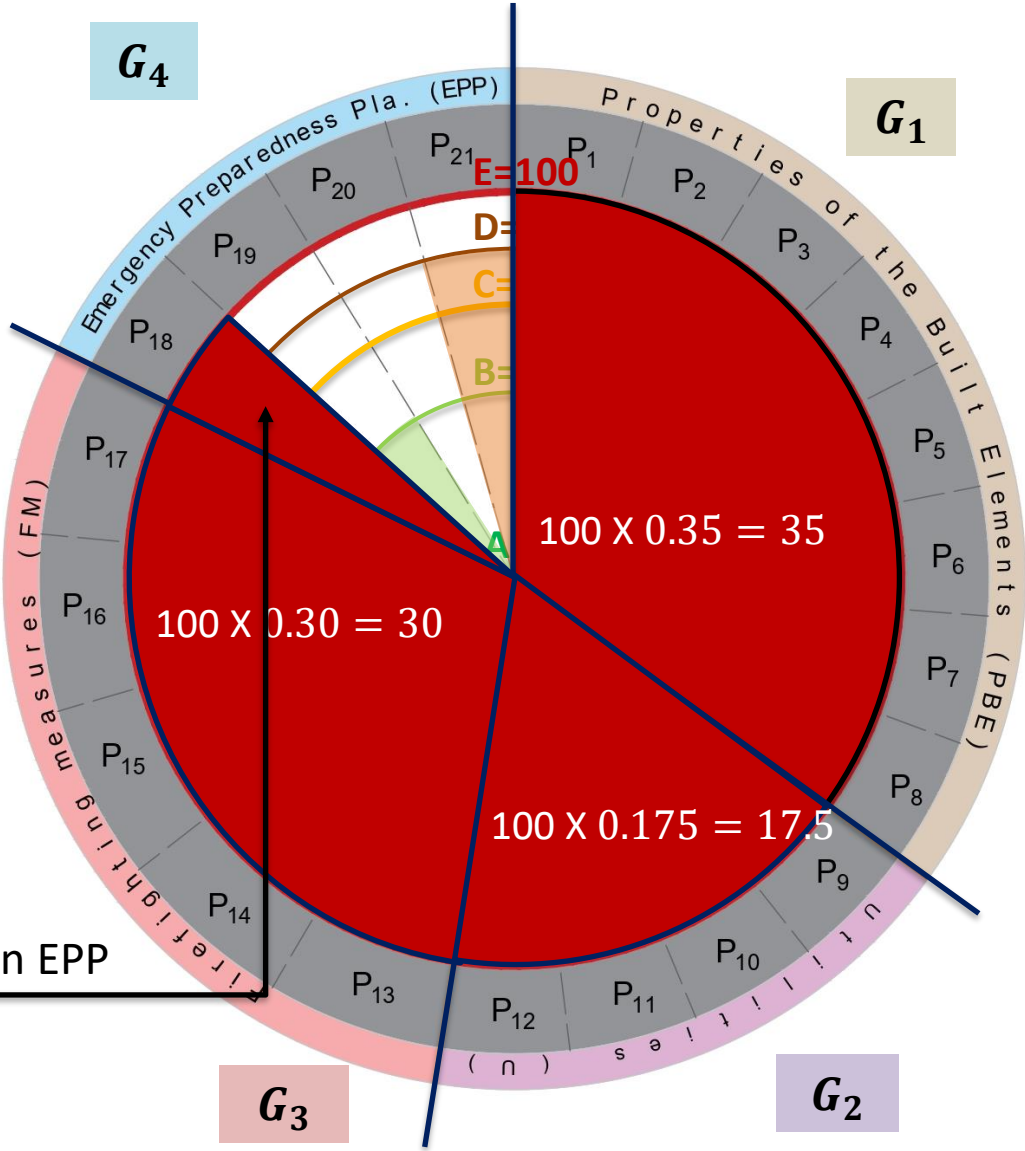
G3 - Firefighting Measures (FM)

<i>P</i> ₁₃ - Alarm and Detection	E	There is no human surveillance and the warning system does not exist
<i>P</i> ₁₄ - Smoke Control	E	There is no smoke system (neither passive nor active system) that prevent damages to the cultural heritage
<i>P</i> ₁₅ - Active Suppression	E	There is no active suppression system

G4 - Emergency Preparedness Planning (EPP)

<i>P</i> ₁₈ - Emergency Planning	E	No emergency planning
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Worst case in EPP



Worst cases per category

G1 – Properties of the Built Elements (PBE)

P_3 - Finishes and linings	E	Abundant combustible material in the building is timber in vertical linings (flash point $\geq 230^{\circ}\text{C}$) and horizontal finishes (floors and ceilings)
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G2 – Utilities (U)

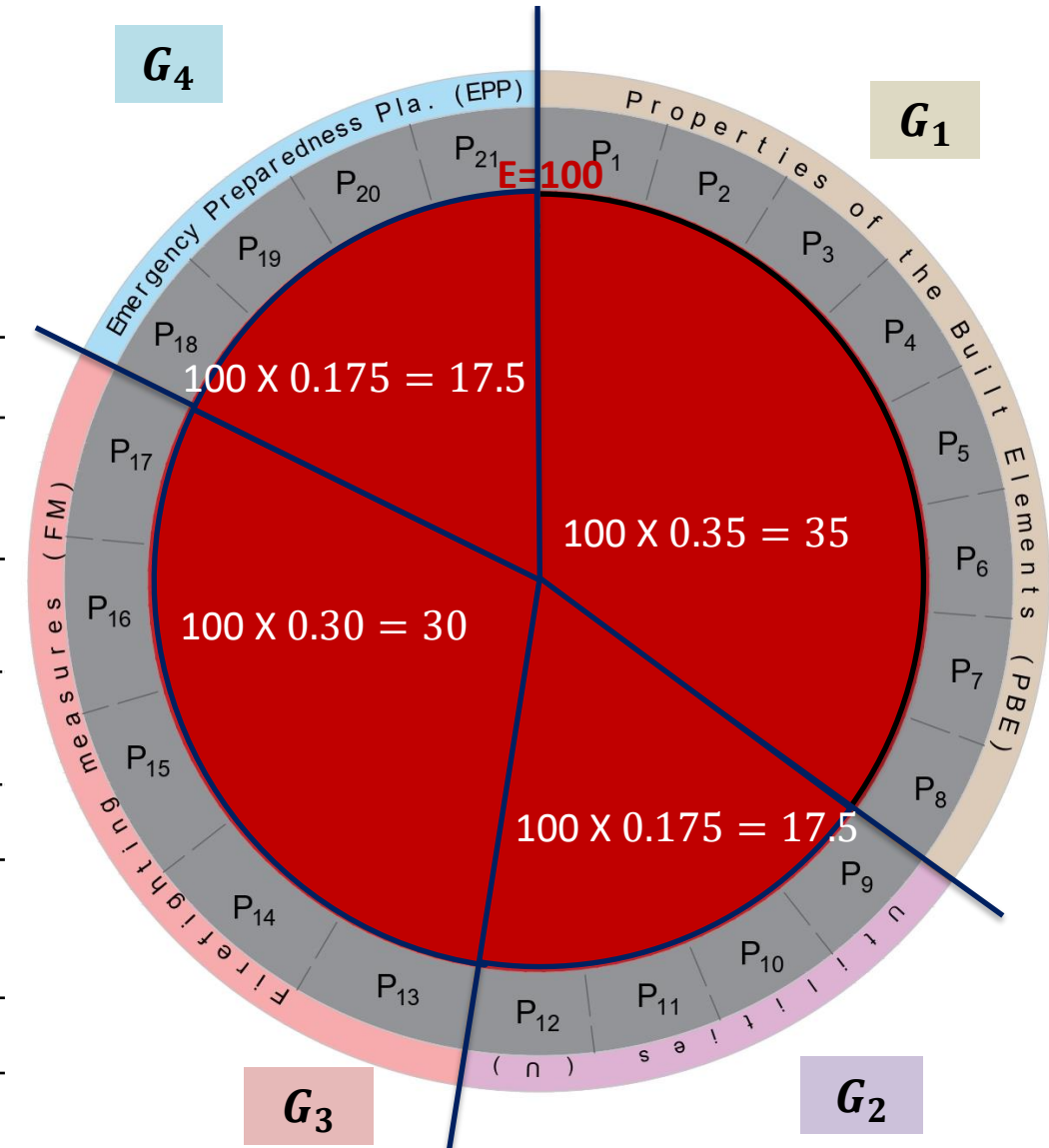
P_{10} - Gas Installation	E	Gas containers stored in a poorly-ventilated area inside the building located near combustible materials.
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G3 - Firefighting Measures (FM)

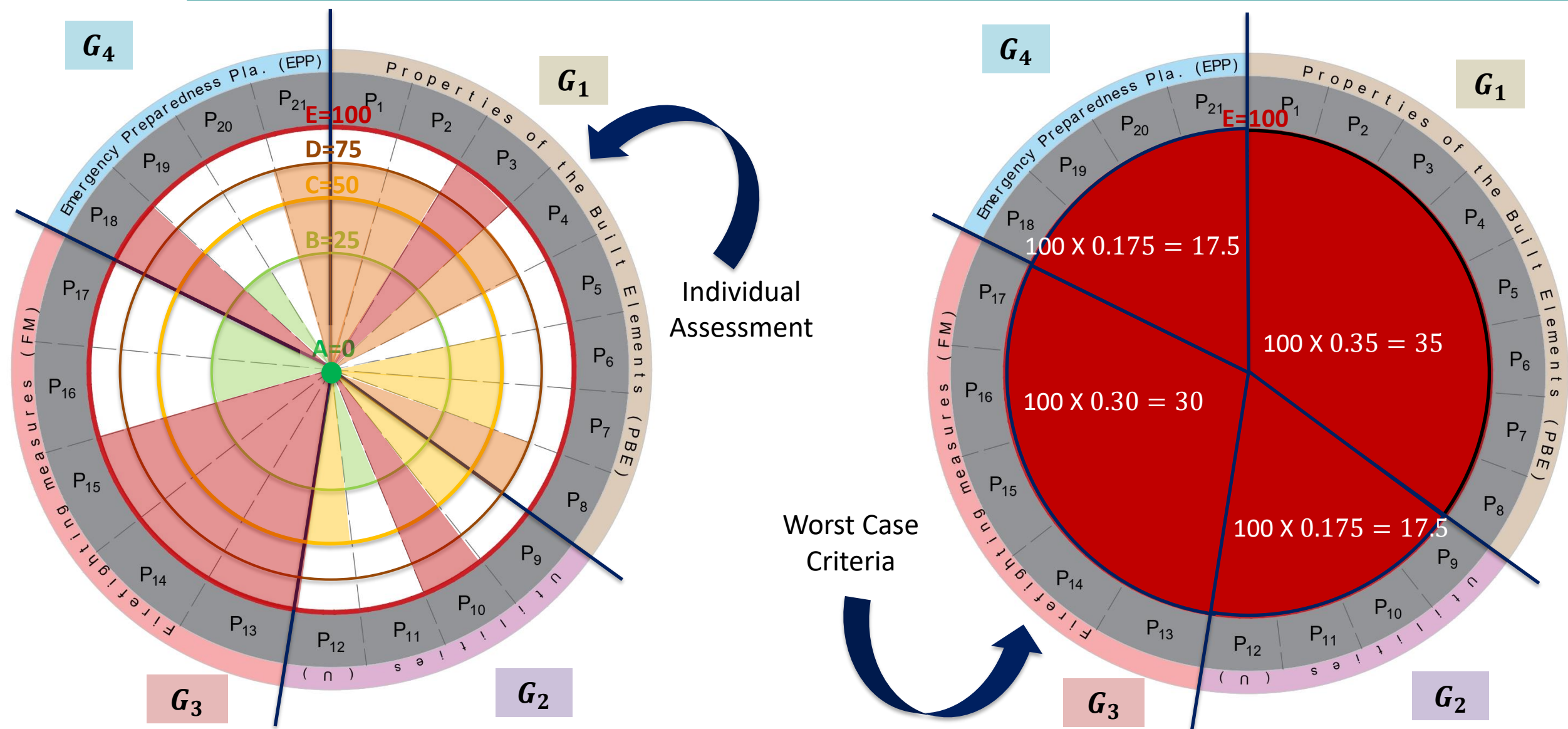
P_{13} - Alarm and Detection	E	There is no human surveillance and the warning system does not exist
P_{14} - Smoke Control	E	There is no smoke system (neither passive nor active system) that prevent damages to the cultural heritage
P_{15} - Active Suppression	E	There is no active suppression system

G4 - Emergency Preparedness Planning (EPP)

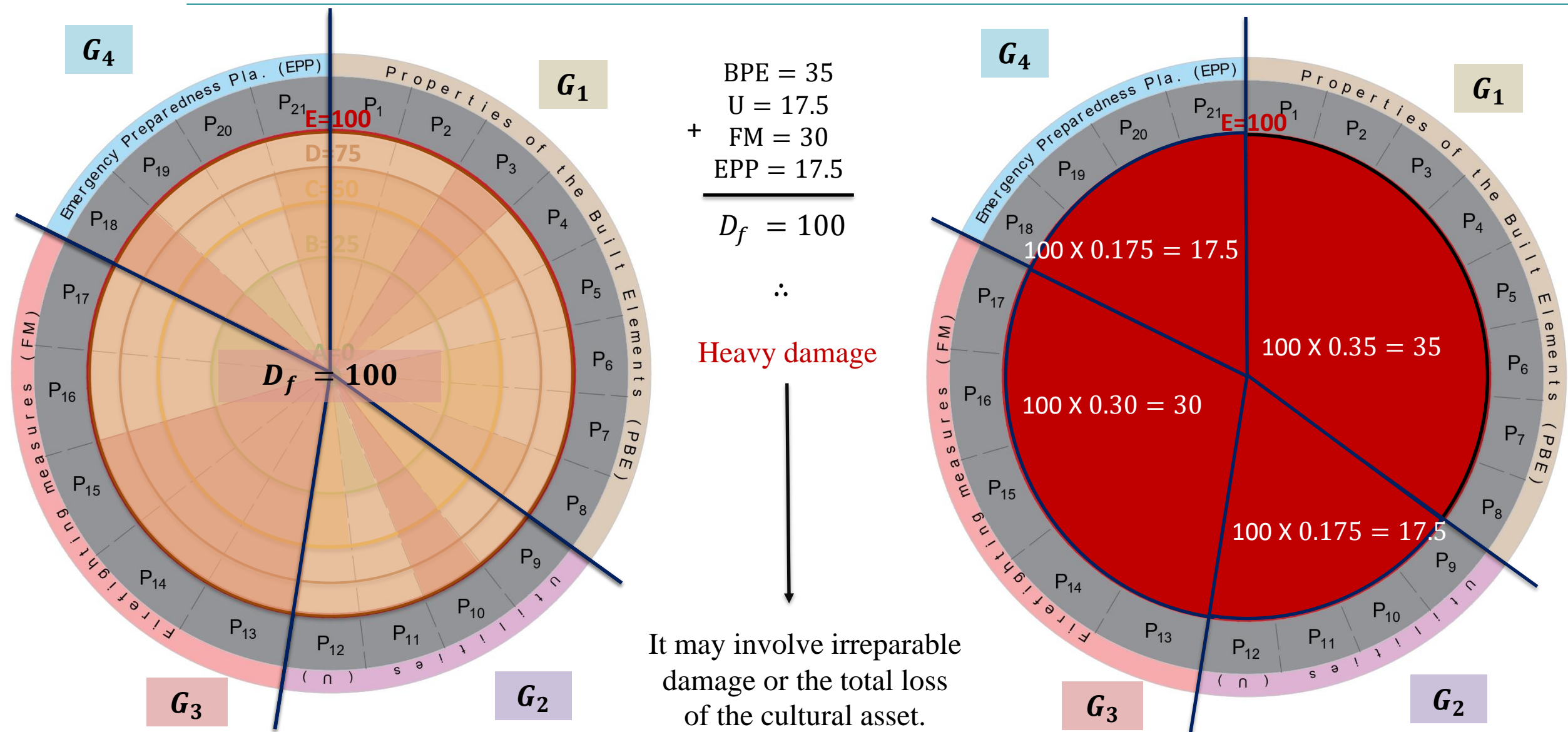
P_{18} -Emergency Planning	E	No emergency planning
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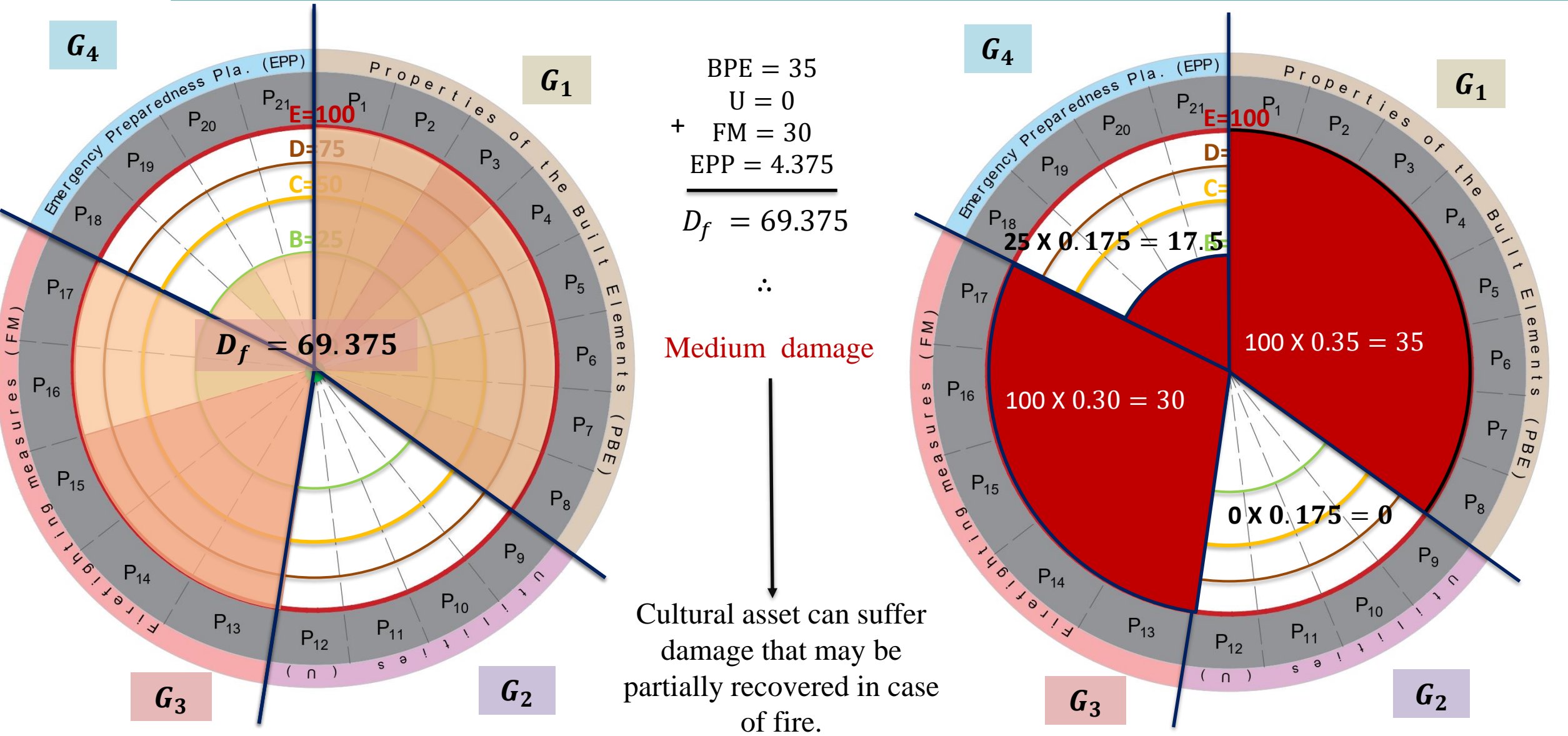
Sum of the scores to measure the expected Level of Damage



Sum of the scores to measure the expected Level of Damage

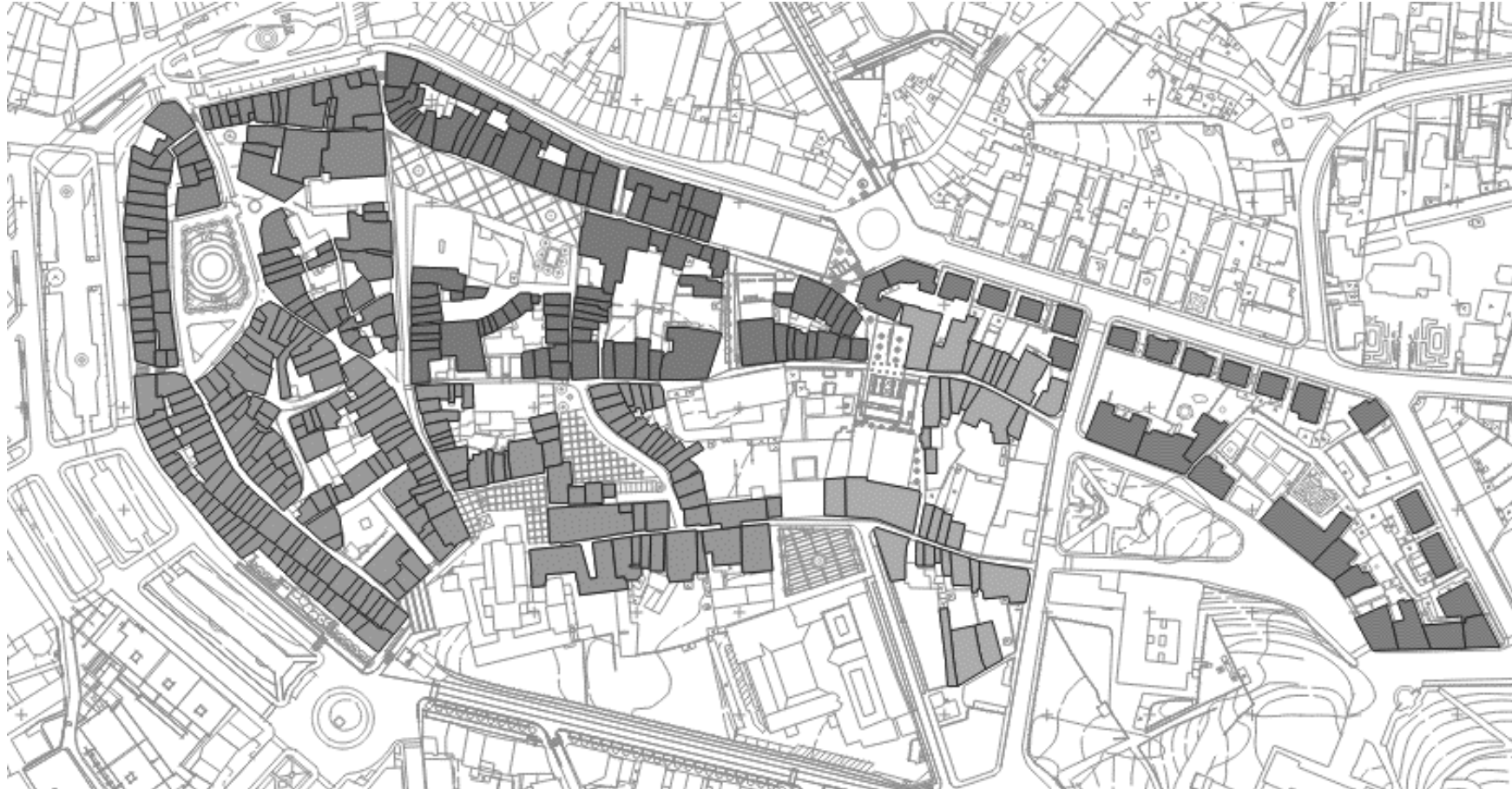


Some Actions to improve the expected Level of Damage



Ongoing Work - Indicators at Urban Level

Involve additional assessment criteria at the urban level (Historic Centres) for some indicators to address clusters of buildings



- **P9 - Electrical installations**
- **P12 – CCTV**
- **P18 - Emergency planning**
- **P20 – Evacuation Routes**

Ongoing Work - Indicators at Urban Level

Involve additional assessment criteria at the urban level (Historic Centres) for some indicators to address clusters of buildings



- **P9 - Electrical installations**
- **P12 - CCTV**
- **P18 - Emergency planning**
- **P20 - Evacuation Routes**

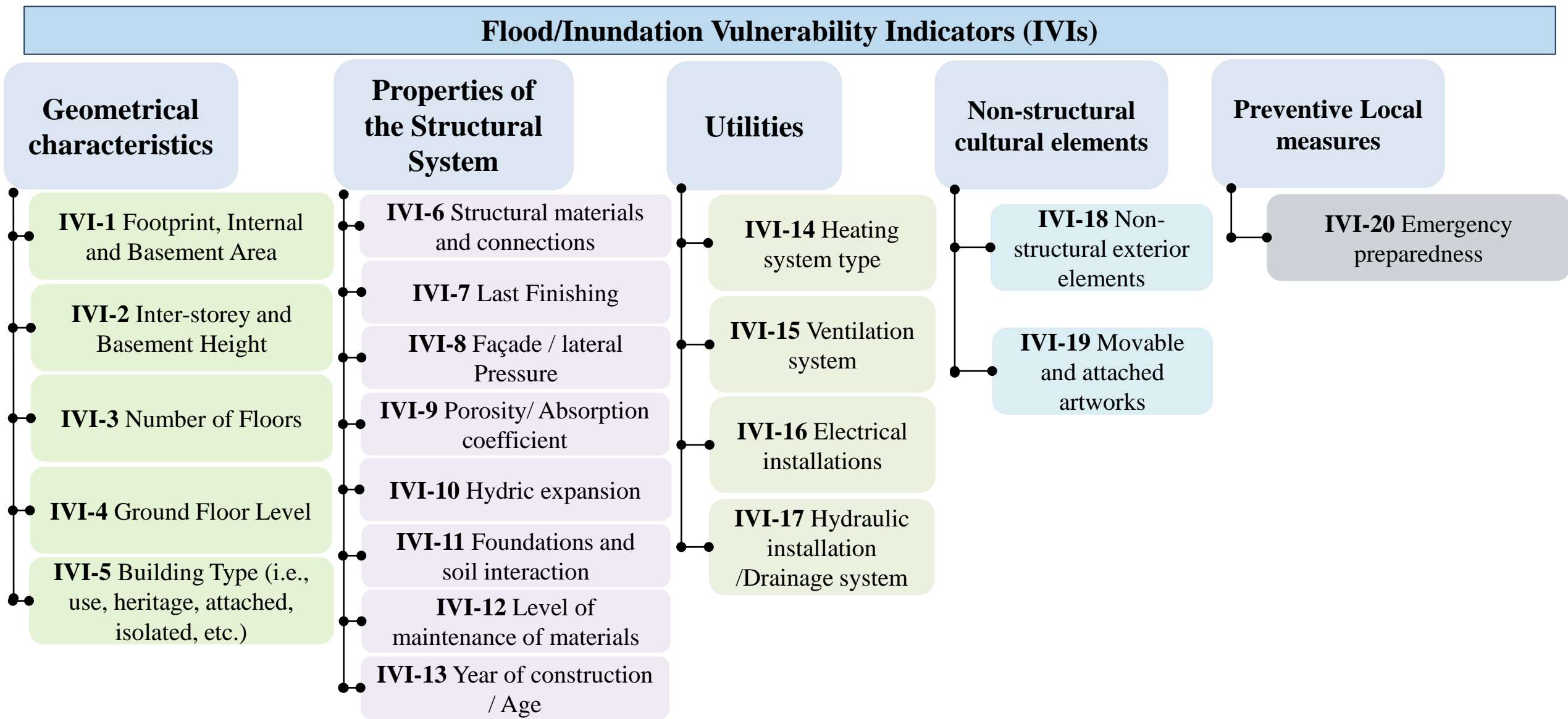
Example in Brazil



[Olinda's historic centre](#)

Example in Guimarães, Portugal

Ongoing Work- Development of Flood Vulnerability Assessment in Cultural Heritage



Research Products and Future Tasks

Published

-G. Salazar, X. Romão, E. Paupério, Review of vulnerability indicators for fire risk assessment in cultural heritage, Int. J. Disaster Risk Reduct. 60 (2021) 102286. <https://doi.org/10.1016/j.ijdr.2021.102286>.

Ongoing Research Articles (21/22)

- **Fire Damage Index for Vulnerability Assessment in Cultural Heritage**
- **Performance of Fire Vulnerability Assessment Method in Historic Centre of Guimarães**
- **Review of Vulnerability Indicators for Flood Risk Assessment in Cultural Heritage**

Future Tasks

- **Development of a Simplified Seismic Vulnerability Assessment in Cultural Heritage using different data sources (e.g. Remote Sensing)**

THANK YOU FOR YOUR ATTENTION

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