

Evaluating wildfire vulnerability of dwellings using fuzzy logic and expert judgement approaches

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International Workshop on Wildfire Modeling & AI
Madrid, March 17-18, 2025

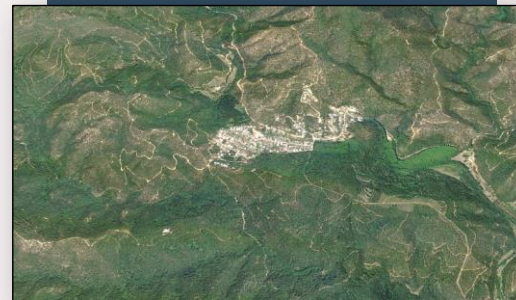


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WILDFIRE RISK ANALYSIS AT PROPERTY SCALE

The WUI fire problem is characterized by the interaction of multiple phenomena of diverse nature occurring a **different observation scales**



Forestry management
 Operational strategies
 Landscape design

LANDSCAPE SCALE



Source: texaswildfirerisk.com

Fuel reduced fringes
 Water network
 Settlement design

COMMUNITY SCALE



Source: D. Binns

Self-defensible spaces
 Shelter-in-place operations
 Property design

HOME-OWNER SCALE

The three scales are **interrelated** and need to be taken into account when studying WUI fire phenomena

RISK FACTORS



Radiation



Flame contact



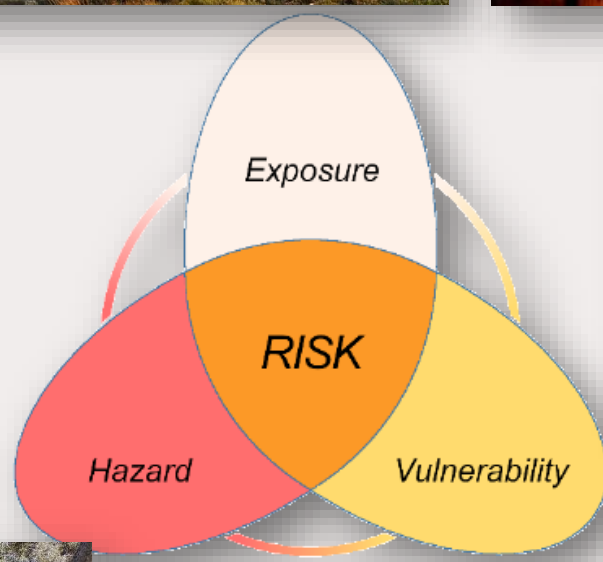
Firebrands

Types of fire exposure



Natural-Ornamental

Fuel types



Structural characteristics



Man-made

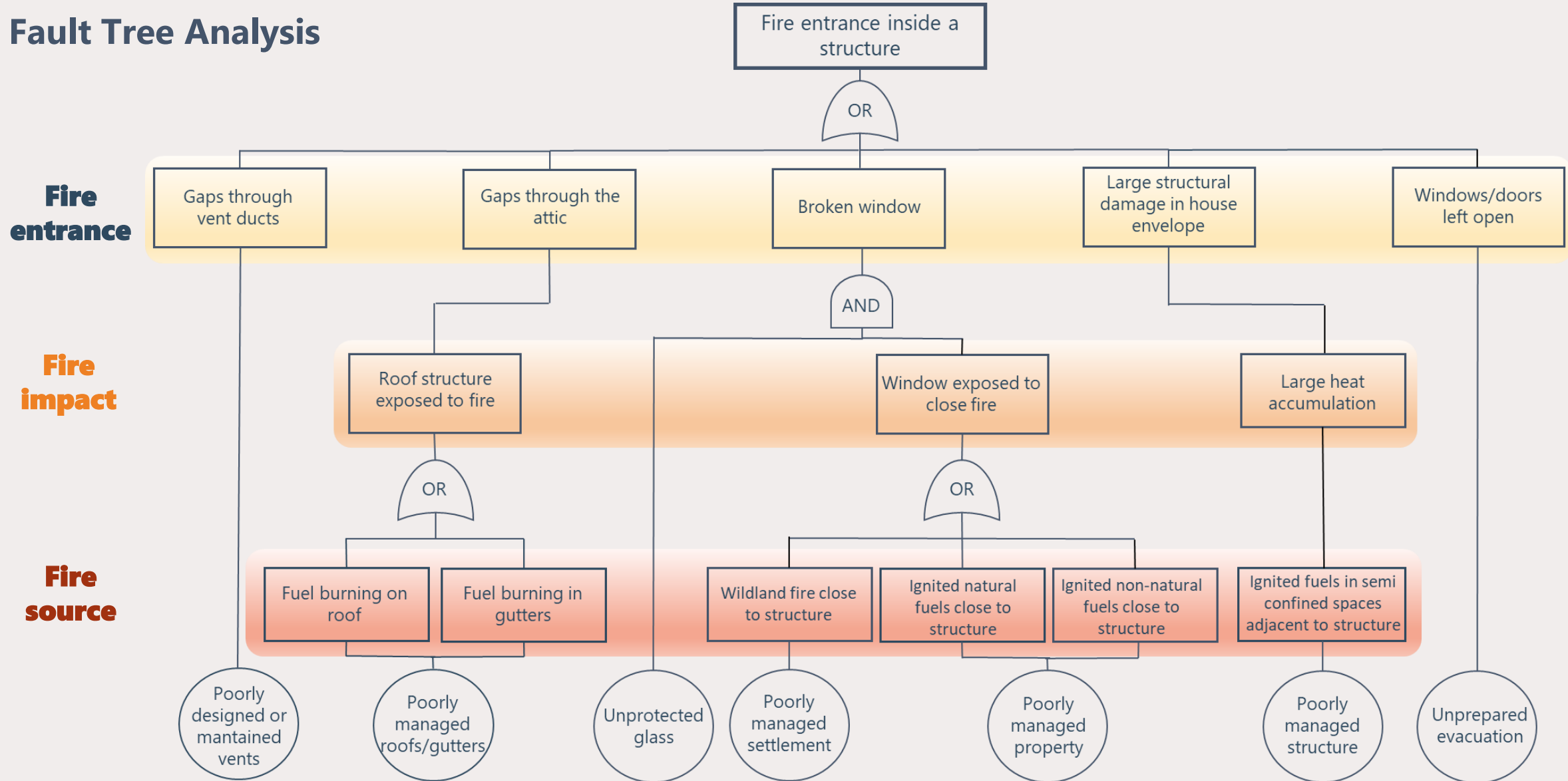


Wildfuels

PATHWAYS LEADING TO BUILDING IGNITION

Vacca et al., 2020(JSSR)

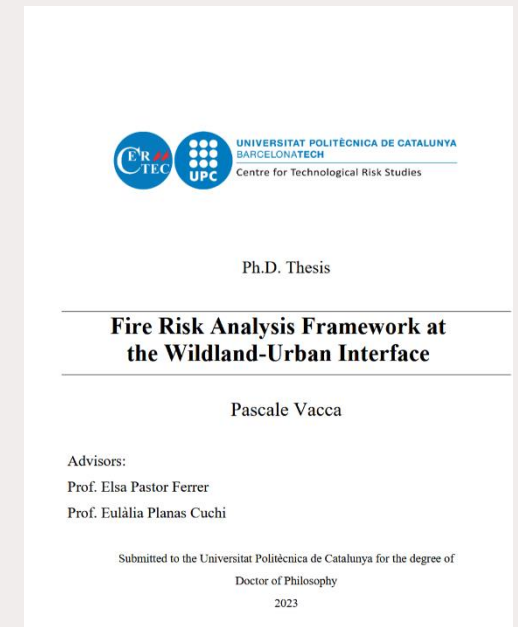
Fault Tree Analysis



VULNERABILITY ASSESSMENT TOOL

- Main characteristics
- Vulnerability assessment rationale
- Initial testing and implementation
- Current improvements

(Àgueda et al., 2023; Vacca, 2023)



MAIN CHARACTERISTICS

- **Main aim:** to identify building and property vulnerability in a quantitative way
- **Target user:** homeowner at the WUI (Mediterranean Europe)
- **Type:** questionnaire-based (checklist):
 - Building characteristics (#14)
 - Surroundings (#45)

Shutters	Do you have protection for all your windows/glazing systems (i.e. shutters)? <input type="checkbox"/> Yes <input type="checkbox"/> No
	What material are the shutters made of? <input type="checkbox"/> Wood <input type="checkbox"/> PVC <input type="checkbox"/> Aluminium <input type="checkbox"/> Fire resistant materials
Roof	Is your roof covering or your roof assembly made of fire-rated material (e.g. clay tiles, concrete tiles, asphalt glass fibre composition singles, slate, etc.)? <input type="checkbox"/> Yes <input type="checkbox"/> No
	Are there missing, displaced or broken tiles? <input type="checkbox"/> Yes <input type="checkbox"/> No
[...]	[...]

Ornamental vegetation	Are the hedges aligned with the wind direction or the main slope? <input type="checkbox"/> Yes <input type="checkbox"/> No
	If you have ornamental bushes, are they less than 5 m wide? <input type="checkbox"/> Yes <input type="checkbox"/> No
Man-made fuels	Are there any artificial fuels (e.g. outdoor furniture, stored materials, gas canisters, small sheds, wood piles) located within 5 m from glazing systems? <input type="checkbox"/> Yes <input type="checkbox"/> No
	Are there any combustible materials (including ornamental vegetation, storage spaces, or combustible eaves) located within 2 m of LPG tanks <input type="checkbox"/> Yes <input type="checkbox"/> No
[...]	[...]

VULNERABILITY ASSESSMENT RATIONALE

- **Modelling:**

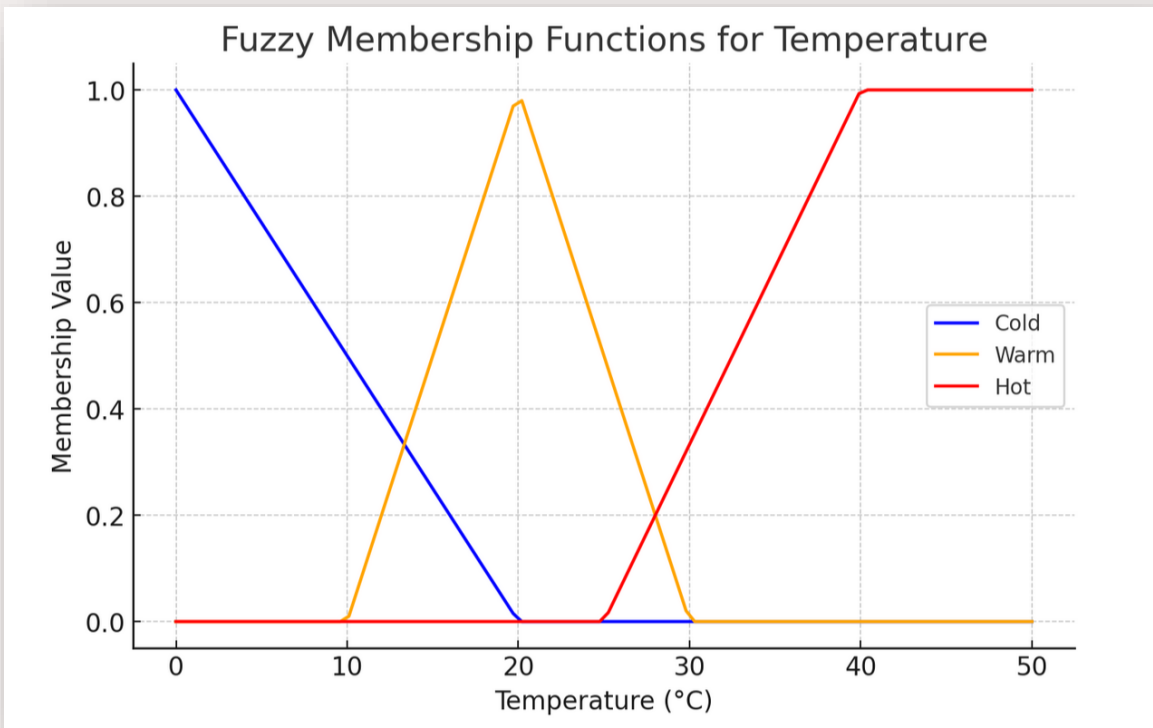
- Based on fault tree analysis (top event: fire entrance inside a building)
- Probabilities assigned to basic events (e.g. failure of windows, poorly managed fuels in the property, etc.) based on *fuzzy preferences of WUI experts*

Fuzzy logic

- Mathematical approach that handles **uncertainty** and **imprecision** by allowing partial truths instead of strict "true or false" (binary) values.

"The weather is cold / warm / hot"

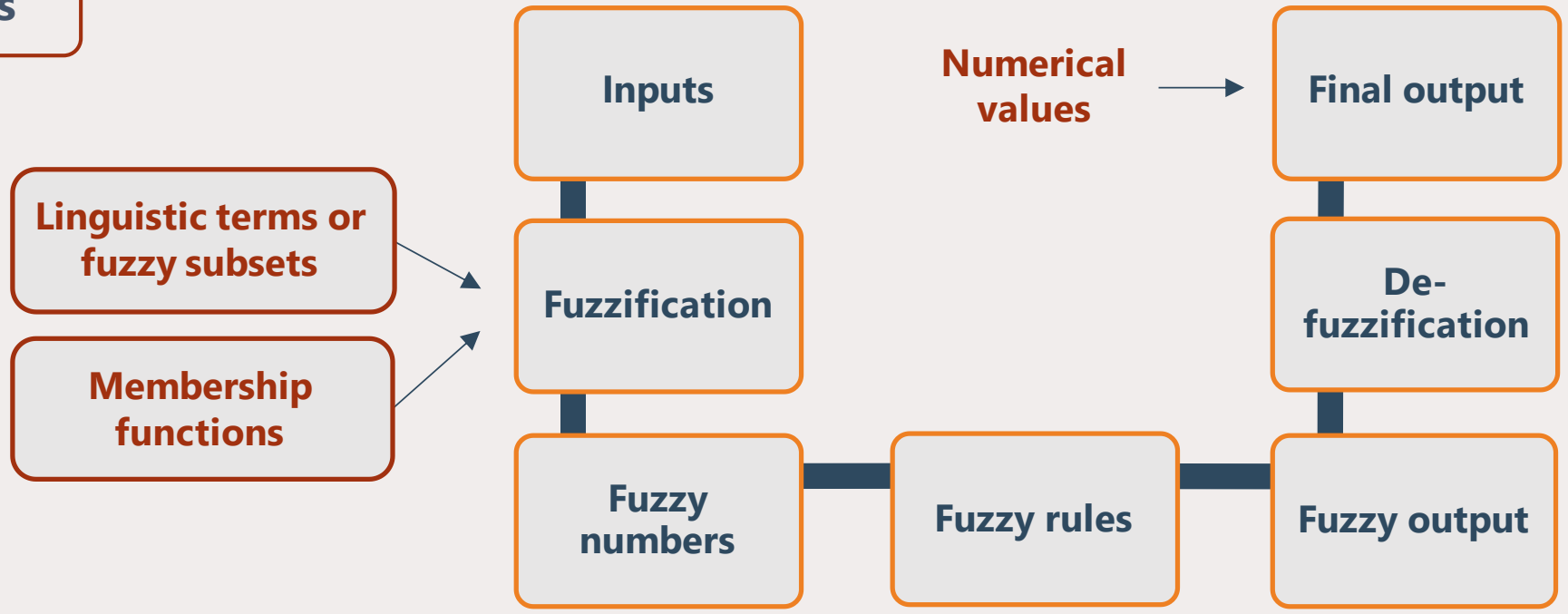
- *Cold: Full membership at 0°C, decreasing to 0 at 20°C.*
- *Warm: Starts at 10°C, peaks at 20°C, and decreases at 30°C.*
- *Hot: Starts at 25°C, increasing to full membership at 40°C.*



At **35°C**, the fuzzy system would consider the temperature **mostly hot (67%)** but **not completely** (it reaches full "hot" at 40°C).

VULNERABILITY ASSESSMENT RATIONALE

Fuzzy Inference Process



Fuzzy Rules

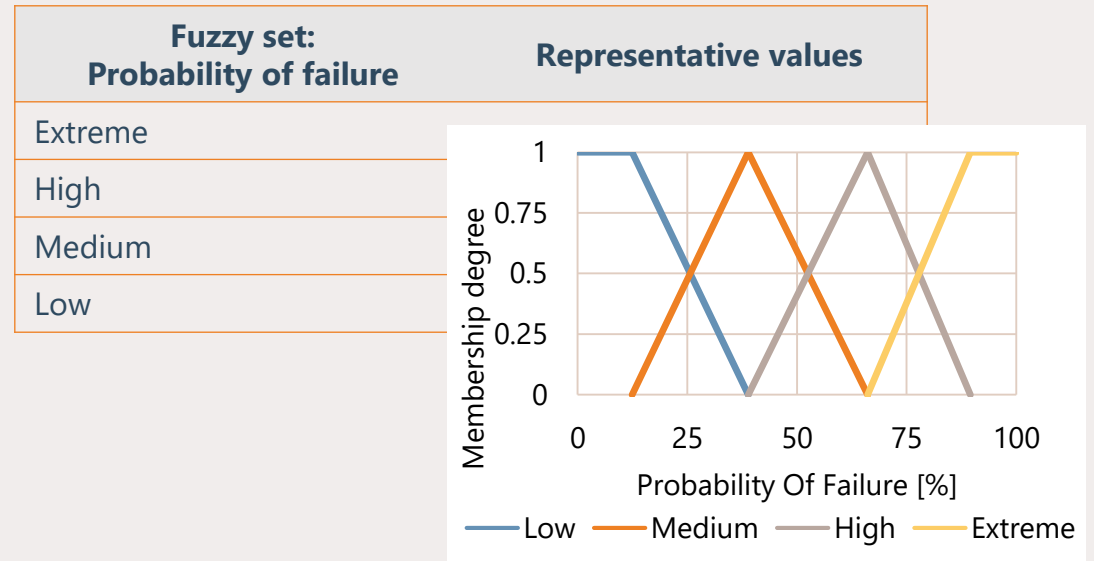
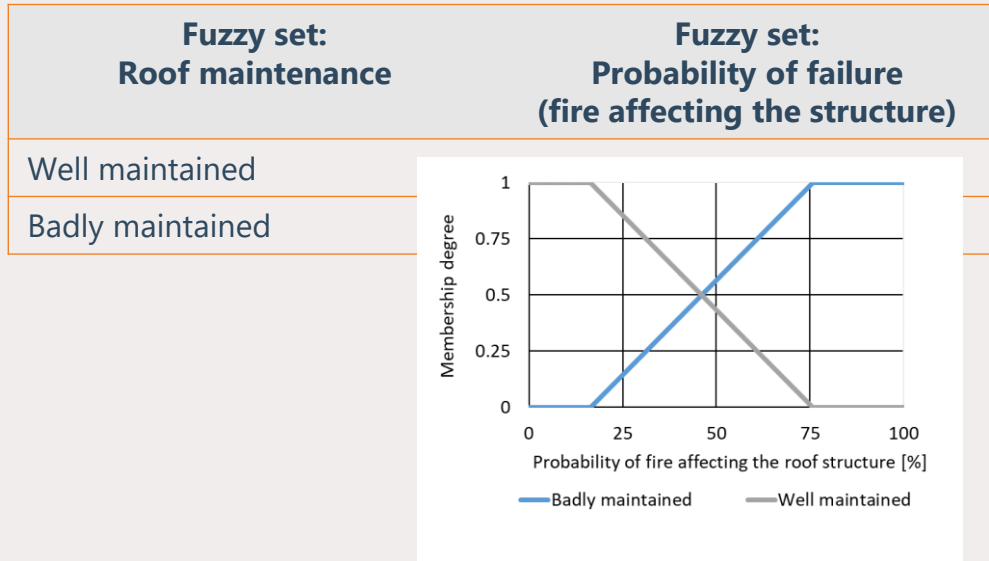
- If-then statement that describes how fuzzy variables relate to each other.
*"If temperature is **high** and humidity is **low**, then wildfire risk is **high**."*

*"If the roof is **highly** combustible and has **bad** maintenance, the probability of failure is **high**"*

VULNERABILITY ASSESSMENT RATIONALE

Fuzzy Inference Process

- A poll of experts was used to generate membership functions and fuzzy rules:



Subsets	Consequences												
IF roof is well maintained AND roof covering is	<table border="1"> <tr> <td>Combustible</td> <td rowspan="4">THEN probability of failure is</td> <td><input type="button" value="▼"/></td> </tr> <tr> <td>Non-combustible</td> <td>Low</td> </tr> <tr> <td></td> <td>Medium</td> </tr> <tr> <td></td> <td>High</td> </tr> <tr> <td></td> <td></td> <td>Extreme</td> </tr> </table>	Combustible	THEN probability of failure is	<input type="button" value="▼"/>	Non-combustible	Low		Medium		High			Extreme
Combustible	THEN probability of failure is	<input type="button" value="▼"/>											
Non-combustible		Low											
		Medium											
		High											
		Extreme											

INITIAL TESTING AND IMPLEMENTATION

- **Testing**

- The tool was tested using three case studies in which there were several dwellings affected with different degree of damage.
- Overall, homes and properties that scored a low probability of fire entrance did not experience fire entrance

Lloret de Mar, SP, July 2021

- ~6 ha burned
- Analysis of 5 affected homes



Castro Marim and Tavira, PT, (2021)

- ~ 6700 ha burned
- Analysis of 6 affected homes



Pont de Vilomara, SP, (2022)

- ~ 1700 ha burned
- Analysis of 6 affected homes



INITIAL TESTING AND IMPLEMENTATION

Pont de Vilomara, SP, (2022)



Issue analysed		H2.6
Prob. of failure of the glazing system	70	No shutters – double pane glazing
Prob. of failure of the roof	65	Non-combustible, badly maintained
Prob. of failure of the vents	65	Combustible vent protection
Prob. of failure of the façade envelope	14	Non-combustible, > 12 cm, 0% window coverage
Prob. of failure of the semi-confined space	35	50% volume occupied by combustible material
Prob. of failure of the building	98	
Prof. of fire spreading through the external ring of the property (10 – 30 m)	88	0% compliance of identified best practices for all fuels
Prof. of fire spreading through the internal ring of the property (<10m)	83	57% compliance for ornamental vegetation, 25% for artificial fuels, 33% for wildland vegetation
Probability of fire entrance	81	

INITIAL TESTING AND IMPLEMENTATION



• Implementation

- WUICOM- BCN "*Fire resilient communities of Barcelona*" (2023)
- VAT tool used to analyse vulnerabilities in Collserola neighbourhood "Mas Sauró"
- Drill planning and emergency management. House triage for horizontal confinement.



CURRENT IMPROVEMENTS



Co-funded by
the European Union



FIREPRIME project: *“European Program for Wildfire-Prepared Communities”* (2024-2026)

- Algorithm improvements to include:
 - Other building practices and vegetation type in central and northern Europe
 - Risk assessment (rather than vulnerability assessment), including the hazard layer (European Forest Information System – EFFIS)
 - List of recommendations linked to the results obtained

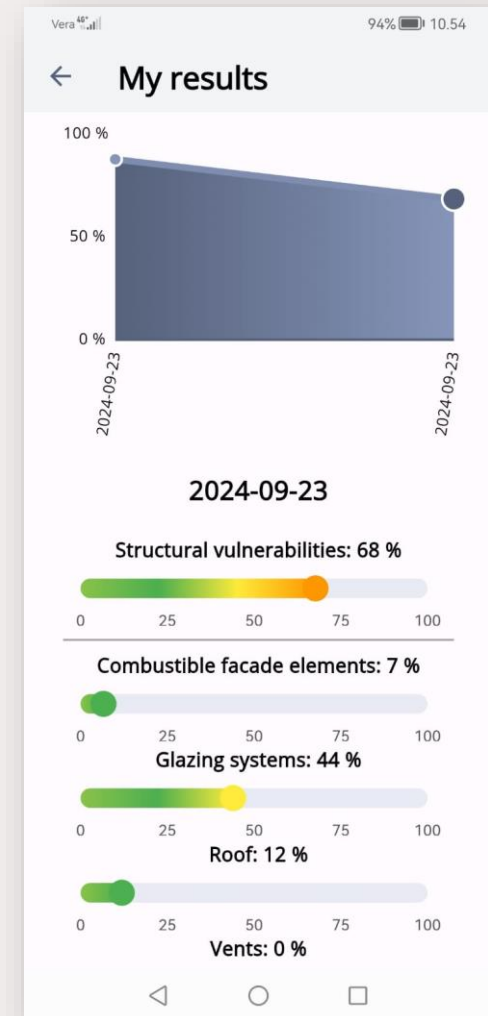
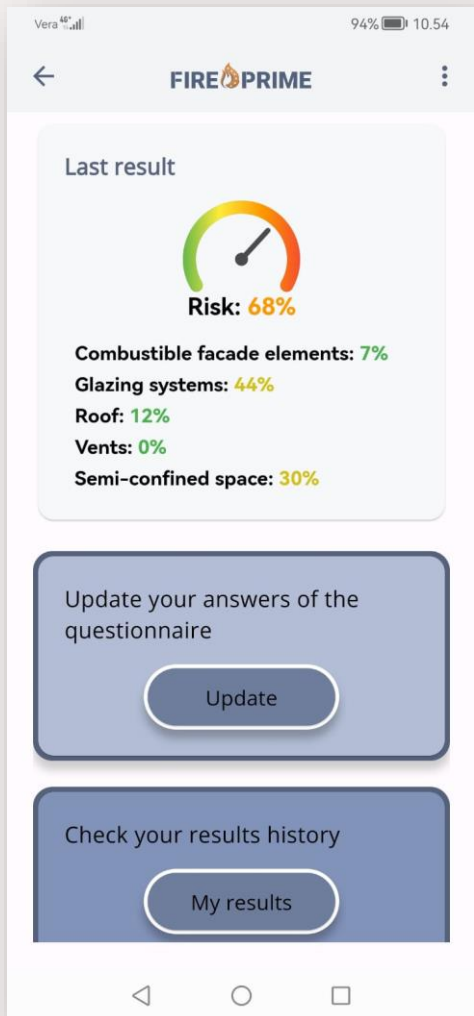
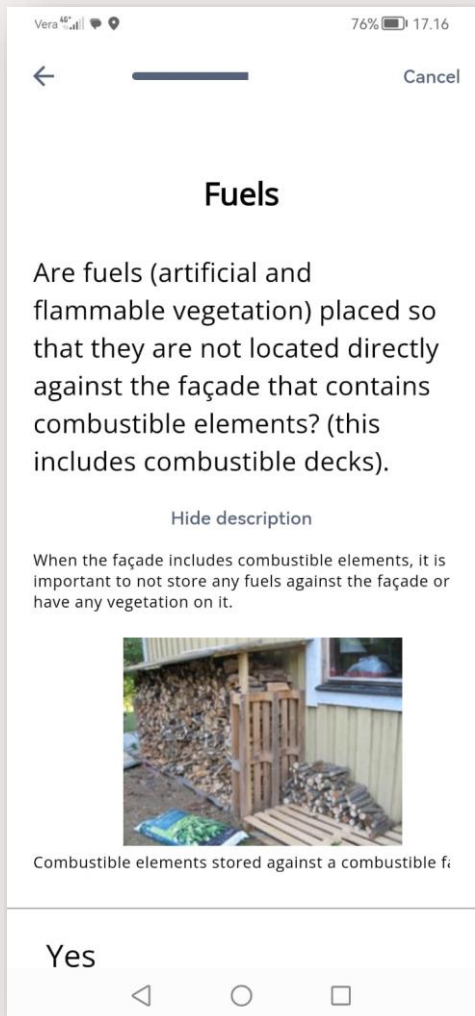
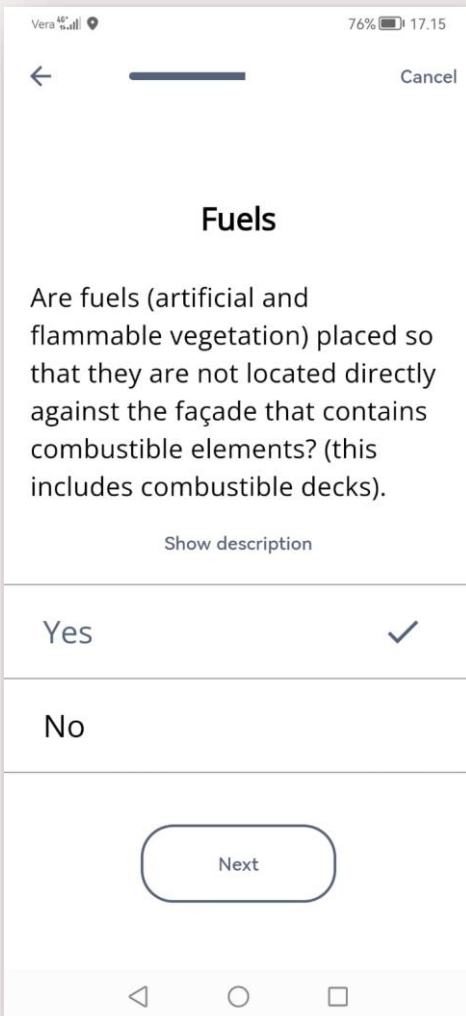




CURRENT IMPROVEMENTS

FIREPRIME project: "European Program for Wildfire-Prepared Communities" (2024-2026)

Questionnaire implemented in an App (IOS and Android)



CURRENT IMPROVEMENTS

FIREPRIME project: “European Program for Wildfire-Prepared Communities” (2024-2026)



Co-funded by the European Union

- Testing (Spring 2025):
 - Sant Cugat municipality (Barcelona, Spain)
 - Local stakeholders: civil protection, fire agencies, self-protection neighbourhood units, Collserola Natural Park rangers
 - Residents at the WUI (selected dwellings, general distribution)
 - Heiming (Tyrol) and Berga (Sweden): (selected dwellings)



AJUNTAMENT DE **SantCugat**



IMPLEMENTATION OPPORTUNITIES AND CHALLENGES

Opportunities

- **Increased awareness and preparedness:** better understanding of wildfire risks, encouraging proactive mitigation efforts.
- **Community engagement:** The app can foster a sense of shared responsibility by connecting residents with local authorities and neighbours.
- **Personalized risk assessment:** the app provides tailored recommendations to mitigate wildfire risk.
- **Integration with fire agencies:** If linked to emergency services, data of the assessments can serve to improve risk prevention and emergency planning.

Challenges

- **User adoption and engagement:** Some residents might not perceive wildfire risk as urgent or may resist using new technology.
- **Data accuracy and reliability:** Ensuring up-to-date hazard data and accurate vulnerability modelling is complex.
- **Privacy concerns:** users may be hesitant to share data.

Thanks for your attention

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