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WUIVIEW
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Deliverable D7.2
Report on case studies

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Abstract	In this deliverable, we demonstrate WUIVIEW products through real case studies in WUI communities. Starting with the VAT and SAT tools, we provide summarized information on how these tools where developed and initially implemented and verified (WP6) and we present the VAT and SAT tools final format and their testing in real WUI properties including the VAT adaptation to Scandinavian WUI. Following, we compile the demonstration of the performance-based design (PBD) methodology through 4 different case studies: being the first two WUI properties in Madrid (Spain), the third one a community shelter located in Central Portugal and the last one a WUI property in Sweden. Concluding remarks are finally stated, detailing the upscaling challenges of WUIVIEW outcomes.

(1) Draft / Final

(2) Public / Restricted / Internal

Disclaimer

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1. About this deliverable

WUIVIEW stands for Wildland-Urban Interface Virtual Essays Workbench, and it is a project funded by the Directorate General for European Civil Protection and Humanitarian Aid Operations (DG ECHO) and coordinated by the Universitat Politècnica de Catalunya (Spain). WUIVIEW final aim has been to reinforce WUI fires risk reduction strategies by developing innovative risk management tools to help WUI communities adapting to extreme wildfire events. The project has been conceived and performed through a clear product-oriented approach, so that to come up with tools within technology readiness levels (TRL) values around 4-5 (i.e. with developments performed in experimental/demonstration pilots) ready to be tested in real environments in subsequent follow-up. WUIVIEW products consist on: *i)* basic, easy-to-use tools for vulnerability and sheltering capacity self-assessment (D6.1) and *ii)* in-depth analysis tool of fire impact in properties based on fire safety engineering methods (performance-based design guideline, D7.1).

This deliverable gathers all the information concerning the pilots that have allowed WUIVIEW products to be tested in relevant environments. In one hand, the deliverable reports development and demonstration efforts devoted to test the VAT (Vulnerability Assessment Tools, Mediterranean and Scandinavian versions) and SAT (Sheltering Assessment Tool) check-lists, starting with a preliminary campaign for tools' fine-tuning in which 18 WUI properties (12 in Portugal, 5 in Spain and 1 in Italy) have been involved, and continuing with the final testing where a total of 6 WUI properties have been checked: 3 for the Mediterranean VAT and SAT, and 3 more for the Scandinavian VAT.

Following, the PBD guideline developed to perform a detailed vulnerability assessment in WUI properties has been showcased in four different properties entailing different PBD objectives and fire scenarios. These properties are: two dwellings in the Madrid region, with different characteristics in terms of building systems and residential fuels configuration; one community shelter located in Leiria District in Portugal, analysed thanks to the joint effort between the Portuguese National Project "Aldeias Resilientes/Abrigo Coletivo" and the Fire Brigade of Savona/WUIFI-21 project, and one Swedish WUI property reflecting typical building practices and landscape in Scandinavia.

Case studies have shown the readiness of the WUIVIEW tools to be demonstrated in operational environments. To this end, this deliverable also gathers final remarks highlighting challenges that further development and deployment activities may encounter.

2. Demonstration of SAT and VAT tools

2.1. Summary of development

In past WUIVIEW work package 6, structure survivability and sheltering capacity at the WUI microscale was analysed in detail through literature survey of WUI standards and research articles and through simulation by means of CFD tools (FDS and ANSYS-FLUENT). Results from these analyses were distilled and translated into two simple (checklist type) self-assessment tools of structure vulnerability and sheltering capacity, available in their primary format in Deliverable 6.1. The tools have experienced a complete cycle of implementation, testing and refining (detailed in following section 1.2) that has allowed the development of final versions to be showcased in relevant environments.

Final VAT and SAT tools have been defined and implemented through user-friendly interfaces (section 2.3) to be tested in Mediterranean dwellings (section 2.4), and further adapted for Scandinavian WUI communities (2.5). It has to be highlighted that Northern WUI has significant differences from Mediterranean WUI regarding landscape and wildfire behaviour, building practices and residential fuels and also community behaviour, risk perception and preparedness. To provide context on these issues, section 2.5.1 gathers background information on Scandinavian fire incidence and regimes, regulations and building practices.

2.2. Initial implementation, testing and refinement

The methodology for quick self-assessment of structures survivability and sheltering capacity presented in Deliverable 6.1 was initially implemented using the ArcGis Survey123 tool (Esri, 2020) in Portuguese language (Figure 1a). By using this tool, data collected were immediately available in the ArcGIS platform (Figure 1b).

The resulting survey is available here:

https://survey123.arcgis.com/share/9db266bd708e45d99e5bbc86bde70fdb

a) b)

Figure 1. Initial implementation of the SAT and VAT tools through ArcGis Survey123: a) Presentation of the survey; b) First fields to be filled and map for locating the structure of interest.

Several WUIVIEW participants tested the survey on real structures (Figure 2) located in Portugal (12), Spain (5) and Italy (1). According to the results obtained and the feedback given by those handling the survey, the design of the tools was improved.

Figure 2. General view of the location of the structures tested in summer 2020 to check the first version of the Vulnerability Assessment Tool (VAT) and the Sheltering Assessment Tool (SAT).

Points detected for improvement were the following ones:

1. Several questions were not specific enough.
2. Respondents could see questions that did not apply to them.
3. An automatic value for the Fire Vulnerability Index (FVI) was not calculated and respondents gave incorrect scores.
4. Images were not available.
5. Respondents did not get a detailed summary of their score.

Based on these main issues, we decided to overcome them by:

1. Reformulating several questions for the sake of clarification.
2. Introducing conditional branching in several blocks of questions.
3. Calculating the Fire Vulnerability Index (FVI) automatically based on respondent's answers.
4. Inserting images in the introductory section of each block in order to make them more understandable and visually appealing.
5. Programming the automatic processing of the responses and sending an email afterwards (more details about this approach are given in the following section).

In order to implement these changes the tool used to deliver the survey was modified. The ArcGIS Survey123 format was no longer used because, although it was rather interesting to get the exact location of the property, it was limiting. Instead, two Google Forms were prepared for both questionnaires.

2.3. SAT and VAT tools final format

The VAT and SAT tools have finally been implemented through Google Forms. They have been set as quizzes so that scores can be assigned to each question.

Both VAT and SAT questionnaires follow a similar general structure:

A first section for the presentation of the form with logos of the project and the European Union (

1. Figure 3).
2. A second section with a detailed description of the rationale behind the form (Figure 4a, c) and, for the VAT questionnaire exclusively, a third section describing two conditions that have to be fulfilled to respond the questionnaire (Figure 4b). These are:
    a. The VAT index is adequate only for structures made of concrete, bricks, etc., but not for structures made of wood (or other combustible materials).
    b. The VAT index is planned to be applied on structures that are located in moderate to very high fire hazard rating areas during fire season.
3. A general data section where the following information is collected: full name of the owner, email to receive score notification, location (Google Maps URL), address, city, state/province/region, ZIP/postal code, country, full name of the surveyor, email of the surveyor, comments. In this section, three mandatory fields have been set: email to receive score notification, location (Google Maps URL) and email of the surveyor.
   The location of the property is set using Google Maps: respondents have to pin the location on this tool and copy/paste the corresponding URL. The steps to follow to obtain the Google Maps URL are included in the same form (Figure 5).
4. The following sections refer to the block of questions specifically established for each tool. Each block has auxiliary comments and images (those already provided in D6.1. (Vacca et al., 2020)) to better contextualize the questions. In Figure 6, an example of the introductory section of Block 3 of the VAT tool is shown.
5. A last section for the uploading of images of the structure and the surroundings. This section is set as mandatory and is intended to provide a better description of the structure. It is limited to the VAT questionnaire to avoid duplicating the information.

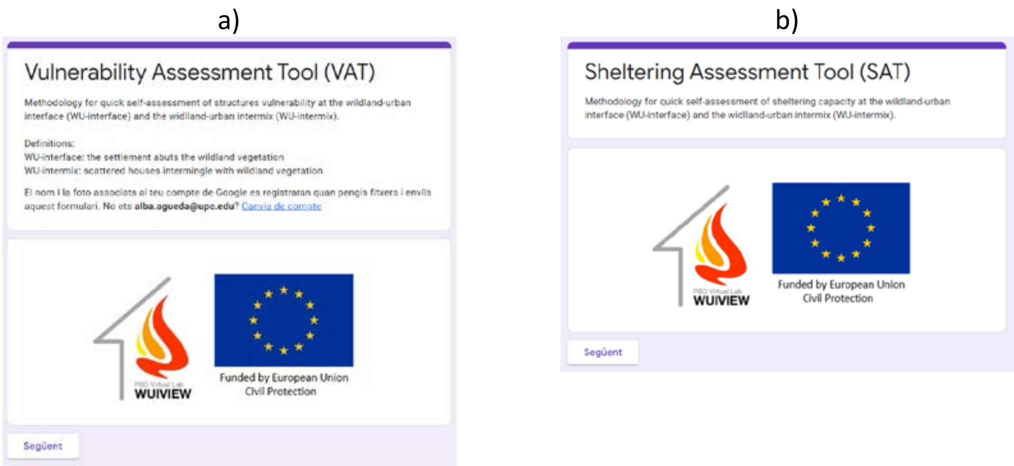
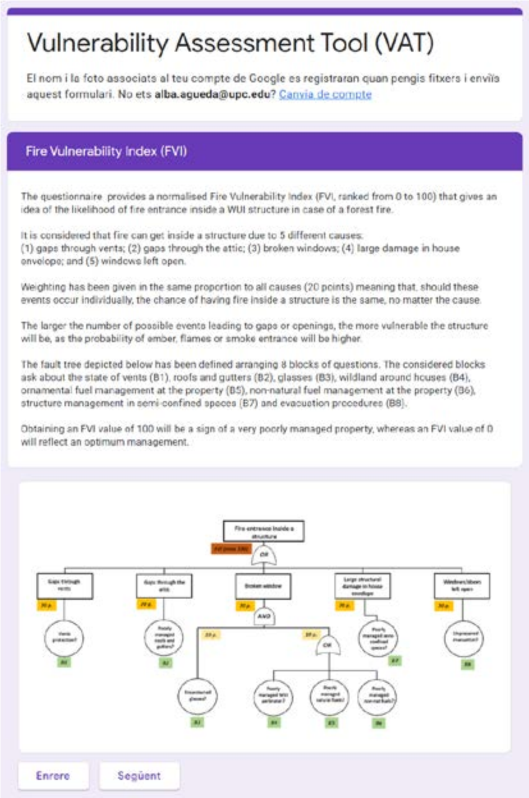


Figure 3. First screen of the questionnaires: a) VAT; b) SAT.

a)



Vulnerability Assessment Tool (VAT)

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Fire Vulnerability Index (FVI)

The questionnaire provides a normalised Fire Vulnerability Index (FVI, ranked from 0 to 100) that gives an idea of the likelihood of fire entrance inside a WUI structure in case of a forest fire.

It is considered that fire can get inside a structure due to 5 different causes:
(1) gaps through vents; (2) gaps through the attic; (3) broken windows; (4) large damage in house envelope; and (5) windows left open.

Weighting has been given in the same proportion to all causes (20 points) meaning that, should these events occur individually, the chance of having fire inside a structure is the same, no matter the cause.

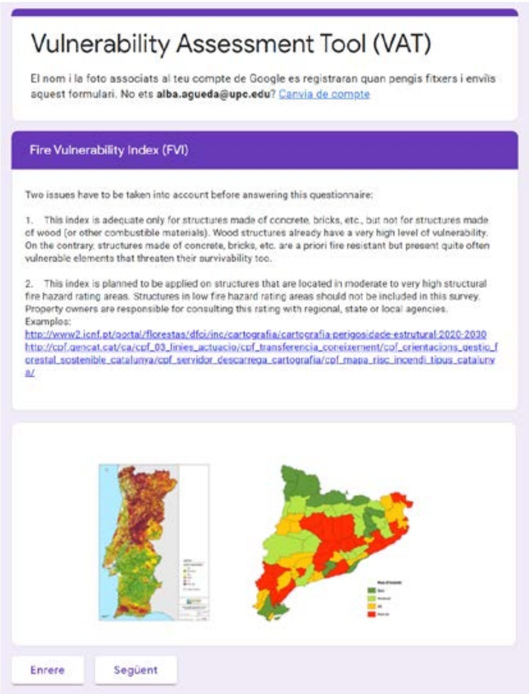
The larger the number of possible events leading to gaps or openings, the more vulnerable the structure will be, as the probability of ember, flames or smoke entrance will be higher.

The fault tree depicted below has been defined arranging 8 blocks of questions. The considered blocks ask about the state of vents (B1), roofs and gutters (B2), glasses (B3), wildland around houses (B4), ornamental fuel management at the property (B5), non-natural fuel management at the property (B6), structure management in semi-confined spaces (B7) and evacuation procedures (B8).

Obtaining an FVI value of 100 will be a sign of a very poorly managed property, whereas an FVI value of 0 will reflect an optimum management.

Enrere Següent

b)



Vulnerability Assessment Tool (VAT)

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Fire Vulnerability Index (FVI)

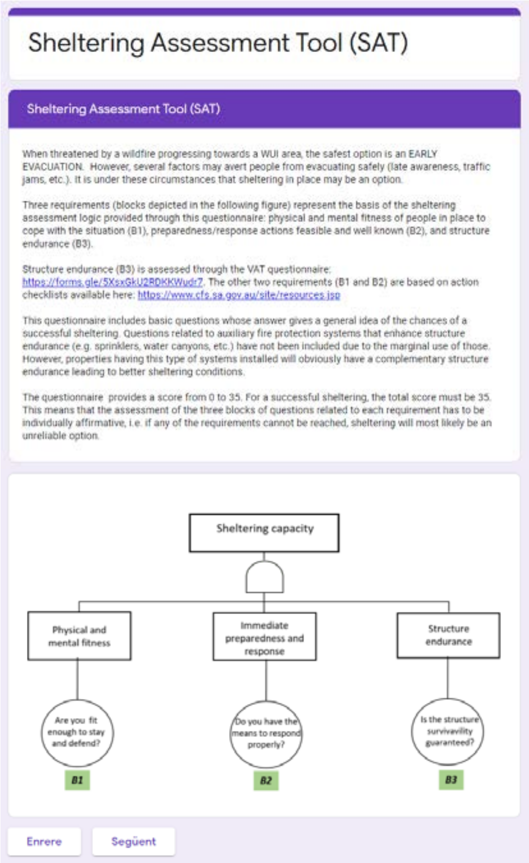
Two issues have to be taken into account before answering this questionnaire:

1. This index is adequate only for structures made of concrete, bricks, etc., but not for structures made of wood (or other combustible materials). Wood structures already have a very high level of vulnerability. On the contrary, structures made of concrete, bricks, etc. are a priori fire resistant but present quite often vulnerable elements that threaten their survivability too.

2. This index is planned to be applied on structures that are located in moderate to very high structural fire hazard rating areas. Structures in low fire hazard rating areas should not be included in this survey. Property owners are responsible for consulting this rating with regional, state or local agencies.
Examples:
http://www2.icnf.pt/portal/florestas/dfci/inc/cartografia/cartografia-perigosidade-estrutural-2020-2030
http://cpf.gencat.cat/ca/cpf_03_linies_actuacio/cpf_transferencia_coneixement/cpf_orientacions_gestio_forestal_sostenible_catalunya/cpf_servidor_descarrega_cartografia/cpf_mapa_risc_incendi_tipus_catalunya/

Enrere Següent

c)



Sheltering Assessment Tool (SAT)

Sheltering Assessment Tool (SAT)

When threatened by a wildfire progressing towards a WUI area, the safest option is an EARLY EVACUATION. However, several factors may avert people from evacuating safely (late awareness, traffic jams, etc.). It is under these circumstances that sheltering in place may be an option.

Three requirements (blocks depicted in the following figure) represent the basis of the sheltering assessment logic provided through this questionnaire: physical and mental fitness of people in place to cope with the situation (B1), preparedness/response actions feasible and well known (B2), and structure endurance (B3).

Structure endurance (B3) is assessed through the VAT questionnaire: https://forms.gle/5XsxGkU2RDKKWudr7. The other two requirements (B1 and B2) are based on action checklists available here: https://www.cfs.sa.gov.au/site/resources.jsp

This questionnaire includes basic questions whose answer gives a general idea of the chances of a successful sheltering. Questions related to auxiliary fire protection systems that enhance structure endurance (e.g. sprinklers, water canyons, etc.) have not been included due to the marginal use of those. However, properties having this type of systems installed will obviously have a complementary structure endurance leading to better sheltering conditions.

The questionnaire provides a score from 0 to 35. For a successful sheltering, the total score must be 35. This means that the assessment of the three blocks of questions related to each requirement has to be individually affirmative, i.e. if any of the requirements cannot be reached, sheltering will most likely be an unreliable option.

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Figure 4. Introductory sections of the questionnaires: a) Second screen of the VAT questionnaire describing the rationale behind the form; b) Third screen of the VAT questionnaire specifying two conditions that have to be fulfilled to respond the questionnaire; c) Second screen of the SAT questionnaire describing the rationale behind the form.

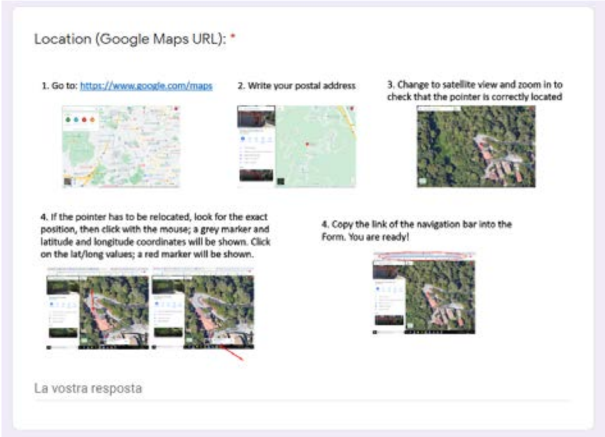


Figure 5. Guidelines included in the general data section to help respondents introduce the Google Maps URL of the structure.

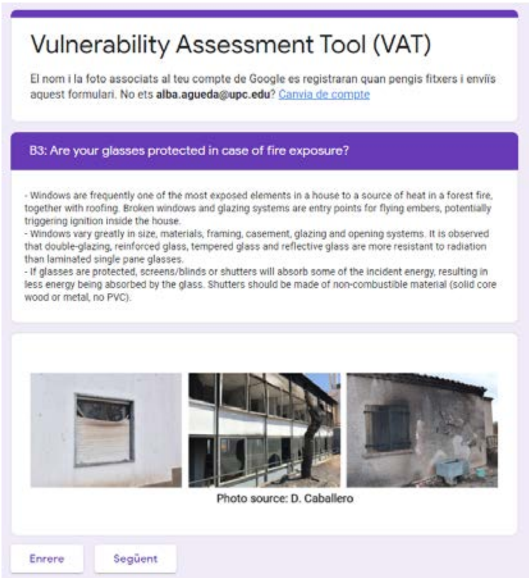


Figure 6. Example (e.g. Block 3 of the VAT tool) of explanations and images included in the introductory section of each block.

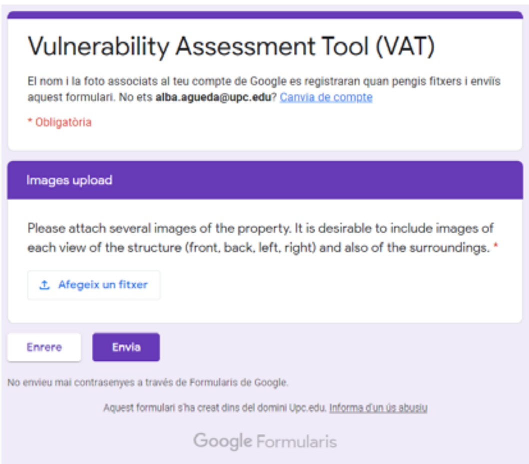


Figure 7. Images upload set mandatory in the VAT tool.

2.3.1. VAT and SAT questions and scores

VAT and SAT questionnaires are available here:

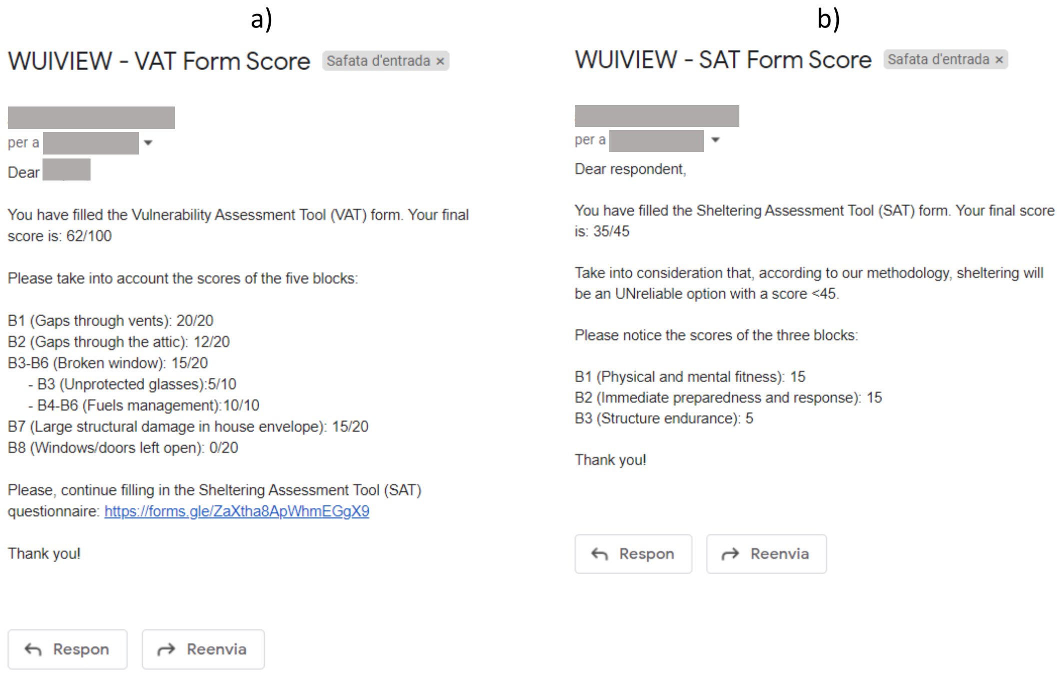
VAT: https://forms.gle/cga9EM2LGsdMXXG66 SAT: https://forms.gle/Fc9AwVN4cDfK8wdy7

The VAT questionnaire consists of the eight different blocks, as already described in D6.1 (Vacca et al., 2020). Slight wording edits have been made in this version of the tool compared to the previous one. See Annex A for the final version of the questions and a refreshment on the rationale.

SAT questions content has not been modified in this version. Only a minor modification has been required here regarding the assessment logic, i.e. the block corresponding to structure endurance (previously named as Block 2) has been relocated and now is positioned as Block 3. This has been done because when the Fire Vulnerability Index is at the limit (FVI = 20) the response to this block has to be based on the responses of the other two. Find in Annex A the final SAT rationale and questionnaire.

2.3.2. Preliminary processing of answers

To make a preliminary processing of the answers given in the forms, a function has been programmed in the Google Apps Script, a JavaScript platform in the cloud. On form submission, a trigger is set to do simple processing steps in the corresponding Google Sheet of responses (summing up questions for each block, for example) and to send an email afterwards to the respondent and the surveyor showing the main results, i.e. scores for each block of questions and total score. In Annex A an example of the implemented functions can be found. Figure 8 depicts an example of the type of email received after submitting the form. After completing the VAT form, respondents are encouraged to continue filling the SAT form through the corresponding link.


a)

WUIVIEW - VAT Form Score Safata d'entrada ×

[redacted]
per a [redacted]
Dear [redacted]

You have filled the Vulnerability Assessment Tool (VAT) form. Your final score is: 62/100

Please take into account the scores of the five blocks:

B1 (Gaps through vents): 20/20
B2 (Gaps through the attic): 12/20
B3-B6 (Broken window): 15/20
- B3 (Unprotected glasses):5/10
- B4-B6 (Fuels management):10/10
B7 (Large structural damage in house envelope): 15/20
B8 (Windows/doors left open): 0/20

Please, continue filling in the Sheltering Assessment Tool (SAT) questionnaire: https://forms.gle/ZaXtha8ApWhmEGgX9

Thank you!

Respon Reenvia

b)

WUIVIEW - SAT Form Score Safata d'entrada ×

[redacted]
per a [redacted]
Dear respondent,

You have filled the Sheltering Assessment Tool (SAT) form. Your final score is: 35/45

Take into consideration that, according to our methodology, sheltering will be an UNreliable option with a score <45.

Please notice the scores of the three blocks:

B1 (Physical and mental fitness): 15
B2 (Immediate preparedness and response): 15
B3 (Structure endurance): 5

Thank you!

Respon Reenvia

Figure 8. Example of email received automatically after submitting: a) VAT form; b) SAT form.

2.4. SAT and VAT tools final testing

SAT and VAT tools have been tested in 3 real dwellings affected by fires during the 2020 fire season in Spain, one at the settlement of Valdepiélagos and two at the settlement of Eurovillas, both located in the Madrid region. The survey has been performed counting on the cooperation of home-owners. Check-list outcomes have been able to be confronted to real fire impact showing great coherence with the results of the WUI fire event.

For more information on these real fire incidents, a technical annex reporting fires occurred during the 2020 fire season has been included in the WUIVIEW webpage https://wuiview.org

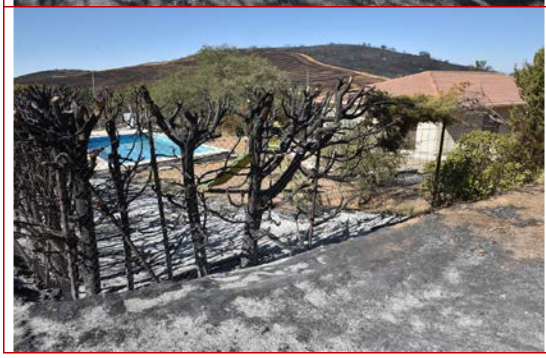
2.4.1. VAT and SAT testing at Valdepiélagos

General information of the testing

The dwelling is located at the municipality of Valdepiélagos, Madrid (28170), Spain. Table 1 gathers some images of the dwelling. See location at the Google Maps URL:

https://goo.gl/maps/sakdLQsc6zKUFUwT7

Table 1. Photo collection of the dwelling at Valdepiélagos

Detail of the dwelling	Comment
	General view of the property from the East bound, in which a large piece of land includes a pool and a few ornamental plants. A green edge of flammable species (*Cupressus arizónica*) burned almost completely. Two pines (*Pinus pinea*) were just scorched by the combustion of the green hedge.
	The line of green hedge enclosing the property was almost completely burned. Beyond limits, there were just laboured agricultural fields. The owner of one of them said that most of the olive trees would die, although they were just scorched by the passing fire over the cured grass.

	The main building has iron fences guarding the door and windows, because of frequent robberies in the area. As seen, the doors and windows were properly closed before leaving the house in the evacuation process. A fabric was hanging in front of every shutter, none of them were affected.

VAT evaluation

The results of the questionnaire regarding the Valdepiélagos dwelling are summarized in Table 2. The partial VAT scoring is B1 – Gaps through vents (0/20), B2 - Gaps through the attic (8/20), B3-B6 – broken window(0/20); B7 - Large structural damage in house envelope (0/20) and B8 (Windows/doors left open): 0/20.

Table 2. Answers of the VAT checklist (yellow answer cell corresponds to the result of the survey)

BLOCK/ID	Questions for each block	Answers	
ID	Question	YES	NO
B1.1	Do you have unprotected ventilation openings (i.e. vents without any type of screening)?	20	0
B1.2	Are your vents protected with non-combustible corrosion-resistant materials/meshes (e.g. aluminium, galvanized steel, stainless steel, copper, intumescent coating)?	0	10
B1.3	Are your fire-resistant mesh openings less than 2 mm in characteristic length?	0	5
MAX = 20 points (If question B1.1 is affirmative, B1.2 and B1.3 are non-applicable)			
ID	Question	YES	NO
B2.1	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.)?	0	20
B2.2	Is your fire-rated roof covering in good state? (To be in good state means that there are not missing, displaced or broken tiles; the underlying roof sheeting is not exposed; there are not unsealed spaces between the roof and the external walls or between the roof covering and the roof decking, particularly in roof edges)	0	4
B2.3	Are your roof or gutters not exposed to overhanging tree branches?	0	4
B2.4	Do you perform periodic roof maintenance?	0	4
B2.5	Does your roof present geometry favourable for the deposition of fuels and firebrands? (Is your roof flat? Are there roof valleys? Are there intersections between roofs and external vertical walls/sidings?)	4	0
B2.6	Do you perform regular cleaning of debris piling up on roof or gutters?	0	4
Comments from the surveyor: Roofing is covered with clay tiles. There are some broken tiles. The edge of the roof needs some repair in some points. There are no trees overhanging the house. Regular maintenance for reparation of leakages. It is a simple roofing system without valleys or corners. Do not specifically clean roof or gutters as there are no trees overhanging and little or no debris is accumulated.			
MAX = 20 points (If question B2.1 is negative, B2.2-B2.6 are non-applicable) (If questions B2.1-B2.3 are positive, B2.4-B2.6 are non-applicable)			
ID	Question	YES	NO
B3.1	Do you have protection for all your windows/glazing systems (i.e. shutters, blinds) made of non-combustible materials (solid core wood fire-resistant, metal like aluminium)?	0	5

B3.2	Are your glazing systems double or made of fire-resistant tested material (e.g. tempered glass) or have a thickness ≥ 6 mm?	0	5
MAX = 10 points			
Comments from the surveyor: PVC shutters are present in all windows. Glazing systems are double pane.			
ID	**Question**	**YES**	**NO**
B4.1	Do you have a fuel-managed area around your settlement (in case of WU-interface) or your property (in case of WU-intermix) well maintained? To answer affirmatively this question take into consideration the following criteria: - *In case of structures located midslope, ridges or hilltops:* fuel-managed ring of at least 50 m from the foundation of the structure, separation between crown trees/high shrubs of at least 8 m, lower tree branches pruned at ⅓ of tree height, low surface fuel load of 10 cm depth maximum. - *In case of structures located in flat terrain:* fuel-managed ring of at least 30 m, separation between crown trees/high shrubs of at least 6 m, lower tree branches pruned at ⅓ of tree height, low surface fuel load of 10 cm depth maximum	0	10
MAX = 10 points			
Comments from the surveyor: There is a road and the property is surrounded by laboured agricultural lands.			
ID	**Question**	**YES**	**NO**
B5.1	Do you have a 10-m wide area around your structure with ornamental vegetation properly managed? To answer affirmatively this question, the following conditions have to be met: - Fire-resistant species (for trees or shrubs) or separated 6 m - Trees/hedges separated at least 4 m from any glazing system - Non-continuous litter layer - Hedges not aligned with wind or main slopes - No presence of dead fuels	0	10
MAX = 10 points			
Comments from the surveyor: Highly flammable green hedges surrounding all property but a minimum separation of 8 m and a maximum of 30m exists from the house.			
ID	**Question**	**YES**	**NO**
B6.1	Are there any non-natural fuels (e.g. outdoor furniture, stored materials, gas canisters, small sheds, wood piles) located within 5 m from vulnerable structure elements (e.g. doors or windows, gutters)?	5	0
B6.2	Are there any combustible materials (including ornamental vegetation, storage spaces, or combustible eaves) located within 2 m from LPG tanks? *(*) Answer this question only if you have LPG tanks.*	5	0
MAX = 10 points			
Comments from the surveyor: All the area near to the façade is clean of objects or materials. There are no LPG tanks in the property. Some empty gas canisters were exposed to flames (confined combustion), but they were separated more than 10m from the main building.			
ID	**Question**	**YES**	**NO**
B7.1	Is there combustible material in any semi-confined space adjacent to your house?	10	0
B7.2	Are there openings (e.g. windows, doors) connecting the house to any semi-confined space with combustible material?	5	0
B7.3	Are the walls of the house connecting to the semi-confined space with combustible material made out of concrete or bricks (20 cm thick minimum)?	0	5
MAX = 20 points (If question B7.1 is negative, B7.2-B7.3 are non-applicable)			
Comments from the surveyor: There are no confined or semi-confined spaces.			
ID	**Question**	**YES**	**NO**
B8.1	Would you be capable of shutting all the doors and windows before leaving, tape your windows from the inside so that they remain in place if broken?	0	20
MAX = 20 points			
Comments from the surveyor: There are just a few windows and doors. Never taped the windows, but it is possible to do it in case of fire.			

This house suffered the impact of an approaching front of a wildfire pushed by winds from SW, in July 2020. As a consequence, the flammable green hedge burned completely, providing the most important source of heat. No flame impingement was observed. The family was ordered to evacuate. A senior woman with some walking impediments was moved by the owner with the help of fire fighters. According to testimonies of the owner, he could defend his house perfectly. In this town they are accustomed to self-defence and fire fighting. They offered themselves with their agricultural tractors and water tanks but the help was refused for safety reasons. The house was prepared for the impact of fire. At the opposite side of the road, some pine trees were torching and projecting fire embers, most likely igniting the green hedge. In general this house was well prepared for the impact of a wildfire, except for the fire load caused by the flammable green hedge. Some minor damages were observed in the PVC gutters running along the roofing edge.

Final VAT Scoring: **8/100** which very well represents the real case in a wildfire, as observed. This scoring is also reflecting the lack of maintenance of the roofing, which could have been a problem with fire embers.

SAT evaluation

The results of the questionnaire regarding the Valdepiélagos capability of becoming a shelter in case of fire are summarized in Table 3.

Table 3. Answers of the SAT checklist (yellow answer cell corresponds to the result of the survey)

B1: Are you fit enough to stay and eventually defend your property?			
ID	**Question**	**YES**	**NO**
B1.1	Are you mentally, physically and emotionally able to cope with the intense smoke, heat, stress and noise of a wildfire while defending your home?	5	0
B1.2	Are you physically fit to fight spot fires in and around your home?	5	
B1.3	Will you be able to protect your home while also caring for members of your family, pets, etc.?	5	
B2: Do you have enough means to respond properly when the fire is approaching?			
ID	**Question**	**YES**	**NO**
B2.1	Can you patrol the inside of the home as well as the outside for embers or small fires?	5	
B2.2	Can you prepare the inside of your home (e.g. remove curtains, move furniture away from windows, tape windows from inside so they remain in place if broken)?	5	
B2.3	Do you have a supply of fresh water available to keep hydrated?	5	
B2.4	Are you able to estimate which openings (windows, doors) may influence at most hot gases propagation pathways inside the house depending on fire front position?	5	
B2.5	Do you have the necessary clothes and properly maintained equipment to effectively fight a fire?	5	0
B3: Is your structure survivability adequate?			
ID	**Question**	**YES**	**NO**
B3.1	Does your structure have a high chance of survivability according to VAT (vulnerability assessment tool) checklist (FVI ≤ 20)? (*)	5	
(*) A threshold value of Fire Vulnerability Index (FVI) ≤ 20 is considered in here for an affirmative answer. An FVI of 20 means that there is at least 1 out of 5 possibilities of fire entrance inside the structure due to possible gaps. If Blocks 1 and 3 are affirmative, a value of FVI = 20 is considered manageable.			
Comments from the surveyor: Although the owner and other members of the family could easily manage the situation, there is an old lady with some movement impediments. She is regularly in the house and eventually she could be directly affected. The members of the family, particularly the owner, is used to fight fires in rural areas, as they used to do years			

ago. The only constraint is that the old lady was alone in the house in case of a wildfire. Otherwise, all members of the family are ready for self-defense.

The final scoring in this case is **35/45.** The final scoring well reflects the reality in a forest fire, as observed. The main drawback in a sheltering operation in this case is the presence of old persons with walking difficulties who could suffer consequences. Besides, the lack of specific equipment could lead into some accident, particularly trying to put out fire of the burning flammable green hedges. Besides, the old house, not far away from the main building and used as warehouse, was a real source of potential danger, as it was engulfed by flames and many objects and materials, including several gas canisters, we exposed to fire. In general, the SAT evaluation is very appropriate and accurate to what was observed (Figure 9).

Figure 9. Gas canisters exposed to the combustion of the old house, near the main building.

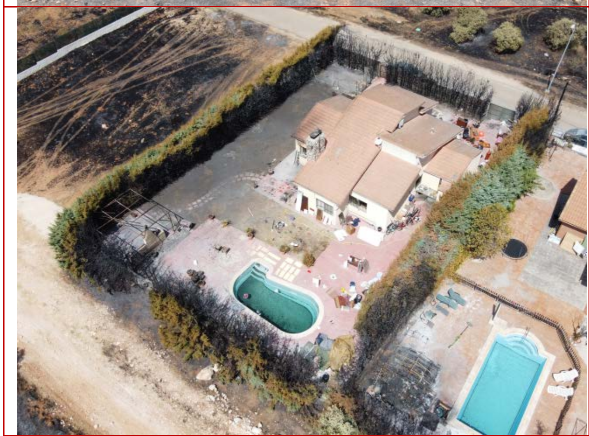
2.4.2. VAT and SAT testing at Eurovillas #H01

General information of the testing

The dwelling #H01 at a settlement called Eurovillas is at the municipality of Villar del Olmo, Madrid (28512), Spain. Table 4 gathers some photos of the dwelling. This is an assisted assessment based upon the onsite observations in a real fire See location at the Google Maps URL:

https://goo.gl/maps/C8N8GCmLQLJFoPWo9

Table 4. Photo collection of the dwelling at Eurovillas #H01

Detail of the dwelling	Comment
	South façade of the house, presenting some objects and materials leaning onto the wall. PVC Shutters are placed behind the glazing system, which is double pane; One of the rooms of the house was affected.
	The property had a covered space where to celebrate BBQ in the SW corner, touching the green hedge. The canvas was burned and some of the materials and objects present.
	The property was enclosed by a flammable green hedge which burned almost completely. The neighbouring plot in the West side was undeveloped, covered with cured grass and burned completely. The interior of the garden was affected by the burning hedge. A small pool was located in the South limit. A hose was deployed to perform last-minute watering of the vegetation.
	The neighbouring lot had a greenhouse close to the hedge in the East border that was completely destroyed. Several objects and materials were also destroyed.

VAT evaluation

The results of the questionnaire regarding the Eurovillas dwelling are summarized in Table 5. The partial VAT scoring is B1 – Gaps through vents (5/20), B2 - Gaps through the attic (0/20), B3 – Glasses (5/20), B4 – wildfuels (0/20), B5 –Ornamental vegetation (10/20); B6 – Non-natural fuels (5/20), B7 – Semiconfined spaces (15/20); B8 – Evacuation (0/20).

Table 5. Answers of the VAT checklist (yellow answer cell corresponds to the result of the survey)

BLOCK/ID	Questions for each block	Answers	
ID	Question	YES	NO
B1.1	Do you have unprotected ventilation openings (i.e. vents without any type of screening)?	20	0
B1.2	Are your vents protected with non-combustible corrosion-resistant materials/meshes (e.g. aluminium, galvanized steel, stainless steel, copper, intumescent coating)?	0	10
B1.3	Are your fire-resistant mesh openings less than 2 mm in characteristic length?	0	5
	MAX = 20 points (If question B1.1 is affirmative, B1.2 and B1.3 are non-applicable)		
Comments from the surveyor: Just a few vents in the corner of the East façade, but are covered with aluminium slates. The space between slates is greater than 2mm.			
ID	Question	YES	NO
B2.1	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.)?	0	20
B2.2	Is your fire-rated roof covering in good state? (To be in good state means that there are not missing, displaced or broken tiles; the underlying roof sheeting is not exposed; there are not unsealed spaces between the roof and the external walls or between the roof covering and the roof decking, particularly in roof edges)	0	4
B2.3	Are your roof or gutters not exposed to overhanging tree branches?	0	4
B2.4	Do you perform periodic roof maintenance?	0	4
B2.5	Does your roof present geometry favourable for the deposition of fuels and firebrands? (Is your roof flat? Are there roof valleys? Are there intersections between roofs and external vertical walls/sidings?)	4	0
B2.6	Do you perform regular cleaning of debris piling up on roof or gutters?	0	4
Comments from the surveyor: All the roofing is clay tiles. The roofing is in perfect state of maintenance, with a couple of recent reparations (replacing broken tiles). No other openings or windows observed. No trees in the lot. Recent repairs of broken tiles. Although the roof is covering 6 different attached modules, the shapes are simple slopes. Besides, there is not so much accumulation of debris or roof due to the absence of overhanging trees.			
	MAX = 20 points (If question B2.1 is negative, B2.2-B2.6 are non-applicable) (If questions B2.1-B2.3 are positive, B2.4-B2.6 are non-applicable)		
ID	Question	YES	NO
B3.1	Do you have protection for all your windows/glazing systems (i.e. shutters, blinds) made of non-combustible materials (solid core wood fire-resistant, metal like aluminium)?	0	5
B3.2	Are your glazing systems double or made of fire-resistant tested material (e.g. tempered glass) or have a thickness ≥ 6 mm?	0	5
	MAX = 10 points		
Comments from the surveyor: The shutters are placed behind the glazing system and are made out of PVC. The glazing system is placed in front of the shutters, potentially exposed to radiation and flame impingement.			
ID	Question	YES	NO
B4.1	Do you have a fuel-managed area around your settlement (in case of WU-interface) or your property (in case of WU-intermix) well maintained? To answer affirmatively this question take into consideration the following criteria: - *In case of structures located midslope, ridges or hilltops:* fuel-managed ring of at least 50 m from the foundation of the structure, separation between crown trees/high shrubs of at least 8 m, lower tree branches pruned at ⅓ of tree height, low surface fuel load of 10 cm depth maximum.	0	10

ID	Question	YES	NO
	- *In case of structures located in flat terrain:* fuel-managed ring of at least 30 m, separation between crown trees/high shrubs of at least 6 m, lower tree branches pruned at ⅓ of tree height, low surface fuel load of 10 cm depth maximum		
	MAX = 10 points		
	Comments from the surveyor:		
ID	**Question**	**YES**	**NO**
B5.1	Do you have a 10-m wide area around your structure with ornamental vegetation properly managed? To answer affirmatively this question, the following conditions have to be met: - Fire-resistant species (for trees or shrubs) or separated 6 m - Trees/hedges separated at least 4 m from any glazing system - Non-continuous litter layer - Hedges not aligned with wind or main slopes - No presence of dead fuels	0	10
	MAX = 10 points		
	Comments from the surveyor: There is a dense and tall hedge in the East part, which is separated less than 3m to the façade and windows.		
ID	**Question**	**YES**	**NO**
B6.1	Are there any non-natural fuels (e.g. outdoor furniture, stored materials, gas canisters, small sheds, wood piles) located within 5 m from vulnerable structure elements (e.g. doors or windows, gutters)?	5	0
B6.2	Are there any combustible materials (including ornamental vegetation, storage spaces, or combustible eaves) located within 2 m from LPG tanks? *(*) Answer this question only if you have LPG tanks.*	5	0
	MAX = 10 points		
	Comments from the surveyor: Many objects and materials, most of which are combustible, are placed leaning onto the wall and corners. There is no LPG tank in the lot.		
ID	**Question**	**YES**	**NO**
B7.1	Is there combustible material in any semi-confined space adjacent to your house?	10	0
B7.2	Are there openings (e.g. windows, doors) connecting the house to any semi-confined space with combustible material?	5	0
B7.3	Are the walls of the house connecting to the semi-confined space with combustible material made out of concrete or bricks (20 cm thick minimum)?	0	5
	MAX = 20 points (If question B7.1 is negative, B7.2-B7.3 are non-applicable)		
	Comments from the surveyor: There are many objects and materials placed in several corners and porches. Corners and confined spaces have at least one window in the wall connecting with the interior.		
ID	**Question**	**YES**	**NO**
B8.1	Would you be capable of shutting all the doors and windows before leaving, tape your windows from the inside so that they remain in place if broken?	0	20
	MAX = 20 points		
	Comments from the surveyor: Although there are many windows, owners are capable of closing the windows and then closing the internal shutters.		

The house #H01 in Eurovillas settlement has a final score of **40/100**. This score well reflects the result in a real fire. One of the rooms was burned and the exterior of the house affected. However, none of the existing materials and objects close to the façade burned nor entailed the combustion of parts of the house. The West façade was directly exposed to the burning green hedge placed at a distance of 6.5 m.

SAT evaluation

The results of the questionnaire regarding the Eurovillas dwelling #H01 of its capability of becoming a shelter in case of fire are summarized in Table 6. Answers of the SAT checklist (yellow answer cell corresponds to the result of the survey).

Table 6. Answers of the SAT checklist (yellow answer cell corresponds to the result of the survey)

B1: Are you fit enough to stay and eventually defend your property?			
ID	**Question**	**YES**	**NO**
B1.1	Are you mentally, physically and emotionally able to cope with the intense smoke, heat, stress and noise of a wildfire while defending your home?	5	0
B1.2	Are you physically fit to fight spot fires in and around your home?	5	
B1.3	Will you be able to protect your home while also caring for members of your family, pets, etc.?	5	0
B2: Do you have enough means to respond properly when the fire is approaching?			
ID	**Question**	**YES**	**NO**
B2.1	Can you patrol the inside of the home as well as the outside for embers or small fires?	5	
B2.2	Can you prepare the inside of your home (e.g. remove curtains, move furniture away from windows, tape windows from inside so they remain in place if broken)?	5	0
B2.3	Do you have a supply of fresh water available to keep hydrated?	5	
B2.4	Are you able to estimate which openings (windows, doors) may influence at most hot gases propagation pathways inside the house depending on fire front position?	5	
B2.5	Do you have the necessary clothes and properly maintained equipment to effectively fight a fire?	5	0
B3: Is your structure survivability adequate?			
ID	**Question**	**YES**	**NO**
B3.1	Does your structure have a high chance of survivability according to VAT (vulnerability assessment tool) checklist (FVI ≤ 20)? (*)	5	0
(*) A threshold value of Fire Vulnerability Index (FVI) ≤ 20 is considered in here for an affirmative answer. An FVI of 20 means that there is at least 1 out of 5 possibilities of fire entrance inside the structure due to possible gaps. If Blocks 1 and 3 are affirmative, a value of FVI = 20 is considered manageable.			
Comments from the surveyor: All members of the family are in good shape and ready to take action in a fire event. The garden is almost deprived of vegetation, saving the green hedge. Most probably many things happen inside and around the house to take care on top of taking care of the family. There are several members of the family that could do such task. There are many objects inside the house that could be affected by fire. The house is complex in shape and has many windows and openings. It will be very hard to estimate hot gases and smoke propagation. We do not have any specific equipment for fire fighting.			

The final scoring in this case is **25/45.** This low score just partially represents the reality. In a approaching fire, like the one experienced in 2020, there was enough time and space to move and evacuate. The house could be prepared for shelter in place if materials and objects in the exterior are previously removed and if the protection of glazing was placed in the exterior instead. There was flame impingement of the West façade, affecting the window and letting the fire enter inside the house, creating the destruction. In case of real confinement, it should be relatively easy to close the window and the shutter.

2.4.3. VAT and SAT testing at Eurovillas #H03

General information of the testing

The dwelling #H03 at a settlement called Eurovillas is at the municipality of Villar del Olmo, Madrid (28512), Spain. Table 7 gathers some photos of the dwelling. This is an assisted assessment based upon the onsite observations in a real fire.

Table 7. Photo collection of the dwelling at Eurovillas #H03

Detail of the dwelling	Comment
	General view of the West façade, mostly affected by the burning materials and vehicles present in an open garage, connected to the underground floor through windows which let the fire pass into and destroy several rooms. The open garage was ignited by the burning green hedge in the neighbouring plot. The fire managed to jump into the plot at the North and progress over grasses.
	View of the South façade and the trajectory of the fire, from the green hedge to the open garage and then the house.
	A view of the North façade from the neighbouring plot covered in cured grass that burned very quickly. Note the high intensity of the fire in the green hedge at the right.

	This image shows the full development of flame length in the moment it is impacting in the open garage. The cars were removed from the place. Moments after, the plot at the right hand burned completely.
	Another view of the West façade from the neighbouring plot with an abandoned house and garden. The green hedge was untreated and the plot presented vegetation everywhere, including inside the abandoned pool. The fire passed through this plot easily and with increasing intensity in the hedge.

VAT evaluation

The results of the questionnaire regarding the #H03 dwelling at Eurovillas are summarized in Table 8. The partial VAT scoring is B1 – Gaps through vents (0/20), B2 - Gaps through the attic (0/20), B3 – Glasses (0/20), B4 – wildfuels (0/20), B5 –Ornamental vegetation (10/20); B6 – Non-natural fuels (5/20), B7 – Semiconfined spaces (15/20); B8 – Evacuation (20/20).

Table 8. Answers of the VAT checklist (yellow answer cell corresponds to the result of the survey)

BLOCK/ID	Questions for each block	Answers	
ID	**Question**	**YES**	**NO**
B1.1	Do you have unprotected ventilation openings (i.e. vents without any type of screening)?	20	0
B1.2	Are your vents protected with non-combustible corrosion-resistant materials/meshes (e.g. aluminium, galvanized steel, stainless steel, copper, intumescent coating)?	0	10
B1.3	Are your fire-resistant mesh openings less than 2 mm in characteristic length?	0	5
MAX = 20 points (If question B1.1 is affirmative, B1.2 and B1.3 are non-applicable)			
Comments from the surveyor: All the openings are protected as required by mandatory regulations. All the coverings are aluminium plates. Metal meshes are less than 2mm.			
ID	**Question**	**YES**	**NO**
B2.1	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.)?	0	20
B2.2	Is your fire-rated roof covering in good state? (To be in good state means that there are not missing, displaced or broken tiles; the underlying roof sheeting is not exposed; there are not unsealed spaces between the roof and the external walls or between the roof covering and the roof decking, particularly in roof edges)	0	4

B2.3	Are your roof or gutters not exposed to overhanging tree branches?	0	4
B2.4	Do you perform periodic roof maintenance?	0	4
B2.5	Does your roof present geometry favourable for the deposition of fuels and firebrands? (Is your roof flat? Are there roof valleys? Are there intersections between roofs and external vertical walls/sidings?)	4	0
B2.6	Do you perform regular cleaning of debris piling up on roof or gutters?	0	4
Comments from the surveyor: There are no overhanging tree branches, there are no trees in the plot. Common repairing and maintenance works. The house has two modules and both are covered with simple geometry roofing, no valleys or corners. Regluar cleaning of debris As part of the maintenance and garden cleaning.			
MAX = 20 points (If question B2.1 is negative, B2.2-B2.6 are non-applicable) (If questions B2.1-B2.3 are positive, B2.4-B2.6 are non-applicable)			
ID	**Question**	**YES**	**NO**
B3.1	Do you have protection for all your windows/glazing systems (i.e. shutters, blinds) made of non-combustible materials (solid core wood fire-resistant, metal like aluminium)?	0	5
B3.2	Are your glazing systems double or made of fire-resistant tested material (e.g. tempered glass) or have a thickness ≥ 6 mm?	0	5
MAX = 10 points			
Comments from the surveyor: Shutters are made of aluminium. All glazing systems are double pane, for thermal and acoustic insulation.			
ID	**Question**	**YES**	**NO**
B4.1	Do you have a fuel-managed area around your settlement (in case of WU-interface) or your property (in case of WU-intermix) well maintained? To answer affirmatively this question take into consideration the following criteria: - *In case of structures located midslope, ridges or hilltops:* fuel-managed ring of at least 50 m from the foundation of the structure, separation between crown trees/high shrubs of at least 8 m, lower tree branches pruned at ⅓ of tree height, low surface fuel load of 10 cm depth maximum. - *In case of structures located in flat terrain:* fuel-managed ring of at least 30 m, separation between crown trees/high shrubs of at least 6 m, lower tree branches pruned at ⅓ of tree height, low surface fuel load of 10 cm depth maximum	0	10
MAX = 10 points			
Comments from the surveyor: There are non developed plots with just cured grass. The forested area is properly managed. The observed fire was low to medium intensity.			
ID	**Question**	**YES**	**NO**
B5.1	Do you have a 10-m wide area around your structure with ornamental vegetation properly managed? To answer affirmatively this question, the following conditions have to be met: - Fire-resistant species (for trees or shrubs) or separated 6 m - Trees/hedges separated at least 4 m from any glazing system - Non-continuous litter layer - Hedges not aligned with wind or main slopes - No presence of dead fuels	0	10
MAX = 10 points			
Comments from the surveyor: There is a neighbouring plot which is abandoned and the flammable green hedges are overgrown, at a distance of 6m.			
ID	**Question**	**YES**	**NO**
B6.1	Are there any non-natural fuels (e.g. outdoor furniture, stored materials, gas canisters, small sheds, wood piles) located within 5 m from vulnerable structure elements (e.g. doors or windows, gutters)?	5	0
B6.2	Are there any combustible materials (including ornamental vegetation, storage spaces, or combustible eaves) located within 2 m from LPG tanks? *(*) Answer this question only if you have LPG tanks.*	5	0
MAX = 10 points			
Comments from the surveyor: Porche has furniture and other objects. No LPG tanks are present in the lot.			

ID	Question	YES	NO
B7.1	Is there combustible material in any semi-confined space adjacent to your house?	10	0
B7.2	Are there openings (e.g. windows, doors) connecting the house to any semi-confined space with combustible material?	5	0
B7.3	Are the walls of the house connecting to the semi-confined space with combustible material made out of concrete or bricks (20 cm thick minimum)?	0	5
MAX = 20 points (If question B7.1 is negative, B7.2-B7.3 are non-applicable)			
Comments from the surveyor: There is an open garage which normally shelters vehicles and other flammable objects. A porche in the entrance with furniture and other objects. The wall closing the open garage has several windows connecting the underground floor. All external walls are masonry with more than 20 cm width.			
ID	Question	YES	NO
B8.1	Would you be capable of shutting all the doors and windows before leaving, tape your windows from the inside so that they remain in place if broken?	0	20
MAX = 20 points			
Comments from the surveyor: There are many windows, some in the basement with relatively difficult access. In case of a fire, some of the windows could be left open.			

This house #H03 at Eurovillas has a final VAT score of **50/100**. This high value of VAT well represents the real case. The house was damaged in the basement rooms and partially in the first floor. The windows were left partially opened in the basement, just in the wall facing towards the incoming fire from the open garage and in line with the prevailing wind direction in that moment. Even without the ignition of the materials in the open garage and in the vicinity of basement windows, the house was exposed to the entrance of flying embers from the burning hedge. Another key factor of risk was the presence of furniture and other objects in semi-enclosed spaces, such as the open garage and the porch, both presenting entrances (windows) to the house.

SAT evaluation

The results of the questionnaire regarding the dwelling Eurovillas #H03 capability of becoming a shelter in case of fire are summarized in Table 9.

Table 9. Answers of the SAT checklist (yellow answer cell corresponds to the result of the survey)

B1: Are you fit enough to stay and eventually defend your property?			
ID	Question	YES	NO
B1.1	Are you mentally, physically and emotionally able to cope with the intense smoke, heat, stress and noise of a wildfire while defending your home?	5	0
B1.2	Are you physically fit to fight spot fires in and around your home?	5	
B1.3	Will you be able to protect your home while also caring for members of your family, pets, etc.?	5	
B2: Do you have enough means to respond properly when the fire is approaching?			
ID	Question	YES	NO
B2.1	Can you patrol the inside of the home as well as the outside for embers or small fires?	5	
B2.2	Can you prepare the inside of your home (e.g. remove curtains, move furniture away from windows, tape windows from inside so they remain in place if broken)?	5	0
B2.3	Do you have a supply of fresh water available to keep hydrated?	5	
B2.4	Are you able to estimate which openings (windows, doors) may influence at most hot gases propagation pathways inside the house depending on fire front position?	5	0

B2.5	Do you have the necessary clothes and properly maintained equipment to effectively fight a fire?	5	0
B3: Is your structure survivability adequate?			
ID	**Question**	**YES**	**NO**
B3.1	Does your structure have a high chance of survivability according to VAT (vulnerability assessment tool) checklist (FVI ≤ 20)? (*)	5	0
(*) A threshold value of Fire Vulnerability Index (FVI) ≤ 20 is considered in here for an affirmative answer. An FVI of 20 means that there is at least 1 out of 5 possibilities of fire entrance inside the structure due to possible gaps. If Blocks 1 and 3 are affirmative, a value of FVI = 20 is considered manageable.			
Comments from the surveyor: We regularly prepare ourselves for self safety and protection. There is few plants in the garden, but a chillout are close to the green hedge in the East border which burned completely. There are some elements in the exterior, such as the open garage, the chillout area, the porche, that could present a challenge. There are many elements in the house, which is big, to remove in case of fire and ensure full protection. Besides, many objects and furniture should be moved from the porche as well. There is a garden watering system, hoses and a pool. No specific tools or equipment, other than garden hoses, are present.			

The final scoring in this case is **55/45.** This score well reflects the reality, as it happened in the real fire in July 2020. However, when evacuation is ordered, there are few chances of active self-protection to save the house. The house served as shelter until the green hedge built up flames and affected severely the West façade and the interior of the house.

2.5. SAT and VAT tools adaptation to Scandinavia

2.5.1. Context analysis

Sweden is a geographically extensive country, with large forested areas. Around 20% of the building stock is located within the WUI, characterized by scattered housing intermixed with the wildland (Vermina Plathner & Sjöström, 2021a).

No national guidelines specific for the WUI exist at presence. Swedish building regulations specify a minimum safety distance of eight meters between buildings to avoid fire spillover effects where multiple buildings are engulfed in flames. For single-family dwelling units the distance of eight meters may be decreased if additional safety measures are taken. The requirements include limitation of window size and an increased integrity and insulation ability of doors facing the nearby structure (Boverket, 2011:6, 5:61). One example of these measures are a minimum distance of 2 m between dwelling and outbuilding if one of the buildings have external walls of fire resistance rating minimum EI30, unrated windows of maximum 1 m^2 and all doors of at least EI30 fire resistance rating. However, these requirements are aimed to stop spread from a fire *within* one building to spread to the next one and do not take combustion of the façade into account.

Regarding forestry regulations, the Swedish Forestry Act (1979:429) does not regulate that pre-commercial thinning of forested land has to be performed, however if thinning is done, the remaining stock must be sufficient to promote wood production capacity.

Building traditions in Sweden promote timber facades and tiled roofing but plastered and brick facades are also common. Due to the cold climate, buildings generally contain multi-glazed windows (2-3 layers) and robust doors. Many single-family dwellings have a fireplace, and firewood is stored in well-vented stacks in the open, in a shed or in a semi-confined space, commonly by the dwelling façade to protect the firewood from getting wet. Numerous houses have porches which are almost exclusively built with timber. Risk perception regarding structure ignition from wildfire is low (mainly due to its low frequency) and vegetation growing in the direct proximity to the façade is a common phenomenon; this is especially true for outbuildings (Vermina Plathner & Sjöström, 2021b).

Wildland fires in Sweden are generally small and of low intensity (Sjöström & Granström, 2020). There are only a few Swedish cases of structure ignition by ember intrusion through vents or other cavities and no confirmed ignition by window breakage due to radiative exposure, in contrast to the ember and radiative ignitions that are responsible for most structure damage in the more intense wildfires in southern Europe. However, this type of ignition could occur in case of high intensity wildfires (which are rare) or when nearby buildings are burning. Actually, there are several examples of dwellings igniting due to a poorly defended outbuilding when it catches fire and produces significant embers once engulfed in a fully developed fire.

The major pathway of structure ignition is instead direct flame impingement, thus something that requires the flame front to reach the structure before ignition. The Swedish tradition of burning garden litter and dead grass during spring is widespread, leading to multiple structure ignitions per year (Vermina Plathner & Sjöström, 2021b).

Inventories of previous large wildfires in Sweden indicate that low flame heights are prevalent in wildfire, and that even an incombustible building foundation could sometimes be enough protection (Vermina Plathner & Sjöström, 2021b). Another consequence of the low intensity of wildfires is that a maintained lawn and a defensible space to the closest wildland are two of the major factors that will protect the house from ignition by wildfire. The low intensity also allows the residents to extinguish the fire themselves. Attempts of extinguishments are indicated to be effective for the survivability of structures (Schroeder & Wennerlund, 2016).

2.5.2. SAT and VAT Scandinavian format

The VAT questionnaire adapted for Scandinavian structures is found here:

https://docs.google.com/forms/d/e/1FAIpQLSdBizP4UqxTMASxMYrSToitGOmTaNkrOglNmoaxeX8YF80YLw/viewform?usp=sf_link

The questionnaire generally follows the same logic as the methodology provided for southern Europe, with the exception that timber buildings are included in the analysis since a large portion of the Scandinavian building stock has timber facades. The questions are presented in Annex A (Section A3). The Scandinavian VAT comprises seven blocks and the rationale behind each block is briefly described in section 2.5.1. The SAT for Scandinavia does not differ from the south-European SAT.

2.5.3. Testing

Testing the VAT questionnaire on a real case has been conducted on three properties. One is the selected property at Toltorpsdalen in the outer part of Gothenburg which we use as study case for the PBD analysis in section 3.5 as well. The property is not exactly adjacent to the wildland, which begins yet one building away but it has a high and combustible hedge row close to a garage and the neighboring building. The two following properties have both been exposed to wildfires. One survived the Västmanland fire raging around it in 2014 and the other is a horse farm in which both the dwelling and the large stable was ignited by a grass fire in April, 2019.

Property #1: Dwelling with a large hedge row

The timber building has never been exposed to wildfire. The main reason for selecting it is the very large *Thuja occidentalis* hedge marking the boarder to the neighbouring property (Figure 10). The building across the street is adjacent to a forested area with mostly conifer trees and a very steep slope against the buildings studied here.

Figure 10. Photos of the property with a hedge selected for the Scandinavian VAT testing.

The property owner answered the questions and the results are found in Table 1.

Table 10. VAT results for the Scandinavian property selected for the PBD in section 3.5.

B1.1	Is your façade material entirely composed of timber?	No: 0p
B1.2	Is your façade material entirely composed of timber, but the lower part is protected by a ground surface border of non-combustible material, such as pebbles, or a high non-combustible building foundation (min 40 cm)?	Yes: 16p
B1.3	Is the ground floor externally covered by non-combustible cladding and the upper floor has timber façade material?	No: 0p
SUM B1		**16p**
B2.1	Do you perform regular cleaning of debris piling up on roof or gutters?	No: 5p
SUM B2		**5p**
B3.1	Do you have a wooden porch?	Yes: 3p
B3.2	Does your porch have a ceiling?	Yes: 5p
B3.3	Do you have combustibles stored on the porch?	Yes: 2p
SUM B.3		**10p**
B4.1	Do you have a managed lawn or another low-combustible surface such as pebbled ground?	Yes: 0p
B4.2	Does your managed lawn (or other low-combustible surface) surround the entire building?	Yes: 0p
B4.3	Does your managed lawn (or other low-combustible surface) surround more than half of the building?	Yes: 0p
SUM B.4		**0p**
B5.1	Do you have a high degree of ornamental plants within 5 m of your building?	Yes: 2p
B5.2	Are they all deciduous?	No: 3p
SUM B.5		**5p**
B6.1	Do you have stored fuels (>20 kg) directly to the façade?	No: 0p
B6.2	Do you have additional combustible material (>100 kg) or a shed within 10 m from the building?	Yes: 7p
SUM B.6		**7p**
B7.1	To what percentage is the garden surrounded by:	

	- Conifers?	25% (5p)
	- Grassland?	0%
	- Deciduous trees?	0%
	- Arable land?	0%
SUM B.7		**5p**
TOTAL SCORE		**48 p**

A total score of 48 p in the VAT indicates a housing of reasonable fire protection but with risk-enhancing features that can be significantly improved. An analysis after the questionnaire should include overlooking the areas where full or near-full score was obtained. In this particular case, the structure itself gained most of the vulnerability points due to the mostly wooden façade and the semi-confined space with combustibles. Even though ornamental plants constitute a relatively small portion of the total possible points in the questionnaire the property scores full, for reasons obvious from Figure 10. These threats are balanced by a very well-maintained garden and the absence of adjacent fire prone wildland. Scores would be improved by maintaining gutters frequently and by e.g. removing the hedge to the neighbouring property.

Property #2: Single dwelling in the Västmanland fire

The second building survived the Västmanland fire 2014 with the help of the rescue services. The property is mostly surrounded by conifers and a high intensity fire raged just passed it. Two outbuildings with very close distances to the conifers were ignited and burnt down while the main building and other outbuildings were saved by the managed lawn at which the fire stopped (Figure 11).

Figure 11. Photo of the structure from the Västmanland fire that was selected for VAT testing.

Filling out the questionnaire for this property yields a score of 38.5 (Table 11). The property is threatened by the large portion of conifers surrounding it and the combustible timber façade of the house. The property as a whole is instead protected by the well-maintained lawn surrounding the whole building, the absence of a porch or semi-confined space as well as little fuel next to the façade. One can imagine that significant ember production occurred while the crownfire was ongoing and the outbuildings were burning. It is evident that the situation was a close call for the building since the ground just to the left of the closest outbuilding was scorched. If the outbuilding had ignited the house would have been seriously threatened. However, the very low intensity and inability of the lawn to transport the flame front saved the house this time.

Table 11. VAT results for the single dwelling within the Västmanland fire, 2014

B1.1	Is your façade material entirely composed of timber?	No: 0p
B1.2	Is your façade material entirely composed of timber, but the lower part is protected by a ground surface border of non-combustible material, such as pebbles, or a high non-combustible building foundation (min 40 cm)?	Yes: 16p
B1.3	Is the ground floor externally covered by non-combustible cladding and the upper floor has timber façade material?	No: 0p
SUM B1		**16p**
B2.1	Do you perform regular cleaning of debris piling up on roof or gutters?	Yes: 0p
SUM B2		**0p**
B3.1	Do you have a wooden porch?	Yes: 0p
B3.2	Does your porch have a ceiling?	N/A
B3.3	Do you have combustibles stored on the porch?	N/A
SUM B.3		**0p**
B4.1	Do you have a managed lawn or another low-combustible surface such as pebbled ground?	Yes: 0p
B4.2	Does your managed lawn (or other low-combustible surface) surround the entire building?	Yes: 0p
B4.3	Does your managed lawn (or other low-combustible surface) surround more than half of the building?	Yes: 0p
SUM B.4		**0p**
B5.1	Do you have a high degree of ornamental plants within 5 m of your building?	No: 0p
B5.2	Are they all deciduous?	N/A
SUM B.5		**0p**
B6.1	Do you have stored fuels (>20 kg) directly to the façade?	No: 0p
B6.2	Do you have additional combustible material (>100 kg) or a shed within 10 m from the building?	Yes: 7p
SUM B.6		**7p**
B7.1	To what percentage is the garden surrounded by:	
	- Conifers?	70% (14p)
	- Grassland?	0%
	- Deciduous trees?	30% (1.5p)
	- Arable land?	0%
SUM B.7		**15.5p**
TOTAL SCORE		**38.5**

Property #3: Horse farm in Skåne, 2019

The farm lost both it's dwelling and the large stable in an unusually large grass fire during April, 2019. The fire had started in a peat bog after 30 days of very low precipitation before the forest fire season had not really begun and while the grass fire season was on its way to finish in large parts of the country. The fire was easily contained and handed to the landowner but surveillance was not sufficient and the next day the fire caught into flames again.

This day the wind speed was 7 m/s on average with gusts up to 20 m/s. Thus, the fire spread rapidly to the nearby regeneration forest with low-crown-height spruce which, in turn, burnt in the canopies generating embers in the strong wind (Sjöström et al, 2019). The embers spot-ignited dead grass from last season on the farm which were efficiently extinguished by the farm employees. Eventually an ember landed under the tiles on the edge of the ceiling of the stable. The whole roof was thereafter in flames within minutes and shortly after the large fire in the stable spread further to the dwelling (see overview in Figure 12). All buildings were completely burnt down but luckily no people or horses were hurt (Figure 13). The final burnt area was 160 ha and additionally 15-20 buildings were severely threatened by the fire but could be saved by the rescue service.

Figure 12. The fire spread from the peat bog to the horse farm in Skåne, 2019.

Figure 13. Collapsed stable (foreground) and burning dwelling (background) on the horse farm, 2019. Photo: Mikael Nilsson.

Table 12. VAT results for the horse farm exposed to a large grass fire in 2019

B1.1	Is your façade material entirely composed of timber?	Yes: 20p
B1.2	Is your façade material entirely composed of timber, but the lower part is protected by a ground surface border of non-combustible material, such as pebbles, or a high non-combustible building foundation (min 40 cm)?	No: 0p
B1.3	Is the ground floor externally covered by non-combustible cladding and the upper floor has timber façade material?	No: 0p
SUM B1		**20p**
B2.1	Do you perform regular cleaning of debris piling up on roof or gutters?	No: 5p
SUM B2		**5p**
B3.1	Do you have a wooden porch?	Yes: 0p
B3.2	Does your porch have a ceiling?	Yes: 0p
B3.3	Do you have combustibles stored on the porch?	No: 0p
SUM B.3		**0p**
B4.1	Do you have a managed lawn or another low-combustible surface such as pebbled ground?	Yes: 0p
B4.2	Does your managed lawn (or other low-combustible surface) surround the entire building?	No: 15p
B4.3	Does your managed lawn (or other low-combustible surface) surround more than half of the building?	Yes: 0p
SUM B.4		**15p**
B5.1	Do you have a high degree of ornamental plants within 5 m of your building?	Yes: 2p
B5.2	Are they all deciduous?	Yes: 0p
SUM B.5		**2p**
B6.1	Do you have stored fuels (>20 kg) directly to the façade?	Yes: 8p
B6.2	Do you have additional combustible material (>100 kg) or a shed within 10 m from the building?	Yes: 7p
SUM B.6		**15p**

B7.1	To what percentage is the garden surrounded by:	
	- Conifers?	0%
	- Grassland?	50% (7.5p)
(7.5p)	- Deciduous trees?	25% (1.25p)
	- Arable land?	25%(0.5p)
SUM B.7		**9.25p**
TOTAL SCORE		**66.25**

The score is significantly higher than for the two other cases, this is mostly due to the grassland which constitute unmanaged fuel around the stable and dwelling as well as the building envelope of timber leading to fire spread from the grass to the façade.

3. Demonstration of PBD methodology for vulnerability assessment at the microscale

3.1. Summary of development

In past WUIVIEW work package 4, the foundations of a PBD methodology applied to WUI properties were established (see deliverable D4.2). The PBD method has been applied and further developed and fine tuned through 4 pilot studies, two located in Madrid region, one located in Central Portugal (Leiria district) and the last one located in Goteborg region (Sweden).

The workflow for pilot PBD analysis has involved three phases, which can be summarized as follows (for detailed information on the overall process, please read deliverable D7.1 "PBD WUI-specfici final guideline):

- *Data collection phase.* In this phase rough data needed to construct the CFD model has been gathered and processed according to protocols established along the project. In two cases (Madrid region) 3D photogrammetry and modelling has been used to obtain the initial 3D model of the property, whereas in the other two, the model was already available (Leiria district) or obtained through measurements on the field. Also, data from building materials, residential fuels, wildfuels and fire weather has also been obtained.
- *Simulation phase.* In this phase, the PBD framework has been defined in terms of goals, objectives, performance criteria and design fire scenarios, with an initial outline of types and number of simulations to be run. Scenarios have been specified (inputs, outputs and computational parameters) and run by supercomputing machines.
- *Analysis and reporting phase*. Simulation results have been analysed and discussed in terms of overall fire impact at the property and are main conclusions are reported.

Selected study cases represent a rather wide variety of structures in terms of materials, fuels involved and fire safety objectives. In the first two study case, we analyse typical dwellings in WUI residential areas of Madrid. The goal of the study is property protection, with the objective of maintaining the building's structural integrity in case of fire. Next, the PDB methodology is applied to a Swedish property in southwest Sweden. The property has a typical Swedish style single dwelling, wooden with a wooden garage. We analyse its vulnerability to fire from long and tall coniferous hedge separating the garden to two neighbouring properties. Finally, the last case study is based on a community shelter that will be built in the village of Moninhos Cimeiros, in the Municipality of Figueiró dos Vinhos, Portugal. This community shelter will enable people to take refuge during a large fire event or any other threat that force them to search for a refuge. It is not intended here to assess the vulnerability of the construction itself, since it has been designed using materials and practices that confer a good resistance to fire. The main intention is hence to estimate the time at which tenability criteria are exceeded in the surroundings of the shelter.

3.2. "Entrepinos" property case study

3.2.1. Description of the study site

Parque Residencial Entrepinos is a settlement constituted in 1972, located in the municipality of Cadalso de los Vidrios, Madrid Autonomous Region, Spain, spanning over 140 hectares and enclosing 833 structures, mostly single family homes. These represent the 32% of total structures in the municipality. Currently, about 205 people are registered as permanent residents in Entrepinos, while the rest commute from Madrid City and the nearby towns for vacations and weekends (Figure 14).

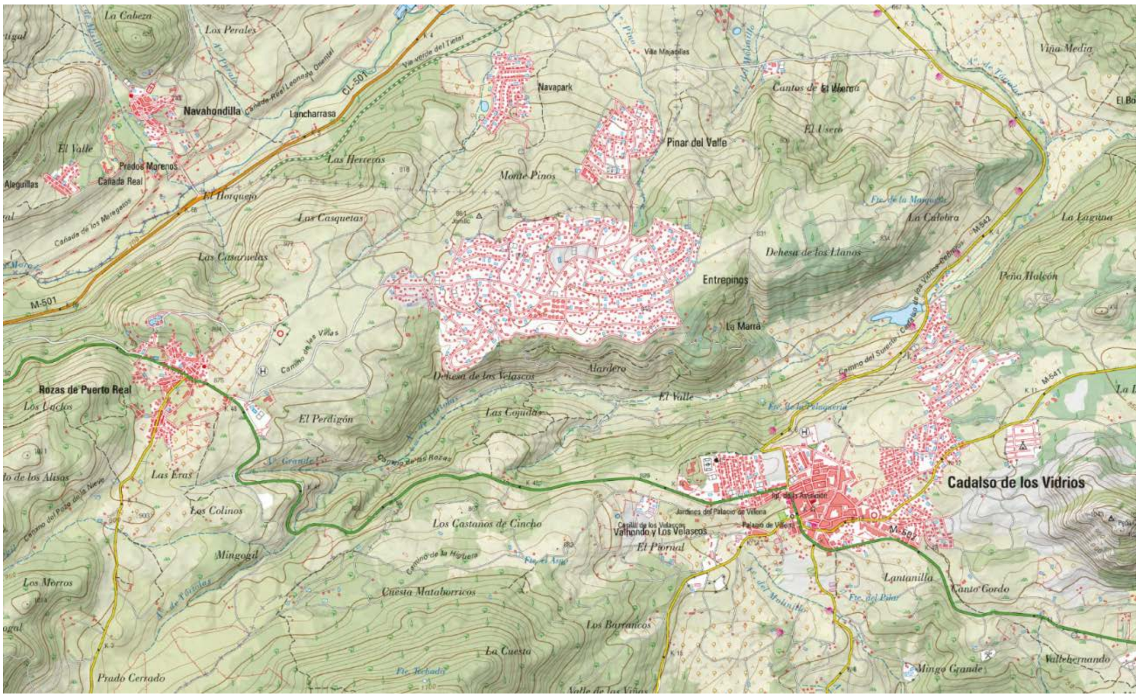


Figure 14. A general view of Entrepinos and the surrounding topography. Note the relatively steep slopes at the South face, covered with pine stands.

The area is profusely covered with cluster pine (Pinus pinaster) and the accompanying understory, creating a highly flammable forest fuel in a fire-prone area. Although the community is currently elaborating a self-defence plan, no surrounding fire breaks or other protection infrastructure is developed, as it is mandatory by the regional law. The houses are high-standard, the majority well made, with just a few of them from the 70's when the urbanisation was constituted. Most of the houses are relatively new and made out of masonry, brick and other non-burnable elements. The road and street network is generous with two access points, one of them surrounded by grasslands grazed by livestock. The topography is locally rough, with box canyons running from south and Southwest up to the fringe of the developed area, with average steep slopes (Figure 15).

Entrepinos is classified as intermix type, in which the urban area intermingles with the pine stand and mixes with the garden vegetation.

The area suffered several wild fires of a certain consideration. The last one happened in 2019, spanning over more than 3,000 hectares and nearly affecting Entrepinos in the last run, which was consequently evacuated. From this very event, homeowners acquired much more sense of risk and seriously committed to undertake prevention actions (Figure 16). The study case is one of the houses placed in the North limit at the West end (Figure 17 - Figure 20).

Figure 15. A general view of the South limit of the settlement. Note that there is no separation between the forested area and the urban development.

Figure 16. A general view of the fire scar in Cadalso de los Vidrios, in July 2019. This is a fire-prone area with recurrent fire events. In the right of the image, several affected pine stands show very intense fire behaviour.

Figure 17. A general view of the North-West limit of the settlement, where the study case is located.

Figure 18. A general view of the West side of the study case. The green hedges are a mix of perennial and conifer (cypress) species. Note the cluster of trees in the East side and the pine stand behind.

Figure 19. Location of the study case (*)

Figure 20. A view of the area where the house is located. Note the local cluster of vegetation and the network of green hedges enclosing properties.

The building is formed by three modules of masonry with roofing covered with cement tiles. The garden is mostly deprived of ornamental plants, saving the South side, in which several conifers, fruit trees and garden plants are present. There are several undeveloped plots in the vicinity, with cured grass and green hedges of flammable species. In the exterior the main fuel found is grassland and, further towards East, some shrubs of Juniperus oxycedrus and Quercus ilex, which provides continuity with the pine stand in the East. The accessibility to the property is ensured through a dead-end street to the main entrance. The North limit is fringed by a free-access dirt road

3.2.2. Transferring property characteristics into a Pyrosim model

The precedure described in WUIVIEW Deliverable 5.2 was used to extrapolate a 3D model of the property.

The geometry of the plot and of the house is uploaded in the sofwtare Pyrosim (Thunderhead Engineering 2020), which converts these inputs into a FDS script (Figure 21) . The total dimensions of the domain are 84m x 29.2m x 21.2 m. The house is repilacted within a mesh of 0.1x0.1x0.1 m cells, with materials such as brick and concrete for walls and floors, tiles for the roof, steel for the doors and glass for the windows. The materials' properties are those present in WUIVIEW's materials database. The glazing systems consist of single pane 3 mm glass. The assigned names of the windows are given in Figure 22. A LPG tank of 1 m^3 is located in the south-east corner of the property, at a distance of 1 m from the southern and eatern hedgerows. The cells size for the tank mesh is 0.05x0.05x0.05 m. The area where the fire is located is simulated in a mesh with 0.1x0.1x0.1 m cells. The rest of the property is simulated in meshes with cell sizes of 0.2x0.2x0.2 m and 0.4x0.4x0.4 m.

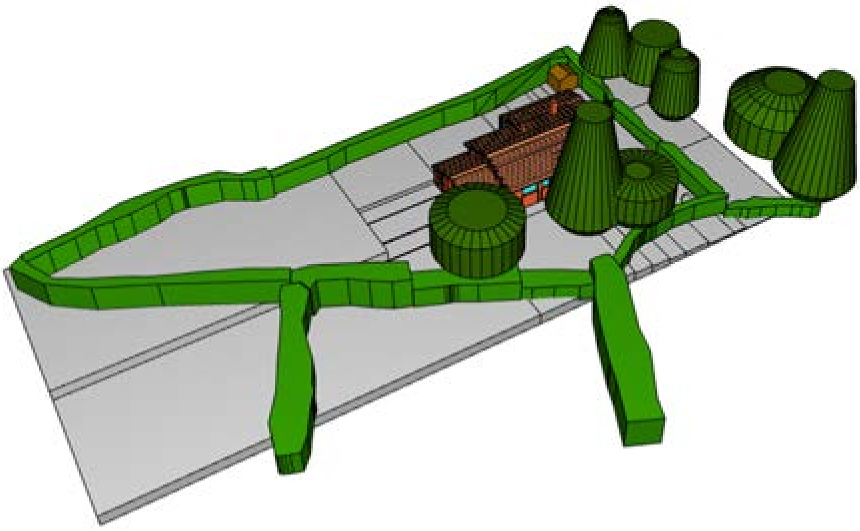


Figure 21: Representation of the "Entrepinos" property in Pyrosim

Figure 22: Analysed glazing systems for the Entrepinos case study

3.2.3. PBD analysis

Scope, goals and objectives

The PBD analysis is performed on the whole property. The goal of the project is property protection, with the objectives of no structural damage in case of fire and reduction of fire spread through the property. Should the building meet this goal, a second one can be set for life safety, if the house is used as a shelter. In this case the objective is to protect the occupants of the building as well.

Performance criteria

The performance criteria for structural survivability and subsequent sheltering tenability and survivability set for the case study are those described in D6.1 of the project (Vacca et al. 2020). These are briefly listed in Table 13.

Table 13: Performance criteria

Criteria	Threshold Values
Life safety	
Fractional Effective Dose	FED < 1
Interior air temperature	T < 45°C
Interior wall temperature	T < 70°C
Radiant heat flux	$\dot{q}'' < 1.7$ kW/m^2
Non-life safety	
Window breakage	Surface temperature < 150°C ΔT < 58°C Received heat dose < 1840 $[(\frac{kW}{m^2})^{\frac{4}{3}} \cdot s]$
LPG tank integrity	Incident heat flux < 22 kW/m^2 Pressure Relief Valve Index < 0.9 Weakened Surface Index < 0.9
Concrete wall load bearing capacity	> 74%

Design fire scenarios

Fire scenarios have been identified based on the VAT results of the property and the possible available fire sources, and the scenario population has been reduced according to the steps described in WUIVIEW Deliverable 7.1. Four critical scenarios have been identified for this case study: two *special problem* scenarios, one with *high frequency, low consequences* and one with *low frequency, high consequences*. Within the simulated domain, ambient temperature and humidity are set at 35°C and 15% respectively. The property and building are analysed in their current condition.

Scenario 1 – Low Frequency, High Consequences

This scenario consists of the simultaneous burning of the hedgerow and the trees located on the north-eastern side of the property (Figure 23). The fire is simulated as a flat surface, with an assigned prescribed HRRPUA and residence time. The wind is blowing from the north-east with a speed of 20 km/h at 10 m, pushing the flames toward the eastern façade of the house.

For the hedgerow, a HRRPUA of 4500 kW/m^2 was estimated from the results obtained from the tests performed in Coimbra for WP2 (average MLR of 0.04 kg/s and an area of about 0.16 m^2) and assuming a net fuel low heat of 18000 kJ/kg (Alexander and Cruz 2019). For the trees, the forward rate of spread is estimated to be 10% of the wind speed, thus 33 m/min (0.55 m/s). The minimum value of fuel consumption for conifers is 2 kg/m^2 (Alexander and Cruz 2019). Byram's intensity is then calculated as:

$$\boldsymbol{I_B} = \Delta\boldsymbol{H} \cdot \boldsymbol{m_c} \cdot \boldsymbol{r} = 18000 \cdot 2 \cdot 0.55 = 20000 \text{ kW/m}$$

With a fuel bed of 4 m, the calculated HRRPUA for the trees is 5000 kW/m^2. The residence time for forests is 45 s, while for shrubs it is 20 s (Alexander, Mutch, and Davis 2007). The combustion reaction is the same as the one described in D6.1. The total HRR curve is given in Figure 24.

Figure 23: Entrepinos – Scenario scenario low frequency, high consequences

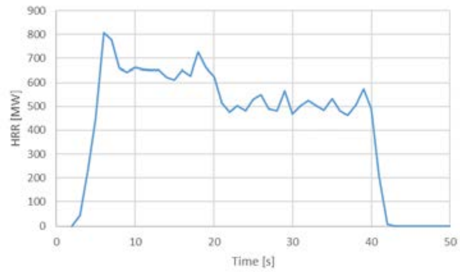


Figure 24: HRR curve for Entrepinos scenario 1

Scenario 2 – High Frequency, Low Consequences

In this scenario the fire spreads through both sides of the hedgerow starting from the furthest point on the west side of the property. The wind blows from the south-west at a speed of 20 km/h at 10 m. The fire spreads through the hedge at a rate of 0.55 m/s, with a residence time of 20 s, as for the previous scenario. Once the flames reach the trees on the south side of the house, these will ignite too, with the same characteristics as those in scenario 1, but with an HRRPUA adapted to the size of the fuel bed, which is 5 m for the two trees on the sides, and 5.8 m for the middle one. This results in a HRRPUA of 4000 kW/m^2 and 3450 kW/m^2 respectively. As for the previous scenario, the fire is simulated with the aid of vents located on the ground (Figure 25). The total fire duration is 153 s, and the resulting HRR curve is the one given in Figure 26.

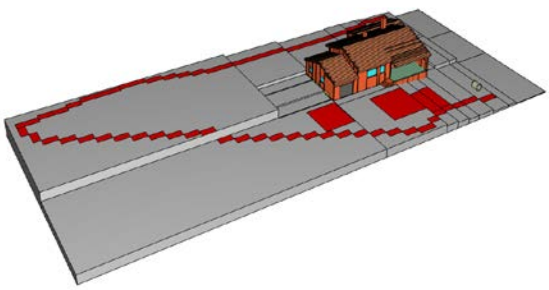


Figure 25: Entrepinos – Scenario high frequency, low consequences

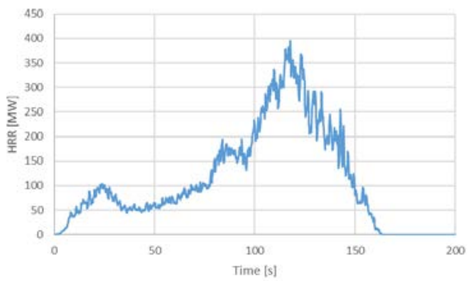


Figure 26: HRR curve for Entepinos scenario 2

Scenario 3 – Special problem 1

A special problem given by artificial fuels located in a semi-confined space (the porch) is analysed in this scenario (Figure 27). The simulated fuel pack consists of a set of garden furniture, including a table, 6 chairs, 6 cushions and a parasol. The HRR curve for this scenario is given in Figure 28.

Figure 27: Entrepinos – Scenario special problem 1

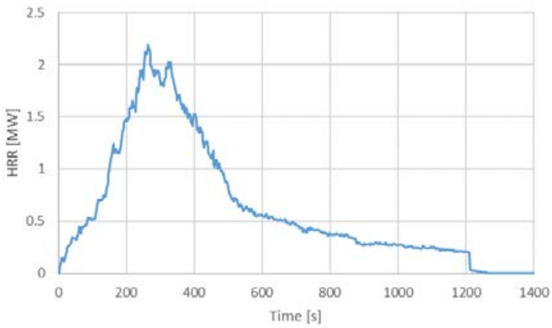


Figure 28: HRR curve for Entrepinos scenario 3

Scenario 4 – Special problem 2

The second special problem scenario entails the analysis of the LPG tank located in the south-east corner of the property (Figure 29). The fire and environmental inputs are the same as those simulated in scenario 1.

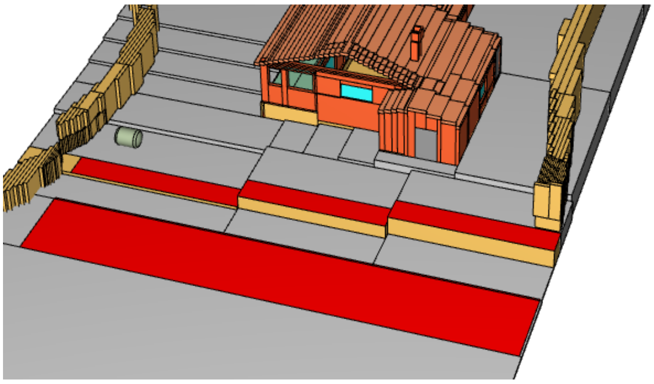


Figure 29: Entrepinos - Scenario special problem 1

3.2.4. Results and recommendations

Scenario 1 – Low Frequency, High Consequences

In scenario 1 the flames engulf the east façade and part of the south façade through the porch, as can be seen in Figure 30. This means that the flames are covering a horizontal distance of about 10 m.

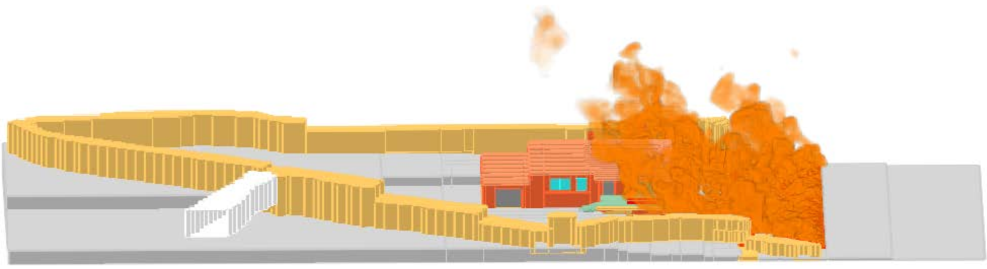


Figure 30: Entrepinos - Scenario low frequency, high consequences at 10 s

The four windows located the closest to the fire source failed very soon after the start of the fire, as given in Table 19.

Table 14: Window failure for Entrepinos scenario 1

Window	Time of failure [s]
E	6
Porch	10
S1	14
N	9

Given the fact that the windows will break, allowing smoke and fire to enter the building, this scenario cannot be deemed safe for both property protection and life safety.

Scenario 2 – High Frequency, Low Consequences

Figure 31 shows the fire spread through the property over time for scenario 2. As shown in Table 20, only the windows located on the southern façade failed, due to the ignition of the trees located on that side of the property.

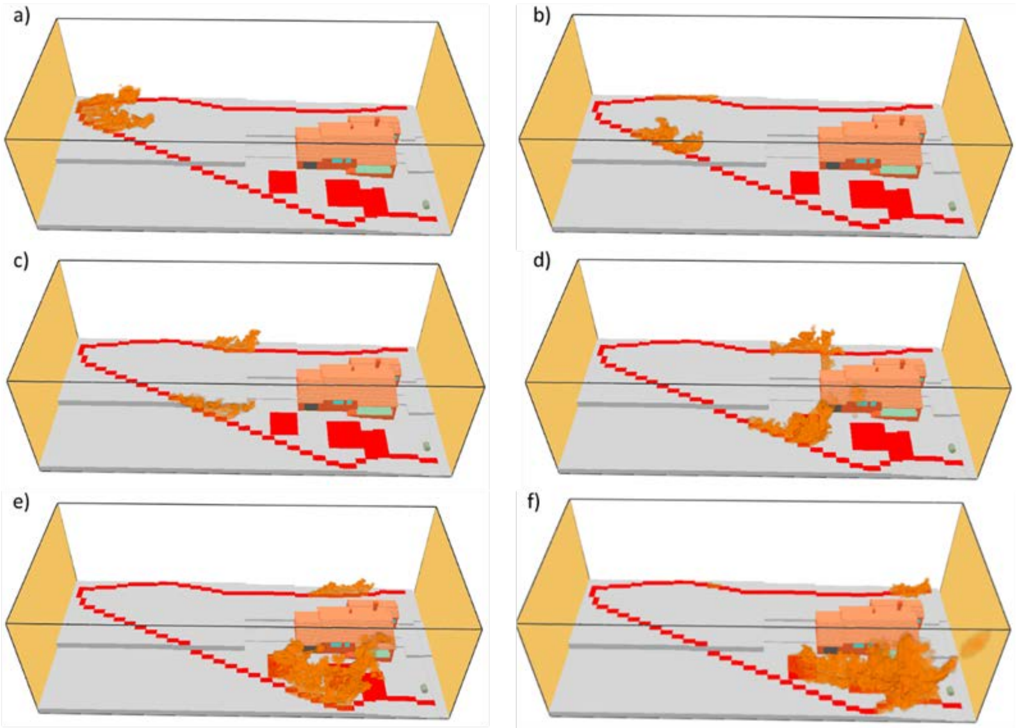


Figure 31: Entrepinos - Scenario 2 at 20 s (a), 40 s (b), 60 s (c), 80 s (d), 100 s (e), 120 s (f)

Table 15: Window failure for Entrepinos scenario 2

Window	Time of failure [s]
Porch	127
S1	101
S2	94

As for the first scenario, this one cannot be deemed safe for both property protection and life safety.

Scenario 3 – Special problem 1

Figure 32 shows the combustion of the fuel pack on the porch at 250 s. As given in Table 16, the only glazing system that fails in this scenario is the one located on the porch, which is also the closest to the fire. Failure of the glass will happen before the fire reaches its peak HRR value.

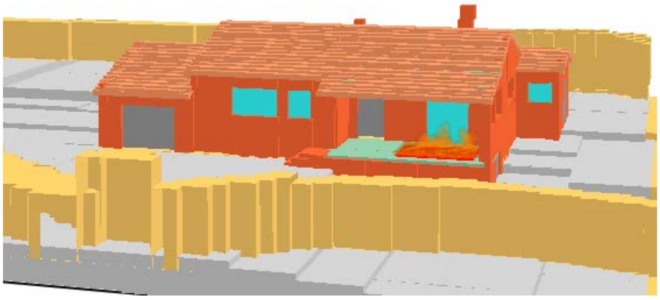


Figure 32: Entrepinos – Scenario 3 at 250 s

Table 16: Window failure for Entrepinos scenario 3

Window	Time of failure [s]
Porch	156

Given the semi-confined characteristics of the porch, an analysis of the load bearing capacity of the walls of the porch is also performed. Temperature profiles through the wall located to the left of the window are measured during the duration of the fire. As can be seen from the blue line in Figure 33, the load bearing capacity of the wall never falls below 74%.

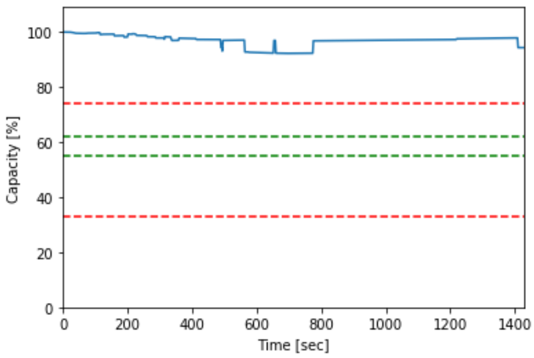


Figure 33: Load bearing capacity of the wall over time

This scenario cannot be deemed safe for both property protection and life safety due to the failure of the glazing system located on the porch.

Scenario 4 – Special problem 2

The incident heat flux onto the tank is greater than 22 kW/m^2 already after 1 s of the simulation. Further investigation with ANSYS Fluent shows that the Pressure Release Valve Index is 0.9, while the temperature of the tank walls remains below the critical value of 400°C, resulting in a null Weakened Surface Index (Figure 34). It can be concluded that this scenario does not have the potential to compromise the integrity of the LPG tank. However, it may lead to the opening of the PRV, which, is an unwanted situation.

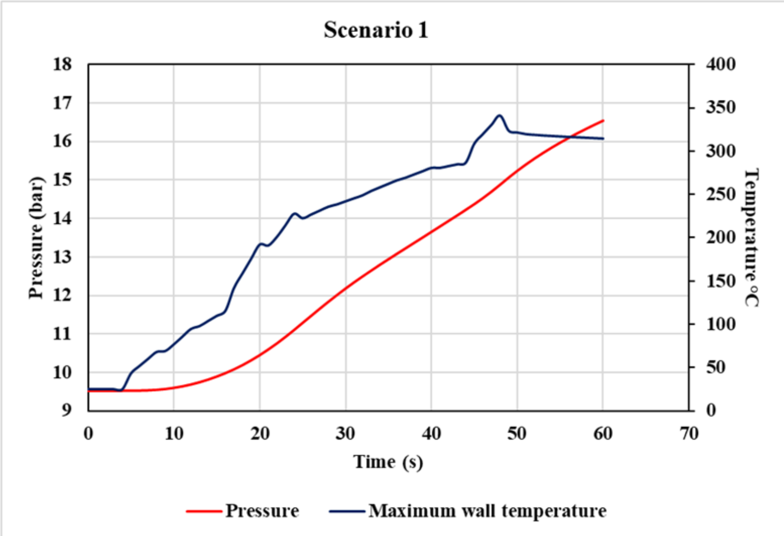


Figure 34: Pressure evolution inside the tank and tank wall temperature

3.3. "Los Barrancos" property study case

3.3.1. Description of the study site

Los Barrancos urbanisation is a small private settlement located a rural area in the municipality of Valdemorillo, Madrid Autonomous Region, Spain, spanning over 170 hectares and embracing a scattered development with 141 structures, out of which 41 are homes. Just half of the properties are used as permanent residence, and the rest are occupied mostly in summer and weekends (Figure 35).

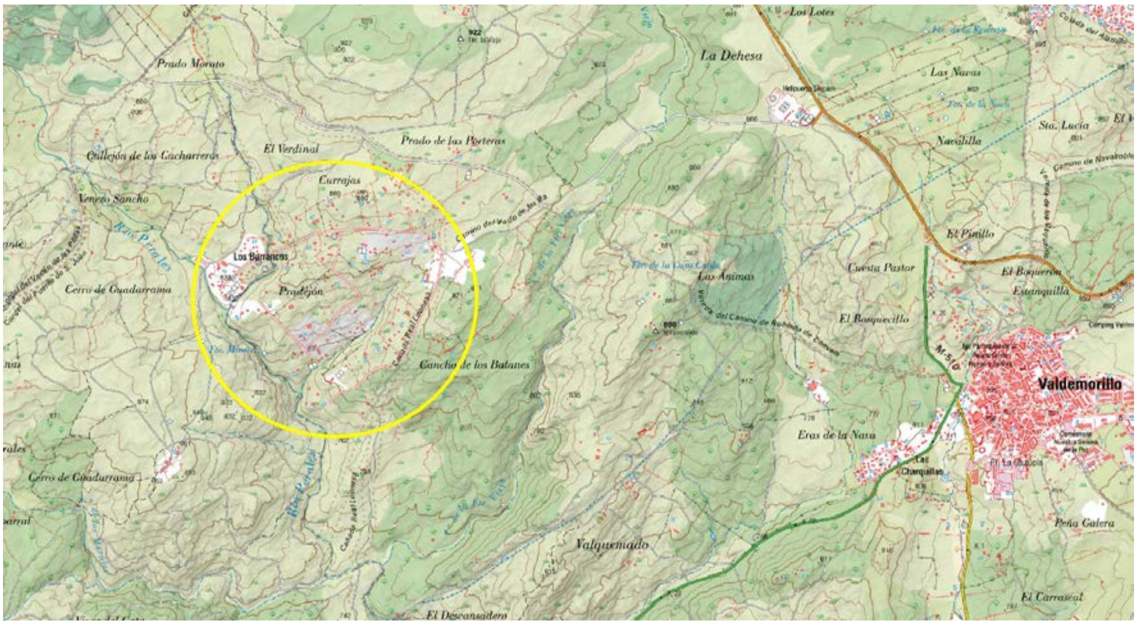


Figure 35. Location of Los Barrancos study site

This low density of houses (2.4 houses per square kilometer) allows the free pass of a forest fire over a vegetation composed mainly by shrubs (Juniperus, Cistus, Quercus) tall cured grass and sparse trees (Quercus ilex, Pinus pinea). This settlement is divided into relatively large plots of land which are covered, mostly, by the original vegetation, providing continuity with the surrounding forest fuels. Topography is gentle, with some ravines running South-North mostly, one of which is dividing the West limit of the community. The only access to the housing areas is performed through a local road, partially paved and continuing to a dirt road towards the houses in the West end and the South limit. As seen, this could be potentially compromised in case of a wildfire cutting the access route in the South-North axis.

Los Barrancos is placed in a fire-prone area with recurrent events mostly starting and developing over grassland and shrublands. A fire fighting helicrew base is precisely located at the entrance of the access road, providing service to the area. In July 2013 a fire started in one of the plots of Los Barrancos, in a day with strong wind blowing SW to W and with tall cured grass ready to burn. The fire quickly increased speed and intensity and reached a dense patch of shrubs and trees, jumping a road and progressing towards the big settlement of Cerro Alarcon. Population of the affected settlements were evacuated, some of the under the uncertainty of the flame front affecting the escape route (Figure 36 - Figure 38).

Figure 36. Displaced people from the nearby settlements in the fire of 2013.

Figure 37. One of the houses threatened by the approaching fire in the event of 2013. The fire started in one of the properties in Los Barrancos and quickly expanded towards other nearby settlements. All population was evacuated to the town of Valdemorillo.

Figure 38. A view of the type of vegetation in the area.

The house of the study case is sitting in a relatively large plot of land covered with natural vegetation, cured grass and rocks. It is accessed through a dirt track. There is no separation with the natural vegetation and no devices or other installations for fire fighting. This house has been expanded in several occasions, giving the final ‘O’ shape with a patio in the interior. The original family house is completely made of masonry and the roofing is traditional clay tile. Several refurbishments took place to improve energy efficiency and isolation. Glazing was substituted for a more efficient double pane glasses. Construciton elements and materials were selected to be ecologically friendly. Thermal insulation is completed with several strategies, such as double coating in the roof. The extended modules of the house, beyond the original one, present flat roofing but the same materials used in the previous one. All windows are covered with sliding blinds, and two roof windows provide direct lightning in the main hall (Figure 39, Figure 40).

Figure 39. An ortophoto showing the location of the study case.

Figure 40. A general view of the study case and the surrounding environment, which suffered a forest fire in 2013.

A porche is facing the South-West side and it is flanked by two large oak trees. Small vegetation is present around the house, in some cases touching the façade, and inside the patio. No other side structures, except a small one to protect cars from sunlight, are found in the property. Owner is very aware of fire risks, as well as other homeowners in the settlement, and is committed to proceed with prevention measures to improve chances of structure survivability in case of fire. All the family is aware of using the house as shelter, in case of entrapment, which is very likely given the only access to the urbanisation (Figure 41).

Figure 41. A view of the South-East side with the porche and the surrounding vegetation. Note that some of the ornamental species are touching the façade. Also note the tree inside the patio

3.3.2. Transferring property characteristics into a Pyrosim model

As for the first case study, the geometry of the plot and of the house is uploaded in the software Pyrosim (Thunderhead Engineering 2020). The total dimensions of the domain vary depending on each selected fire scenario. The biggest domain is 43m x 39m x 23m. The domain is replicated in meshes with sizes that vary from 0.015x0.015x0.015 m for the glazing systems (in order to replicate the double pane windows) to 0.48x0.48x0.48 m for the areas that are less interesting for the analysis of each scenario. The building is replicated with materials such as concrete for walls, floors and flat roofs, tiles for the main roof, glass for the windows and aluminium for the window frames. The properties of these materials are given in WUIVIEW's materials database. This case has a higher level of detail compared to the previous one. A representation of the building is given in Figure 42.

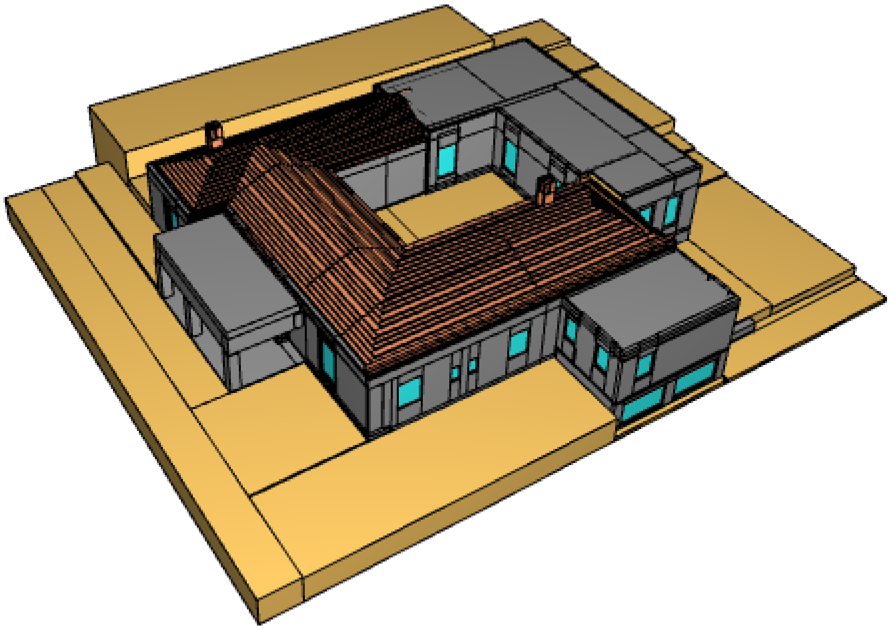


Figure 42: Representation of "Los Barrancos" property in Pyrosim

3.3.3. PBD analysis

Scope, goals and objectives

As in the previous case, the PBD analysis is performed on the whole property. The goal of the project is property protection, with the objectives of no structural damage in case of fire and reduction of fire spread through the property. Should the building meet this goal, a second one can be set for life safety, if the house is used as a shelter. In this case the objective is to protect the occupants of the building as well.

Performance criteria

The performance criteria used for this case study are those given in Table 13. In addition to those, a criterion is also set to identify the failure of the aluminium window frame. This criterion is set at 660°C, which is the melting point of aluminium.

Design fire scenarios

Also for this case, fire scenarios have been identified based on the VAT results of the property and the possible available fire sources, and the scenario population has been reduced according to the steps described in WUIVIEW Deliverable 7.1. Three critical scenarios have been identified for this case study: a *special problem* scenario, one with *high frequency, low consequences* and one with *low frequency, high consequences*. The property and building are analysed in their current condition.

Scenario 1 – Low Frequency, High Consequences

This scenario consists of the simultaneous burning of the vegetation located around the building. The fire is simulated as a flat surface (red surfaces in Figure 43), with an assigned prescribed HRRPUA of 443 kW/m^2, calculated taking into account fuel model 6 of the tool BehavePlus 5.0.5 (Heinsch et al. 2019) and residence time of 20 s (Alexander, Mutch, and Davis 2007). The total simulated HRR curve is given in Figure 44. The wind is blowing from the south with a speed of 25 km/h at 10 m, pushing the flames toward the southern part of the building. Within the simulated domain, ambient temperature and humidity are set at 38°C and 10% respectively.

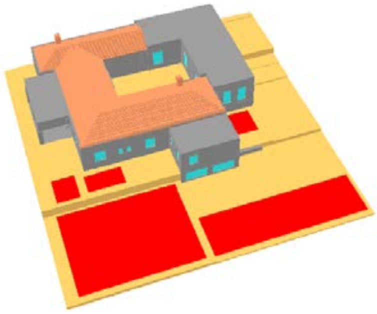


Figure 43: Los Barrancos – Scenarios 1 and 2

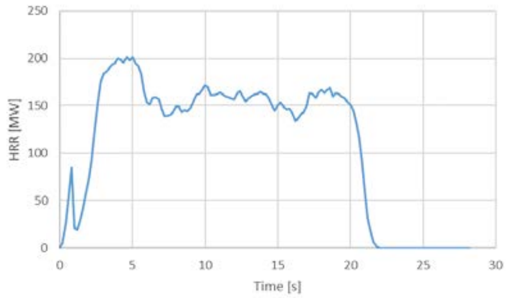


Figure 44: HRR curve for Los Barrancos scenario 1

Scenario 2 – High Frequency, Low Consequences

The second scenario entails the burning of the vegetation located around the building with a spread rate of 0.28 m/s (obtained from BehavePlus), starting from the southern side of the property. The HRR curve for this scenario is given in Figure 45. The wind is blowing from the south at a speed of 22.5 km/h at 10 m. Within the simulated domain, ambient temperature and humidity ate set at 35°C and 15% respectively. These are the average summer values in the area.

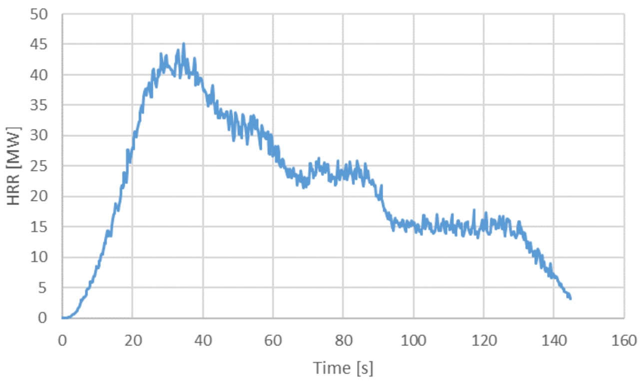


Figure 45: HRR curve for Los Barrancos scenario 2

Scenario 3 – Special problem 1

A special problem on this property is given by the tree located in the central patio of the house. The tree is simulated as an obstacle with 5 burning surfaces, as shown in Figure 46. The dimensions of the tree are 6.36m x 6.36m x 4m, and the HRRPUA has been assigned according to the data on Norwegian spruce located in the WUIVIEW natural fuels database (65.3 kW/m^2). The resulting HRR curve is given in Figure 47.

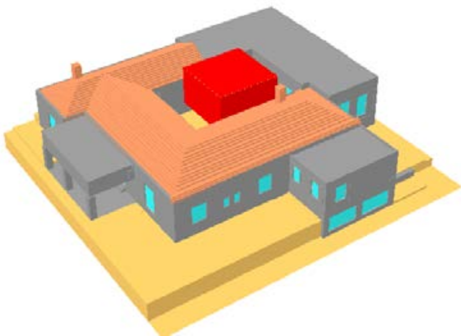


Figure 46: Los Barrancos – Scenario special problem 1

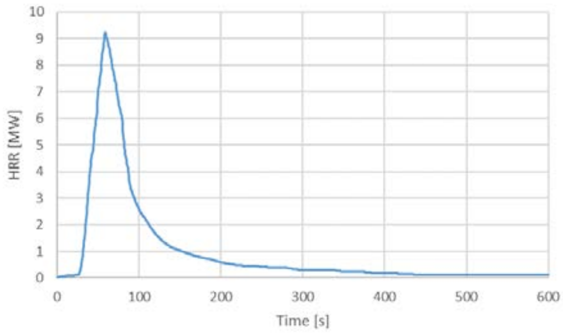


Figure 47: HRR curve for Los Barrancos scenario 3

3.3.4. Results and recommendations

Scenario 1 – Low Frequency, High Consequences

In this scenario, the first pane of window 16 (identified in Figure 48) fails almost immediately while the second pane will fail after 18 seconds, as given in Table 17. This will allow for smoke and firebrand entrance. All other glazing systems will meet the set performance criteria.

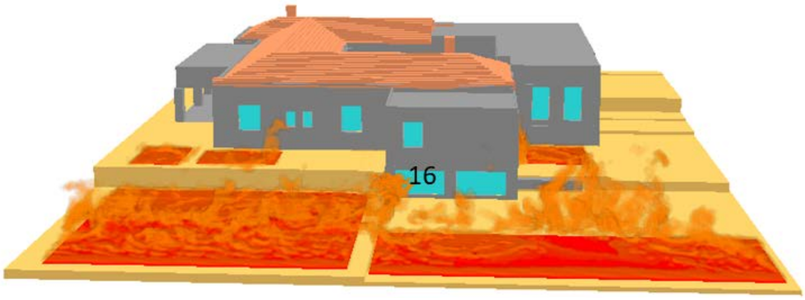


Figure 48: Los Barrancos – scenario low frequency, high consequences at 10 s

Table 17: Window failure for Los Barrancos scenario 1

Window	Time of failure 1st pane [s]	Time of failure 2nd pane [s]
16	8	18

Scenario 2 – High Frequency, Low Consequences

The fire spread through the property is shown in Figure 49. In this scenario none of the windows will fail, since the temperature of the glass never reaches the set performance criteria. The design of the building can thus be considered safe in this scenario.

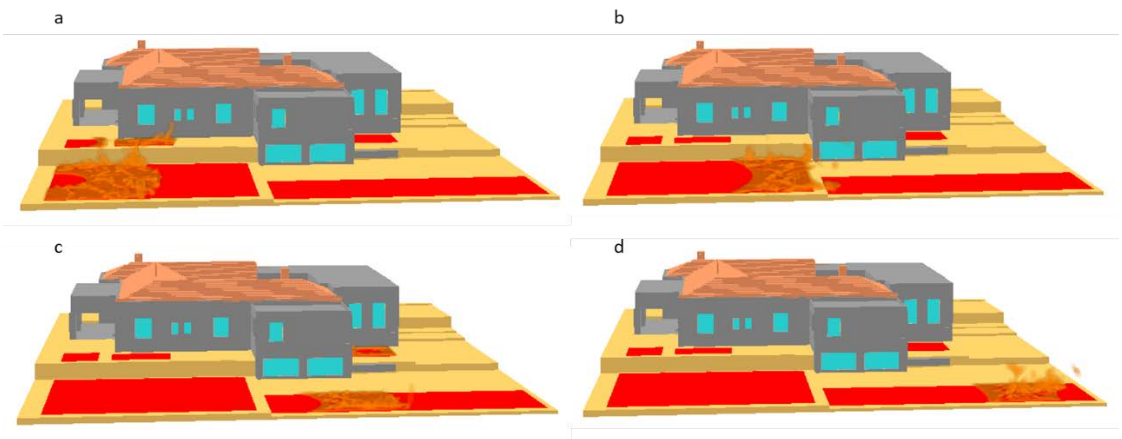


Figure 49: Los Barrancos – Scenario high frequency, low consequences at 30 s (a), 60 s (b), 90 s (c) and 120 s (d)

Scenario 3 – Special problem 1

Also in this scenario, none of the glazing systems will fail, and the design can thus be deemed safe.

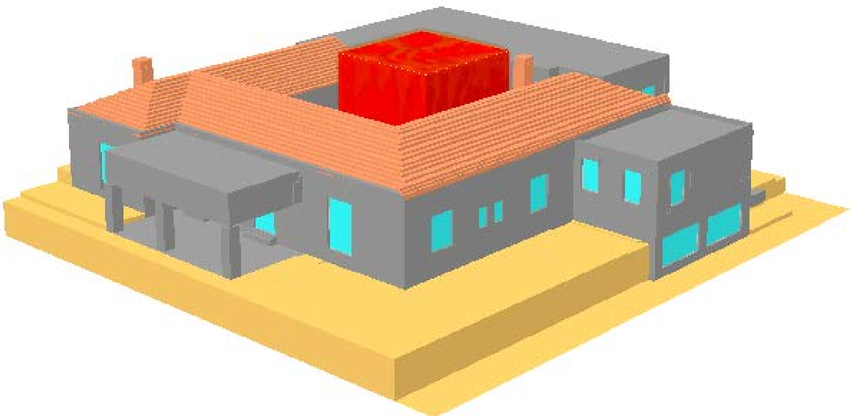


Figure 50: Los Barrancos – Scenario special problem 1 at 68 s

3.4. “Moninhos Cimeiros” community shelter study case

3.4.1. Description of the study site

The following case study is applied to a structure that is intended to be used as a community fire shelter and is located in the Moninhos Cimeiros parish council (Figueiró dos Vinhos, Leiria District), Portugal (Figure 51a). This area was affected by the large wildfire occurred in June 2017 in Pedrógão Grande (total area burned = $45.3 \cdot 10^3$ ha; 7.2 ha in the area of Moninhos). Apart from this one, six fires have been registered in the area over the last 40 years (Table 18).

Table 18. Forest fires registered nearby Moninhos Cimeiros during the last 40 years (Source: https://geocatalogo.icnf.pt/catalogo.html).

Burned area (ha)	243	44	4484	908	357	9
Year	1981	1981	1983	1990	2000	2013

Moninhos Cimeiros has about 70 structures, including houses, warehouses, parkings, etc. Many of them are in poor condition. Most of the year there are 13 inhabitants but in summer the number of people increases significantly and can reach a value of 80 people in August (Almeida, 2021). The structure to be used as community shelter is on the top of a hill at about 387 m a.s.l. It is located only 200 m away from the village and it is mainly surrounded by shrublands. The building is currently used during the festivities of the village as a stage and its current state can be seen in Figure 51b. The works to convert it into a shelter will be conducted by an architects' office from Portugal, who have already prepared the drawings of the project. This will be possible thanks to the project "Aldeias Resilientes/Abrigo Coletivo", which is coordinated by the Association of Victims of the Fire in Pedrogão Grande (AVIPG) (http://avipg.org/).

Monthly average wind velocity and direction observed at different stations near the structure are shown in Table 19. Also, average wind conditions observed during the Pedrógão Grande wildfire (Viegas et al., 2017) are included.

Table 19. Monthly average wind velocity and direction observed at different stations near the structure during the Pedrogão Grande wildfire from 2017. A. Monthly average available from www.wunderground.com; B. Average from requested hourly data; C. Pedrógão Grande fire report (Viegas et al., 2017).

Station / Fire	Year	Month	WD	WS - average (km/h)
Penela[A]	2019	June	WNW	6.1
	2019	July	WNW	6.4
	2019	August	WNW	6.8
	2019	September	SSE	5.6
	2018	June	WNW	6.0
	2018	July	WNW	6.1
	2018	August	WSW	5.6
	2018	September	SSW	4.7
Gramatinha[A]	2019	June	WNW	1.8
	2019	July	W	1.8
	2019	August	NW	2.3
	2019	September	WSW	1.9
IPMA 716[B]	2017	June	NWN	12.6
	2017	July	NWN	14.3
Pedrogão[C]	2017	June	Erratic	25

a) b)

Figure 51. a) Overview of the location of the shelter with respect to the Moninhos Cimeiros village; b) Current state of the structure.

3.4.2. Transferring information into a FDS model

Several type of information was used in this case study to define the FDS scenario. A sketch of the type of data and the software used is shown in Figure 52.

More specifically, Geographic Information Systems (GIS) data about elevation and landuse have been used as inputs into the simulation. GIS data were exported into FDS code using an open source plugin (qgis2fds) developed for QGIS (https://github.com/firetools/qgis2fds). &GEOM objects, the geometrical entity used in FDS for complex geometry objects, were generated with this tool.

The digital terrain model (DTM) used had a resolution of 5 m and covered a squared area of 2 km x 2 km centred in the structure. It was generated manually using ArcGIS®. A raster layer containing information about the fuel models surrounding the structure had the same resolution and extent as the DTM layer. It was dowbloaded from Instituto da Conservação da Natureza e das Florestas (http://www2.icnf.pt/portal/florestas/dfci/cartografia-dfci). The main fuel models observed around the area were timbergrass (fuel model #2) and dormant brushes (fuel model #6), according to Northern Forest Fire Laboratory (NFFL) models (Anderson, 1982).

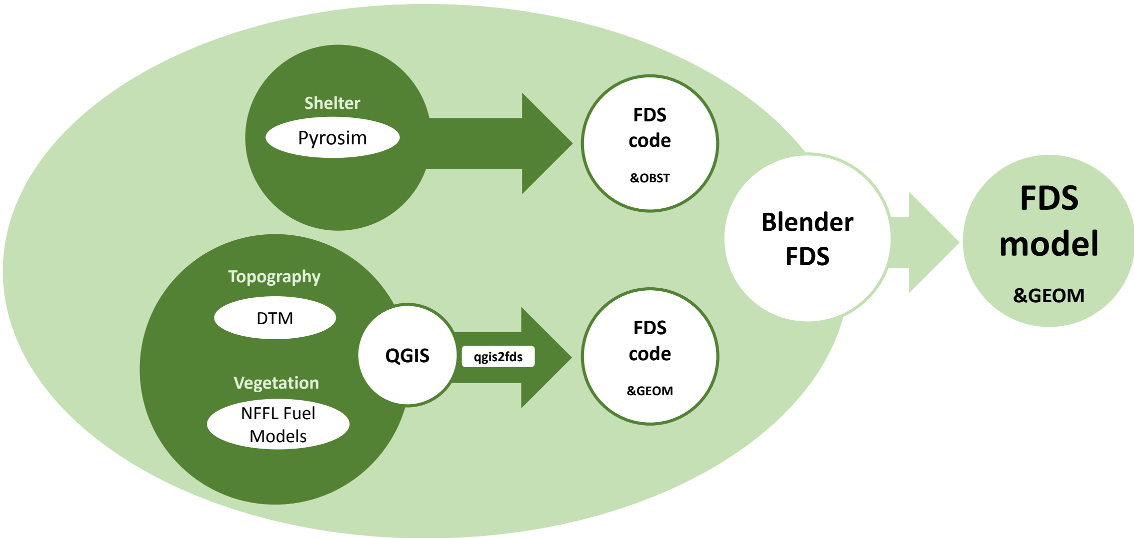


Figure 52. Sketch of the type of data and software used to prepare the FDS scenario for the Moninhos Cimeiros case study.

The structure of the shelter itself was prepared with Pyrosim software (https://www.thunderheadeng.com/pyrosim/), a licensed GUI for FDS, according to the drawings prepared by the architects (Figure 53). This information was exported into FDS code using obstructions, i.e. rectangular solids associated with the OBST namelist group of the FDS software. BlenderFDS was used afterwards to include the building volume as a &GEOM object. Since the material that will be used for the walls of the shelter is non-combustible and the resolution of GIS data was coarse, a very detailed model of the shelter was not required and the walls/boundaries of the building were finally set as inert.

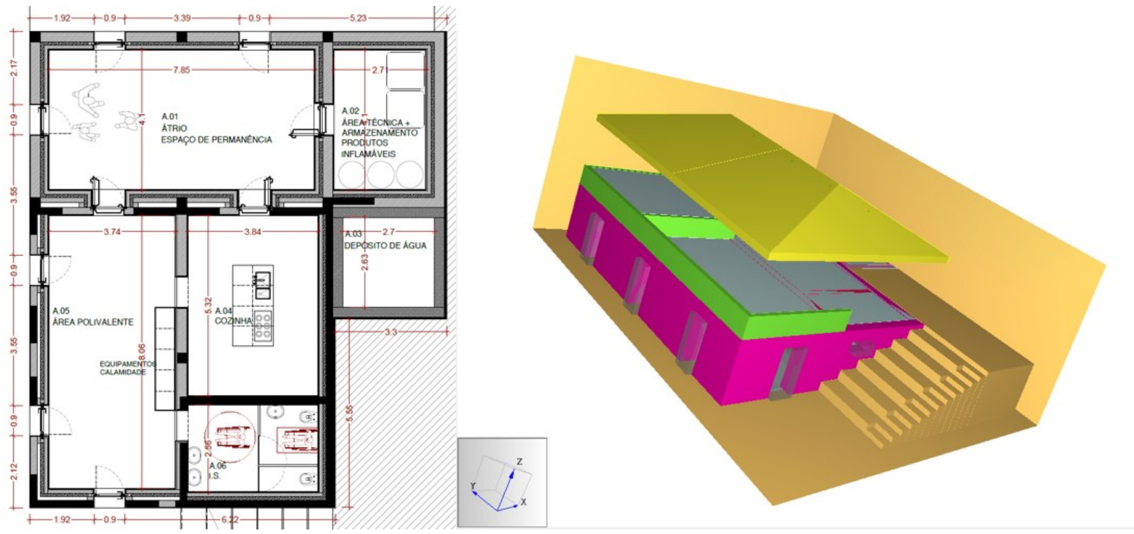


Figure 53. CAD drawing of the top view of the shelter and Pyrosim model.

3.4.3. PBD analysis

Scope, goals and objectives

The PBD analysis performed in this case study is different from the previous ones. Since the property of this case study is already designed to be fire resistant, we focus our study on the time at which tenability criteria are exceeded in the surroundings of the shelter. So, our main goal here is to improve WUI evacuation decision-making processes.

In evacuation, the level of safety is normally established through the comparison between two values (Ronchi et al., 2017):

- ASET (Available Safe Escape Time), i.e. the time at which tenability criteria are exceeded by environmental conditions.
- RSET (Required Safe Escape Time), i.e. the time taken by the evacuees to reach the shelter.

In this case study, we want to establish ASET based on the results of FDS simulations. We do not intend to perform a detailed analysis of the WUI evacuation associated to this shelter (i.e., we do not want to estimate specifically WUI timelines by addressing all aspects of the WUI evacuation), but we want to test a new toolchain where GIS tools and wildfire functionalities from FDS are included.

To achieve this we established a collaboration with E. Gissi, fire chief of the Fire Brigade of Savona (Italy) and researcher of the WUIFI-21 effort, an Italian-US project funded by the Italian Ministry of foreign affairs (https://vimeo.com/342723125). He is the developer of two basic tools dealing with GIS data and generic-shaped obstacles: qgis2fds (https://github.com/firetools/qgis2fds) and BlenderFDS (http://www.blenderfds.org).

Performance criteria

To establish ASET based on the results of FDS simulations, we calculate the elapsed time between ignition and the time at which the fire front arrives at the urban area of Moninhos Cimeiros.

Design fire scenario

- **Simple case**

Firstly, we tested a simple scenario to check that wildfire functionalities and GEOM features were correctly working in FDS. This simple scenario contained all the elements we wanted to model afterwards, i.e. several meshes, a sloped surface boundary, two types of landuse, a generic structure and the effect of wind (Figure 54a). Regarding the wind, several directions were tested to check that this effect was correctly modelled.

In this simple scenario the fire propagation method tested was the Level Set Model. This is an empirical method that reproduces the FARSITE model to simulate the propagation of the fire front (FDS, 2020). We set the Level Set Mode = 4, which means that wind and fire are coupled and that the burning of the cells when the fire front arrives is considered. The simulation worked for this simple case, as it is shown in Figure 54b.

a) b)

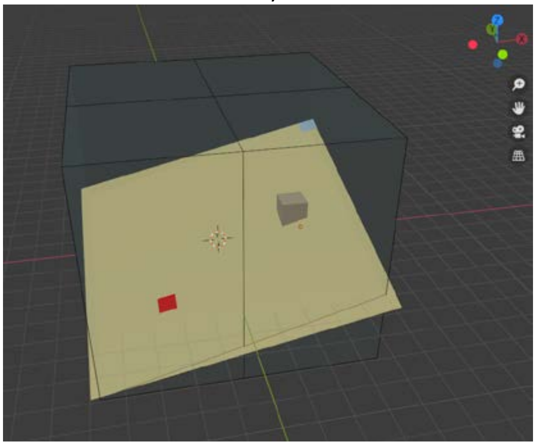



Figure 54. Views of the simple case: a) Blender; b) Smokeview.

- **Large case**

The large fire scenario was defined using elevation and landuse data, and the shelter was also included in the FDS file (Figure 55). We defined 16 meshes to cover all the domain (972,000 total cells; coarse cells; ~10 m cell size).

A wind blowing northwesterly (NW), the predominant wind direction within the area, was specified. A wind velocity of 10 m/s (33 km/h > 25 km/h (i.e., Pedrogão Grande wildfire wind speed)) was set to test worst case conditions we could expect during the local wildfire season.

The ignition point was positioned at the NW corner of the domain in order to maximize the propagation length of the fire. The distance between the ignition point and the shelter was of around 1 km.

We tested the Level Set Mode = 1, which means that the wind is not affected by the terrain and there is no fire (FDS, 2020) and the simulation worked. We also tried to test Level Set Mode = 4, but the simulation crashed due to numerical instabilities after 700 s.

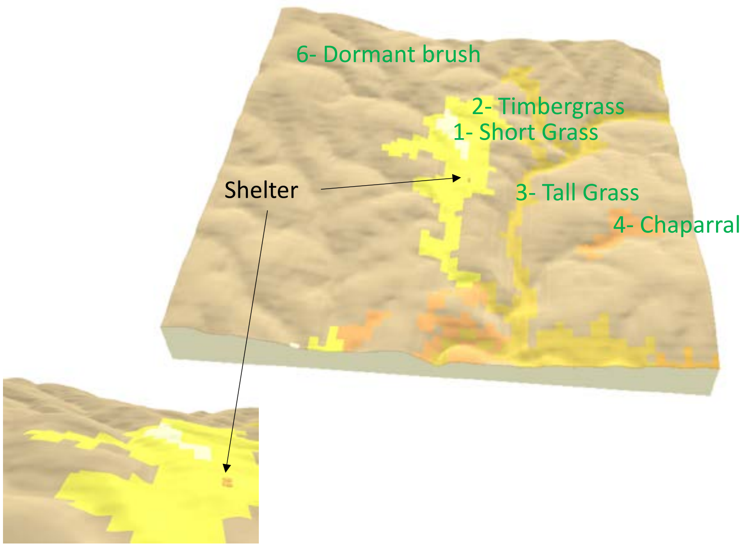


Figure 55. Smokeview visualization of elevation, landuse (fuel models identified within the domain are specified) and shelter location.

3.4.4. Results

Based on the results obtained from the large scenario test, we could estimate an ASET value based on the fire front arrival of 25-33 min (Figure 56). We considered the time at which the fire front arrived at the border with the first white cells (short grass; urban area of Moninhos Cimeiros) (25 min) and the time at which the fire front arrived close to the shelter location (33 min).

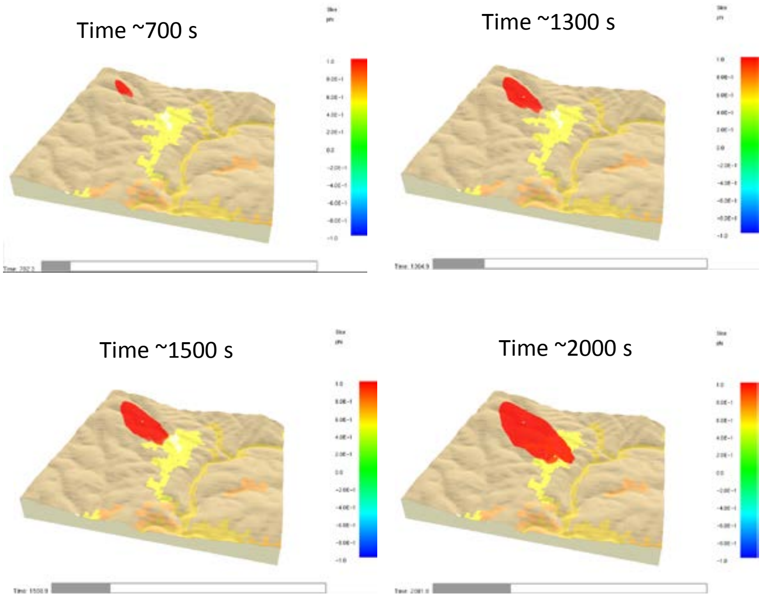


Figure 56. Burned area at different times for the large scenario.

3.4.5. Further steps

Due to numerical instabilities and geometry issues we could not simulate fire propagation considering the burning of the cells when the fire front arrives (Level Set Mode = 4) for the large scenario. These issues have to be handled and FDS developers are considering this case study to solve them. Once they are solved, the toolchain proposed seems promising to establish WUI ASET values.

Therefore, this is a work-in-progress and our main further steps include the following ideas:

- We want to set ASET values based on different performance criteria (apart from fire front arrival) and analyze the differences. Other criteria that we want to consider are the following ones:
  (1) Visibility levels around the area where the evacuees live. There may be different local codes and standards that dictate different visibility values, depending on the own view on risk tolerance.
  (2) Radiant heat flux around the area where the evacuees live reach the critical value of 1.7 kW/m^2 (SFPE, 2016). It is critical that evacuees are not exposed to radiant heat flux during their journey to the shelter because even a short period of exposure to low levels of radiant heat can cause significant burning (ABCB, 2014).
- We also want to analyse the influence of the ignition point location and of meteorological conditions.
- We need to establish a methodology for the definition of relevant scenarios according to stakeholders experience.

- We want to include the houses from Moninhos Cimeiros into the FDS model. We want to use OpenStreetMap (OSM), a collaborative project to create a free editable map of the world (https://www.openstreetmap.org). We have already done part of this work by inserting in OSM polygons representing each individual property of Moninhos Cimeiros based on ESRI imagery available. We have also indicated the type of construction and whether it had more than one floor. Individual properties will be imported afterwards into QGIS and afterwards into BlenderFDS.

3.5. "Toltorpsdalen" property study case

3.5.1. Description of the study site

The selected property for PBD analysis is located in Toltorpsdalen, Göteborg, Sweden. The structure constitutes a typical single-family Swedish housing unit, with timber façade cladding and tile roof. The main entrance is connected to a wooden porch. The main structure is centralized in the garden property and a garage/workshop is located at the property border, 7 m from the main building (Figure 57).

Figure 57. The Göteborg PBD case study: overview and photo of the neighbourhood.

Garden vegetation is sparse. The lawn is well maintained, and a pebbled walkway surrounds the entire structure. However, hedges of different species surround the entire property. Swedish whitebeam (*Sorbus intermedia*) marks the property border towards the street, whilst a wild-grown, partly dead row of Northern white cedar (*Thuja occidentalis*) demarcates the property on its eastern border to the neighbouring structure (Figure 58).

Figure 58. Photos of the Thuja Occidentalis hedge row and garage.

The property has no direct boarder to wildland but the next property does. It boarders to the forested area Ängårdsbergen, which comprise of 400 ha of mixed forests and heather. There is a steep slope from the forest towards the neighbourhood of the study site.

Figure 59. The surrounding wildland with mixed forest and patches of Calluna.

The study focuses on a fire in the hedgerow starting from the edge at the street. As it spreads the hedge threatens the garage, the dwelling and also the neighbouring house further along the hedge (top left corner in Figure 57 – middle). The garden to the top left of the same figure is not well managed and often contains tall grass and different deciduous shrubs.

Figure 60. The neighbouring garden through which the partially dead hedge continues.

3.5.2. Transferring property characteristics into a Pyrosim model

The model was built directly in Pyrosim from distances measure by hand on site and from the map service provided by the Swedish company Eniro. All thermal properties of the building materials (timber, tiles, stone, glass) are extracted from the WUIVIEW database (D4.3). The design of hedge is discussed in the following section. The neighbouring houses are defined as inert to save computing time. A fuel pack of timber and plastics were located behind the garage (Figure 61).

The simulations are done using a mesh size of 0.0625 m around details such as windows, eave, porch etc. and 0.25 m on larger volumes (Figure 61). A coarser mesh of twice the length (8 x volume) is also constructed and run in order to check grid size stability.

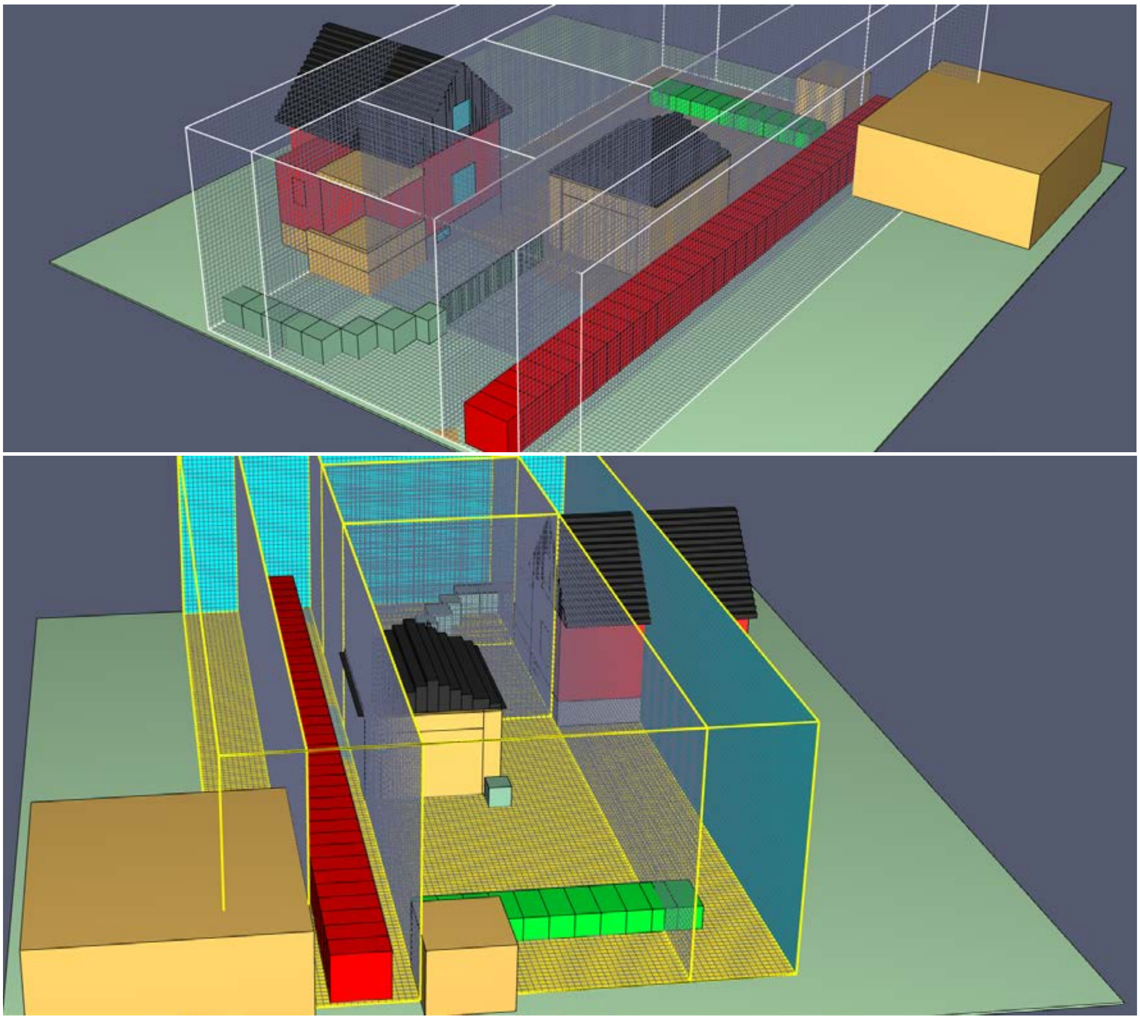


Figure 61. The geometrical model and the meshes used for the simulations, front (top figure) and back (lower figure) view, Scandinavian case study.

In addition, separate simulations were done for scenario 1 using a refined version of the porch as well as roofs in a straight slope to investigate if detailing in the geometry had an impact on the results (Figure 62). The geometry was in this case constructed in a CAD software and imported to Pyrosim.

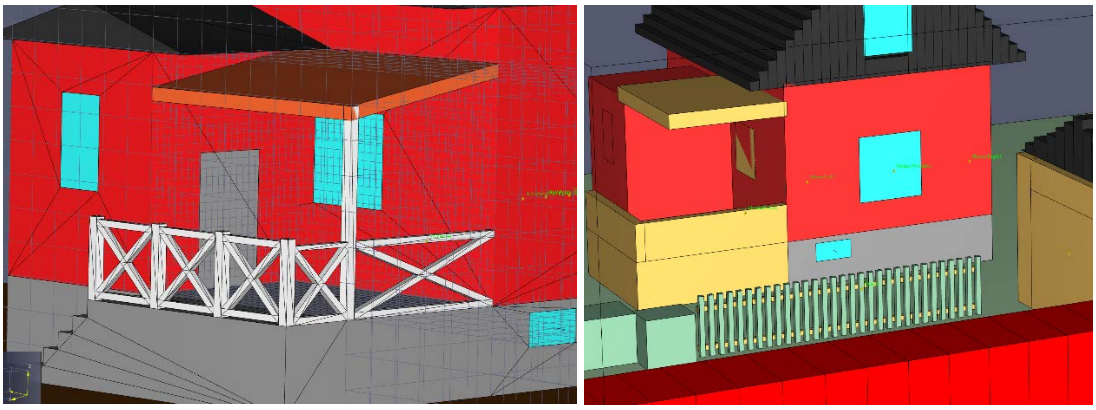


Figure 62. (Left) The detailed geometry of the porch and straight slopes of the ceiling for simulation 1. (Right) The simplified geometry for all scenarios including the fence between the hedge and porch, Scandinavian case study.

3.5.3. PBD analysis

Scenarios

The scenario studied for the case in Sweden, representing a fire danger (described by the Canadian Forest Fire Danger rating System, Stocks et al, 1989) that for all forest fires > 10 ha constitute the 80th percentile for FFMC, 90th percentile for DMC and 75th percentile for DC (Sjöström & Granström, 2020). Two scenarios with a relative air humidity of 40% and a 10-meters average wind speed of 4 m/s are simulated. One scenario is for wind blowing parallel to the hedge and the other scenario is for the wind direction in a 45° angle towards the house. Another scenario with an average wind speed of 6 m/s is also simulated. The parameters are summarised in Table 20.

Table 20. Parameters for the Swedish case study for the hedge fire

Parameter	Value		
FFMC	91.8 (yesterday 92)		
DMC	74.6 (70)		
DC	258 (250)		
ISI	11.2		
BUI	86.4		
FWI	31.6		
RH	40 %		
Temp	26 °C		
Wind speed	4 m/s (14 km/h)	6 m/s (22 km/h) 45°C	4 m/s (14 km/h) 45°C
Slope	0°		
Initial (1min) rate of spread of fire along hedge.	0.40 m/s (24 m/min)	0.31 m/s (18.5 m/min)	0.35 m/s (20.8 m/min)
Flank hedge rate of spread	0.0092 m/s (0.55 m/min)	0.31 m/s (18.5 m/min)	0.35 m/s (20.8 m/min)
Total heat release	1000 MJ/m (Schults Baker, 2011; White, 1996)		
Residence time	90 s (Schults Baker, 2011)		
Time to peak	20 s (White, 1996)		
Max HRR (per unit length)	5.56 MW/m		

For the spread rate along the hedge we use the Canadian Forest Fire Behavior Prediction System (FBP) (Forestry Canada, 1992). Since this kind of hedge is non-existing in the FBP fuel models we use a conifer plantation with 0.5 m distance from ground to crown. For the scenarios with 45° angel of the wind direction the wind speed is scaled by sin(45°).

The actual burning of the hedge uses empirical results from Schultz Baker (2011) and White (1996) in which Douglas fir trees of up to almost 4 meters are burnt in laboratory. The total heat release from 3 meters tall trees were in the order of 1 000 MJ with a rate reaching its maximum just after 20 s from substantial initiation of the flames. The total residence time is 90 minutes long and we use the previously tested simplification of a triangular HRR for the trees (Schultz Baker, 2011). Assuming one tree per meter length of the hedge gives us the following curve of the HRR per meter if ignition occurs at t = 0 s, Figure 63.

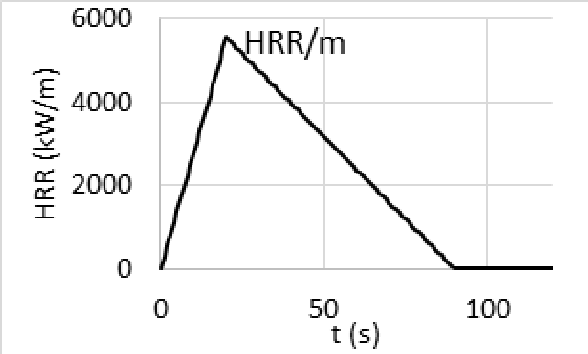


Figure 63. Heat release rate per unit length of the hedge, Scandinavian case study.

The first meter is initiated at t = 0 s and the consecutive trees (one per meter) are ignited according to the spread rates specified in Table 20.

The total HRR is smeared out uniformly on the full surface of the hedge, treated as an obstacle. However, this might hinder many of the features of the real hedge, being mostly gas permeable and partly translucent. Therefore, we shorten the 4 m height of the hedge to 1/3 of its real height to let flames pass more easily over the garden and incorporate also the burning of the side not facing the dwelling. The same is done for the smaller hedge marking the boundary to the neighbour above.

The same soot yield and radiative fraction as in the burning hedge from Entrepinos case (section 3.2) is used.

Evaluation

We evaluate temperatures in the centre and edge of the lower window facing the hedge, at the façade wall of the house to the left and right of the window, at the porch and the garage on the door and the wall facing the hedge. In addition, there are temperature devices on the wooden fence between the house and the hedge (facing the hedge) as well as on the neighbouring house and the fuel pack behind the garage.

3.5.4. Results and recommendations

The difference in temperature between the finer geometry and the simplified on (see Figure 24) is negligible as is the difference between the fine mesh and the one being twice as large, indicating that the simulated scenarios are stable with respect to mesh sizes.

The total heat release rates from the three scenarios show very high values as the total 38 m of the tall hedge and parts of the 11 m long smaller hedge are burning simultaneously (Figure 26).

Temperature slice from the three simulated scenarios are shown in Figure 27. The slices are from the moment when the fire front of the hedge reaches the level of the garage front wall. It is clear that, for scenario 1, with the wind parallel to the hedge, the fire will only affect the front of the garage and the dwelling by radiation while convective heating is possible also for scenario 2 and 3.

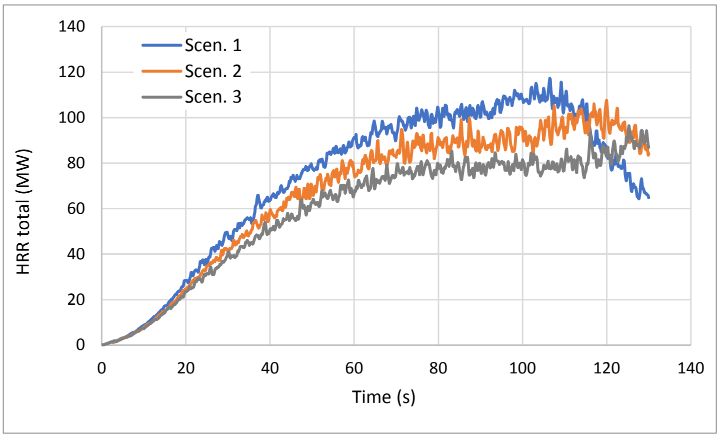


Figure 64. Total heat release rate for the three scenarios, Scandinavian case study.

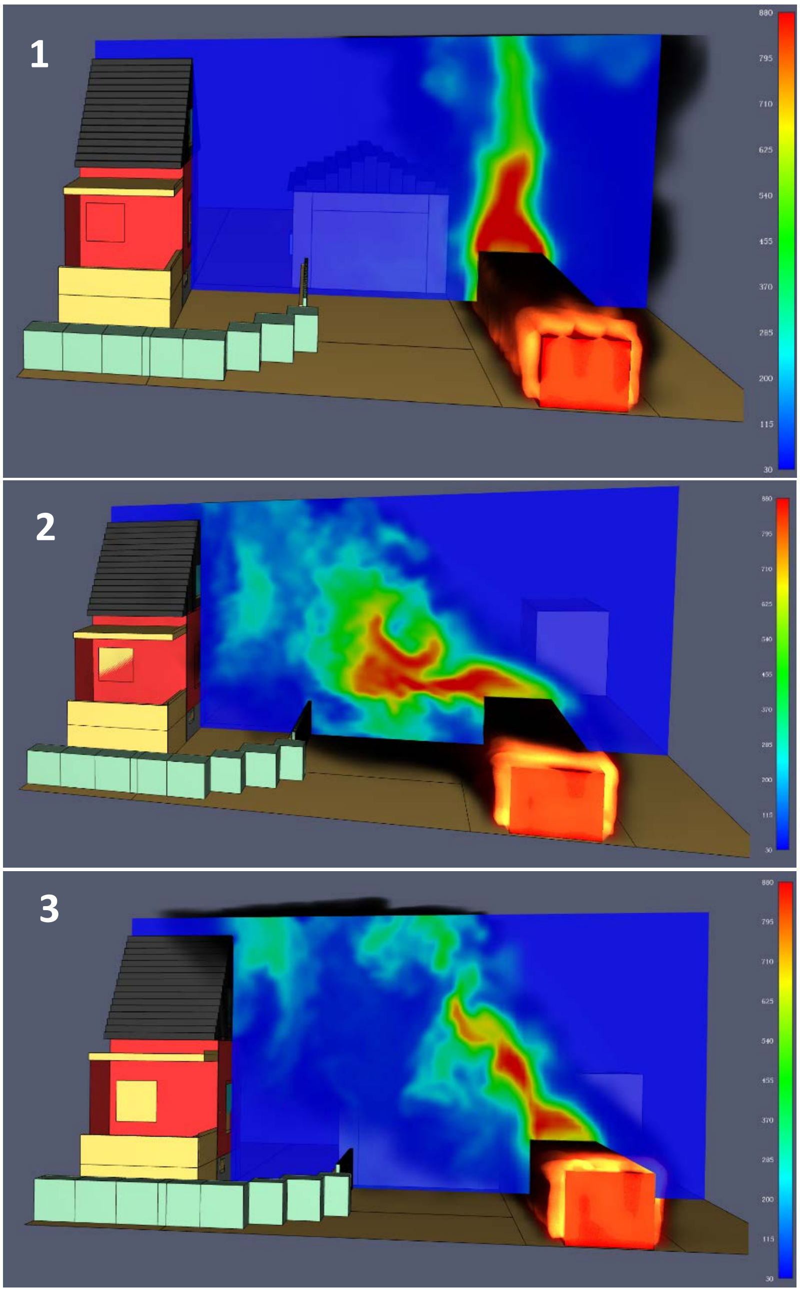


Figure 65. Temperature slices of the scenarios just as the fire front reaches the door of the garage

The temperature of the wooden façade of the main dwelling does not reach critical temperatures (300 °C) for any scenario. Thus, no significant convective heating is taking place in scenario 2 or 3 at the distance of the dwelling and the radiative output from the hedge is not sufficient to ignite the façade (Figure 66).

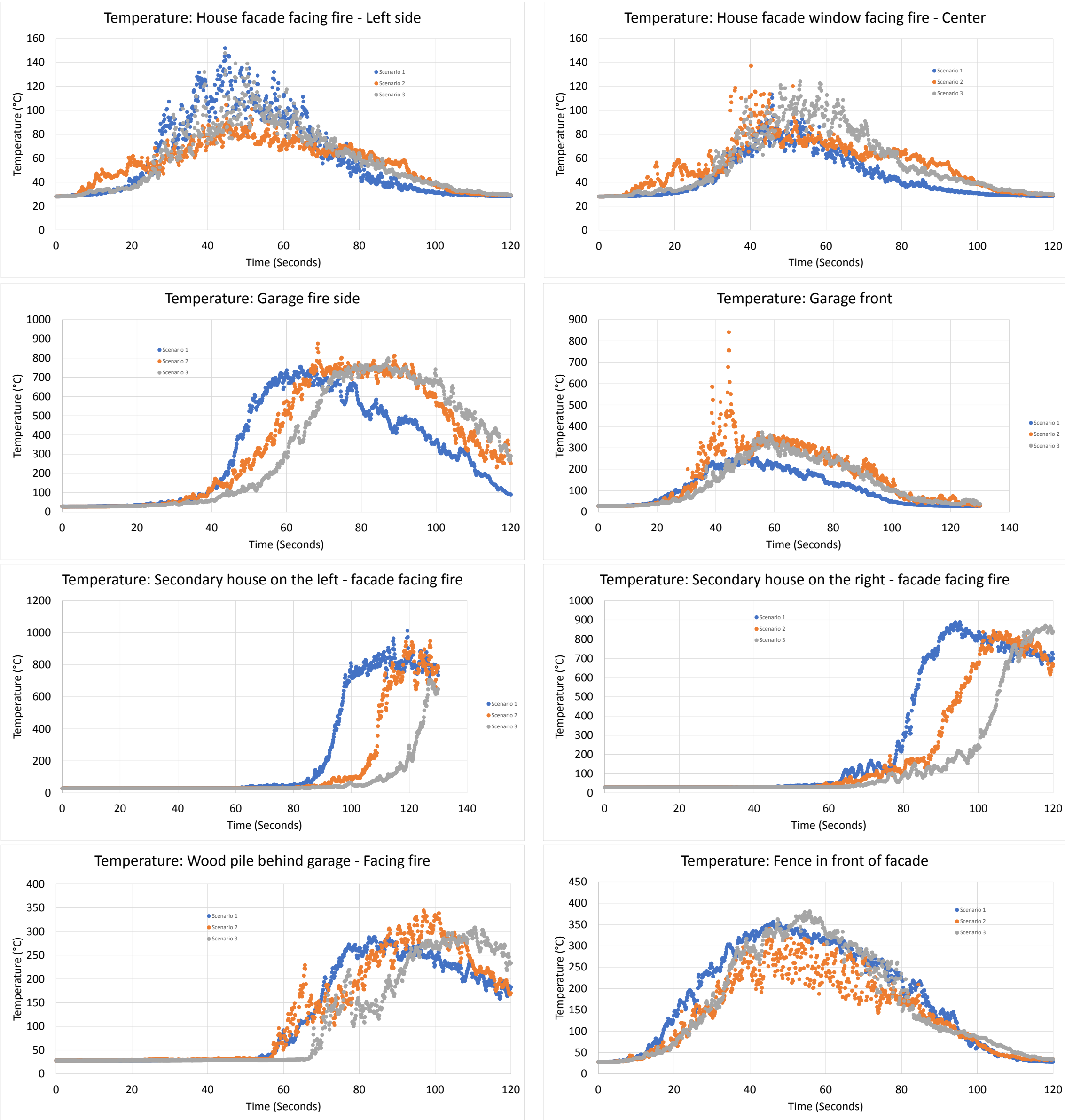


Figure 66. Temperatures outputs from the simulations, Scandinavian case study.

The temperature of the window however, is somewhat larger for scenario 2 and 3, given the higher susceptibility of convective heating for glazing materials. The temperature reaches roughly 100 °C for scenario 2 and 3 while it is limited to 80 °C for scenario 1 (Figure 66). The temperature difference criterion of ΔT = 58 °C for window breakage can be applied to this case using characteristic diffusion of heat in the window plane. Normal window glass has a thermal diffusivity of ~0.35 mm^2/s and assuming a shaded distance behind the window frame of 10 mm the characteristic time for heat diffusion is roughly 5 minutes. Thus, the <60 s until temperatures maxima in these simulations will in all three scenarios exhibit temperature differences above the breakage criteria.

Not surprisingly, the wooden façade of the garage facing the hedge will ignite in all scenarios as soon as the fire front of the hedge reaches the garage while it is not certain that the garage front side will ignite as easily. There will of course be a gradual ignition from the right to left side of the garage and the final output will be subject to detailing of the building.

The shed in the neighbouring garden to the left will ignite easily as the fire approaches, but the house to the right, having an incombustible envelope remains unknown. However, temperatures of 800 °C puts a high demand on detailing in the façade/doors/ventilations for the fire not to penetrate the envelope and reach the building interior.

The fuel pack behind the garage is not subject to guaranteed ignition from the radiation while the fence between the main dwelling and the hedge is likely to ignite in scenario 1 and 3. For scenario 2, the stronger wind, the fence is actually more cooled by the ambient air than it is additionally heated by the gases from the hedge, Figure 66.

As the simulations do not consider ember generations and ignition thereof, the outcome for the buildings are hard to predict. We can quite safely state that the hedge fire will not in itself, from radiation of convection ignite the wooden façade of the dwelling. However, it is quite clear that the windows of the main building are likely to break and that this constitute a major hazard for ignition within the building from embers that are easily generated from the partly dead conifer hedge. Also, as the garage right wall is destined to ignite the chances of a fully developed fire of the garage is likely without intervention from the fire brigade. A fully developed fire in a garage with only 4 m distance to a wooden building along the wind direction is naturally a severe scenario. The same is true for the neighbouring building, even though its incombustible façade constitute a significant robustness for ignition of the structure.

4. Concluding remarks

WUIVIEW main products (VAT and SAT checklists and PBD methodology) have been showcased using a wide variety of properties located in different European countries.

As for the self-assessment check-lists, their final format (google forms questionnaire) has proved convenient and user-friendly to check quickly (in 40 min approx.) the structure vulnerability and sheltering capacity of WUI properties. Moreover, check-list outcomes have been able to be confronted to real fire impact showing great coherence with the results of the WUI fire event.

To become an operational tool covering all sorts of WUI assets, check-lists have to be improved to include all types of WUI realities. At present, two versions have been developed, one covering Mediterranean realities and the other covering Scandinavia. However, more specificity is still needed in terms of types of WUI zones: touristic, rural, metropolitan, etc. In addition, the checklists could be adapted to other types of structures like public buildings, industrial infrastructure and critical infrastructure.

As for the PBD methodology, it has been successfully applied to different dwellings posing mainly structure survivability objectives. The impact of both wildfires and fires resulting from residential fuels have been quantified and assessed. Properties' weaknesses and vulnerabilities to fires regarding residential fuel, semi-confined spaces and glazing systems have been simulated with a high level of detail, entailing, however, large computational times. Further development is needed for ASET/RSET approaches to deal with evacuation/sheltering problem analysis, since FDS is not directly prepared for these issues.

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Annex A

A1. VULNERABILITY ASSESSMENT TOOL – MEDITERRANEAN VERSION

VAT tool rationale

A simple methodology for quick self-assessment of structures survivability has been developed. In a form of a **checklist**, eight blocks of questions are arranged following the structure of the fault tree depicted in Figure 67. The checklist provides a normalised Fire Vulnerability Index (FVI, ranked from 0 to 100) that gives an idea of the likelihood of fire entrance inside a WUI structure in case of a forest fire.

As explained in D6.1., section 2 (Vacca et al., 2020), fire can get inside a structure by five different causes (gaps through vents, gaps through the attic, broken windows, large damage in house envelope and windows left open). Weighting has been given in the same proportion to all causes in the vulnerability assessment methodology (20 points) meaning that, should these events occur individually, the chance of having fire inside a structure is the same, no matter the cause. The larger the number of possible events leading to gaps or openings, the more vulnerable the structure will be, as the probability of ember, flames or smoke entrance will be higher. For this reason, we have set a maximum value of FVI of 100, resulting from the sum of the five different possible causes set in our method. Therefore, after going through the checklist, obtaining a FVI value of 100 will be a sign of very poorly managed property, whereas a FVI value of 0 will reflect an optimum management.

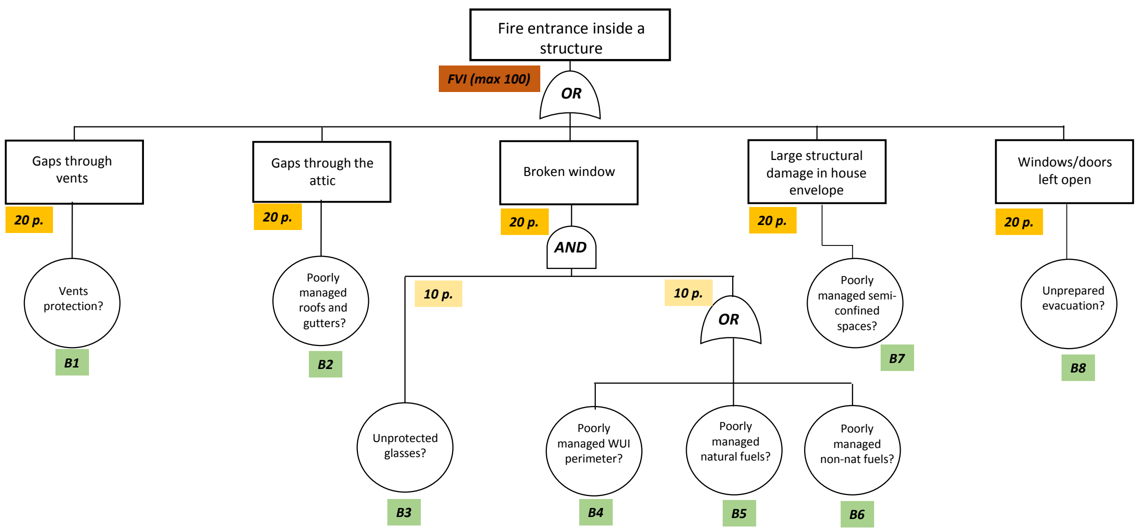

Figure 67. Logical structure of the Vulnerability Assessment Tool in the WUI microscale. Bn: Block of questions #n; FVI: Fire vulnerability index; p.: points.

VAT tool questions and scores

The score associated to each positive (YES) or negative (NO) answer is provided in the following tables and the maximum score associated to each block is also shown in the last row. Filtering questions are also indicated (i.e. some questions have to be formulated only if the previous one/s is/are positive/negative). For example, in Block 2 the responses of the first three questions condition the appearance of the other three. Auxiliary comments and images are provided to better understand the questions.

B1: Are your vents well protected in case of fire exposure?

- Ventilation openings are potential entry points for flying embers that could ignite the building from inside. Typical types of vents found in houses are roof openings for attic ventilation (e.g. vent tiles, ridge closer vents), vents in eaves, weep holes, baseboard vents and vent pipes.

- To avoid fire intrusion, vents should be screened with corrosion-resistant, non-combustible wire meshes (e.g. aluminium, galvanized steel, stainless steel, copper, intumescent coating), with a characteristic length small enough to prevent the pass of firebrands.

- International codes recommend different diameters for meshes (between 2 and 6 mm), but scientific studies provide evidences that firebrands can penetrate meshes of these diameters leading to indoor fire ignition potential.

Photo source: D. Caballero; https://ucanr.edu/sites/fire/Prepare/Building/Vents/

ID	Question	YES	NO
B1.1	Do you have unprotected ventilation openings (i.e. vents without any type of screening)?	20	0
B1.2	Are your vents protected with non-combustible corrosion-resistant materials/meshes (e.g. aluminium, galvanized steel, stainless steel, copper, intumescent coating)?	0	10
B1.3	Are your fire-resistant mesh openings less than 2 mm in characteristic length?	0	5

MAX = 20 points
(If question B1.1 is affirmative, B1.2 and B1.3 are non-applicable)

B2: Is your roof-gutters system protected in case of fire exposure?

- The roof is one of the parts of the house most exposed to the fire front radiation and eventually the landing firebrands. Roof under overhanging tree branches, particularly in the valleys or flat roofing, tend to accumulate fine fuel that can be ignited by firebrands causing undesired damage. To avoid fire damage at the roof, scientific studies and regulations agree that fire-rated materials are required for roof covering, however, roof cover is in most cases inherently safe (i.e. made of non-combustible materials) in Europe. In addition, good sealing of gaps between roof covering and decking, particularly in roof edges is also required. The shape of the roof does not have any type of consideration in standards, however, it has been scientifically proved to be a key factor in firebrand accumulation and ignition likelihood.

- Roof and gutters maintenance and cleaning are also key aspects when analysing vulnerability. Non-maintained roofs and gutters with accumulated fine fuel (e.g. debris, pine needles) increase the likelihood of fire entrance inside a structure. Burning debris in a gutter will provide a flame contact exposure to the edge of the roof.

- Regarding the constructive material of gutters, there is not a clear consensus across standards of whether gutters should be non-combustible or rather, plastic materials (i.e. PVC) should be allowed. If accumulated material is ignited, non-combustible gutters may drive the fire through the roof. On the other side, PVC gutters may melt and fall in case of fire, carrying the fire to the ground level. Gutter covers are required in all codes; however, effectiveness of these type of devices has not been scientifically proven. Research indicates that it seems to be more important to maintain gutters clean, than the material used in their construction.

Photo source: https://ucanr.edu/sites/fire/Prepare/Building/Vents/

ID	Question	YES	NO
B2.1	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.)?	0	20
B2.2	Is your fire-rated roof covering in good state? (To be in good state means that there are not missing, displaced or broken tiles; the underlying roof sheeting is not exposed; there are not unsealed spaces between the roof and the external walls or between the roof covering and the roof decking, particularly in roof edges)	0	4
B2.3	Are your roof or gutters not exposed to overhanging tree branches?	0	4
B2.4	Do you perform periodic roof maintenance?	0	4
B2.5	Does your roof present geometry favourable for the deposition of fuels and firebrands? (Is your roof flat? Are there roof valleys? Are there intersections between roofs and external vertical walls/sidings?)	4	0
B2.6	Do you perform regular cleaning of debris piling up on roof or gutters?	0	4
MAX = 20 points (If question B2.1 is negative, B2.2-B2.6 are non-applicable) (If questions B2.1-B2.3 are positive, B2.4-B2.6 are non-applicable)			

B3: Are your gazing systems protected in case of fire exposure?

- Windows are frequently one of the most exposed elements in a house to a source of heat in a forest fire, together with roofing. Broken windows and glazing systems are entry points for flying embers, potentially triggering ignition inside the house.

- Windows vary greatly in size, materials, framing, casement, glazing and opening systems. It is observed that double-glazing, reinforced glass, tempered glass and reflective glass are more resistant to radiation than laminated single pane glasses.

- If glasses are protected, screens/blinds or shutters will absorb some of the incident energy, resulting in less energy being absorbed by the glass. Shutters should be made of non-combustible material (solid core wood or metal, no PVC).



Photo source: D. Caballero

ID	Question	YES	NO
B3.1	Do you have protection for all your windows/glazing systems (i.e. shutters, blinds) made of non-combustible materials (solid core wood fire-resistant, metal like aluminium)?	0	5
B3.2	Are your glazing systems double or made of fire-resistant tested material (e.g. tempered glass) or have a thickness ≥ 6 mm?	0	5
MAX = 10 points			

B4: How vulnerable is your structure due to the vicinity of wildland fuels? (*)
(*) *Answer this block if your property is located at the fringe of a WU-interface or at the WU-intermix*

- Location of the lot where the house is installed in the landscape plays a key role in the type, extension and intensity of exposure to flame fronts, fire embers and smoke. Houses placed midslope, ridges or hilltops are potentially more exposed than those located in the lower parts, wide valleys or flat terrain.

- All standards dealing with the WUI fire problem include prescriptions regarding wildland fuel management around WUI settlements or structures to reduce fire intensity. Accepted knowledge on wildfire behaviour indicates that, to achieve a significant reduction of a fire-front intensity, it is necessary to avoid any type of crowning activity and to reduce the surface fuel load up to a certain level.

- Recommended treatments focus on breaking vertical and horizontal fuel continuity with different levels of demand depending on how and where the structure is installed in the landscape.

Photo source: D. Caballero

ID	Question	YES	NO
B4.1	Do you have a fuel-managed area around your settlement (in case of WU-interface) or your property (in case of WU-intermix) well maintained? To answer affirmatively this question take into consideration the following criteria: - *In case of structures located midslope, ridges or hilltops:* fuel-managed ring of at least 50 m from the foundation of the structure, separation between crown trees/high shrubs of at least 8 m, lower tree branches pruned at ⅓ of tree height, low surface fuel load of 10 cm depth maximum. - *In case of structures located in flat terrain:* fuel-managed ring of at least 30 m, separation between crown trees/high shrubs of at least 6 m, lower tree branches pruned at ⅓ of tree height, low surface fuel load of 10 cm depth maximum	0	10
			MAX = 10 points

B5: Do you have your ornamental vegetation properly managed?

- Ornamental vegetation must be properly selected, placed and managed to minimize impact at property level in case of fire. Recommendations to reduce fire hazard of residential vegetation are generally established within the first 10 meters around the house.

- Management actions focus on breaking litter layer continuity, maintaining separation distances between ornamental trees and selecting fire resistant species (pittosporum, plumbago, scarlet firethorn, wall germander, etc.).

- Special attention is devoted to ornamental hedgerows, that if aligned with slopes and main winds, can drive the fire through neighbouring properties.

Photo source: D. Caballero

ID	Question	YES	NO
B5.1	Do you have a 10-m wide area around your structure with ornamental vegetation properly managed? To answer affirmatively this question, the following conditions have to be met: - Fire-resistant species (for trees or shrubs) or separated 6 m - Trees/hedges separated at least 4 m from any glazing system - Non-continuous litter layer - Hedges not aligned with wind or main slopes - No presence of dead fuels	0	10
			MAX = 10 points

B6: Do you have your non-natural fuels properly managed?

- Non-natural fuels are all type of materials and objects located around the house which may eventually entail combustion. These include outdoor furniture, stored materials, gas canisters, small sheds, wood piles, etc., which have the potential to keep burning for a long time after the main fire front passes, and eventually reaching high intensities.

- Particular attention has to be paid at domestic Liquified Petroleum Gas (LPG) infrastructure. When exposed to a fire, LPG tanks will heat up and pressurize. If the tank pressure reaches the Pressure Relief Valve (PRV) set point, this will open, releasing LPG that will immediately ignite forming a jet fire, which will worsen the heat load to the tank and its surroundings. In the worst case it may evolve into an explosion (BLEVE) and the ignition of surrounding objects.



Photo source: D. Caballero; E. Planas

ID	Question	YES	NO
B6.1	Are there any non-natural fuels (e.g. outdoor furniture, stored materials, gas canisters, small sheds, wood piles) located within 5 m from vulnerable structure elements (e.g. doors or windows, gutters)?	5	0
B6.2	Are there any combustible materials (including ornamental vegetation, storage spaces, or combustible eaves) located within 2 m from LPG tanks? *(*) Answer this question only if you have LPG tanks.*	5	0
			MAX = 10 points

B7: Do you have semi-confined spaces properly managed?
(*) *Answer this block only if your property has semi-confined spaces*

- Semi-confined spaces are areas that are partially open, such as those located under terraces, porches, decks, eaves or canopies, or the spaces enclosed in open sheds and warehouses.

- The presence of combustible materials in such spaces entails large heat accumulation should these materials be ignited, leading potentially to structural damage of the envelope of the semi-confined space.



Photo source: D. Caballero

ID	Question	YES	NO
B7.1	Is there combustible material in any semi-confined space adjacent to your house?	10	0
B7.2	Are there openings (e.g. windows, doors) connecting the house to any semi-confined space with combustible material?	5	0
B7.3	Are the walls of the house connecting to the semi-confined space with combustible material made out of concrete or bricks (20 cm thick minimum)?	0	5
			MAX = 20 points (If question B7.1 is negative, B7.2-B7.3 are non-applicable)

B8: Are you properly prepared for an evacuation?

- When threatened by a wildland fire, the safest option usually considered is an early evacuation, if it is possible and the evacuation route is not cut-off by smoke or flame front. But before leaving the house, some precautions may be observed.

ID	Question	YES	NO
- Houses left with open windows, which is frequent in last-minute, unprepared evacuations, are exposed to the entrance of fire embers and flames, potentially entailing the destruction of the house. Windows must be shut and taped from the inside, so that they may remain in place if broken. Also, inner fuels close to windows have to be removed to minimize risk.			
B8.1	Would you be capable of shutting all the doors and windows before leaving, tape your windows from the inside so that they remain in place if broken?	0	20
			MAX = 20 points

VAT tool processing of responses on form submission

The following lines of code have been used to process responses from the VAT questionnaire and send an email to the respondent and surveyor on form submission. The Google Apps Script platform has been used. A similar function has been implemented for SAT and VAT-Scandinavian.

```
------------------------------------------------------------------------------------------------------------------------
/**
 * This trigger has to be created only once; afterwards the corresponding line has to be commented (here it is already created, so it is commented).
 */

var sheet = SpreadsheetApp.openById("16_xfX7WgrupceZGeOS4k66OtjjxnwtptW3aNnLN1utY");
ScriptApp.newTrigger("scoresVAT")
  .forSpreadsheet(sheet)
  .onFormSubmit()
  //.create();


/**
 * Includes scores for each question, sums up per blocks and sets sending email action.
 */
function scoresVAT(){
  // Get the responses range
  var ss = SpreadsheetApp.getActiveSpreadsheet();
  var ss = SpreadsheetApp.openById("16_xfX7WgrupceZGeOS4k66OtjjxnwtptW3aNnLN1utY");
  var sheet = ss.getSheets()[0];

  // The last row is detected, i.e. the last form submitted
  var lastRow = sheet.getLastRow()
  Logger.log(lastRow)

  // var activeRange = sheet.getRange('M2:AF2');
  eval("var activeRange = sheet.getRange('N" + lastRow + ":AG" + lastRow + "');");
  activeRange.activate();

  var scoreRange = activeRange.offset(
    0, 21, activeRange.getHeight(), activeRange.getWidth());

  // Get the current values of the selected response column cells.
  // This is a 2D array.
  var responseValues = activeRange.getValues();
  var scoreValues = scoreRange.getValues();

  // Create a variable of logical responses with scores
```

```
 var responseLogicalScore = ["YES", "NO","NO","NO","NO","NO","NO","NO", "YES",
"NO","NO","NO","NO","NO","YES", "YES", "YES", "YES", "NO", "NO"];

 // Create a variable of scores for responses
 var responseScore = [20,10,5,20,4,4,4,4,4,4,5,5,10,10,5,5,10,5,5,20];

 // Update values according to response
 for (var col = 0; col < 20; col++){
 //  var col = 1

   for (var row = 0; row < responseValues.length; row++){
   //Logger.log(row)
     var responseQuestion = responseValues[row][col];

     Logger.log(responseQuestion)

     if(responseQuestion == responseLogicalScore[col]){
       scoreValues[row][col] = responseScore[col];
     }
     else {
       scoreValues[row][col] = 0;
     }
     //Logger.log(scoreValues)

    // Put the updated values back into the spreadsheet.
    scoreRange.setValues(scoreValues);
   }
 }
 Logger.log(scoreRange)


 //Get final score
 var scoreTotal = 0;
 for (var col = 0; col < 20; col++){
   scoreTotal += scoreValues[0][col];
 }
 Logger.log(scoreTotal)

 //Get B4B6 score
 var scoreB4B6 = 0;
 for (var col = 12; col < 16; col++){
   scoreB4B6 += scoreValues[0][col];
 }
 Logger.log(scoreB4B6)

 if (scoreB4B6 > 10) {
   scoreTotal = scoreTotal - (scoreB4B6 - 10);
   scoreB4B6 = 10;
```

```
  }
  Logger.log(scoreTotal)

  //Get B1 score
  var scoreB1 = 0;
  for (var col = 0; col < 3; col++){
    scoreB1 += scoreValues[0][col];
  }
  Logger.log(scoreB1)

  //Get B2 score
  var scoreB2 = 0;
  for (var col = 3; col < 10; col++){
    scoreB2 += scoreValues[0][col];
  }
  Logger.log(scoreB2)

  //Get B3 score
  var scoreB3 = 0;
  for (var col = 10; col < 12; col++){
    scoreB3 += scoreValues[0][col];
  }
  Logger.log(scoreB3)

  var scoreB3B6 = scoreB3 + scoreB4B6;

  //Get B7 score
  var scoreB7 = 0;
  for (var col = 16; col < 19; col++){
    scoreB7 += scoreValues[0][col];
  }
  Logger.log(scoreB7)

  //Get B8 score
  var scoreB8 = scoreValues[0][19];
  Logger.log(scoreB8)


//////
  var startRow = lastRow; // First row of data to process
  var numRows = 1; // Number of rows to process
  // Fetch the range of cells C3:D3
  var dataRange = sheet.getRange(startRow, 3, numRows, 2);
  // Fetch values for each row in the Range.
  var data = dataRange.getValues();
  Logger.log(data)

  // Fetch the range of cells L3:L3
```

```
  var dataRange = sheet.getRange(startRow, 12, numRows, 1);
  // Fetch values for each row in the Range.
  var emailSurveyor = dataRange.getValues();
  Logger.log(emailSurveyor)

  var emailAddress = data[0][1] + ',' + emailSurveyor[0][0] + ',' +'alba.agueda@upc.edu'; // First
column
  Logger.log(emailAddress)

  var responderName = data[0][0];
  Logger.log(responderName)
  if (responderName.length == 0) {
    var responderName = 'respondent';
  }


  var message = 'Dear ' + responderName + ',\n\n' + 'You have filled the Vulnerability Assessment
Tool (VAT) form. Your final score is: ' + scoreTotal + '/100' + '\n\n' +
  'Please take into account the scores of the five blocks:' + '\n\n' + 'B1 (Gaps through vents): ' +
scoreB1 + '/20'+
  '\n' + 'B2 (Gaps through the attic): ' + scoreB2 + '/20' + '\n' + 'B3-B6 (Broken window): ' +
scoreB3B6 + '/20' +
  '\n' + '    - B3 (Unprotected glasses):' + scoreB3 + '/10' +
  '\n' + '    - B4-B6 (Fuels management):' + scoreB4B6 + '/10' +
  '\n' + 'B7 (Large structural damage in house envelope): ' + scoreB7 + '/20' + '\n' + 'B8
(Windows/doors left open): ' + scoreB8 + '/20' +
   '\n\n' + 'Please, continue filling in the Sheltering Assessment Tool (SAT) questionnaire:
https://forms.gle/ZaXtha8ApWhmEGgX9' +
  '\n\n' + 'Thank you!';

  var subject = 'WUIVIEW - VAT Form Score';
  var emailCheckSent = 'sent';

  var flag = sheet.getRange(lastRow, 54 + 1).getValue()
  if (flag === 'sent') {
  }
  else {
    MailApp.sendEmail(emailAddress, subject, message)
    // mark the cell as sent
    sheet.getRange(lastRow, 54 + 1).setValue(emailCheckSent);
  };

}
```

A2. SHELTERING ASSESSMENT TOOL

SAT tool rationale

A simple method for sheltering assessment is herein provided. For a successful shelter-in-place action, homeowners should have a certain physical and mental fitness to cope with the situation that sheltering in case of an approaching fire may represent (e.g. stress, anxiety, heat, smoke, noise, etc.). In addition, actions to get immediately prepared and respond accordingly have to be feasible and well known for successful sheltering. It is also required that houses offer enough sheltering capabilities provided their degree of survivability is high when exposed to fire.

These three requirements (i.e. physical and mental fitness, preparedness/response and structure endurance) are the basis of our sheltering assessment logic (Figure 68). For a successful sheltering, the assessment of three blocks of questions related to each requirement (B1-B3 in Figure 68) has to be individually affirmative, i.e. if any of these requirements cannot be reached, sheltering will most likely be an unreliable option.

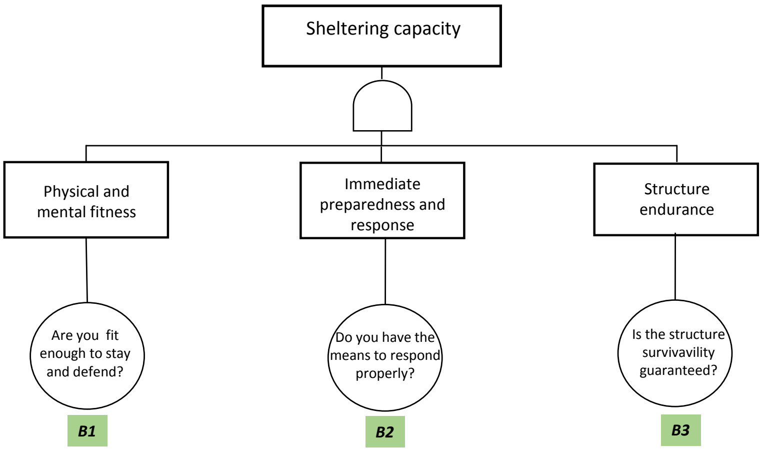

Figure 68. Logical structure of the Sheltering Assessment Tool in the WUI microscale. Bn: Block of questions #n.

SAT tool questions and scores

A score of 5 has been assigned to each affirmative question. This way, only a total score of 45 is set to be adequate to guarantee sheltering in place. If the total score is lower than 45 sheltering will most likely be an unreliable option. There are auxiliary comments to provide a better understanding of questions.

Questions in blocks 1 and 2 are similar to action checklists from South Australian Country Fire Service (https://www.cfs.sa.gov.au/site/resources.jsp).

B1: Are you fit enough to stay and eventually defend your property?			
- Population deciding to stay in place in case of fire should have a certain physical and mental fitness to cope with the situation that sheltering in case of an approaching fire may represent (e.g. stress, anxiety, heat, smoke, noise, etc.) *- Sheltering in place may eventually involve active defence actions (e.g. firefighting of spot fires) and protective actions towards family and pets.*			
ID	**Question**	**YES**	**NO**
B1.1	Are you mentally, physically and emotionally able to cope with the intense smoke, heat, stress and noise of a wildfire while defending your home?	5	
B1.2	Are you physically fit to fight spot fires in and around your home?	5	

B1.3	Will you be able to protect your home while also caring for members of your family, pets, etc.?	5	

B2: Do you have enough means to respond properly when the fire is approaching?			
- Actions to get immediately prepared and respond accordingly have to be feasible and well known for successful sheltering.			
ID	**Question**	**YES**	**NO**
B2.1	Can you patrol the inside of the home as well as the outside for embers or small fires?	5	
B2.2	Can you prepare the inside of your home (e.g. remove curtains, move furniture away from windows, tape windows from inside so they remain in place if broken)?	5	
B2.3	Do you have a supply of fresh water available to keep hydrated?	5	
B2.4	Are you able to estimate which openings (windows, doors) may influence at most hot gases propagation pathways inside the house depending on fire front position?	5	
B2.5	Do you have the necessary clothes and properly maintained equipment to effectively fight a fire?	5	

B3: Is your structure survivability adequate?			
- Mediterranean type of houses may offer enough sheltering capabilities provided their degree of survivability is high when exposed to fire. This block is linked to the WUIVIEW Vulnerability Assessment Tool (VAT).			
ID	**Question**	**YES**	**NO**
B3.1	Does your structure have a high chance of survivability according to VAT (vulnerability assessment tool) checklist (FVI ≤ 20)? (*)	5	
(*) A threshold value of Fire Vulnerability Index (FVI) ≤ 20 is considered in here for an affirmative answer. An FVI of 20 means that there is at least 1 out of 5 possibilities of fire entrance inside the structure due to possible gaps. If Blocks 1 and 3 are affirmative, a value of FVI = 20 is considered manageable.			

A3. VULNERABILITY ASSESSMENT TOOL – SCANDINAVIAN VERSION

The questionnaire provides a normalised Fire Vulnerability Index (FVI, ranked from 0 to 100) that gives an idea of the likelihood of fire entrance inside a WUI structure in case of a forest fire.

It is considered that fire can ignite a structure in three ways:

(1) direct flame impingement; (2) radiation exposure; and (3) ember intrusion.

Due to the vast amount of wood products in Swedish buildings and gardens and evidence of continuous fuel beds carrying the flame to the structures, the FVI is weighted towards the most probable cause of ignition for Scandinavian fires, namely direct flame impingement. A larger number of vulnerable building and garden features, such as stored combustible fuel loads, yields a more vulnerable structure, as the probability of ember, flames or smoke entrance will be higher.

This questionnaire has been defined by arranging 7 blocks of questions. The considered blocks ask about the state of the structure (B1-B3), garden vegetation (B4-B5), other garden fuels (B6), and the wildland around the house (B7).

The FVI is arranged such that a value of 100 is a sign of most poorly managed property, whereas a value of 0 reflects an optimum structure and management thereof.

B1: Is your façade vulnerable to wildfire exposure?

- Combustible façade claddings are vulnerable to all types of ignition from wildfire. Even low-intensity flames may ignite a timber façade if they impinge the material.

-The connection between the façade and garden floor is object to special attention, since fires with low flame heights may be stopped by simple solutions, such as a high non-combustible building foundation or a non-combustible line of stone or pebbles. 40 cm heigh is chosen as a characteristic height from previous studies https://www.nwcg.gov/publications/pms437/surface-fire/behavior-lookup-tables#TOC-Fuel-Model-1-Short-Grass-1-ft-

Photo source: J. Sjöström

ID	Question	YES	NO
B1.1	Is your façade material entirely composed of timber?	20	0
B1.2	Is your façade material entirely composed of timber, but the lower part is protected by a ground surface border of non-combustible material, such as pebbles, or a high non-combustible building foundation (min 40 cm)?	16	0
B1.3	Is the ground floor externally covered by non-combustible cladding and the upper floor has timber façade material?	8	0

MAX = 20 points
(If question B1.1 is affirmative, B1.2- B1.4 are non-applicable)

B2: Is your roof-gutters system protected in case of fire exposure?

- In high intensity wildfires, cleaning of roof and gutters are key aspects for vulnerability. Non-maintained roofs and gutters with accumulated fine fuel (e.g. debris or pine needles) increase the likelihood of fire entrance inside a structure by embers. Burning debris in a gutter will provide a flame contact exposure to the edge of the roof. Research indicates that it seems to be more important to maintain gutters clean, than the material used in their construction.

Photo source: J. Sjöström & https://entretakstockholm.se/takpapp/

ID	Question	YES	NO
B2.1	Do you perform regular cleaning of debris piling up on roof or gutters?	0	5
			MAX = 5 points

B3: Do you have a combustible outdoor space?

- Wooden porches entail a large horizontal surface on which embers may land. Their close contact with the garden floor also makes them vulnerable to flame impingement.

-Special attention is considered for semi-confined spaces, since a roofing system on the porch may add to the fire intensity by re-radiation and additional fuel load if the porch is ignited.

Photo source: J. Sjöström & F. Vermina Plathner

ID	Question	YES	NO
B3.1	Do you have a wooden porch?	3	0
B3.2	Does your porch have a ceiling?	5	0
B3.3	Do you have combustibles stored on the porch?	2	0
			MAX = 10 points (If question B3.1 is negative, B3.2-B3.3 are non-applicable)

B4: Is your garden floor properly managed?

-The presence of a lawn is the single most important parameter for structure survivability in a wildfire, in many cases providing a defensible space between wildland fuels and the structure.

-Mowing the lawn will significantly increase the chances of structure survival.

-U.S. guidelines recommend a maximum grass length of 10 cm.

Photo source: J. Sjöström

ID	Question	YES	NO
B4.1	Do you have a managed lawn or another low-combustible surface such as pebbled ground?	0	25
B4.2	Does your managed lawn (or other low-combustible surface) surround the entire building?	0	15
B4.3	Does your managed lawn (or other low-combustible surface) surround more than half of the building?	0	5
	MAX = 25 points (If question B4.1 is negative, B4.2-B4.3 are non-applicable)		

B5: Do you have ornamental vegetation close to your building?

- Removing ornamental vegetation growing close to the façade increase structure robustness against wildfire exposure.

- Ornamental vegetation can be properly selected, placed and managed to minimize impact at property level in case of fire. International recommendations to reduce fire hazard of residential vegetation are generally established within the first 10 meters around the house. With shorter distance between burning object and structure, radiation exposure as well as ember and flame impingement increases.

- International management actions focus on breaking litter layer continuity, maintaining separation distances between ornamental trees and selecting fire resistant species (pittosporum, plumbago, scarlet firethorn, wall germander, etc.).

Photo source: J. Sjöström

ID	Question	YES	NO
B5.1	Do you have a high degree of ornamental plants within 10 m of your building? A high degree involves trees or shrubs separated less than 4 meters from each other or any glazing system.	2	0
B5.2	Are they all deciduous?	0	3
	MAX = 5 points (If question B5.1 is negative, B5.2 is non-applicable)		

B6: Does your garden contain any non-vegetation fuel?

- Non-vegetation fuel is here defined as any type of materials and objects located around the house which may eventually entail combustion. This includes car tires, outdoor furniture, wood pallets, other stored materials, gas canisters, small sheds, firewood piles, etc., which have the potential to keep burning for a long time after the main fire front passes, and eventually reaching high intensities.

-Special attention is given to (often weather-sheltered) firewood stacks stored directly against the façade. Such stacks have a large total area on which embers may land, a connection to the garden floor that enables direct flame impingement, while comprising a large amount of fuel when ignited.

Photo source: J. Sjöström

ID	Question	YES	NO
B6.1	Do you have stored fuels (<20 kg) directly to the façade?	8	0
B6.2	Do you have additional combustible material (<100 kg) or a shed within 10 m from the building?	7	0
			MAX = 15 points

B7: How vulnerable is your structure to wildfuels? (*)

(*) *Answer this block if your property is facing wildland*

- Different wildland fuel have different potential to provide a high fire intensity. Statistics show that structures with a high degree of deciduous trees surrounding the garden perimeter have a better chance of survival than structures facing pine forest.

Photo source: J.Sjöström

ID	Question	NO
B7.1	To what percentage is the garden surrounded by:	%*
	- Conifers?	20
	- Grassland or shrubs?	15
	- Deciduous trees?	5
	- Arable land?	2

The score for this question is the sum of each percentage of fuel type multiplied with the corresponding multiplier in the right column. For a structure surrounded by 50% conifers, 25% deciduous trees and 25% none of the above (e.g. a road) the score is: 0.50*20 + 0.25*5 = 11.25 points.

MAX = 20 points