ADVANCES IN FOREST FIRE RESEARCH

2022

Edited by

DOMINGOS XAVIER VIEGAS
LUÍS MÁRIO RIBEIRO

Impact of the WUI vegetation management on damage to building: comparing post-fire damage assessment and CFD modelling results.

Anne Ganteaume*[1], Bruno Guillaume[2], Bertrand Girardin[2]

[1]*INRAE, RECOVER, Aix-en-Provence, France, {anne.ganteaume@inrae.fr}*
[2]*EFECTIS, Bordeaux, France, {bruno.guillaume, bertrand.girardin}@efectis.com*

**Corresponding author*

Keywords:

Vegetation management; post-fire damage; CFD modelling; Wildland-Urban Interface

Abstract

In most Wildland-Urban Interface (WUI) fires, damage to building can result from poor vegetation management, comprising a lack of mandatory brush-clearing around building or an unwise location of trees (e.g. too close to building or overhanging the roof). It was interesting to check if post fire damage can be predicted by CFD fire modelling in different scenarios of vegetation management (treated vs untreated) according to different past-fire events. Ultimately, this work will help to assess if the fuel treatment regulation in the framework of fire prevention is efficient and to pinpoint possible limitations.

Different scenarios of vegetation treatments were tested on four study cases of dwellings surrounded by gardens juxtaposed to wildland vegetation (therefore submitted to the regulation on fuel management in WUI) that were affected by the Rognac fire in 2016 (SE France). In each case, comparisons of modelled and observed fire behaviour and impacts on buildings were performed using the Fire Dynamic Simulator model (FDS) and very accurate georeferenced ornamental vegetation mapping, especially around buildings.

Despite problems to adapt FDS modelling to the high fuel moisture content (FMC) of some species, results showed that overall brush-clearing mitigated fire intensity and propagation and therefore damage to building and ornamental vegetation, sometimes highlighting that this fuel management measure could be softened (decreasing the radius treated) or, on the contrary, strengthened according to the topography and wind. The fuel biomass treatment involving vegetation residues left on site was also found as deleterious as the lack of treatment.

Overall, the modelling using FDS, at the WUI scale and taking into account a very refined vegetation distribution, was mostly successfully validated by post-fire damage recorded during the past-fire events, which was rarely attempted in the complex environment of forest fires in the French Mediterranean area. The current scientific limitations of the model did not allowed obtaining realistic results in terms of heat flux received by the building, even if they were coherent in global intensity comparing treated and untreated vegetation, and have to be addressed in future improvements of the model.

1. Introduction

In some Mediterranean countries, the culture of fire risk has declined slowly with the decreasing trend of fire occurrence and burned area over the past decades (Fox et al. 2015). However, peaks of large fire occurrence still occur during extreme weather events (e.g. 2003, 2016 in SE France), often resulting in catastrophic fires difficult to suppress (Maditinos & Vassiliadis 2011; Jones et al. 2016). As a prevention measure in SE France, implementing the regulations on fuel reduction around housing (i.e. mandatory brush-clearing) at the wildland-Urban Interfaces (WUI) is of the upmost importance to mitigate the fire effects on buildings and to keep safer people and firefighters during a fire. However, these regulations are difficult to control and little respected, even if experience feedbacks also showed that the environment surrounding the housing (e.g. location of hedges, no fuel areas, etc.) can play an important role during WUI fires, especially on the resulting damage (Syphard et al. 2019).

In order to improve the fire prevention at WUI along identifying the different environmental factors surrounding the housing that can contribute to increase or decrease its vulnerability (usually, vegetation types, slope, and wind), it is also necessary to verify if the regulations in terms of fuel reduction are still efficient in critical scenarios of wind and slope or if they can be softened or strengthened in some cases.

Previous studies revealed that WUI fire issue is mostly due to the building susceptibility to fire rather than a difficulty to control the fire (Cohen 2000, Cohen 2008). Fire behaviour modelling is a useful alternative tool, when properly calibrated and validated, to forecast the fire intensity and propagation as well as the fire impact on building in different scenarios of vegetation, terrain, and weather conditions. Despite several fire behaviour models (Sullivan, 2009) applied to forest fires, few are used for simulation at WUI, for instance, because WUI vegetation differs from that of wildland (more heterogeneous in terms of species composition and spatial distribution; Ganteaume 2018). Only complex CFD physics-based models (e.g. the wildland-urban fire dynamics simulator WFDS, Mell et al., 2007) or raster-based models (e.g. SWIFFT, De Gennaro et al. 2017; Fernandez et al. 2018), for instance, have achieved this goal. HRR and heat fluxes received have been validated on isolated dry tree experiment (Mell et al, 2009) at the laboratory scale but there is a gap on the validation at meso scale (i.e. the scale of the garden). The current study is therefore an attempt to validate simulation results using post-fire damage.

This work aimed at comparing post-fire damage recorded during past-fires to results of CFD modelling run on different scenarios of vegetation management (brush-clearing *vs* no brush-clearing) to validate the modelling results and assess the role of the regulation on fuel reduction on the fire mitigation at WUI.

2. Material & Methods

2.1. Study cases

Three study cases of housing, located at WUI and differently affected (from partial damage to total destruction) by a large past fire event in SE France (Rognac fire that occurred in 2016 ; Fig. 1) was considered in this work. Regarding this fire, three areas have been selected: « Griffons » (community of Vitrolles) as well as « Barnouins » and « Château » (community of Les Pennes-Mirabeau). Damage recorded during post-fire surveys were used as a validation of the modelled fire behaviour and impact on buildings. According to the French regulation, buildings located at WUI were theoretically subjected to fuel reduction within a 50 m-radius. Depending on the case, this regulation was implemented, sometimes partially, or not at all. Some cases presented, around the building, an area corresponding to a garden, with ornamental lawn, trees and shrubs, others presented a home ignition zone (HIZ) composed of natural vegetation, brush-cleared or not, similar to the neighbouring natural vegetation (Table 1).

2.2. Modelling

So far, the models FDS (version 6.7.5) (Vanella et al., 2021) and WFDS developed by NIST (McGrattan et al. 2013) regarding wildfires have been validated by laboratory experiments (e.g. Mell et al. 2009, Perez-Ramirez et al. 2017 ; Morandini et al. 2019) or grass fires (Mell et al. 2007).

In this work, the inputs used for the simulations (see table 1) were :

(i) topographical data (EU-DEM-v1.1 COPERNICUS program, available with a resolution of 25m) ;

(ii) vegetation data : Vegetation was recorded with as much as precision as possible (in the field during the post-fire survey and using aerial or satellite images available before the fire), given its strong heterogeneity, according to three strata (litter and grass, understorey, and overstorey). The WUI vegetation can be composed, according to the study case, of exotic species and/or native species similar to the wildland vegetation and was managed or not according to the regulation;

(iii) wind data : the wind direction was taken from the fire-fighter reports of the events. The wind speed considered is 11 m s^{-1} on average over 5 min. The intermittent wind is modelled by a simple alternation every 15s of 2 m s^{-1} and 20 m s^{-1} (typical of the dominant wind, Mistral, in the study area).

The outputs of the modelling are the flame front position and vegetation mass loss variation at different times of simulation, and the temporal variation of the total power and of heat fluxes (located at different heights on buildings) during the simulation.

The modelling was run for each study case on the two vegetation management scenarios (with or without brush-clearing), except in the study case « Château » which was divided into three different scenarios (one of them comparing the ignition by firebrands and by flame propagation from a hedge) given the extended area damaged by the fire (Fig. 2).

3. Results and discussion

Post-fire surveys carried out in the four study cases showed a large range of damage from scorched vegetation to building destruction (Fig. 3).

Overall, the results of the modelling run on brush-cleared vegetation showed a fire behaviour less intense than when the fuel treatment was not implemented (Fig. 4), however, with a fire heat release similar during the first 10 to 20s (up to 40s in the case Château C2) according to the study case.

3.1. Griffon

Post-fire damage assessment : Only the windward house was severely burned and it sheltered the neighbouring house, which was undamaged (Fig. 3). The facade exposed to the fire was the most damaged (window with broken glass allowing the fire to impact the inside) mostly because the close by ornamental hedge acted as a vector for fire propagation. The southern hedge was burned by a surface fire fueled by the brush-clearing residues and spread the flame to the neighbouring ornamental shrubs located in the garden.

Modelling : During the first part, flames propagated further in the modality brush-cleared because the lower tree density (Fig. 5) and possibly because of the tilt angle between the flame and the slope located between the forest and the garden. Beyond 20s of simulation, the HIZ (and thus the ornamental vegetation) seems to be unaffected by the fire in this modality in contrast to the other scenario.

This study case allowed highlighting the importance of cleaning the residues after treatment. Indeed, the modality with brush-clearing, without vegetation residues, showed that the fire intensity would have been decreased avoiding the damage to the building.

3.2. Barnouins

Post-fire damage assessment : The fire propagated uphill in the brush-cleared garrigue towards the house (slope of ~50%), the damage was mostly due to a windward window that had been left open, allowing the firebands generated by the pine stand downhill to enter the building and set it on fire. A large part of the windward ornamental vegetation (located on the left of the house) was also impacted in contrast of the leeward side of the house (Fig. 3).

Modelling : Regarding the fire spread (Fig. 6), after the first 15s of simulation, the flames were more scattered in the modality with brush-clearing, especially at T0+50s and T0+65s and the tree canopy burned (higher tree mass loss), probably because of the low simulated FMC. Flux sensors located at different heights on the house windward facage, in both modalities, were quickly reached by the flames and intensities higher than 80kW m^{-2} were recorded, showing that the contribution of the vegetation, even brush cleared in this case, was significant (Fig. 7).

The heat sensor positioned the highest (13m) was strongly affected by the wind gusts. It is then possible that, even if the window had been closed, the combination between the steep slope and the strong wind could have provoked intensity to break the window pane allowing the fire propagation into the house and its destruction. With this combination of two important factors (terrain and wind), the limitation of the mandatory brush-clearing is reached, showing that the area treated should have been extended beyond the mandatory 50m.

3.3. Château

Post-fire damage assessment C1 : In this case, the fire propagated from the NNW to the SSE, first in an untreated wildland vegetation (pine stand) and reached the tall northern cypress hedge located to the South of the south-werstern building that completely burned.

Modelling : In the modality with brush-clearing, the fire propagated less intensely, limiting the spread on the flanks, therefore avoiding the cypress hedge and the other trees around the building (Fig. 8). This was due to two main factors : i) a lower intensity in all of the vegetation strata in the modelling and ii) a stronger wind in the HIZ in the modality with brush-clearing because of the lower tree density. In contrast, in the modality without brush-clearing the hedge partially burned.

In this case, the scenario without brush-clearing underestimated the fire effects on the hedge which did not totally burned, despite the simulated low FMC, unless the ignition be provoked or enhanced by the firebrand shower generated by the burning pine stand (highly likely synergy). In contrast, in the modality with brush-clearing, the fire impact on the ornamental vegetation located East of the building was low, highlighting the importance of the mandatory fuel treatment.

Post-fire damage assessment C2 : In this case, the fire behaviour was assessed when the flame front reached the northern building. The tall pine (11m) located close to the building (overhanging the roof) completely burned participating to the building destruction.

Modelling : Beyond the first 40s of simulation in the modality with brush-clearing, the fire spread in the pine stand and in the brush-cleared area but with decreasing intensity when approaching the buildings. After 45s, the tall pine was reached by the fire in both modalities but more intensively (totally burned) in the modality without brush-clearing (Fig. 9) according to the post-fire damage assessment.

In this case, the impact of the fire on the pine was moderate highlighting once more the effect of the vegetation treatment, especially in the area submitted to the dominant wind, therefore to the fire.

Post-fire damage assessment C3 : In this case, three tall trees, a cedar, a palm tree, and a linden tree, located close to the southernmost building (and partially overhanging the roof) have been impacted by the fire (the two formers having mostly or totally burned while the latter was heavily scorched), participating to the building destruction.

Modelling : The simulation presenting the fire propagation due to firebrands showed that the fire could ignite the tree canopy and spread progressively towards the ground (Fig. 10), igniting then the lower branches and the vegetation close by. This was possible thanks to local wind currents of different directions generated by neighbouring obstacles (buildings, trees, etc.) during wind gusts (i.e. 11.7 m s^{-1}). This result was not observed in the post-fire survey, especially for the linden, possibly because the higher FMC than in the modelling.

The simulation presenting the fire propagation involving the cypress hedge located to the North (Fig. 11) showed that the tall cedar burned. The fire then reach the side of the building where the linden tree was located, but without succeeding in its ignition while, at 100s, the fire ignited the southern cypress hedge. According to the post fire damage recorded, the linden tree was less impacted than the cedar, even with a lower simulated FMC. However, the synergy with the firebrand shower is also probable.

4. Conclusions

This work consisted in implementing the CFD model FDS on three different study cases impacted by a past fire event and comparing the results to the post-fire damage recorded in the field for validation. For each case, two scenarios of vegetation management were tested (brush-clearing *vs* no brush-clearing). Simulations results could mostly be validated by the post-fire survey and underlined once more the relevance of the fuel reduction measures in terms of fire mitigation. In some cases, they highlighted the necessity to strengthen this regulation. This work also proved the functional capacities of the model used to assess the fire behaviour at the WUI scale despite the bias inherent to the model, mainly regarding the simulated FMC, which was lower than in the field. This hypothesis is common to all of the calculation codes (e.g. Swifft, WFDS, etc.) and cannot be by-passed in the current state of knowledge

5. Acknowledgements

This work was funded by the French Ministry of Environment (Ministère de la Transition Ecologique) and by the Interreg program Marittimo InterMed IT-FR Maritime.

6. References

Cohen J (2000) Preventing disaster: Home ignitability in the wildland-urban interface. Journal of Forestry 98(3): 15-21.

Cohen J (2008) The wildland-urban interface fire problem: A consequence of the fire exclusion paradigm. Forest History Today. Fall: 20-26.

De Gennaro M, Billaud Y, Pizzo Y, Garivait S, Loraud J-C, El Hajj M, Porterie B (2017) Real-time wildland fire spread modeling using tabulated flame properties. Fire Safety Journal 91, 872-881. doi: 10.1016/j.firesaf.2017.03.006.

Fernandez F., Guillaume B., Porterie B., Ganteaume A., Guerra F., 2018. Modelling fire spread and damage in wildland-urban interfaces. VIII International Conference on Forest Fire Research, Coimbra, Portugal, 12 - 16 Novembre 2018.

Fox D. M., Martin N., Carrega P., Andrieu J., Adnes C., Emsellem K. & Fox E. A. (2015), "Increases in fire risk due to warmer summer temperatures and wildland urban interface changes do not necessarily lead to more fires", Applied Geogra- phy 56, pp. 1-12.

Ganteaume A ,2018 Ornamental Vegetation, in: S. Manzello (Ed.), Encyclopedia of Wild- fires and Wildland-Urban Interface (WUI) Fires, Springer, Cham, 2018 .

Jones GM, Gutiérrez RJ, Tempel DJ, Whitmore SA, Berigan WJ, Peery MZ, 2016.Megafires: an emerging threat to old-forest species, Front. Ecol. Environ. 14 300–306, doi: 10.1002/FEE.1298 .

Maditinos Z, Vassiliadis C, Mega fires: can they be managed effectively? Disaster Prevent. Manage. 20 (2011) 41–52, doi: 10.1108/09653561111111072 .

McGrattan K, Hostikka S, McDermott R, Floyd J, Weinschenk C, Overholt K (2013) Fire Dynamics Simulator user's guide. National Institute of Standards and Technology, Technical Report NIST Special Publication 1019–6. (Gaithersburg, MD, USA)

Mell W, Jenkins MA, Gould J, Cheney P (2007) A physics based approach to modeling grassland fires. 2007. International Journal of Wildland fire. 16(1): 1-22.

Mell W., Maranghides A., McDermott R., and Manzello S.L. (2009) Numerical simulation and experiments of burning douglas fire trees, Combustion and Flame, vol. 156, no. 10, pp. 2023–2041.

Mell, W.; Jenkins, M.A.; Gould, J.; Cheney, P. 2007 A physics based approach to modeling grassland fires. 2007. International Journal of Wildland fire. 16(1): 1-22

Morandini, F.; Santoni, P.A.; Tramoni, J.B.; Mell, W.E. 2019. Experimental investigation of flammability and numerical study of combustion of shrub of rockrose under severe drought conditions. Fire Safety Journal. 108: 102836

Perez-Ramirez Y, Mell WE, Santoni PA, Tramoni J-B, Bosseur F (2017) Examination of WFDS in modeling spreading fires in a furniture calorimeter. Fire Technology 53(5), 1795–1832. doi:10.1007/s10694-017-0657-z

Sullivan A (2009) Wildland surface fire spread modelling, 1990–2007. 1: Physical and quasi-physical models. International Journal of Wildland Fire. 18. 349-368. 10.1071/WF06143.

Syphard A. D., Rustigian-Romsos H., Mann M., Conlisk E., Moritz M. A. & Ackerly D. (2019), "The relative influence of climate and housing development on current and projected future fire patterns and structure loss across three California land- scapes", Global Environmental Change 56, pp. 41-55.

Vanella M, McGrattan K, McDermott R, Forney G, Mell W, Gissi E, Fiorucci P. A (2021) Multi-Fidelity Framework for Wildland Fire Behavior Simulations over Complex Terrain. Atmosphere. 12(2):273.

Table 1 - Characteristics of the three study cases. Wind direction is given according to the World Meteorological Organisation.

Study case	Wind/Fire direction (°)	Topography between building and natural vegetation	Type of vegetation outside HIZ	Mandatory brush-clearing (legal fuel management : 50m-buffer around the building)	Damage
Griffon (Rognac fire 2016)	300	Slope	*Quercus pubescent* stand, understorey, grass	Yes but vegetation treated left on site resulting in a modality equivalent to a lack of brush-clearing (high amount of dead fuel)	Partial damage to the building and to ornamental vegetation
Barnouins (Rognac fire 2016)	345	Slope	*Quercus coccifera* shrubland and *pinus halepensis* stand, grass	Yes	Building destroyed and ornamental vegetation mostly burned
Château (Rognac fire 2016)	350	Flat	*Pinus halepensis* stand, shrubland, grass	Not implemented windward	Building destroyed and ornamental vegetation burned or scorched

FIGURES

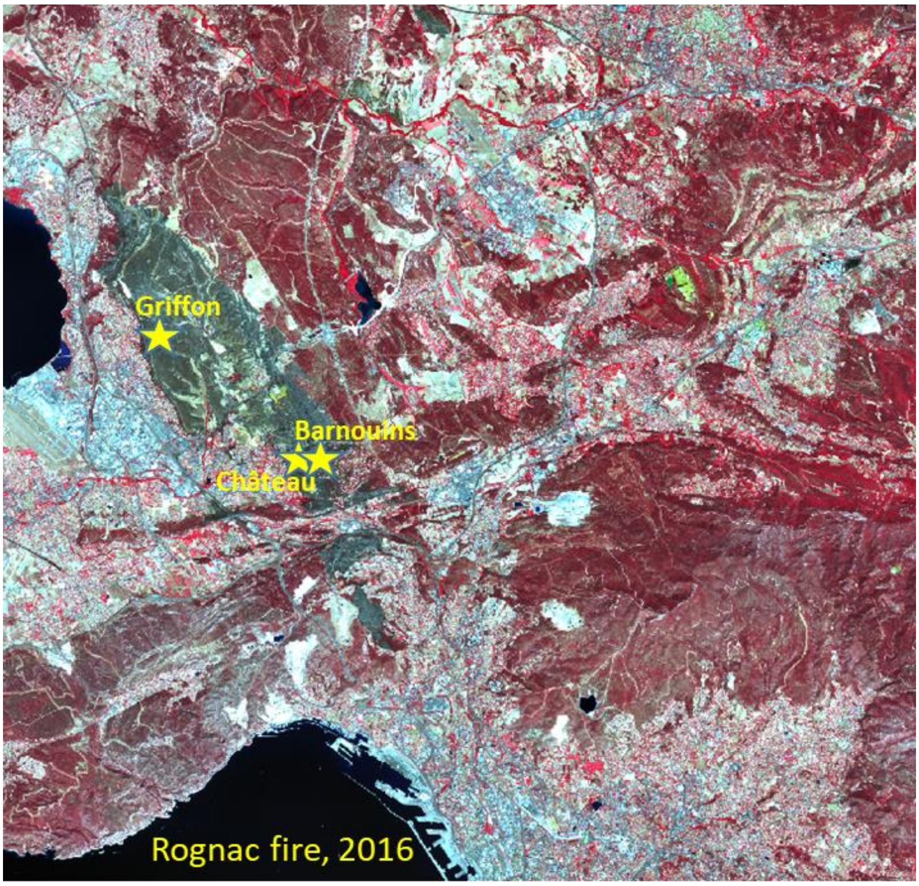

Figure 1 - Near Infra Red aerial imageries of the Rognac fire and locations of the three study cases.

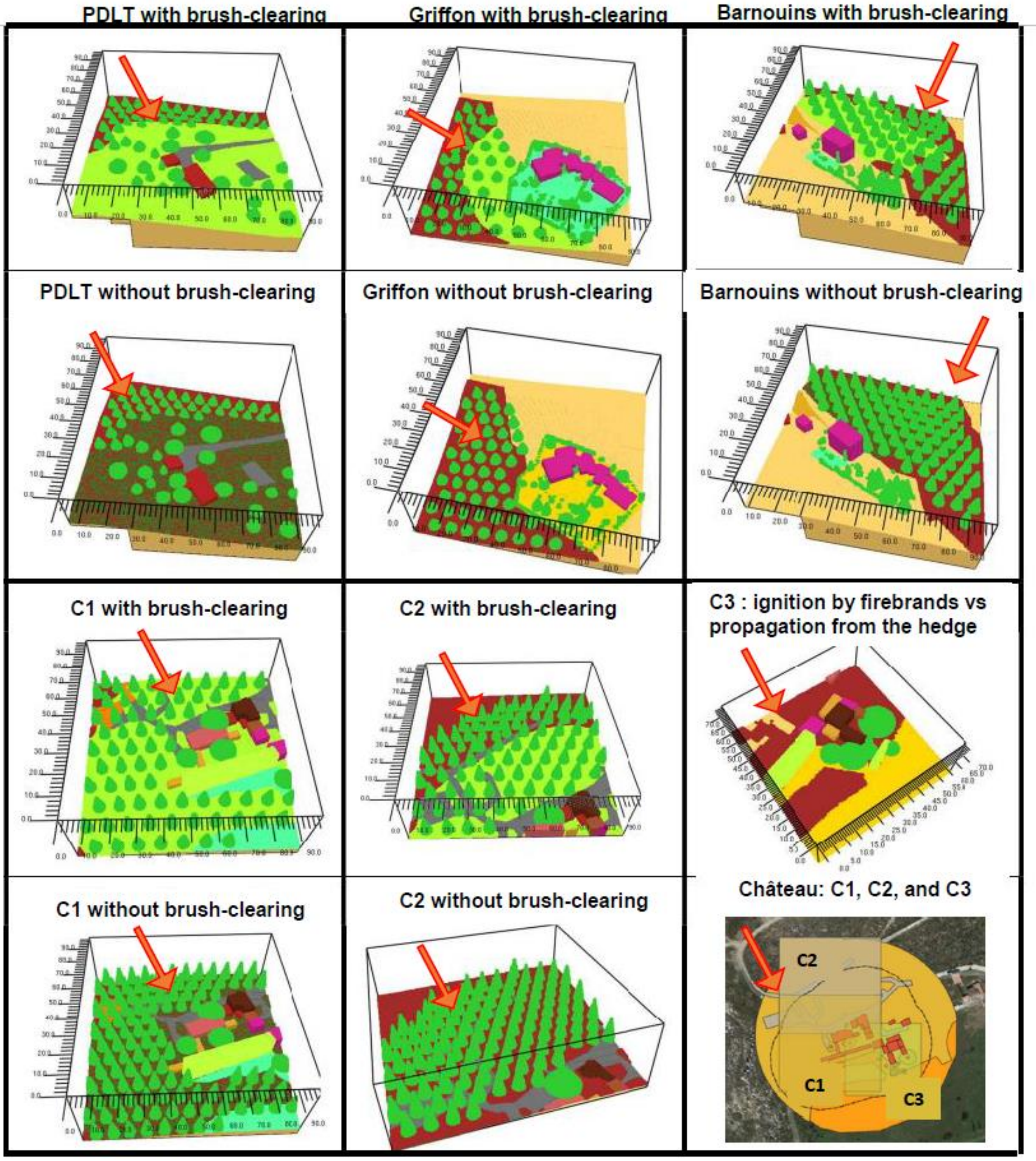

Figure 2 - The different configurations (with or without brush-clearing) of the 4 study cases (PDLT : Plan de la Tour) used in the modelling. The arrow shows the fire direction.

Figure 3 – Pictures of the post-fire damage recorded in the three study cases.

Figure 4 - Temporal evolution of the power released by the fire in the entire simulation domain (« Château C1 ») according to the fuel treatment.

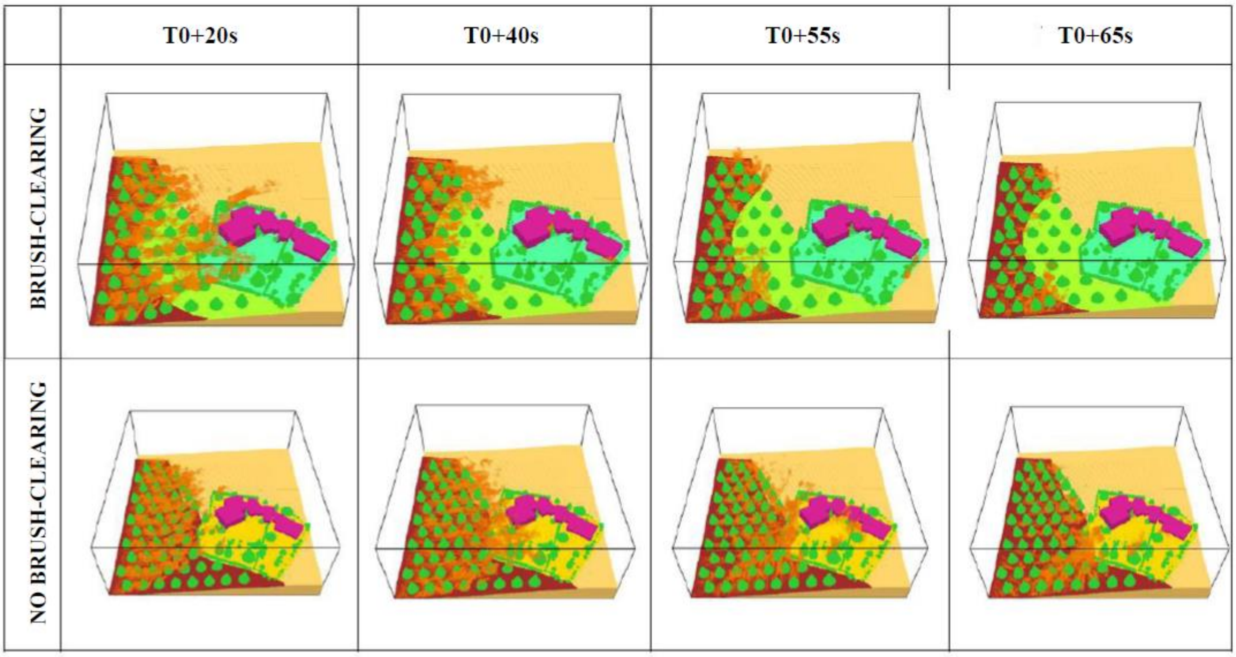

Figure 5 - Temporal evolution of the simulated flame front (« Griffon ») according to the fuel treatment.

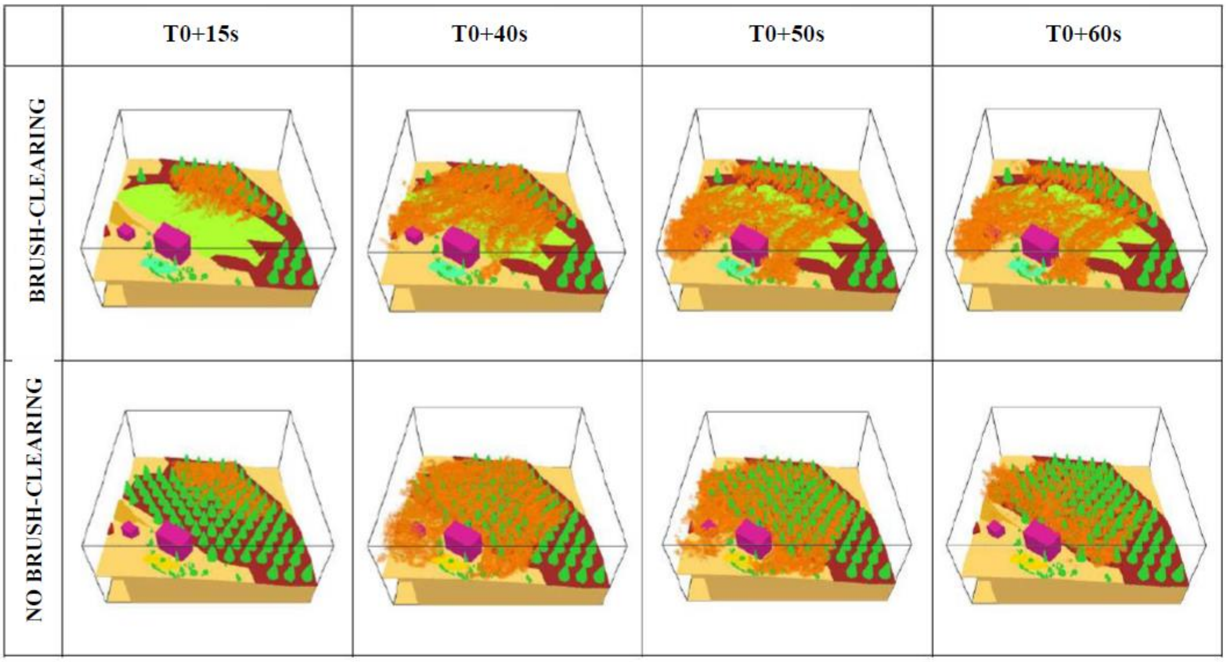

Figure 6 - Temporal evolution of the simulated flame front (« Barnouins ») according to the fuel treatment.

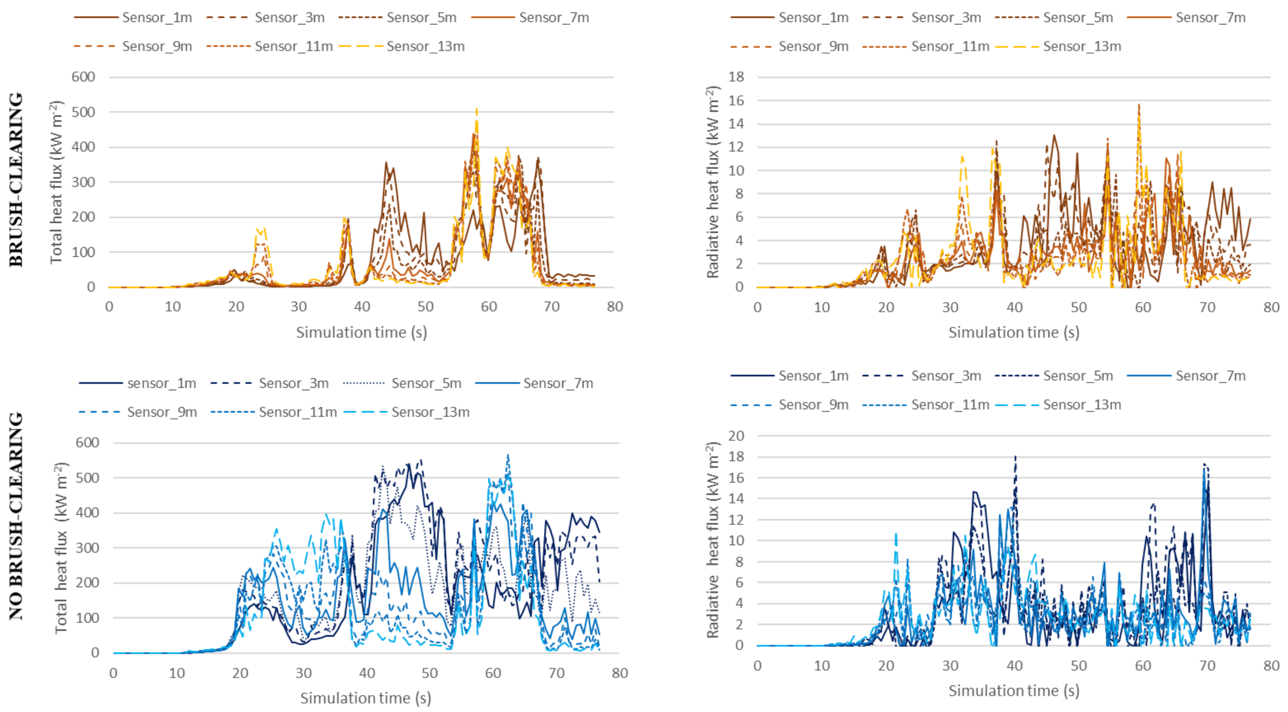

Figure 7 - Temporal evolution of the simulated heat flux (total and radiative) recorded by flux sensors located at different heights on the side of the house (« Barnouins ») exposed to the flame front according to the fuel treatment.

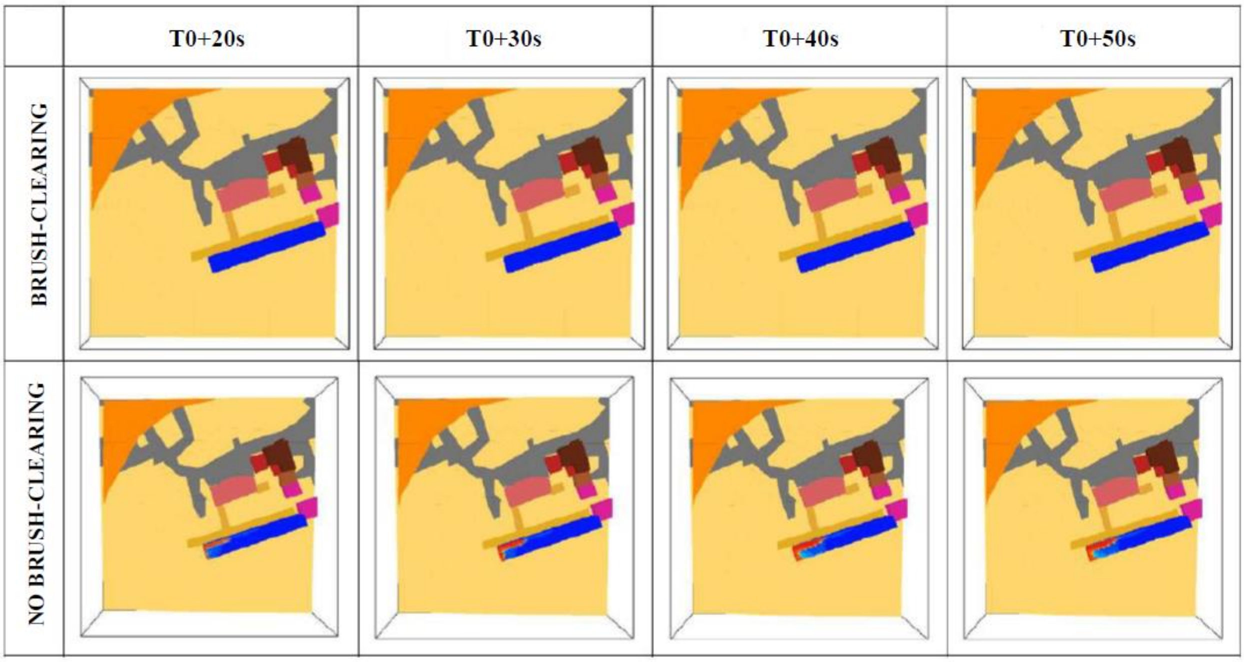

Figure 8 - Temporal evolution of the simulated mass loss of the northern cypress hedge (« Château C1 ») according to the fuel treatment (Colors ranging from blue to red: initial to totally burned fuel mass).

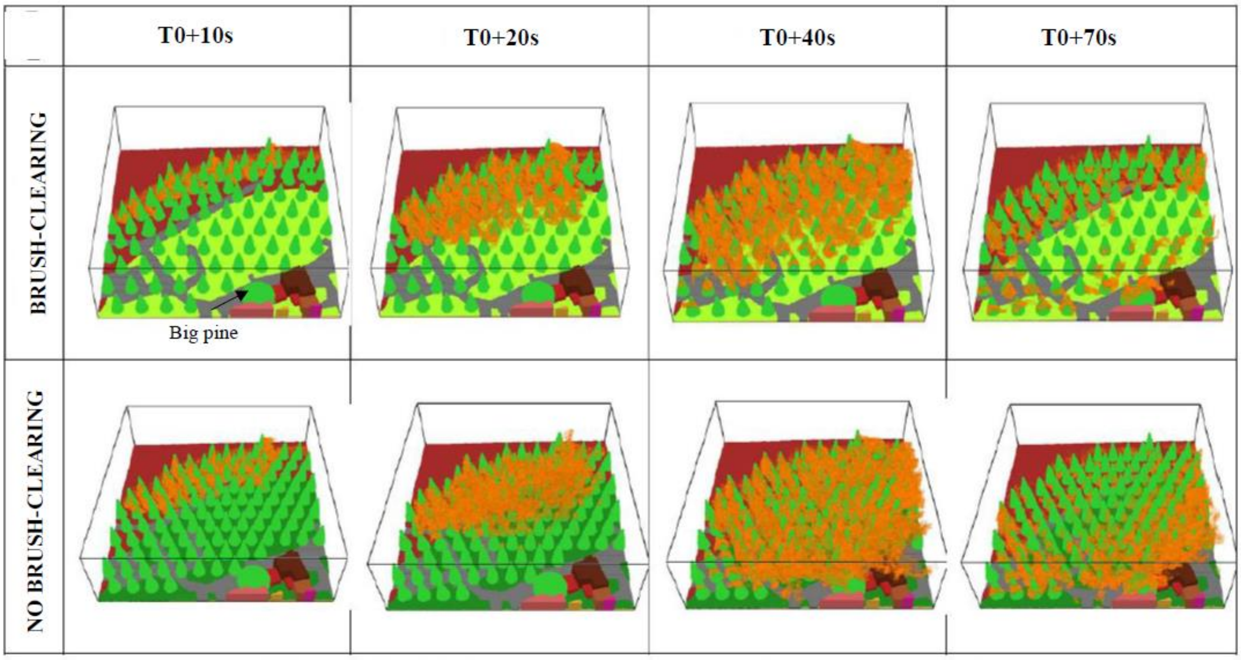

Figure 9 - Temporal evolution of the simulated flame front (« Château C2 ») according to the fuel treatment.

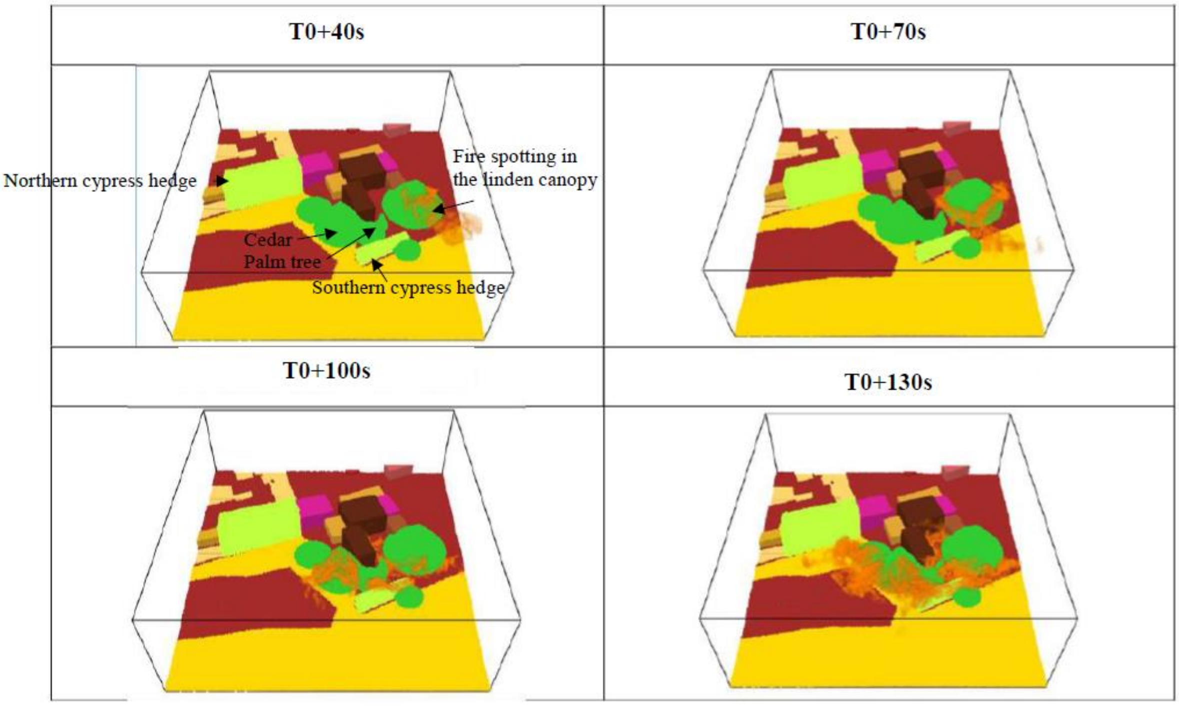

Figure 10 - Temporal evolution of the simulated flame propagation after ignition by fire spotting of the linden canopy (« Château C3 »).

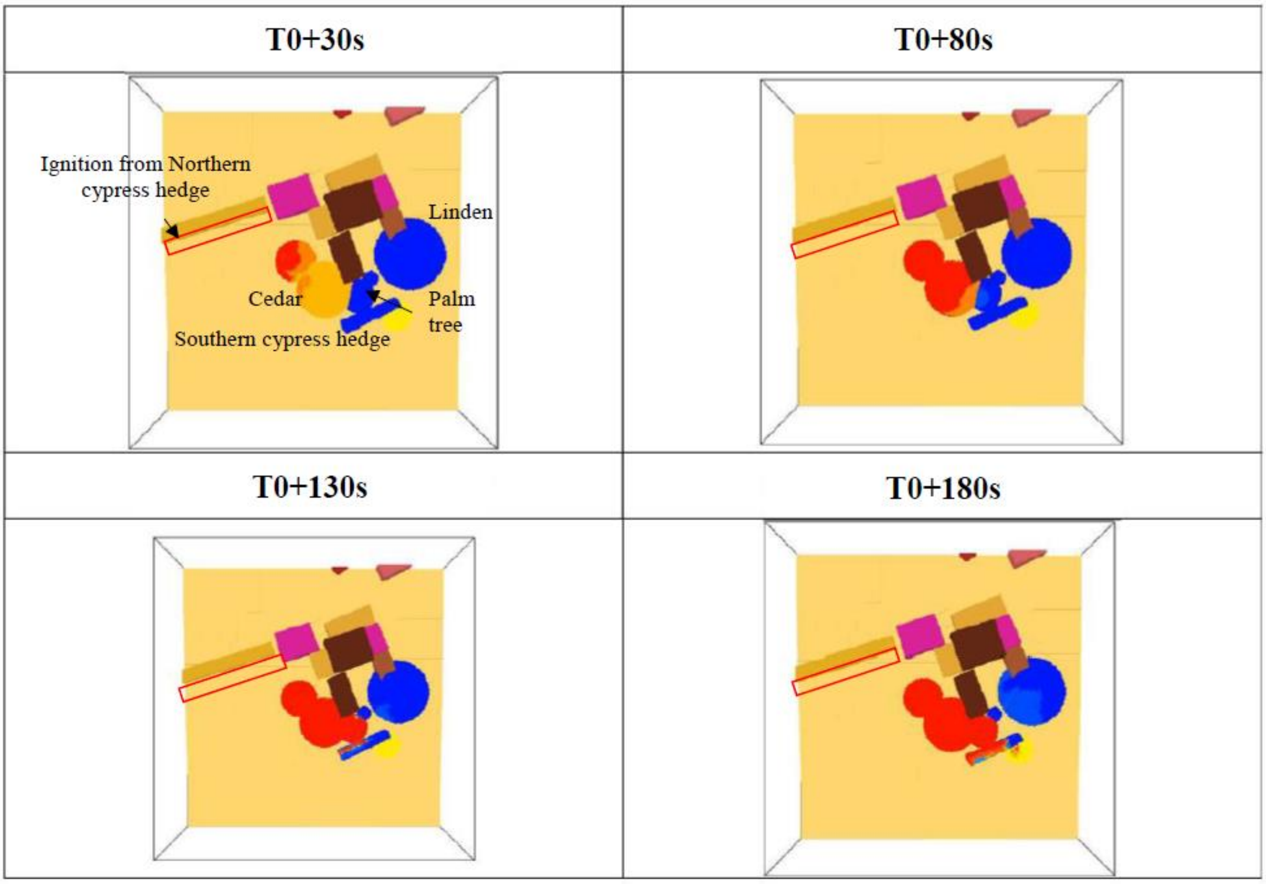

Figure 11 - Temporal evolution of the simulated mass loss of the ornamental vegetation ignited by the burning northern cypress hedge (« Château C3 ». Colors ranging from blue to red: initial to totally burned fuel mass)

.