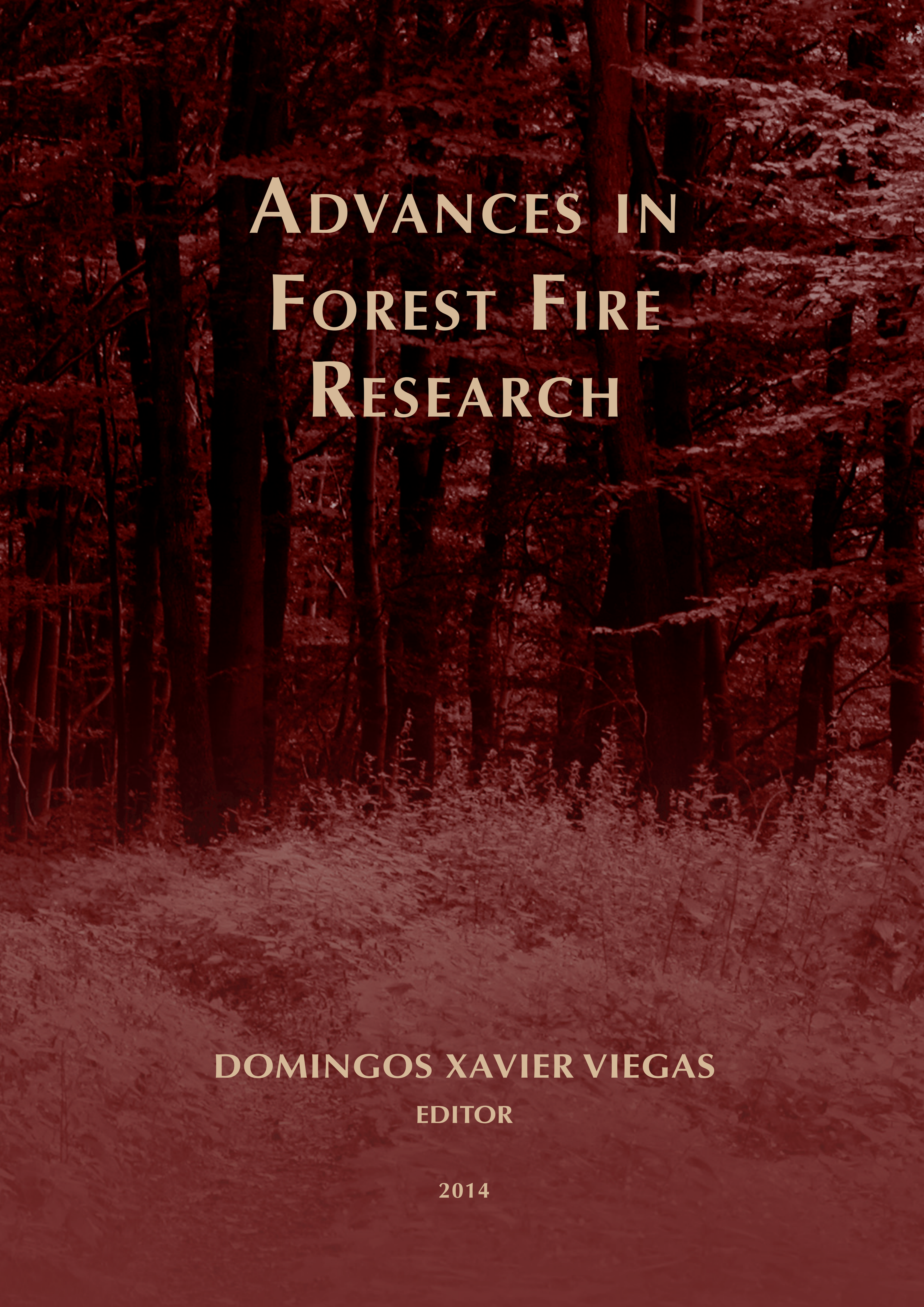

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Analysis of fire hazard in camping park areas

Miguel Almeida[a], José Raul Azinheira[b], Jorge Barata[c], Kouamana Bousson[c], Rita Ervilha[e], Marta Martins[d], Alexandra Moutinho[b], José Carlos Pereira[e], João Caldas Pinto[b], Luís Mário Ribeiro[a], Jorge Silva[c], Domingos Xavier Viegas[a]

[a] *Centre for Forest Fire Research ADAI – LAETA, Rua Pedro Hispano, 12, PT-3030-289 Coimbra, Portugal, miguellmd@yahoo.com, luis.mario@adai.pt, Xavier.viegas@dem.uc.pt*
[b] *IDMEC/CSI – LAETA, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, PT-1049-001 Lisboa, Portugal, jraz@dem.ist.utl.pt, alexandra.moutinho@tecnico.ulisboa.pt, jcpinto@dem.ist.utl.pt*
[c] *AEROG – LAETA, Departamento de Ciências Aeroespaciais, Faculdade de Engenharia, Universidade da Beira Interior, Calçada Fonte do Lameiro, PT-6201-001 Covilhã, Portugal; jbarata@ubi.pt, bousson@ubi.pt*
[d] *INEGI – LAETA, Instituto de Engenharia Mecânica e Gestão Industrial, Campus da FEUP. Rua Dr. Roberto Frias 400, PT-4200-465 Porto, Portugal; mmartins@inegi.up.pt*
[e] *IDMEC/LASEF – LAETA, Instituto Superior Técnico, Universidade de Lisboa, Av. Rovisco Pais 1, PT-1049-001 Lisboa, Portugal, rita.ervilha@tecnico.ulisboa.pt, jcfpereira@tecnico.ulisboa.pt*

Abstract

The common location of camping parks in forested or wooded areas, the normal use of combustible material by the campers and the frequent use of campfires to cook turn camping parks into areas with a high propensity for the occurrence of fires. Moreover, fires occurring close to parks induce to evacuations that disturb their normal activities. Despite the occurrence of several of such events, the associated risk is not yet well studied.

Project FireCamp is being developed in Portugal to analyse the propensity of fires in camping parks. This project has as main objectives: (1) analysis of past occurrences; (2) analysis of the combustibility of typical materials used in camping parks such as tents, sleeping bags or camping mattresses; (3) characterization of the camping park fuel cover and its surrounding by image analysis taken by UAV; (4) modelling of fire spread in camping parks; and (5) security measures for fire prevention and mitigation. A pilot study is being carried out in the Camping Park of Coja, in Arganil - Coimbra, which in September of 2012 was threatened by a forest fire that arrived to the perimeter of the camping park. A survey of this occurrence was done.

Several laboratory tests have been carried out in order to analyse the properties of the camping materials. Real tents with and without typical material inside (e.g., sleeping beds) were burnt in controlled environment in order to determine the mass loss decay, the increase of temperature and the convective winds produced. In parallel, each type of typical camping materials were analysed to determine the calorific power value.

Considering that external fires frequently threat camping parks, the survey of the neighbourhood of camping parks is also of great interest. In FireCamp Project, the aerial photographic survey of the camping park of Coja was carried out in order to produce a fuel map of this area. Based on this fuel map, a stochastic model to predict the fire spread in the covered area was set up.

The results obtained in the pilot study of the project applied to the Camping Park of Coja are also presented.

***Keywords**: forest fire, camping parks, wildland urban interface, WUI, modelling, mapping, fuel characterization, tents, camping materials*

1. Introduction

The occurrence of fires in Camping Parks (CP) are relatively frequent and in several cases they drive to wounded people or even to dead fatalities. The most serious fire incident occurred in camping parks took place in the CP Los Alfaques, in Terragona-Spain in 1978, where cascading explosions of fuel storages led to 217 deaths and more than 300 wounded people. Several other fire incidents have been reported by, for example, Fraser *et al*. (2003) or Klein *et al*. (2005).

Fires affecting camping parks may have origin inside the park or may come from the outside since parks are typically located in forested areas. The main ignition sources of fires starting inside the park are: electric equipment, use of fire for cooking or other practices, or neglect use of some common potentially igniter camping accessories like gas lighting, candles and others. Fires coming from outside the camping area may request the evacuation of the CP, endangering people and goods.

Fires in camping parks also assume great relevance given the many common ignitable camping accessories used such as tents, caravans, sleeping beds, mattresses, etc, which can sustain the fire and, when supported by other forest fuels, increase the fire spread through the camping park by conductivity and radiation mechanisms or by spotting. Besides all these risks, the knowledge of fire ignition, spreading and suppression in camping parks is still poor and requires a methodical analysis.

In Portugal there is a set of regulations about this matter like the regimes applicable to the installation and operation of public and private camping parks to simplify and standardize the respective licensing procedures, or the measures to prevent and control any actions that may cause damage to natural resources and facilities including (naturally) fire hazards:

- outside the CP and during the highest fire hazard season it is prohibited to burn anything within a certain distance of any woodland or brushland during the most part of the day; the law is intended to prevent forest fires by allowing outdoor burning only when the weather conditions are in general less favourable to spread an eventual wildfire;
- there are peripheral circulation paths with a reasonable width along the CP not only to prevent the spread of any fire to its interior but also to facilitate the passage of emergency and fire fighting vehicles;
- inside the CP only campfires and charcoal BBQs are allowed, and in specified fixed places; even so it is prohibited leaving a fire without completely extinguishing it, or failing to maintain it under control.

Albeit in a more or less insipid way and yet revealing the positive trend of the authorities in this matter, among the legislation set out one can list: the impacts of the legislation on CP in specific emergency plans of some Portuguese municipalities; the framework of CP in broader plans for local and regional spatial planning and management; and the existence of specific emergency plans for temporary CP.

The work presented in this paper is integrated in the FireCamp Project that is an internal project of the Associated Laboratory for Energy, Transports and Aeronautics (LAETA). The main objective of FireCamp is to understand and model the fire spread in camping parks as well as present alternatives to reduce the fire risk in CP. A pilot case study to apply the methodologies established in FireCamp was developed in the Camping Park of Coja. Several laboratorial experiments were carried out in order to determine the most important characteristics for modelling the fire spread. Burning tests with real tents and other camping accessories were performed as well. A survey of the area where the CP of Coja is located using Unmanned Aerial Vehicles (UAV) was carried out. A stochastic model to predict the fire spread in CP was produced. The methodologies used and the main results of the work developed are described in the following chapters. Some simulations of the fire spread in the CP of Coja are presented.

2. **Methodology**

In order to develop a tool for simulate the fire spread in a camping park, two set of inputs related to the combustible materials are necessary. The first set of inputs consists of the properties of typical camping accessories that can influence the fire spread. Several laboratorial tests were carried out with several different materials under different conditions to obtain these data. The second set of results is related to the characterization of the fuel cover of the area where the CP is located. As it was previously mentioned, the survey methodology was applied to the Camping Park of Coja that was the pilot case of the project. The methodologies used to achieve the required inputs to modelling are described below.

2.1. Analysis of the combustibility of typical accessories used in camping parks

There are many combustible accessories used in camping activities and, for a question of simplicity, tests were restricted to the accessories that were considered to be more relevant, namely: tents, sleeping beds and camping mattresses. On the other side, accessories have different shapes and sizes, and these accessories may be composed by several different materials depending on the brand manufacturer, quality, etc. For example, the walls of some tents only have one layer of fabric while other tents have an additional interior layer of cotton. Therefore, a limited but representative number of the existing types of materials and accessories were analysed. Table 1 and Table 2 resume the accessories and materials tested.

Table 1. Resume of the materials analysed.

Code Sample	R1	E1	B1	W1	I1	P1	SB1	CP1
Picture								
Description	Tent roof	Tent entrance door	Tent base	Tent wall	Tent interior	Tent entrance mosquito protective net	Sleeping bag	Camping mattress
Material	Polyester or polyamide coated with a PU or silicone	Rip stop nylon	Woven PE Sheeting “Poly Tarp”	coated polyester and vinyl	cotton with polyester	Oxford cloth and mesh	100% polyester	PE foam

Since the amount of materials to be tested was limited, it was decided that focus should be given on the determination of the Higher Calorific Value (HCV) of sample materials mainly used in camping tents. These tests were performed in the calorimetric bomb according to standard EN ISO 1716. The bomb calorimeter is the most common device for measuring the heat of combustion or calorific value of a material. A small test specimen with a specified weight is combusted completely during constant volume and oxygen atmosphere inside a high-pressure calorimetric bomb. The calorimeter measures the temperature rise of the surrounding water and calculates the gross heat of combustion. Before testing, samples were conditioned at a temperature of 23 ± 2 ºC and relative humidity of 50 ± 5 %.

Besides the analysis of HCV, other tests of burning tents were also performed in order to understand the mechanism and the main factors affecting the burning. Table 3 resumes the burning tests carried out varying the initial conditions.

Table 2. Resume of the accessories tested.

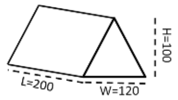
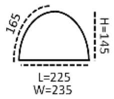
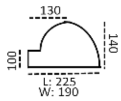
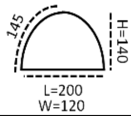
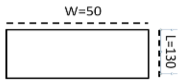
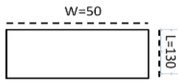
Ref.	Weight (kg)			Fabric composition (m^2)	Number of layers of fabric	Dimensions (cm)	Photo
	total	structure	fabric				
Can01	0.92	0.64	0.28	B1: 2.28 W1: 3.71 E1: 0.92 P1: 0.46	1		
Igl01	6.44	1.86	4.58	B1:6.67 W1: 9.42 P:0.38 I1: 6.14	2		
Igl02	3.67	1.30	2.37	B1: 4.19 W1: 9.51 P1: 0.95 I1: 5.73	2		
Igl03	1.15	0.47	0.68	B1:3.36 W:4.64 P:0.20	1		
SB01	0.86	--	--	SB:0.9	--		
CM01	0.16	--	--	CM:0.9	--		

Table 3. Resume of the burning tests.

Reference	Type of tent	Filling	Induced wind	Type of ignition
110516_TC01	Igl01	1 blanket 4 duvets	no	Fb+St
130125_TC02	Can01	empty	no	Fb*
130616_TC03	Igl02	empty	no	Fb
140127_TC04	Igl03	1 sleeping bag 1 camping mattress	no	St**
140127_TC05	Igl03	1 sleeping bag 1 camping mattress	1.1 m.s-1	St

* Fb – Ignition by firebrands falling over the tent.
**St – Propagation of the fire to the tent by a linear fire front spreading on a straw fuel bed.

Tent ignition was achieved using a firebrand generator as can be seen in Figure 1. The firebrands were provided from the burning of cylindrical pellets with less than 10mm high and with a diameter lower than 4mm. In some cases, the firebrands were directly projected to the tent (Fb). In other experimental tests, a linear fire front spreading on a straw fuel bed propagates the fire to the tent. In one particularly case, the firebrands were simultaneously projected to the tent and to the straw fuel bed adjacent to the tent (Fb+St), resulting in several ignition points in both tent and straw fuel bed. The fuel load of the straw fuel bed was always 0.6 $kg.m^{-2}$.

Figure 1. Experimental apparatus of the burning tests.

The total mass decay (tent, filling and fuel bed) and the convective velocity were the parameters considered for control. The burning tests were carried out in the Forest Fire Research Laboratory (LEIF) using the platform of combustion that is a combustion table fitted on a weight balance that automatically registers for every second the total weight during the experiment. Up flow velocity was automatically measured using Pitot tubes installed on the top of the tent. The experimental installation and equipments can be seen in Figure 1.

2.2. Characterization of the camping park fuel cover and its surrounding by image analysis taken by UAV

The determination of the risk of fire in a CP area requires the characterization of factors such as vegetation type, fuel load, distribution of occupied spaces, neighbour water sources and available access routes. In order to facilitate the characterization procedure, either by doing it remotely or even automatically, a high-resolution digital mosaic may be obtained from aerial images acquired by UAVs flying over the camping park area.

With this purpose, some flight tests were made in June 2013 over the CP of Coja, near of Coimbra – Portugal, using the UX-401 quadcopter from UAVision. The quadcopter was equipped with a GoPro HD Hero camera, set for 5MP still image acquisition every 2 seconds. In each of these flights a set of pre-determined waypoints was defined as reference for the quadcopter autonomous navigation. One of these flights is represented in the left image of Figure 2. The right image shows one of the photos taken during the flight.

Figure 2. Left: Trajectory described by the quadcopter while on autonomous navigation over the area of the CP of Coja (seen on Google Earth). Right: One of the pictures taken during the flight with a GoPro camera.

In order to be used as an input variable in fire spread modelling systems, the fuel cover of the camping site and surrounding must be spatially characterized. The processed followed was based on photointerpretation of the produced high-resolution digital mosaic. The photo mosaic was loaded into ArcGIS and the different fuels were identified and vectorized. The fuel models used to characterize the vegetation were the ones produced by M. Cruz (2005) and represent the typical vegetation found in Portugal. A fuel model is by definition a complete set of fuel inputs needed for a mathematical fire spread model (e.g., Rothermel, 1972). It represents a homogeneous vegetation formation in which fire behaviour is expected to be constant and predictable. For each continuous vegetation group identified in the photos a polygon was designed and the corresponding fuel model was assigned in the attributes table. The same was done to non-fuels such as roads, urban areas or water bodies. In the end of the process a continuous fuel map of the entire region was produced.

2.3. Modelling of fire spread in camping parks

Based on the laboratorial experiments results and on the characterization of the camping park fuel cover and its surrounding by image analysis taken by UAV a simulation of a fire front propagation was made. Given the non-deterministic nature of some available data, the fire propagation model was also developed to investigate the quantification of the complex fire propagation uncertainty using stochastic equations and a parametric study (number of variables, stochastic dimension of space) to determine the various parametric influences on the numerical solution of the asymptotic state.

Faster than real time stochastic fire spread predictions were obtained using a Non-Intrusive Spectral Projection (NISP) method in which the solution is expanded in a series using Polynomial Chaos. The unknown coefficients of the expansion terms were calculated from deterministic solutions using a conventional fire growth model. In the present case, the fireLib functions were used for the calculation of the rate of spread together with raster surface fire growth algorithms. The fire growth model of the raster type was ported to the Graphical Processor Units (GPUs) architecture using the Compute Unified Device Architecture (CUDA) programming language.

For the present case three input parameters were considered uncertain, namely the wind speed, the wind direction and the fuel moisture. These three variables were characterized by a Gaussian Distribution with a coefficient of variation of 20%. The stochastic simulations with input parametric uncertainty as random variables were simulated under the complex realistic terrain of the camping park of Coja.

3. Results and discussion

The methodologies previously described were applied in order to obtain the results detailed and discussed in this section. The division into different themes follows the same approach of the previous chapter.

3.1. Analysis of the combustibility of typical materials used in camping parks

The tests performed with the typical camping materials previously described resulted in the values of HCV shown inTable 4.

Table 4. Values of HCV for the different materials tested.

Code Sample	R1	E1	B1	W1	I1	P1	SB1	CP1
HCV (MJ/Kg)	23.13	29.27	45.51	22.58*	22.09	22.86	22.45	41.45

*this sample requires specific accessories for measurements as it contains halogenated components

According to the Portuguese legislation, the tested materials fall within the use-type IX "Leisure and Sports Venues" whose characterization is described in paragraph 1i) of Article 8 of Decree-Law no. 220/2008. This decree-law is regulated by Decree no. 1532/2008 of 29 December, which in point a) of Article 282 stipulates that "in camping parks, coverings used in camping tents, caravans or motorhomes are allowed only when they are constructed with materials with fire reaction classification of at least grade C-S2-d0”. This kind of classification is obtained by performing SBI (Single Burning Item test) or the small flame test. However, for SBI tests a very large amount of material is requested by test ($1.5x1.5m^2$) restraining this to be used mainly for certification of construction and building materials.
Classifications A-B-C-D are dependent of materials fire reaction properties. According to standard NP EN 13501-1, these classes can be related with HCV according to Table 5. In this table, class C does not have a correspondence with HCV.

Table 5. Relation between material classes and HCV according to NP EN 13501-1.

Class	Classification Criteria*
A1	HCV ≤ 1.4MJ/Kg HCV ≤ 3.0MJ/Kg
A2	HCV ≤ 3.0MJ/Kg HCV ≤ 4.0MJ/Kg

*depending on the application

The analysed materials have high calorific values (about 7 to 13 times) above the criteria stipulated for A1 or A2 classes. Based on these high values, it is predicted that they cannot be categorized as class C, suitable for use-type IX "Leisure and Sports Venues" in Portuguese legislation.
The parameters initially considered for control show some problems of measurement due to the convective flow effects, as can be seen in Figure 3. When a tent starts burning, the temperature inside the tent increases creating an uplift which drives to a fake reduction of weight. Occasionally, during the burning some holes in the top of the tent are created and thus the hot air inside the tent can be dissipated. Consequently, the total weight increases suddenly and the up flow velocity abruptly increases to higher values. As the hole enlarges, the exhaust air velocity decreases, even if the tent is burning more intensively. Therefore, these measurements were considered invalid and a qualitative evaluation was made as it is presented in Table 6.

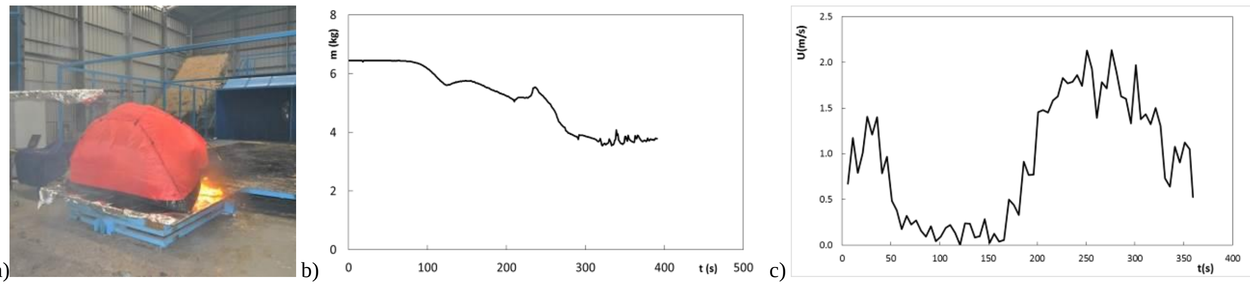
a) b) c)


Figure 3. (a) Evidence of the up lift effect caused by the convective flow (140127_TC04); (b) mass loss decay (110516_TC01); (c) up flow variation (140127_TC04).

It was observed the shape of the tent is an important parameter to have ignition. The Canadian tent burned completely because the firebrands felled in the wrinkles accumulating heat. In igloos tents with the fabric well taut, the firebrands did not have that heat accumulation and firebrands just made a hole in the fabric not leading to a sustainable combustion.

The existence of flammable materials inside the tent, a common situation in camping parks, leads to a complete burning of the tent, even if the tent has a specific fabric with favourable combustion behaviour.

Table 6. Qualitative results of the burning tests.

Reference	Characteristics	Results
110516_TC01	Igloo with 2 layers and filling inside; ignition by firebrands and fire line	Complete burn. Ignition in parallel by the straw and by the firebrands. Some firebrands fell on the tent making some holes with no sustainable combustion. Some firebrands passed the fabric of the tent and fell in the blanket and in the duvets that started burning intensively.
130125_TC02	Canadian with 1 layer and no filling inside; ignition by firebrands	Complete burn. Some firebrands fell in the wrinkles of the fabric igniting the tent.
130616_TC03	Igloo with 2 layers and no filling inside; ignition by firebrands	Not burned. Some firebrands fell on the tent making some holes with no sustainable combustion. Some firebrands passed to the floor creating holes which rapidly self-extinguished.
140127_TC04	Igloo with 1 layer and filling inside; ignition by fire line.	Complete burn. The sleeping bed and the camping mattress started burning very intensively, however, when the fire reached these accessories the tent was already burning sustainably.
140127_TC05	Igloo with 1 layer and filling inside; ignition by fire line; induced wind of $1.1 m.s^{-1}$.	Partially burned. The tent started burning very intensively and the filling was completely burned. At a certain time the tent was inflated by the wind and turned over stopping the experience.

In the presence of wind, if a tent starts burning it can be inflated and dragged by the wind and, consequently, behaving itself as a firebrand spreading the fire to other tents or wounding people. This is a very dangerous situation that shall be taken into account.

3.2. Characterization of the camping park fuel cover and its surrounding by image analysis taken by UAV

The images acquired during the flights in Coja allowed to automatically construct a high-resolution mosaic of the camping site (Coito, 2013), (Costa, 2013). This mosaic is represented in the left image of Figure 4, as an over layer in Google Earth, while the right image represents a zoom of the area indicated by the red rectangle in the left image.

Figure 4. Left: High-resolution mosaic, constructed from aerial images acquired by a quadcopter over the camping site of Côja, overlaying Google Earth. Right: Zoom of the area indicated in red in the image on the left.

Observing the zoom image, one confirms the higher resolution of the resulting mosaic when compared with the available aerial images provided by Google Earth, allowing a clearer identification of the area. Another advantage of the UAV based imagery is that it may be acquired when conveniently, allowing, for example, the characterization of the camping site in different seasons (e.g., summer and winter) corresponding to a quite different distribution of occupied spaces as well as vegetation type and fuel load.

During the photointerpretation phase four fuels were identified: herbaceous (HER-01), low shrubs (MAT-01), pine stand with understory (PPIN-04), and deciduous broadleaves (FOLC-01). The physical parameters of these fuels can be found in Table 7.

Table 7 –Fuel models parameters (from Cruz, 2005)

	Fuel load ($kg.m^{-2}$)				S/V ratio ($cm^2.cm^{-3}$)		Depth (m)	Heat content ($kJ.kg^{-1}$)	Moisture of extinction (%)
	Dead fuels			Live woody					
Model	1 hr	10 hr	100 hr	(Ø<6mm)	1 hr	Live woody			
HER-01	0.3	0	0	0	80	-	0.35	18000	30
MAT-01	0.2	0	0	0.7	60	60	0.4	22500	40
PPIN-04	0.7	0.3	0.2	0.6	60	60	0.7	22000	50
FOLC-01	0.3	0.3	0.2	0	79	-	0.06	18500	21

The area covered by the quadcopter was limited to the Coja camping site but in order to simulate the approach of a wildfire, the surroundings were mapped as well. To do so, Google Earth imagery were used. The final fuel map for the area is shown in Figure 5. The red polygon shows the area covered by the photo mosaic. The surroundings were mapped based on Google Earth.

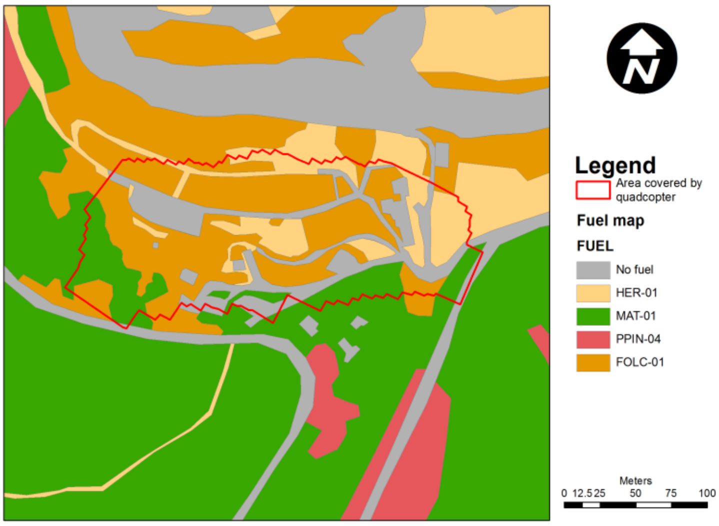


Figure 5. Fuel map of the Coja Camping Site

The fuel map was produced at a resolution of 1 m. The detail obtained with the photographs of the quadcopter is undoubtedly better than the one on Google Earth, thus, the precision of the fuel map inside the camping site is greater than outside. Besides the use of the quadcopter, a fixed-wing UAV (a Twinstar II) is planned to be used for imaging the surroundings of the camping park area. Preliminary imaging will be conducted with a remotely controlled flight of the vehicle and then autonomous flight tests will be performed for the same task. While the quadcopter dealt with the imaging of the camping park and its immediate surroundings, the fixed-wing UAV will focus on taking images of the outer surrounding area.

3.3. Modelling of fire spread in camping parks

Stochastic simulations allow predicting the effect of parametric input uncertainty through the model and, consequently, on the simulation results such as: burned area; fire front velocity and fire front propagation direction. Figure 6 shows the forecast of the fire front (stochastic mean) and its error bar area, based on a 95% confidence interval, at 4 hours of fire propagation.

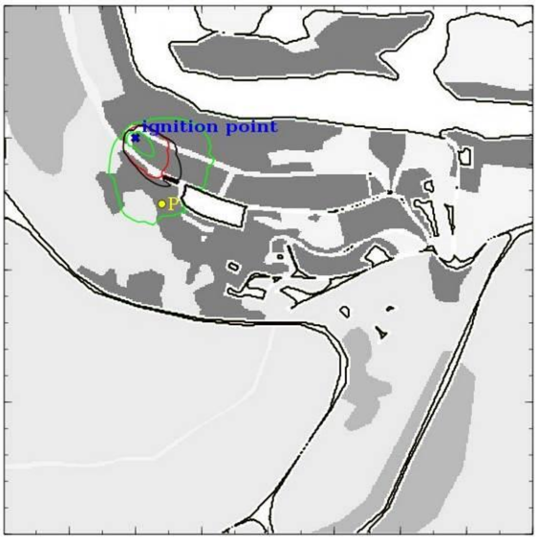


Figure 6. Forecast of the fire front in the CP of Coja after4 hours of ignition: deterministic mean (black); stochastic mean (red); error area with 95% CI (between green lines).

The statistical output of the predicted fields allows to know the probability of fire occurrence at a selected point (any location, as a function of time) and to decide accordingly about actions to have in real wildfires. This becomes particularly interesting when specific locations are of utmost importance and require priority protection. Figure 7 presents the temporal normalized Probability Density Function (PDF) at a selected point (see Figure 6, yellow point) that quantify the uncertainty on the fire spread.

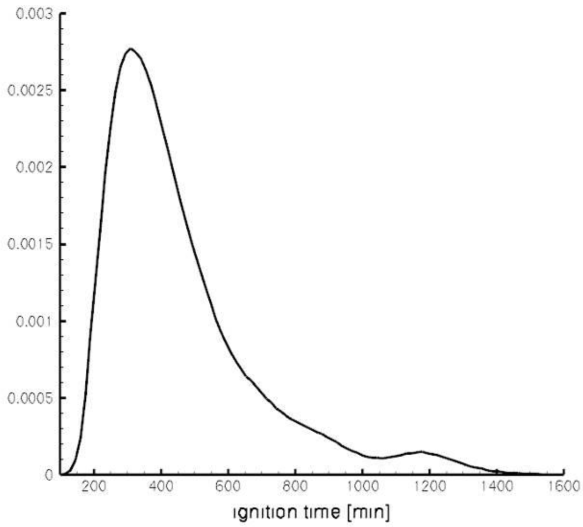


Figure 7. Normalized Probability Density Function (PDF) of ignition time at P location (see Figure 6, yellow point P)

The novel algorithm targeted for GPU architectures achieved a speedup of 176x against serial Central Processing Unit (CPU) execution. The GPU have allowed to obtained two orders of magnitude faster

stochastic fire spread predictions than the real time fire propagation. These results may prove useful toward firefighting methodologies.
The proposed methodology can be used for any camping park scenario. The output provides the time evolution of the ensemble mean fire front location and burned area error bars for a certain confidence interval and the PDF at each point as a function of time. In addition, the hierarchy of input parametric uncertainties based on the stochastic coefficients in the fire spread simulation was quantified. These estimators may add relevant information because wildland fire growth is an intrinsic stochastic process.
Figure 8 shows the stochastic mean (first bar) and the first (second to fourth bars) and second order (last six bars) stochastic coefficients at point P (see Figure 6), where v1, v2 and v3 represent wind speed, wind direction and fuel moisture, respectively. For instance, v1.v2 is the second order cross stochastic coefficient between wind speed and wind direction parameters. The stochastic coefficients characterize the respective parameter variability weight into the final solution. These results permit a sensitivity analysis about the influence of each parameter variability on the fire propagation.

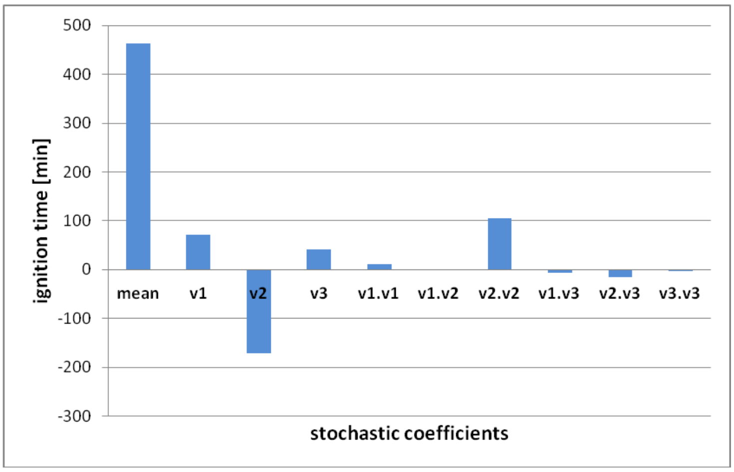


Figure 8. Stochastic coefficients at point P, being the uncertain input parameters: v1 – wind speed; v2 – wind direction; and v3 – fuel moisture.

4. **Conclusion**

Several conclusions can be vased on the work performed previously described.
The burning tests of tents resulted in some interesting conclusions. The ignition of the tent by a fire front is very effective, showing the importance of having the area adjacent to the tent free of fuels like straw, needles, garbage, etc. The ignition of tents by firebrands is very alike, and tents not well stretched have a greater probability to ignite as the firebrands accumulate in the wrinkles. The material inside the tent has a great relevance on the probability of the tent burning. Tents should be made of non-flammable fabrics (class C), being observed that when the fabric was taut, firebrands only caused some holes in the tent not leading to a sustained combustion. However, when firebrands crossed the fabric, falling in the other fuel accessories (for example, sleeping beds), they ignited and the tents were completely burned, even if the fabric material was of class C. Since the common situation is tents with accessories inside, it is extremely important to reflect about the need of the actual existing mandatory rules demanding the use of fabric class C in tents or if other camping materials, namely accessories, should have the same compulsory.
This set of tests also highlighted the fact that on windy days a burning tent may become very dangerous. The holes in the tent created by the fire allow the entrance of air, causing the inflation of the tent that is easily pulled from the ground. In this situation, the tent may be dragged over the CP

causing spot fires or even wounding people. As the material of tents is synthetic, the flaming drops released by this kind of materials may cause deep burns.
Regarding to the characterization of the camping park fuel cover and its surrounding, it is clear the advantage of using imagery acquired by an UAV as opposed to Google Earth images. UAV-based imagery results in a high resolution mosaic from which a more detailed fuel map may be obtained. Moreover, with UAVs it is possible to determine when the images are acquired, and thus have fuel maps for different times of the year, corresponding to different camping park occupancies or vegetation degrees of curing.
An accurate and reliable characterization of input variables is necessary because they strongly affect forest fire simulations. Despite the successfully effort in characterizing some fire spread dependencies, such as the fuel cover well featured during this work, there are some parameters that are not easily defined because their values are not constant neither in time nor in space. The non-deterministic behaviour of such parameters leads to stochastic simulations of fire propagation with methods that consider the input variability in the model used. The results obtained provide, admitting a certain confidence interval, error bars of the ignition time in space, as well as sensitivity analysis studies about the influence of each input parameter variability into the final solution. Moreover, the results obtained were faster than real time fire propagation which is mandatory when model predictions are applied to real-time fires.

5. List of abbreviations

BBQ – Barbeque
CP – Camping Park
CPU – Central Processing Unit
CUDA – Compute Unified Device Architecture
GHC – Gross Heat of Combustion
GPU – Graphical Processor Units
HCV – Higher Calorific Value
LAETA – Associated Laboratory for Energy, Transports and Aeronautics
LEIF – Forest Fire Research Laboratory
NISP – Non-Intrusive Spectral Projection
PDF – Probability Density Function
PE – Polyethilen
PU – Polyurethan
SBI – Single Burning Item test
UAV – Unmanned Aerial Vehicle
WUI – Wildland Urban Interface

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7. References

Fraser JF, Choo KL, Sutch D, Kimble RM (2003). The morning after the night before: campfires revisited. Med J Aust 2003.

Cruz, MG (2005). Guia fotográfico para identificação de combustíveis florestais – Região Centro de Portugal. Centro de Estudos sobre Incêndios Florestais - ADAI, Coimbra. 38 p

Coito T, Caldas Pinto JR, Azinheira JR (2013). Building and Evaluation of a Mosaic of Images using Aerial Photographs. Proceedings of International Conference on Image Analysis and Recognition, Póvoa de Varzim, Portugal, June 2013.

Costa J, Coito T, Caldas Pinto JR, Azinheira JR (2013). Building and Evaluation of a Mosaic of Images using Aerial Photographs", Proceedings of 19th Portuguese Conference on Pattern Recognition, Lisbon, Portugal, November 2013.

Klein MB, Heimbach DM, Honari S, Engrav LH, Gibran NS (2005). Adult campfire burns: two avenues for prevention. J Burn Care Rehabil.

Rothermel RC (1972). A mathematical model for predicting fire spread in wildland fuels. Research Paper INT-115. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 40 p.