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Integrated GIS-based simulation for civil protection and crisis management

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Abstract

Every day mankind faces threats capable of destroying in the blink of an eye someone's life or property. Those events may sometimes gain gigantic proportions and therefore affect whole regions. While it is possible to extinguish most of these events at the outset, it is the few that can not be countered that end up creating more impact on society. Uncontrolled disasters require the work of many corporations spread through the terrain to minimize damages. Proper planning and prevention are needed to avoid irreversible damages. In emergency situations the people tasked with solving these issues need to be informed relative to the spatial state of the scene. Geographic Information Systems can provide the location of any mapped object, allowing it to be compared through any desired calculation. During a crisis it may be relevant to know the location and state of critical elements, such as infrastructure, buildings, people, threats, defenses and so on. Some of these elements tend be static. Infrastructure and buildings location won't vary that much, however their state can be affected by a threat. Those threats behaviour can be unpredictable, but they usually depend on some factors that can be measured.

The use of simulation tools to predict the effect threats can provoke in space are a useful source of information to prepare a proper response. Ideally a system should be able to provide the user information relative to the expected outcome of a certain monitored event, while allowing him to modify some factors, such as defense measures. The use of a system of this kind may be important to decide allocation of some elements to a new location, priorityzing critic elements that may be in danger of being affected and as a result cause a bigger problem. Geographic data resulted from the simulation of hazards may of importance to many circunstances. Either it being for study of those events behaviour, territorial planning or risk analysis. It can also be useful in active events to monitor its progress and adapt acoordingly. Prevention can vary depending on the associated risk returned from simulations, even being possible to simulate multiple scenarios to know what would be the desired prevention methods to apply.

For this dissertation it was developed a web server capable of providing over the web simulation techniques for fire and flood simulations. Fire simulation is assured by FARSITE, which allows to perform fire simulations using data relative to topography, fuel, weather, wind and others customized by the user. The necessary data to perform simulations for Portugal can be found in some public institutes. Other data relative to infrastructure and buildings can be found in OpenStreetMaps, although it may not be as complete as it is desired. To solve this problem it is also provided in the server the option to edit the data stored in the database to enrich as much as possible the information to be used. To alert the user about elements that may be in danger of being affected, simulation results are analysed based on time and the data that is considered to be spatially affected highlighted in a map.

A study case was realized for Tondela Region. Comparison between simulations is done to address the effect how different scenarios would impact the landscape. Using the methodology of the study case, other regions could also be implemented, allowing the use of such a system to a broader area. It was noticeable the usefulness this type of technology can offer to civil protection and crisis management. The upgrade of the presented solution with other important features and enhancement of the current will ultimately prove to be a valuable tool to protect the population from multiple risks.

Keywords: Geographic Information System, Modeling and Simulation, risk prevention

Resumo

A Humanidade enfrenta todos os dias ameaças capazes de destruir a vida ou propriedade de alguém num piscar de olhos. Esses eventos podem por vezes ganhar proporções gigantescas e portanto afetar regiões inteiras. Embora seja possível estinguir a maioria no início, são os poucos que não são combatidos que acabam por criar maior impacto na sociedade. Desastres não controlados requerem o trabalho de muitas coporações espalads pelo terreno para minimizar os danos. Planeamento e prevenção adequados são necessários para evitar danos irreversíveis. Em situações de emergência, as pessoas encarregadas em resolver tais problemas precisa de estar informadas em relação ao estado espacial da cena. Sistemas de Informação Geográfica podem fornecer a localização de qualquer objeto mapeado, permitindo que seja comparado através de qualquer cálculo desejado. Durante uma crise pode ser relevante saber a localização e estado de elementos críticos, tais como infraestrutura, edifícios, pessoas, ameaças, defesas, entre outros. Alguns desses elementos tendem a ser estáticos. A localização de infraestrutura e edifícios não varia muito, mas o seu estado pode ser afetado por uma ameaça. O comportamento dessas ameaças pode ser imprevisível, mas normalmente dependem em alguns fatores que podem ser medidos.

O uso de ferramentas de simulação para prever o efeito que as ameaças podem provocar no espaço é uma fonte útil de informações para preparar uma resposta adequada. Idealmente, um sistema deve ser capaz de fornecer informações ao utilizador em relação ao resultado esperado de um determinado evento monitorizado, permitindo-lhe modificar alguns fatores, tais como medidas de defesa. O uso de um sistema deste tipo pode ser importante para decidir a alocação de alguns elementos para um novo local, priorizando os elementos críticos que podem estar em perigo de serem afetados e, como resultado, causar um problema maior. Dados geográficos resultantes da simulação de perigos podem ser importantes para muitas circunstâncias. Seja para estudo de comportamento de eventos, ordenamento de território ou análise de risco. Também pode ser útil em eventos ativos para monitorizar seu progresso e adaptar-se a eles. A prevenção pode variar dependendo do risco associado retornado das simulações, mesmo sendo possível simular vários cenários para saber quais seriam os métodos de prevenção desejados a serem aplicados.

Para esta dissertação foi desenvolvido um servidor web capaz de fornecer técnicas de simulação via web para simulação de incêndios e cheias. A simulação de incêndios é assegurada pelo FARSITE, que permite realizar simulações de incêndio usando dados relativos à topografia, combustível, clima, vento e outros personalizados pelo utilizador. Os dados necessários para realizar simulações para Portugal podem ser encontrados em algumas instituições públicas. Outros dados relativos à infraestrutura e edifícios podem ser encontrados no OpenStreetMaps, embora possam não ser tão completos quanto desejado. Para resolver esse problema, também é fornecida no servidor a opção de editar os dados armazenados na base de dados para enriquecer, tanto quanto possível, as informações a serem utilizadas. Para alertar o utilizador sobre os elementos que podem estar em risco de serem afetados, os resultados da simulação são analisados com base no tempo e os dados que são considerados espacialmente afetados são destacados no mapa.

Um caso de estudo foi realizado para a região de Tondela. A comparação entre simulações é

feita para abordar o efeito de como diferentes cenários afetariam a paisagem. Usando a metodologia do caso do estudo, outras regiões também poderiam ser implementadas, permitindo o uso de tal sistema para uma área mais ampla. Percebeu-se a utilidade que este tipo de tecnologia pode oferecer à proteção civil e ao apoio à gestão de crises. A atualização da solução apresentada com outras características importantes e melhoria da atual acabará por revelar uma ferramenta valiosa para proteger a população de múltiplos riscos.

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A special thanks to my parents, who supported me in everything I needed and provided me the opportunity to complete my studies. There is simply no words to describe what they may have gone through to provide me the chance to succeed my dreams, and for that I will allways be thankful to them. My brother and family, who allways supported me aswell and were present for the best and worst. They are the ones that will allways be a part of my life.

My friends, whom I don't want to name, so no one is left behind. Be they old or new friends, they have allways been a good companionship. Most of what I am today, I owe it to them, just as surely some of them changed some aspects of their lives thanks to me. I just hope you know that if you are reading this and you consider me as a friend, you certainly are dear to me as well, and I hope to see what you will eventually accomplish and cheer for you, as you have done and will keep doing for me.

I can't forget FEUP, my second home for the past five years. From the friendships I collected, to the knowledge and preparation it has given me to face future challenges and overall the good times it provided. I am sure I will miss these years, as they may have been the most important in defining my future, not only in my career, but as a human being.

Last but not least, I would like to thank my country, Portugal, for constantly trying to improve itself. We, as a society, may have many flaws, but the good things make it worth. Portugal may not be the best country in the world, but certainly is relevant in many subjects that matter for everyone, and will allways matter as long as we keep taking the correct decisions to keep us progressing as a whole.

João David Gonçalves Baião

“Mudam-se os tempos, mudam-se as vontades,
Muda-se o ser, muda-se a confiança:
Todo o mundo é composto de mudança,
Tomando sempre novas qualidades.”

Luís Vaz de Camões

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Abbreviations

ADF	Auto-lead Data Format
ANPC	Autoridade Nacional de Proteção Civil
API	Application Programming Interface
ASCII	American Standard Code for Information Interchange
CA	Cellular Automaton
CB	Corporação de Bombeiros
CLC	Corine Land Cover
CQL	Common Query Language
CRS	Coordinate Reference System
CSS	Cascading Style Sheets
DECIF	Dispositivo Especial de Combate a Incêndios Rurais
DEM	Digital Elevation Model
DGT	Direção Geral do Território
EPSG	European Petroleum Survey Group
GDAL	Geospatial Data Abstraction Library
GI	Geographic Information
GIPS	Grupo de Intervenção de Proteção e Socorro
GIS	Geographic Information System
GML	Geographic Markup Language
GNR	Guarda Nacional Republicana
GPX	GPS Exchange Format
HTML	Hypertext Markup Language
ICNF	Instituto da Conservação da Natureza e das Florestas
INE	Instituto Nacional de Estatística
INSPIRE	Infrastructure for Spatial Information in the European Community
IPMA	Instituto Português do Mar e da Atmosfera
JPEG	Joint Photographic Experts Group
JSON	JavaScript Object Notation
LCP	Landscape
MDT	Modelo Digital de Terreno
NASA	National Aeronautics and Space Administration
NUTS	Nomenclatura das Unidades Territoriais
OGC	Open Geospatial Consortium
OSM	Open Street Maps
PCO	Posto de Comando Operacional
PNG	Portable Network Graphics

ABBREVIATIONS

SDFCI	Sistema Nacional de Defesa da Floresta contra Incêndios
SDI	Spatial Data Infrastructure
SHP	ShapeFile
SLD	Styled Layer Descriptor
SNIG	Sistema Nacional de Informação Geográfica
SNIRH	Sistema Nacional de Informação de Recursos Hídricos
SNIT	Sistema Nacional de Informação Territorial
SRS	Spatial Reference System
TIF	Tagged Image File
URL	Uniform Resource Locator
US	United States
USA	United States of America
UTM	Universal Transverse Mercator
WFS	Web Feature Services
WGS	World Geodetic System
WKB	Well-known Binary
WMS	Warehouse Management System
XML	Extensible Markup Language

Chapter 1

Introduction

1.1 Context

Natural and Technological Disasters are a problem that cause unpredictable destruction in critic aspects of our daily life, not only threatening the lives of the people caught in them but also taking away the work of a lifetime in many cases. Even if they do not directly threaten the people involved, such problems may cause a sense of emergency that will make the people around it worried and force them to fight for what they have which produces insecurity in the population.

In fact those events usually escalate really quickly, giving short time to respond and mitigate the damages, so to do that there are public organizations responsible for prevention and act if an emergency occurs. Due to the rapid scalability of these events, quick and under pressure decisions are required to manage the situation, so crisis management may not be the best approach to minimize the impact and preventive measures are required to avoid bigger evils. Preventing damages by protecting key areas and avoiding situations of risk is important to keep the population safe and consequently increasing the overall quality of life.

1.1.1 Disasters

Each year multiple kinds of hazards strike the territory of Portugal, from forest fires that burn areas of a size that can be seen from space [DN17] to floods that turn streets into rivers [Obs17], earthquakes capable of shaking the entire territory [CM18]. Some examples of an infinite type of situations that question the well being of us all. Such events may be of natural or human origin, have different type, shapes and source locations, so when people less expect, a disaster may come from either the sea as the form of a tsunami, from the forest on the opposite direction as a wildfire, from the sky as lightning strikes, from underground as an earthquake or even as all of the previous examples combined. Depending on several factors, from the risk of being hit by something to the preparation to fight it, an hazard may produce incalculable damage and deaths to the point of non return or if people are prepared, what could be a disaster may be a simple occurrence with nothing to worry about.

Just by looking at the fire scenarios from the last few years, there were hundreds of innocent people killed in Portugal alone [Alb17], most of them in a few hours period. It was so chaotic that from then (the riskier fire periods of last year) up until the same period of the following year, fire prevention and fight preparation were constant in the daily talks of the population and even in the political scenario of this country. The government is forcing population to clean the land 50 or even 100 meters around their properties before the most problematic time of the year [Lus18], authorities are being improved in quantity and quality, the help of armed forces will be used and more aerial fighting and reconnaissance means are being acquired to avoid the same catastrophic scenarios that happened before. A whole lot of preparation is being taken care of, so we can avoid losing more lives, infrastructure, money and a whole lot more that is threaten by hazards.

Disaster occurrences may be one of the most problematic themes nowadays, but it is also one reason that unites society, bringing people to work together with a common goal in mind, to avoid bringing back the sense of insecurity to our minds and above all to avoid loose our own lives or the lives of the one's closest to us. During the year of this writing, it was noticeable that much effort was put into solving this issue, which is a good sign that the same problems will not affect us again. Although this may be true for this year, many of the solutions prepared, mainly the prevention measures, will not be enough to prevent the same catastrophes from happening the following years, especially if the memory of those events fade over time, as it happened before. To avoid that, the methods of prevention and fight should be automated or improved so they stop demanding the huge effort this year needed and still be effective. Technology, in its multiple forms, plays a huge role in this, making previous techniques obsolete by replacing them with better ones.

To be able to properly fight an hazard, people should know how it works to avoid risking their lives unnecessarily, so preparation should start in school because saving lives should be a prioritized common knowledge in each one, and it should not stop there because professionals are needed for the more extreme situations when common sense is not enough to provide a valid response. It is taught already how to proceed in situations like earthquakes and schools usually make drills to raise public awareness for the possible sudden occurrence of disasters. However arises the question of whether that is enough or if something more should be made in order to prepare everyone to future situations. Should the knowledge of fire, one of the oldest techniques used by mankind, be upgraded for everyone or is the common sense now enough?

In case of emergence there are authorities trained to protect people and property, just like there is also those responsible to try to predict and prevent such scenarios because if they do not get to be a problem then there is no need for an emergence response. Patrolling forests susceptible to fires or using barriers to stop the progression of the water in floods are examples of today's prevention methods that keep us protected, but when that is not enough, a rational plan and experience is required to take control of the situation just like cooperation between authorities and population is a must have considering the work some operations may need to combat severe situations.

1.1.2 Civil Protection

Since a long time ago, the corporations responsible to defend Portugal population from multiple problems have been the firefighters, most of them volunteers. They are responsible to respond to multiple help missions, being patient transport, prehospital, accidents and fire fighting their most noticeable interventions. With the developing of times, the risks and dangers increased as well, being it due to new technological problems or because of the increased awareness due to media, and because of that, the work required from a firefighter and the means he needs are also increasing, resulting in new cases that are not solved in time or with the quality needed due to the lack of economic or human resources.

When a danger situation exceeds its normal state it becomes a crisis that endanger important or even vital goods and implies urgency and extreme measures in response to restore normality. When a situation escalates, the means available may not be enough to even control it, so the support of others is required, either from other corporations, municipalities or even countries. Such cooperation is important and should be facilitated to the point where help requests are fulfilled in the minimum time possible, being time an huge factor in emergency response, even more when the issue is potentially becoming a disaster.

In the year of 2003 there were great scale fires, and the civil protection was unprepared to solve them, resulting in the death of 18 people [Car17]. Taking this into account, National Authority of Civil Protection (ANPC) was given more responsibility in civil protection and crisis management, being today the most important organization directly connected to the government (Ministry of Internal Affairs and Prime Minister), responsible to coordinate the defense of the population in case of a crisis occurrence.

As said in the report of independent technical commission to the republic assembly about 2017 fires [JCaFP+], the operation ran by authorities may be really complex and require previous planning for extreme situations. In the referenced fires the institutes used to combat them involved:

- National Authority of Civil Protection (ANPC), responsible to plan, coordinate and execute policies in prevention and reaction to serious accidents and disasters and to protect and rescue the population

- Institute for Conservation of Nature and Forestry (ICNF), as the national forestry authority, is the body responsible for coordinating the pillar of prevention within the Forest Fire Protection System (SDFCI). This responsibility includes the coordination of planning at the general level and monitoring its implementation in certain circumstances.

- Republican National Guard (GNR), responsible to operational prevention, investigate the fire reasons, insulation of areas in critic zones and periods, control of circulation and evacuation of populations. It also participates in the combat through its Intervention Group to Protection and Relief (GIPS) with helicopter transport intervention, field intervention, forestry patrol, controlled fire execution, among others.

- Fire Brigades (CB). The National Civil Protection System, defined in 2006 by legislation, is organized at national, regional, district and municipal level and aims at preventing collective risks, dealing with major accidents or catastrophes resulting therefrom, mitigating and limiting risks. Their effects if they manifest themselves, to promote the relief and assistance to people and other living beings in danger, protecting cultural and environmental assets and values of high public interest and to support the restoration of the normal life of people in areas affected by major accidents or catastrophes.

- Municipality and Parish councils. The Civil Protection Law (Law no. 27/2006, of July 3 with the wording given by Law no. 80/2015, of August 3) establishes several provisions regulating the intervention of the municipal level of the system of protection. Taking into account the principle of subsidiarity as set out in that law, *"The civil protection subsystem at the higher level should only intervene if and to the extent that the objectives of civil protection can not be achieved by the civil protection subsystem immediately and the severity of the effects of the occurrence."*

The forest fire defense system consists of 3 pillars, the first being structural prevention in which ICNF is responsible, the second, operational prevention by GNR and last but not least, the combat, which is guaranteed by the previously mentioned forces and even others, according to the special fire fighting devices (DECIF). The combat starts as an initial attack with integrated and organized intervention, sustained by an initial dispatch up to 2 minutes after the fire was confirmed, mobilizing aerial resources and organized in triangulation of the land resources, followed by an extended attack if, after the first 90 minutes since the dispatch of the initial attack mean, the fire was not given as dominated or in resolution by the relief operations commander. The extended attack can start before the 90 minutes mark if the predicted fire progression so determines. It is also worth mentioning that there is a operational command post (PCO), the lead agency for the on-the-spot operations to support the operations responsible officer in preparing the decisions and in the articulation of the means used for the theater of operations, ensuring maximum coordination of the various forces present.

Civil protection is a demanding task carried out by vital organizations who have the duty to protect the population when it needs it most. Such tasks require a lot a cooperation, expertise and focus, and it cannot be only based in reaction to spontaneous events but also in prevention and preparation for possible future occurrences.

1.1.3 Geographic Information

Geographic Information (GI) is data represented in space that can describe a location, visually known as a map. It can contain names, type of terrain, altitude, elements present, anything a map can show. Such information is an important tool for spacial reconnaissance, planing and navigation used for millennials.

As civilizations progressed such tools have been improved to better understand the whole picture of the space we all live in, from pieces in a table similar to chess, to paper cartography of local maps, the possible creation of a world map and now with modern cartography and databases capable of easily storing this data some things became possible otherwise would not, GPS is a good example.

To put words on top of a location and be able to identify such place as something that distinguishes it from other locations is a way to locate something or someone. The characterization of a geographical location depends in the measured scale and information can even overlap, being possible for a location to have more than one identification depending on what is the important information to extract. The distribution of cultural borders is a good example, for example, the world is divided in continents and continents in countries and those in other divisions, each smaller than the previous. So geographic information is characterized by a defining area that describes where it is or not in space.

When what is right in front of someone vision is not enough for the task required, the ability to identify what is beyond enriches his knowledge of the space around. When such information is static or tends to not be much altered over time, by moving it becomes possible to acknowledge the space without other information sources, however when information change constantly it requires a way of updating it. When applying geographic information to civil protection it is important to distinguish both types, being information relative to borders, infrastructure, buildings, topography and others mostly unchanged over time, while information about constant changing events require a mean to transport it to the responsible entities. The emergency number used by society to call for help is an alert systems that relates and occurrence to a location and informs authorities to proceed with the proper response.

During a big scale operation like the fires of 2017 in Portugal, the response teams are split in the field to combat every front to control its growth. Organization is required and so the knowledge of the space involved to spot areas in major risk of being affected, because decisions about where to place the combat measures and where to evacuate when the danger is imminent need to be done. GI is crucial for this, being able to indicate in space the location of roads, water supply, forests, houses, hospitals, basically anything that can be associated to coordinates in a map. Such data can even be related and calculus made to produce navigation routes, display customized information or simulate real scenarios.

1.1.4 Simulation

Simulation is the representation of a real process or system and is used to understand its behavior and to prepare for a real occurrence. Simulation is used in many contexts, being it to test a software program or to prepare the population over a disaster occurrence. Simulation allows the consciousness about some process without the need of it to be executed as it normally does. This becomes important when the execution of it is not possible, either because it is too dangerous or unacceptable or because it still does not exist in a state possible to execute.

To simulate something, a model representing its key characteristics and behaviors is necessary in order to calculate the progression over time it will reproduce. To produce such models, one should have knowledge of previous examples of real scenarios to mimic its behavior or else it would be based on pure imagination and so the resulting simulation may be incorrect and lead to a misunderstanding of the real scenario.

To be able to address future threats, insurance that such threats are not a major risk to society well being is required, and simulation is a way of insuring the preparation to face multiple risks. *"Insurance takes up external danger and transforms it into manageable risk. It removes accidents and other misfortunes from a moral-legal domain of personal responsibility and places them in a technical frame of calculability. The events insurance typically works on are dangers of relatively limited scope and statistically regular occurrence: illness, injury, accident, fire. When taken individually, such events may appear as misfortunes, but when their occurrence is plotted over a population, they show a normal rate of incidence. Knowledge of this rate, gained through carefully plotted actuarial tables, makes it possible to rationally distribute risk."* [Lak07]

By producing simulations on catastrophic scenarios, one can be alerted about the destruction it may be able to produce and the response techniques available to answer such threat, and so identify what means are ready and what should be changed to improve defense. These are the most important information to take in a simulation scenario, however it can be useful to inform the participants of the importance preparation takes in real-life scenarios and the damage such threats would do if proper measures would not be taken into account. Scenario-based simulations exercise the quality of emergency responses and produce knowledge about needed capabilities, as well as generation of a sense of urgency among participants.

1.2 Motivation

Being such an important matter in Portugal today, it is required to find solutions to help fight hazards that put our society at risk. The study of such events help in finding ways to avoid big consequences like multiple casualties or property damage, so things such as the prediction of behavior of those events or identification of risk situations are relevant matters when planning the defense of the territory.

Since the turn of the XXI century there are dozens of thousands of forest fire occurrences in Continental Portugal alone. Those fires consume thousands of hectares, taking with them not only a big percentage of the national forestries, but also many lives, infrastructure and buildings, sparing nothing at its path and leaving a trail of ashes behind. The most devastating years were 2003, 2005 and 2017, with a total of 425.839, 339.089 and 442.418 hectares of burned area, respectively. This leads to an average of loss near the 200 million euros mark every year [Car17], a significant value, however insignificant compared to the lives lost and the ones put in danger every summer. It should always be present in everyone's minds, not only the more than one hundred deaths of 2017, but also the ones of the years before, including the ones of the firefighters that died trying to save the population.

In a crisis situation, authorities need to analyze the area involved to identify key zones that should be secured and predict vulnerable spots. This is important for a good civil protection in case of emergence so they can prepare and execute the proper manners of action to avoid calamities.

Being such a demanding task that requires a lot of attention to minor details, authorities sometimes need an external help to visualize some events, being it another official information input or even technological tools that track the state of the event. Although there are already some technology used for such purposes, the constant update, upgrade of such tools, as well as creation of new ones is necessary to efficiently tackle new problems and improve the way it is done today.

Hazards are a major threat to life as we know it and leaves everyone in a state of emergency every time something catastrophic happens. It provokes a sense of insecurity that should not affect people, but it does, and in a big way, reducing the ability to focus on other as important subjects. Everyone should be conscious in the process of fighting such problems to reduce or even extinct the losses they cause.

If the behavior of hazards can be predicted, such problems become easier to solve, making it an important method for reducing the number of deaths and property destruction, helping avoid catastrophes of large scale like the fires in Portugal of 2017 by improving the combat measures and coordination.

Cartography always intrigued me, the ability to represent a space and all the features it includes in a smaller scale than the real one is extraordinary, it allows the simplification of a scenario and further analysis to help solve problems in hand. Taking GPS as an example, it has simplified the lives of everyone by a lot, making it possible for someone to navigate to anywhere in the planet and avoid getting lost in locations previously unknown to the subject or even find certain spots that should be impossible before without previous knowledge of the location or asking around.

Combining GIS with a noble cause that is upgrading the fighting capabilities of those who risk their lives everyday to help society when it most needs revealed to be the perfect thesis theme to develop.

1.3 Objectives

Objectives for this thesis consist in specification and implementation of an integrated geo referenced data model to prevent risks and disasters, such as fires, floods, earthquakes, among others. Such model will be responsible to cross information input to simulate output scenarios for each type of hazard. The required data should be sourced and extracted to allow a good analysis of the hazards.

Identification and integration of simulation and machine learning techniques to produce visual results that describe the expected outcome of an Hazard propagation over time.

Identification of visualization metaphors and implementation of a dashboard, with indicators and alarms, on a geographic information system able to help authorities in crisis management support. This may include infrastructure, buildings and other features affected by the hazard.

Integration of the previous functionalities in a web-server that allows a simple access to simulate multiple disasters scenarios, help prevent risk situations and support in crisis management by allowing the user to test different situations regarding the hazard behavior and combat measures.

1.4 Document Structure

Next chapter, a literature review is done regarding the existing similar solutions to the presented one, as well as some concepts related to the work in hands and existing solutions that can be used. Chapter 3 explains the necessary data and technologies to make it work, as well as an architecture of the implemented solution. chapter 4 describes the path taken to implement the system with reasons of why some options were taken over others. Chapter 5 presents some results regarding test cases, difficulties encountered during the development of the solution, a discussion regarding the utility of the program and possible future upgrades. Chapter 6 concludes the thesis.

Chapter 2

Literature Review

2.1 Manual DGT

Proteção Civil and Direção Geral do Território wrote a Methodological guide for the production of municipal cartography of risk and creation of geographical information systems of municipal base [JNR+09]. This guide explains why it is essential to produce risk cartography in prevention matters, as it explains the importance of risk cartography in civil protection and ways of using such information in geographic information systems. It is the result of a joint work carried out by the National Civil Protection Authority (ANPC), the Directorate-General for Spatial Planning and Urban Development and the Portuguese Geographic Institute, assisted by a team of consultants specialized from academia.

This guide allows municipals to have a methodological common base to promote the identification and selection of natural, technological and mixed risks to produce thematic risk cartography of municipal scope in an harmonized manner and to build the base municipal GIS with regard to surveying, monitoring and validation of risk data.

Municipal risk cartography to be developed in accordance to the specification of DGT methodological guide integrates the National System of Territorial Information (SNIT) and should also be accessible from National System of Geographic Information (SNIG). The European Infrastructure of Geographic Information (INSPIRE) forces its member states to manage and provide the data and services of geographic information according to the common principals and rules in order to promote the availability of spatial information, usable in the formulation, implementation and evaluation of the European Union territorial politics. This will allow European citizens to get useful information regarding the environment and other themes through the Internet, also allowing public authorities to easily share Geographic Information (GI) between themselves.

2.1.1 Concepts

According to DGT there are multiple concepts that should be taken into account when analyzing cartography of risk, such as:

Hazard - Process or action natural, technological or mixed that may be susceptible of causing losses or damages identifiable.

Severity - Capacity of a process to produce damages, measured in the size of it and not by the damages itself.

Susceptibility - Represents the tendency of a zone to be affected by a certain danger.

Probability of the Hazard - Probability of the occurrence of a danger in a certain time with a certain degree of severity for a certain zone.

Elements at risk - Population, properties, structures, infrastructures, economic activities, among others who are potentially affected by a possible hazard.

Critical and strategic elements at risk - same as previous but for elements that represent a strategic and vital importance, essential in the response to emergences, such as hospitals, fire stations, water supply zones, etc.

Vulnerability - Degree of loss of an exposed elements result from a process occurrence.

Value - Monetary value (or strategic) of an element or group of elements in risk.

Potential Loss - Consequence or expected damage resulted from an hazard.

$$PotentialLoss = Vulnerability \times Value$$

Risk - Probability of occurrence of a process and estimation of the consequent damages.

$$Risk = ProbabilityOfTheHazard \times PotentialLoss$$

2.1.2 Risks

This guide also refers to some risk that may be verified in Portugal and where to get information on past activities and variables that affect them as well as explaining methods of analyzing such problems.

Fires - Forest and Urban

Weather conditions - snow, fog, heat waves, cold waves, dried.

Hydrology - floods, tsunamis.

Internal and external geodynamics - earthquakes, volcanic activity, natural radioactivity, landslides, coastal erosion.

Transports - road, rail, inland waterways, air accidents, ...

Infrastructure - collapse of tunnels, bridges and other infrastructures, floods due to dam rupture, ...

Industrial - accidents in industrial parks and areas. accidents involving dangerous substances. accidents in establishments manufacturing and storing explosive substances.

Others...

2.2 GIS

As the encyclopedia of database systems explains, a geographic information system (GIS) is a computer application designed to perform a wide range of operations on geographic information. This information describe locations on or near the surface of the Earth, and may be organized in a variety of ways. [Goo09]. Such data must be referenced to the Earth's surface using a coordinate system and the databases containing it are normally conceptualized as a collection of layers, each containing the representation of a field, such as land cover cartography, topographic data or it may contain a collection of discrete objects, like buildings or infrastructure. It can be represented in either vector or raster format, which will be explained later.

The first appearance of the term GIS happened with the launch of the Canada Information System in the decade of 1960, however such systems were already being developed mainly in the United States. Its earliest applications were in land resource management, automated cartography and transportation, however it always was an important tool for military and intelligence agencies, being government institutes the heaviest users of such systems, yet they have today a great relevance for public use, such as navigation or geo referencing. During the last decades the development of new tools is increasing and the public knowledge to use them is improving, providing a good environment to upgrade the capabilities society will have regarding geographic problems solving.

The Google patent for a Geographic Information System which comprises a multi threading client and multi threading server cluster states the importance GIS has been having in everyone's daily lives and affirms the growing possibility in the next decades due to the the huge amount of markets it may be inserted in the Internet. *"GIS serves as a means of communication by conveying information and knowledge to the public. This booming trend of GIS is potentially attributable to many, but at least two primary factors: the building of the Spatial Data Infrastructure (SDI) worldwide, and the dazzling development of computing technology and information technology in general."* [YKW+10]

Using GIS to explore space-time processes can be very useful, due to possibility of a simplified visualization of large-scale time based events. *"To date, GIS has been employed largely in mapping and not for simulating space-time processes. The introduction of GIS-based simulation is an important research direction for enhancing the capacity of GIS. In this new context, GIS can be used as a method for forecasting space-time patterns in a reasonable, repeatable and consistent way."* [Wu99]. There is no doubt that combining space and time is a must in certain processes, and doing so by combining geographic information and time allows the understanding of huge processes that had no better approach before the development of GIS.

"Most of the web GIS-based portals available in Internet are designed for specific theme and are targeted to specific class of users. A single GIS service may not be sufficient to address the requirement of all types of target users" [KSS+12]. In its study, a spatial mashup technology is developed for disaster management support for India. By combining Web and GIS technologies, the access of GIS functionalities becomes easier, allowing it to run in most of today's devices that

can use the Internet. In order to make web-GIS work, different kind of software integration is necessary, like GIS database management (PostgreSQL, POSTGIS), GIS development libraries (GDAL/OGR), Web GIS displayer (OpenLayers, Leaflet), Geo-web Services (GeoServer, OSGEO), Desktop GIS (QGIS, GRASS) and/or Catalogue services (Geonetwork)

Most data relative to Portuguese geographic information is available online in government institutes responsible for territory management. Direção Geral do Território is an example, as it provides in SNIG (Sistema Nacional de Informação Geográfica) geographic information important for systems that requires maps. This system is an online infrastructure of national scope responsible to provide access to metadata and geographic data services produced or maintained by public authorities or on its behalf. [Jul09]

Many data has been gathered with the purpose of creating solutions for planning and emergence, for example data of national and municipal territorial planning, containing information about the type of territory in Portugal, from urban areas, to the types of vegetation present, data of hidrographic information that locate rivers, lakes or supply zones, road locations data or even maps containing the susceptibility of some place to certain kinds of dangers.

During a disaster occurrence there are multiple variables that influence how this one evolves and the damages it will cause, like the wind speed and temperature in case of fires, being the wind an important fact in the direction the fire will follow. Such data can also be found in public institutes (for the most part) depending on the type of hazard in study. Weather values can be found in IPMA and demographics in INE.

Although all data mentioned before is probably enough to predict with some degree of assurance the behavior of hazards, using historical data of previous occurrences to compare with each situation may be good to improve the results or fill certain information that is not available with information of similar disasters that happened in the past. There are multiple data sources for such, like Wildfire historical data from ICNF (Instituto da Conservação da Natureza e das Florestas) or Flood historical data from a Portuguese project called DISASTER [ZPT+14], even data from FireHub2017, a system launched last year by Esri, and American company specialized in geographic systems, that provides detailed data of forest fires in Portugal.

2.2.1 Data

2.2.1.1 PostGIS

PostGIS is an usefull extension for PostgreSQL that can easily handle geographic information. Database tables generated with it usually have a geometry column that represents the type of geometry of the feature(s) and the coordinates that compose the data. PostGIS enables the creation of new data types and aggregate functions.

Regina Obe and Leo Hsu claim PostGIS is the most powerful of the open source relational databases, allowing the handling of terabytes of data and complex SQL constructs easily. It contains features expected of an enterprise-class relational database and functions useful for business intelligence reporting applications [OH11]. PostGIS is clearly the tool necessary to handle the store and extraction of spatial data, being it points, lines, polygons, raster or any other type of geographic data formats. There are no other open source solutions capable of providing everything PostGIS has to offer, which makes it a must have when dealing with geographic data.

PostGIS is developed by Refractions Research Inc, as a spatial database technology research project. The company plans on supporting and developing PostGIS to support a range of important GIS functionality, including full OpenGIS support, advanced topological constructs (coverages, surfaces, networks), desktop user interface tools for viewing and editing GIS data, and web-based access tools. Ramsey wrote an extensive manual relative to the installation and usability of PostGIS [R+05].

2.2.1.2 Data format

GIS data can be classified as:

- Vector

Data in vector format is represented by points, lines or polygons of joined vertex that contain information regarding the coordinates they represent. A single feature/vector may contain multiple attributes associated. It may be a single square or even complex geometries, depending on the scale of measure and the quantity of measured points (Fig. 2.1a). Some formats that represent vector data are shapefile (.shp), VRT, among others.

- Raster

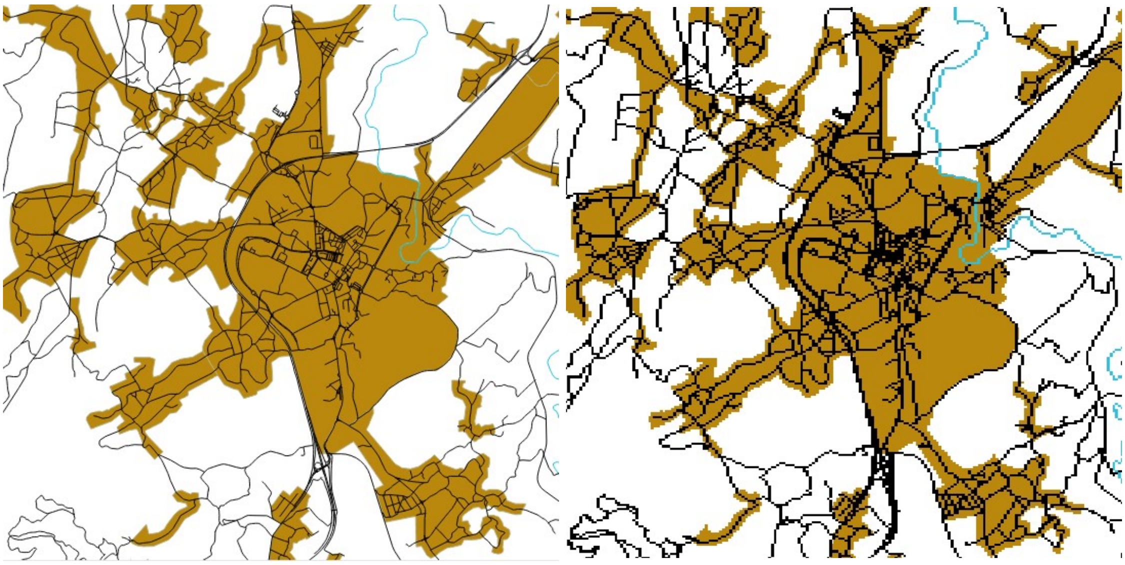
The data is divided in columns and rows and each cell contain attributes regarding spatial information considered constant for the whole area of the cell. Every cell has the same size, meaning round shapes will look straighter as the scale downsizes. It is like the pixels representation of a picture (Fig. 2.1b). They are a poorer representation compared to vectorized data, although they are significantly faster to produce calculations because they are easier to join multiple layer's information (simpler indexing). Some of the used raster formats used to represent spatial information are ArcGRID (.asc), Geotiff (.tif), png, jpeg or even simple arrays.

2.2.2 Models

2.2.2.1 Fire Spread Models

Fire spread models are composed by equations that calculate numerical values related to the behavior of fires, such as spread rate, flame height, ignition risk or fuel consumption. Such models are classified as either theoretical, empiric or semiempirical. [PZPA03].

Theoretical models are representations of real live fire behaviors generated from laws that represent fluid mechanics, combustion and heat transfer. Because they are based in theory, such models are difficult to validate, however they can be applied to many different situations.



(a) Vector (b) Raster

Figure 2.1: Comparison between Vector and Raster Format for the same data representation

Empirical models are built using historical occurrences, trying to learn how they work and formulate similar scenarios, yet they may only be applied correctly in identical situations of the ones used to create them.

Semiempirical models are a junction of both previous. They use theoretical expressions and are completed with experimentation.

Surface fire models are able to simulate the fire spread in the surface bed. Most theoretical models were built to a one-dimensional fire line spread in homogeneous fuel beds, producing calculations for possible fire spread in a single direction that could be used for 2 dimensions if calculations are made in all possible directions, forming an elliptical format. Rothermel's [R+72] surface fire model and Fernandes semiempirical for Portugal [Fer09, FGL+09] are examples of surface fire spread models.

Crown fire models simulate the progression of fires in the canopy of the fuel. These are harder to produce than surface fire due to the complex behavior of crown fire and data quality, nevertheless multiple models have been produced even if they lack some precision in predicting the fire spread. Theoretical Spread modell [Alb85], semiempirical initiation and spread model [SR01].

Spotting consists in the ignition of new fires due to the transmission of embers through the air. It is even hard to predict, but still an important factor to take into account in fire spread modelling because spotting may cause a fire further away from the borders of the initial fire, sometimes trapping firefighters between multiple fires or creating new ignitions in unexpected places capable of causing extreme damages, so the attempt to predict the most probable places of spotting is still important. Not many models were produced for spotting, but some are used in today's tools for fire spread simulation. Albini theoretical model [Alb85].

Table 2.1: Theoretical fire model examples

Author	Reference	Origin	Type
Van Wagner	[VW+67]	Canada	Surface Fire Spread
Albini	[Alb85, Alb86]	United States	Surface Fire Spread
Albini and Stocks	[AS86]	Canada	Crown Fire Spread
Albini	[Alb79, Alb81, Alb83]	United States	Spotting

Probably the most used model is *Richard C. Rothermel*'s fire spread model for surface fire spread [R+72]. It is used in combination with Van Wagner's crown spread [Wag93] and Albini's spotting [Alb85, Alb86] in *Farsite* to calculate for each vertex using the fuel, weather and topographic data the elliptical fire spread rate and direction in an horizontal 2d format.

2.2.2.2 Rothermel's Surface Fire Spread Model

Rothermel's mathematical model for predicting rate of fire spread and intensity is applicable to a wide range of wild land fuels. AS the author puts it, the model is complete in the sense that no prior knowledge of a fuel's burning characteristics is required. All that is necessary are inputs describing the physical and chemical makeup of the fuel and the environmental conditions in which it is expected to burn [R+72]. Such inputs include fuel related values, environmental and slope of terrain.

Early assumptions regarding the relationship between burning conditions and variables that contribute to its spread confirmed that sufficient heat is needed to bring the nearest non burning fuel to ignition temperature at the fire front. Fire spread can then be visualized as a series of successive ignitions and its rate is controlled by the ignition time and the distance between particles. Heat is supplied from the fire to the potential fuel until the surface temperature gets to a point where combustible gases are released and ignited by the flame, allowing the fire to advance to a new position.

Rate of spread and intensity predicted by the model are based on the following equations:

Table 2.2: Empirical fire model examples

Author	Reference	Origin	Type
McArthur	[McA66, McA67]	Australia	Surface Fire Spread
Forestry Canada Fire	[SLL+89]	Canada	Surface Fire Spread
Viegas, Ribeiro and Maricato	[VRM98]	Portugal	Surface Fire Spread
Rothermel	[Rot91]	United States	Crown Fire Spread
Cruz	[GdC99]	Canada	Initiation and Crown Fire Spread
Muraszew and Fedele	[MF76]	United States	Spotting

Table 2.3: Semiempirical Fire model examples

Author	Reference	Origin	Type
Rothermel	[R+72]	United States	Surface Fire Spread
Fernandes	[Fer98]	Portugal	Surface Fire Spread
Vega et al.	[VCF+98]	Spain	Surface Fire Spread
Wagner	[Wag77]	Canada	Initiation and Crown Fire Spread
Finney	[Fin94]	United States	Initiation and Crown Fire Spread
Tarifa, Notario and Moreno	[TdNM65]	United States	Spotting

$$R = \frac{I_R \xi (1 + \phi_w + \phi_s)}{\rho_b \varepsilon Q_{ig}}$$

$$I_R = \Gamma' w_n h \eta_M \eta_s$$

Such formulas take into account concepts like propagating flux ratio wind coefficient and slope factor, ovendry bulk density, effective heating, heat of preignition, optimum reaction velocity, net fuel loading, fuel particle low heat content, moisture damping coefficient and mineral damping coefficient. All equations are explained in detail in the paper [R+72].

Rothermel's model can be applied in management problems in an "hypothetical fire" situation in which operations research techniques are utilized for fire planning, fire training and fuel appraisal and in a "possible fire" situation for which advance planning is needed. Despite being almost half a century old, it is today still an important model used by many fire simulation software.

2.2.2.3 Van Wagner's Crown Fire Spread Model

One of the most important person for the development of crown fire models is Van Wagner [Wag77, Wag93]. His expressions were used in US [F+98] and Canada [SLL+89] early fire simulation systems. His model determines if the fire remains burning in the surface fuels or makes a transition to burning in crown fuels, and whether it spreads actively through the tree crowns or simply torches individual trees [F+98].

The model calculates the threshold for crown fire transition dependent on crown foliar moisture content and crown base height (vertical distance between the ground and the base of the live crown fuels). It also uses concepts such as active crown fire spread rate, crown bulk density, energy flux and crown fraction burned.

Although it found success in North America, *"In its later use (Van Wagner semiempirical procedure) in Mediterranean Europe, erros due to its application with different fuels should be considered or avoided by doing a correct calibration process"* [PZPA03]. It is clear that crown fire spread is hard to predict, due to the difficulty in representing data related to tree canopy distribution and the mixing of multiple vegetation types, also because canopy is subject to changes in a short time compared to the time needed to gather such data in present day.

2.2.2.4 Albini's Spotting Model

The collection of spotting models is not vast, however the few that exist are important in improving the knowledge about this phenomenon. It is even harder to predict and measure the effect such events would do in a fire, however it is known to be a part of such hazards, so they should be considered when studying its progression, even without much assurance of its results.

Albini's equations for spotting from torching trees [Alb79] consider torching trees as a consistent source of embers capable of lofting high with the help of wind that start spot fires far from their initial location. They take into account variables like ember size, shape and density, wind speed and surface topography.

2.2.2.5 Flood Models

Flood modeling, like fire modeling, is a complex task due to the variables it depends on. There are currently some models that try to predict flood related behaviors in multiple domains that are integrated to improve the study of floods. Just like fire, as mentioned before, require information cross from multiple models to be effective in its calculation.

There is a case study for the San Antonio River Basin Summer 2002 storm event in Central Texas, USA that integrates US Environment Agencies rainfall data, GIS and a hydrological model (HEC-RAS) [KYHM05]. This model is dependent in other models to create a more complete flood modeling. It uses a rainfall-runoff model (HEC-HMS) developed by the US Army Corps to simulate the precipitation-runoff processes of watershed systems using a method for determining storm runoff over an area based on land use, soil and land cover type. The hydraulic model (HEC-RAS) calculates one-dimensional steady and unsteady flow and uses as input the output of the rainfall model, parameters for bank locations and coefficients for roughness, contraction and expansion.

2.3 Simulation

A good simulation model should be used for each risk in hand, being able to produce results that can be verified as valid when compared to real occurrences in a short time of simulation, allowing simulations to be done in time to be practical for response teams. The model should be the closest to the real scenario as it can be and accurate data is required for the proper predicted behavior.

2.3.1 Cellular Automaton

Cellular Automaton (CA) is a simulation model in which the space is categorized in states that represent that localization, for example the state "burning" that indicates if that area is burning or not. Each point in space has information containing its neighbors, responsible for the alterations in state over time for that cell. A function is responsible to calculate new values for each cell over each time period, continuously predicting new situations based in the previous verified and each cell's neighbors states.

This type of model can be used to reproduce simulations of hazards, being able to represent how those processes behave. For a fire to be able to evolve in space/time, the current location of it influences the closer area depending in the type of terrain and climacteric data. A similar approach can be used for floods, as the path water takes in floods depend in the height of water a cell has, the altitude of it, increased amount of water (eg: rain) and drainage capacity.

There are multiple documentation in simulation of the propagation of forest fires and floods with examples of how to accurately predict the evolution of those. To be able to simulate it, some variables need to be used, like the wind direction and speed, temperature, the type of the terrain, elevation, etc.

An example of a cellular automata fire simulation model integrated in GIS to characterize forest fire behavior in Canada [YDS08]. Just like most, or even all of the previous fire spread models, this one also uses topographic, fuel and weather variables to calculate fire spread. To validate its performance, some comparisons were done with the Canadian fire modelling tool, Prometheus [TBW+10], based on elliptical wave propagation principles. The model calculates for a full ignited cell the speed of fire and direction of travel to see how it affects neighbor cells. It is concluded that CA either overestimates or underestimates the simulation results when compared to elliptical wave propagation models, however the calculations are easier to make.

Another example, a model for predicting the spread of fire in both homogeneous and inhomogeneous forests incorporating weather conditions and land topography [KT97]. This models was not tested using real forest scenarios, but hypothetical forests that could be compared to real ones. The model distinguishes between complete burned out cells and still burning ones and the state of each individual cell depends upon its neighbors state. The paper describes how the model works in both homogeneous forests (the fire takes a circular shape) and inhomogeneous ones, where the shape tends to be irregular, as well as explaining how the wind and topography affect fire evolution.

2.3.2 Fire Simulation

Programs like FARSITE [F+98], netlogo, FireStation [LCV02], among others can be used to perform simulations for fire spread using different models able to simulate fire progression calculations, useful for predicting its progression in a certain GI. To produce valid simulations, fire spread models cross information related to fuel in surface that is used to calculate the acceleration of the fire, elevation that enables 3d calculations, an important factor for direct effects in spread of fire and incident solar radiation as well as weather and wind data.

FARSITE [F+98] is an American Software for forest fire simulation using models like Rothermel's to calculate the spread of fire in certain type of fuels. This program also uses other models to surface fire, crown fire and spotting to calculate the spread of fire in a landscape. It uses geographic data such as the fuel type, elevation, scope, aspect and canopy cover to generate landscape

Table 2.4: fire simulation software examples

Name	Origin	Reference	Main components
Firemap	USA	[BG92]	Rothermel [R+72], cellular automation
Wildfire	Canada	[Wal93]	Canada Department of Forestry's models
Farsite	USA	[F+98]	combined surface and crown fire models as well as spotting
Geofogo	Portugal	[CdVG+99]	Rothermel [R+72], cellular simulation
Spread	Portugal	[MLA00]	Rothermel [R+72], cellular automation
FireStation	Portugal	[LCV02]	Rothermel [R+72], cellular simulation
Prometheus	Canada	[TBW+10]	Canada Department of Forestry's models, wave simulation

files and other data like adjustments to fuels, fuel moistures, custom fuel models, conversions and coarse woody, being the last 3 optional. It also uses weather and wind data files to help in calculations with values like the daily precipitation, highest and lowest temperature and hours of such values, highest and lowest daily relative humidity and hourly values for wind speed and direction.

FARSITE incorporates surface fire spread, crown fire spread, spotting, point-source fire acceleration and fuel moisture models providing spatial patterns of fire growth and behavior in a two-dimensional format. Fire shapes are assumed to be generally ellipsoidal under uniform conditions, meaning that parameters remain constant in space and time for each step. This usually will not happen in real scenarios.

It uses Huygens' principle method as a fire growth model. *"Huygens supposed that, at any instant t = t0, a point-source of light generates a disturbance which is propagated into the surrounding medium as an isolated spherical wave, which expands with a large constant velocity, the velocity of light"* [BC03]. The model used in farsite assumes that each vertex can serve as the source of an independent elliptical expansion. Each vertex has the information about its orientation on the fire front, the direction of the maximum fire spread rate (which is previously calculated) and the shape of an elliptical fire determined from the conditions local to that vertex.

The equations used were originally developed for flat terrain, however such system cannot take into account sloping terrain, so transformations are required to calculate the proper spread in a 3d terrain surface. To do that, FARSITE adds a slope correction to the vertex being calculated depending on the aspect (radians) of it.

Surface fire is the occurrence of fire in the surface of the ground, easily verifiable in fuel beds with short vegetation. Usually a large scale fire is not only represented by this type of fire, but also fire in the canopy of trees that may increase the spread of the fire by a lot. That is where crown fire comes from. To simulate the progression of fires, besides the surface fire, it is important to calculate the spread of the fire in the canopy since this type of fire progression may accelerate its spread considerably, considering the amount and volume of fuel being burned is much bigger than considering only the surface. Spotting is other major factor in big scale fires, because a forest fire may cause ignitions in locations far away from its original perimeter due to the movement of sparks and ignited particles through the air, ending up falling in zones that are propitious to start a new fire. The ignition of new fires due to spotting is unpredictable, but should not be ignored since the generation of new fire fronts outside the original perimeter may be a really big problem.

Parameters for the calculations need to be chosen, such as the time step, which represents the time between calculations, visible steps time to represent the progression of fire, perimeter resolution and distance resolution. Also, ignition points need to be selected to represent the start of a fire and barriers can be placed to avoid the passage of fire trough them.

The program calculates for every cell currently on fire if it will affect the neighbor cells, producing the spread of the fire by calculating the temperature of each cell affected using all the required parameters. If the resulting temperature is higher than the boiling temperature, than the cell is considered to be on fire. The fire is considered to spread in the surface, crown of the canopy or even by spotting by floating through the air using sparks which enables the fire to spread to places that weren not previously neighbors of the current fire.

The output is the evolution of the fire over time, being able to represent data such as the time of arrival of the fire, spread direction, fire line intensity, flame length and others. This data can be saved as a raster ascii file for further import in a GIS.

It is used for decades to simulate fire spread in American surfaces and can be used for Portuguese landscapes as long as the required data is gathered.

Other worth mentioning program for fire simulation is FireStation [LCV02], a software system developed in Portugal using a semi-empirical model for fire rate of spread, using local terrain slope, fuel properties parameters and wind speed and direction. Like farsite, this one also considers the fire shape as an elliptical format. The model used for fire spread is Rothermel's surface fire spread model [R+72] and takes into account Huygens' principle as well to design the shape of fire spread. The system takes into consideration a fire danger rating system applicable at regional and national level, using the Canadian Fire Weather Index, which integrates weather and fuel parameters affecting fire potential.

Probably the best feature about FireStation is the wind field simulation. Being wind one of the most important parameters in fire spread calculations, this system is able to simulate its values in a way not seen in other systems. It uses two different wind models, NUATMOS [RSMF88], a linear model and CANYON [LSV95], a Navier-Stokes solver. NUATMOS takes as input the values of wind speed and direction measured in certain locations in space. The model then interpolates and/or extrapolates velocity values into all grid points and adjusts those following a method of variational analysis. CANYON employs a control volume approach for the integration of the transport equations.

Overall, FireStation seems to be a reliable software for fire spread simulation capable of creating realistic simulations of wildfire growth that can be used in planning fire suppression operations, and so, a good civil protection and crisis management support system.

2.3.3 Flood Simulation

For flood simulation, *Crayfish* is a QGIS plugin that apply flood models to simulate the visualization of flood behavior in a certain geographic location. Most models require input related to elevation for flow spread calculations, permeability and drainage, as well as weather info.

There are various 1D and 2D flood simulation models, however most of them required complex input data, usually relative to water flow, river basin boundaries, water increase sources and drainage systems.

João Belo wrote a thesis about GIS applied to flood risk analysis in Tejo river [Bel12], using HEC-RAS as the flood simulation model. Most hydrological data used by him was gathered from SNIRH, although the author mentions the lack or unavailability of some necessary data to extract proper results. Other data related to cartography was extracted from similar sources as this thesis data. The output of the simulation is related to depth, extension and velocity of the water, producing rasters that can later be compared with GIS cartography to analyze the impact it would have.

2.4 Visualization in QGIS

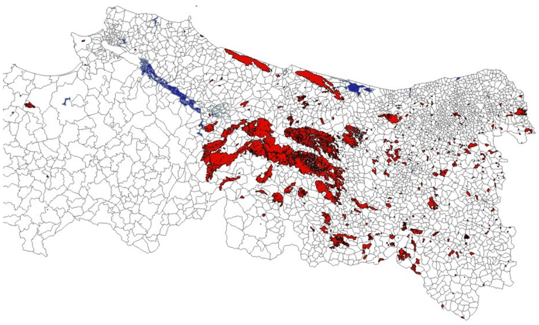
Quantum GIS is an opensource GIS written in C++. Its main focus is interactive two dimensional viewing of spatial data, but it can also be used to edit vector data. Most vector and raster formats are supported by it: PostGIS, GRASS, Shapefile, GML, WFS, GPX, WMS, GeoTiff, PNG, JPG and others. [Hug08]

Due to the necessity of creating heatmaps, indicators and alarms of strategic data, a good visualization tool of geographic information data is required to spot useful information in space. Quantum GIS [T^+14] is capable of joining together multiple geographic information. Overall it seems a good way of visualizing results, being able to prepare multiple kinds of possible analysis with few prior knowledge about geographic systems. It is able to display multiple layers of information provided in the correct location because they all use a format for the geographic information that should be the same, resulting in the display of data in any desired way in space.

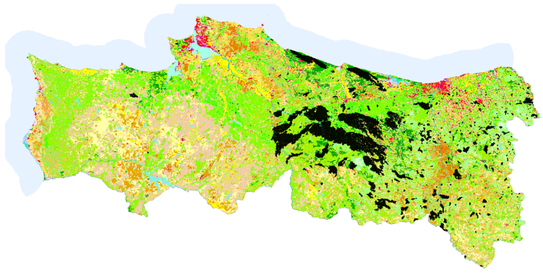
During my first experience with QGIS I could join multiple maps of continental Portugal with the divisions of municipalities, data regarding the territory planning that divide the territory per usage it has, locations of previous fires like the burned area of 2017 fires, road or water networks, zones with susceptibility to certain disasters or even cartography of risk for the whole Portugal (Fig. 2.2a, 2.2b 2.2c).

For this project, QGIS can be used to show the affected area by a certain hazard for a certain time period, as well as the elements caught in it, being able to alert the authorities about key locations that should be secured, otherwise they can be damaged or completely destroyed by such process, as well as identifying which areas should be prioritized over others considering the time it would take for the hazard to affect that place.

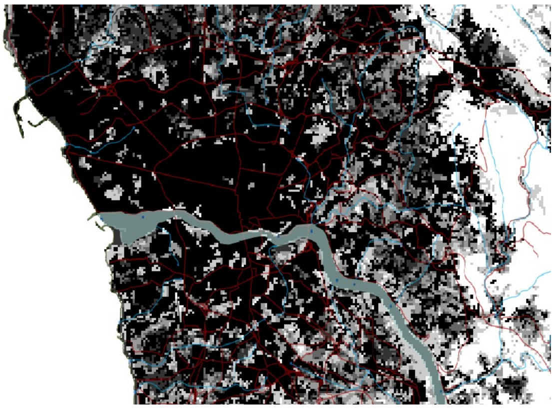
Although QGIS is a powerful visualization tool, it cannot be used to display on the web cartography, and for that others tools should be taken into account. It is not necessary to have one as good as QGIS relative to data support, visualization and editing, but a simple one that can display treated data in a web server. Some examples are Leaflet and OpenLayers, libraries supported by most mobile and desktop platforms, able to display tiled web maps and even give the user some



(a) Risk areas of flood (blue) and area burned in 2017 (red)



(b) Territory planning and burned areas



(c) Risk of an hazard (white to black), water ways (blue) and main roads (red) for Porto

Figure 2.2: Examples of data visualized in QGIS

interactivity using markers and pop ups. Those tools functionalities will be explored further into this writing.

2.5 Related work

GIS based simulation models are being studied for some years to reduce damages of hazards, from fire spread models using concepts like type of fuel present, heat transfer coefficients and climate values [KPS+05, F+98], models using agents like sensors to detect the conditions of each location [NSHK10], some use cellular automata to predict the movement in the grid that represents the location [LWZ+17] and there are even models for estimating large scale damages [HAS+16].

2.5.1 Data

João Costa [dC16] built a geodatabase for his thesis, rich with useful information for decision support in prevention and fight of fires. He mentions multiple important information authorities are interested in an emergency situation like the position of the agents in the field, support cartography, historical data of ignitions, administrative limits, infrastructure, roads and water spots. It is also proposed ways of using geographic information systems as a support in civil defense.

Maria Reis [R+12] developed a decision support system that returns the location of combat structures closer to the fire when asked for by an officer fighting it. The developed solution does not incorporates any simulation tool whatsoever.

2.5.2 Simulation Models

There are some models developed to simulate the spread of fire in Portuguese territory. Some examples could be a spread simulation model developed for Alentejo [M+16] and another one for Serra da Arrábida [S+07].

A simple model for fire spread rate based on energy conservation and detailed heat transfer mechanisms. It calculates the limit of one-dimensional steady-state contiguous spread of a line fire in a thermally-thin uniform porous fuel bed. Eigenvalues are then used with appropriate boundary conditions through a fourth order Runge-Kutta method [KPS+05]. In this paper it is described the formulas used to calculate the fire spread, as well as some comparisons with real-life scenarios that proves the reliability of the model.

An agent-based forest fire simulation model [NSHK10] that combines a virtual overlay multi-agent system validation scheme with fire weather index to validate forest fire simulations. Wireless sensors are randomly deployed for forest monitoring and use the fire weather index to calculate fire probability and compare it with the simulation model. The software used to run the simulation model is netlogo.

A GIS based dynamic model of fire spread using heterogeneous cellular automation simulation [LWZ+17]. Such model calculates the fire spread in hybrid urban scenarios, having forest and concrete buildings represented in different type of cells it can model the fire spread from forest areas to urban areas and vice versa in a single experiment by reproducing the necessary heat transfer for the fire to propagate from one area to the next.

A study using FlamMap, a similar program to FARSITE was used to simulate the effects of vegetation and landscape structure on fire behavior near Bragança [R+16]. For this study, custom fuel models for holm oak based on field data collected in the region were used. It could be concluded that holm oak affect fire behavior by reducing fire intensity and rate of spread.

2.5.3 GIS

A seemingly good system to keep track of every occurrence and authorities involved in fire fighting for Águeda [Car15], even integrating FARSITE into it's use. However apparently only results from FARSITE are used, and not the possibilty of performing new simulations through the application. This system is composed of a web server using PHP, PostgreSQL and OpenLayers.

In 2016 an approach to predict fire growth in an operational setting, with the potential to be used as decision-support tool for fire management was made with mostly deterministic approaches using FARSITE as the simulation program to simulate the growth of large wildfires [PBS+16].

The combination of multiple simulations was conducted to calculate the probabilistic fire spread using heatmaps. It was also used the reported ignition locations and verified burning areas through satellite. The case study used was Tavira wildfire occurred between the 18th and 21st of July 2012. Overall it could be concluded that such method would be useful for civil protection in a forest fire scenario to predict the progression of fire.

FireStation [LCV02] is a software aimed at the simulation of fire spread over complex topography. It uses a semi-empirical model for fire rate of spread. The paper explains the used models and displays some results and conclusions regarding the performance of the developed software. Probably the most interesting feature of it is the way it calculates the wind, being able to produce complex wind behaviors that are seen in real scenarios but are currently hard to measure.

Farsite is a program developed in the United States of America, to be used by the U.S. Forest Service, National Park Service, and other federal and state land management agencies [F+98]. The program incorporates existing models of surface fire, crown fire, point-source fire acceleration, spotting and fuel moisture to produce complex fire simulations. The model produces vector fire perimeters at specified time intervals and the vertices of such vectors contain information on the fire's spread rate and intensity. In the paper, the author also explains the different used models. The program can produce powerful simulations provided the right data, however its usability requires professionals prepared to handle it and does not provide alerts of affected elements in the landscape. Also, this software requires previous install, it has no web service.

A Real-time Web-based Wildfire Simulation System [WCA+16] uses a simple model to calculate spread and direction rate in raster format. It is client-server system, where the system stores the datasets and data is transferred as a JSON to the client. Users can change values of vegetation and wind to perform different simulations.

Xinhao Wang integrated GIS, simulation models and visualization into one system in order to support planning and decision-making, however the prototype produced is related to the traffic impact of automobiles in carbon monoxide concentration along roadways. [Wan05]

A web GIS based integrated flood assessment modeling tool for coastal urban watersheds that produces urban flood simulations for simple web visualization, using an integrated overland flow, channel flow and 2d storage cell based hydrological models, giving as output flood maps. [KME+14]

Although there is a lot of development in this area in the last decade, not much information regarding the use of such systems in Portugal is available, however there are some studies made for specific regions. A project that could be used for the whole territory would be ideal to combat large scale problems that require cooperation from multiple municipals and organizations. It would be good to have a systems that could make use of national data to produce simulations for the whole territory. Even though such data may be found for the whole surface of Portugal, the computation power for it all would be too much to produce results in practical time, requiring it to be divided in multiple sections to be viable.

Taking the systems mentioned previously as examples, to develop a solution that could improve the study of civil protection and crisis management I looked for open software that could be used as a tool to simulate fires and floods using open data available for the territory of Portugal and output results that could be visualized with coordinates matching the correct EPSG. Even though there are many models to simulate hazard behaviours and some systems able to help in a civil protection scenario, none of the encountered is able to alert to the infrastructure and buildings being affected by the simulation results, and that is the main feature this thesis will try to complete.

2.6 Summary

During the literature review analysis, some studies and technologies were identified that are used to help in civil protection and crisis management using GIS technologies. Most of the results were relative to fire simulation, however some other hazard simulations were also explored.

Some concepts and elements were mentioned that need to be taken into account when performing civil protection operations.

A brief history about GIS is provided, as well as some software examples necessary to build one. It is explained how GIS can be useful to conduct civil protection operations. A distinction between the types of data formats used by GIS is also developed in order to understand what kind of information will be handled during this project.

There is a good amount of simulation models prepared to simulate hazards. The easiest to find are fire progression models, although a brief mention about flood models is also made. In order to fully predict the growth of fires, the combination of different fire related models is necessary. An explanation of how any of the desired models to be used is provided, as well as short lists of some others that could be used.

Some existent simulation software are addressed. These programs incorporate simulation models, like the ones mentioned in this chapter to produce simulation result maps.

An open source visualization tool is mentioned. QGIS turns out to be a powerful GIS tool to display and treat spatial data, even though it may not be the best option to use.

The development of a GIS tool able to help in civil protection and crisis management support scenarios seems to be a complex but feasible task. The quality of the used data will be of major influence to the results. The utility of the end program will ultimately depend on the functions determined to be implemented.

Chapter 3

Method

3.1 Architecture

3.1.1 Development Overview

The system (Fig. 3.1) purpose is to provide services of visualization and analysis of hazard behaviours to predict and plan civil protection measures. A "what if" solution is given, in which the user is able to address different possibilities to a theater of operations. To make its features available for other systems, an API is also proposed to share its functionalities.

Many of these services require simulations to visualize the expected outcome of an event. To produce such simulations the necessary models need to be used, either it being by 3rd-party external programs able to produce powerfull simulations or the creation of new ad-hoc solutions. Both options will be addressed in this project to prove multiple simulation options from different backgrounds could be used in the future.

The simulation applications will make use of the necessary models, as mentioned before. These models could be theoretical, empirical or semi empirical.

The used models may require the input data to be previously prepared using the gathered resources. These resourses will consist of data related to topography, fuel, geographic occurrences, river flows, among others, depending on the simulation implemented. The resources could be in either raster or vector format, sometimes requiring some conversions.

3.1.2 Physical Overview

The application is composed of five main devices (Fig. 3.2):

3.1.2.1 User Client

User client containing what the user sees and is able manipulate. The user can access the application through a web browser.

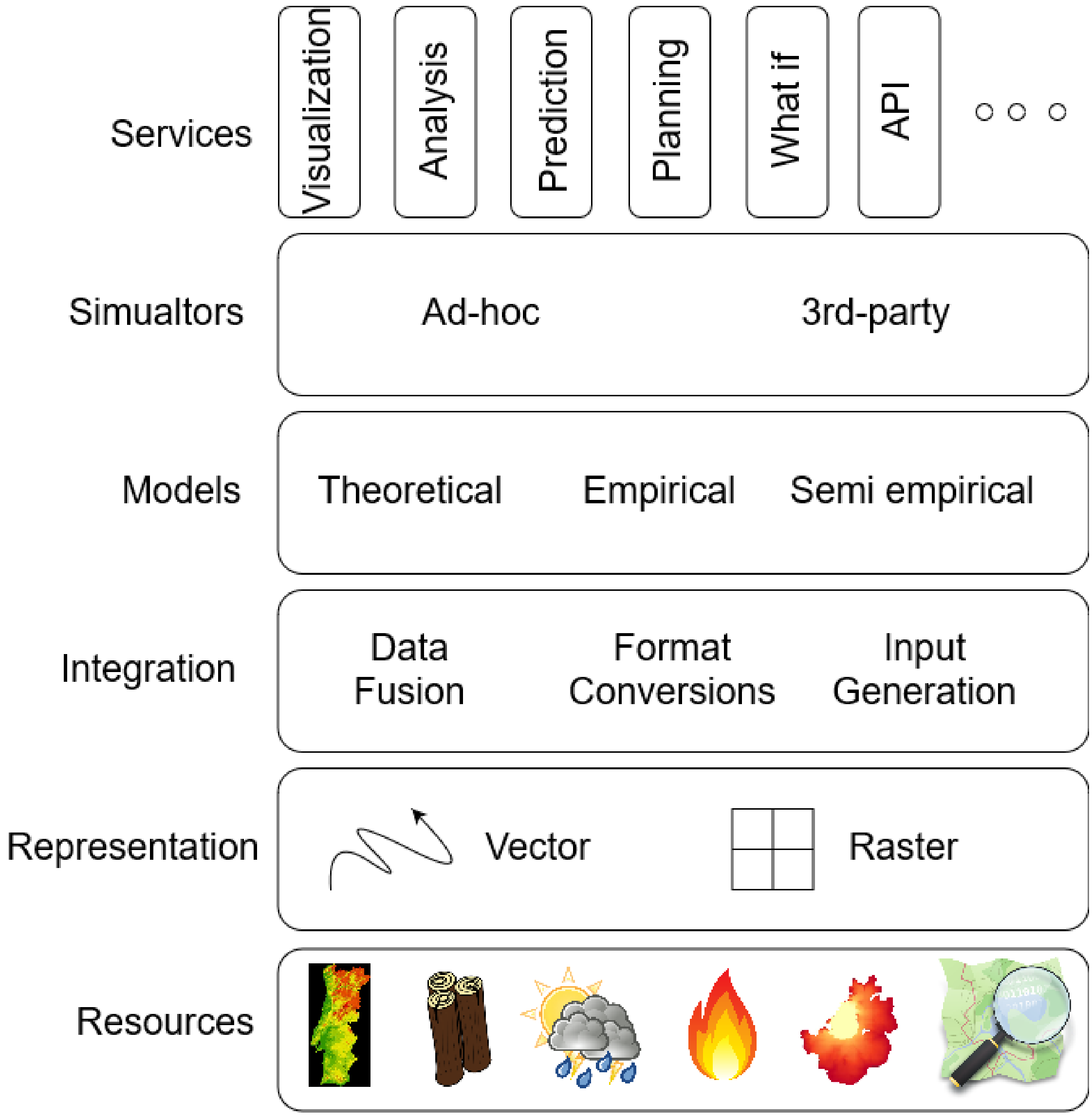


Figure 3.1: Architecture Layers Diagram

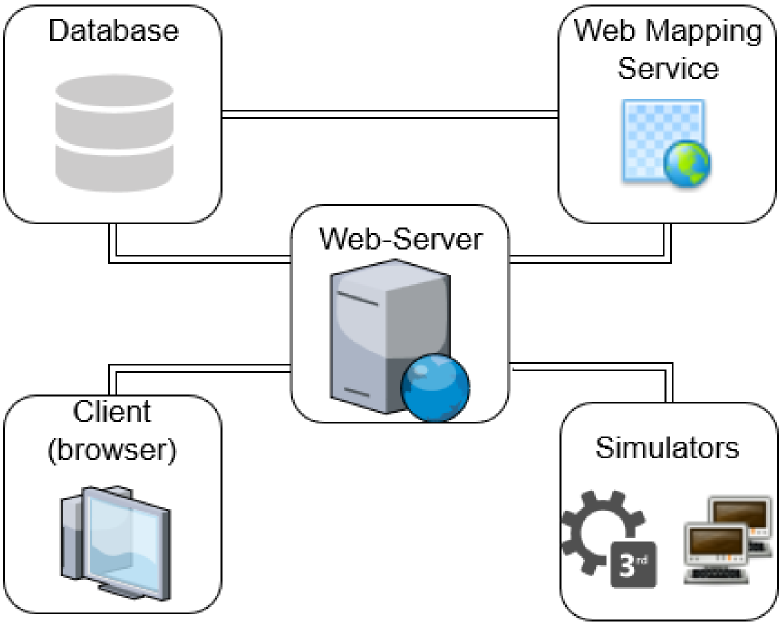


Figure 3.2: Deployment Diagram

3.1.2.2 Web Server

Web Server is responsible to combine all resources for the application to work as intended by accessing necessary information, manipulate and display it to the user.

3.1.2.3 Database

Database server containing all necessary geographic or plain data.

3.1.2.4 Simulators

In order to produce simulations, external 3rd-party simulation programs could be used or ad-hoc implementations of simulation models.

3.1.2.5 Web Mapping Service

To be able to display geographic information in the web, the maps need to be converted and uploaded to a geo-web service. It is required to convert geographic data in multiple formats, such as raster GeoTiff or PostGIS polygons into WMS that can be displayed in a web map as a layer.

3.1.3 Process Overview

Figure 3.3 simplifies the whole process users are able to perform. Admin users only have the functionality of treating the data, being it to add new entries, edit the existing ones or even delete them. The normal user is able to access that data, but not to edit it or add new ones. The process it

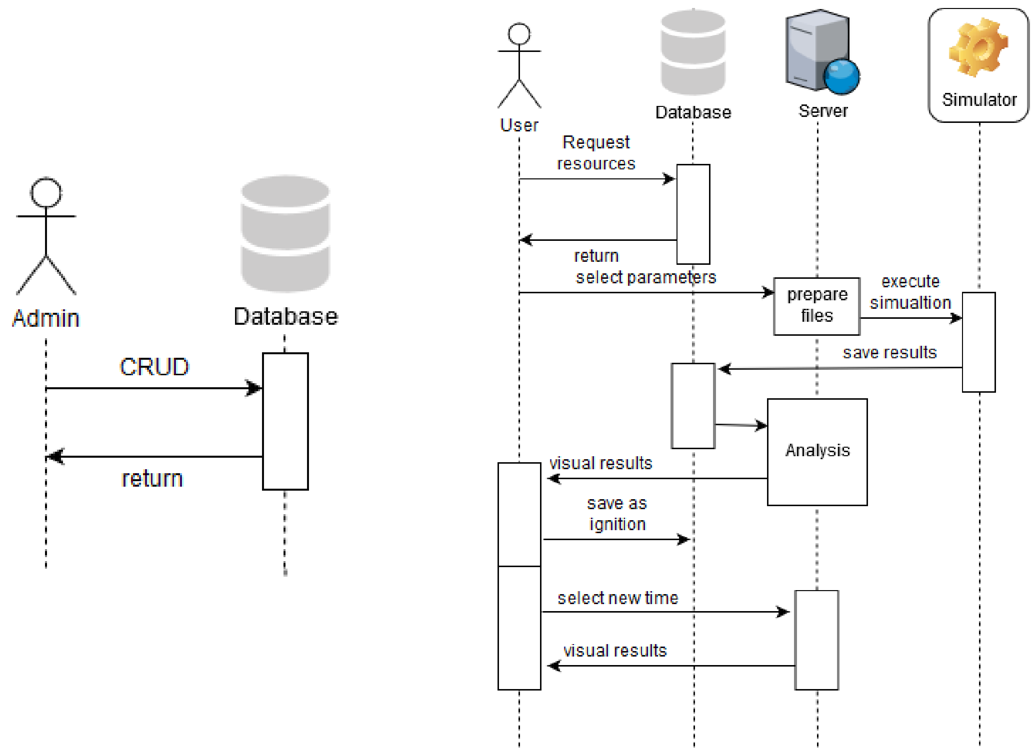


Figure 3.3: Activity Diagrams

can go through is the selection of simulation parameters from the data store, which will then make the system start a simulation, further analyse the results with the OSM data and display it back to the user. Now, with such info, the user is able to select a new hour of simulation result, either by dragging a slider that will cause the server to add a new layer to the map, joining multiple hours of simulation or by inputing the desired value for the hour to be compared with infrastructure. The difference between both inputs is that the slider will not compare the new hour simulation with OSM, but only join multiple layers, while the other compares the result with the infrastructure data once again to get alerts about affected infrastructure. The user is also able to save the current visualized hour into a new ignition that can later be used to new simulations.

3.1.4 Use Cases

As mentioned before, the systems has two types of agents able to interact with it: Admin and normal User (Fig. 3.4).

Admin is responsible to manage sensible information, being able to add, edit and remove it at his will. Overall, the admin is responsible for all data used by the program, with the exception of some farsite parameters that will be talked about later as well as the creation of new ignitions using simulation results, a process that can be done by a normal user. To access the admin interface where the data can be managed, a registered account is required.

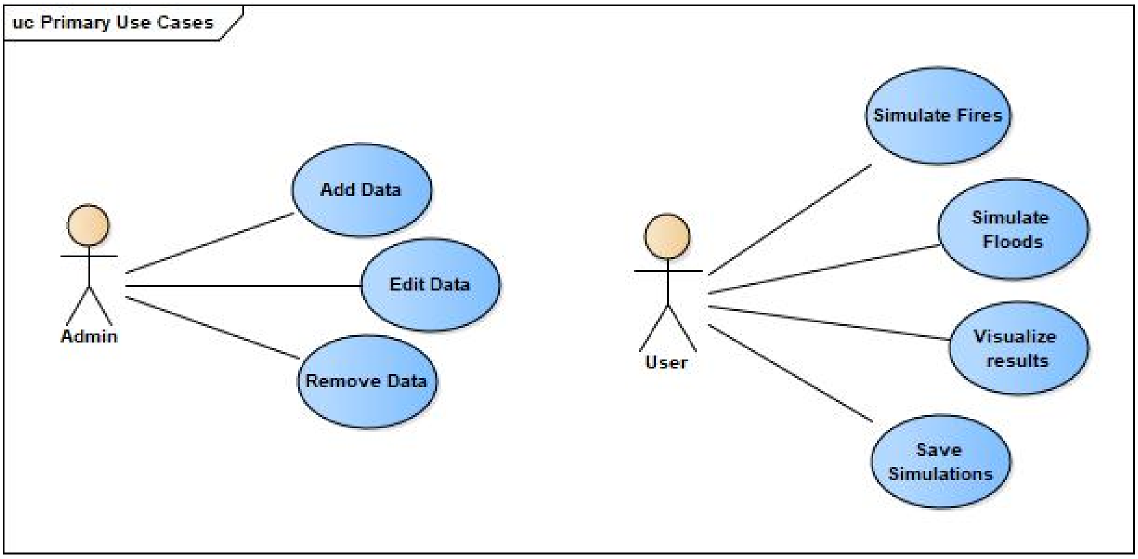


Figure 3.4: Use Cases

Normal Users can use the main functions of the program. They are not registered, so anyone with access to the server is considered a user and can perform simulations of fires and floods, visualize the results of those in comparison with the OSM data and later save the state of fire in a certain hour as an ignition to be used in future simulations.

3.2 Data

Multiple data sources are required for this study, many of them can be found for free online, however the data they contain may be outdated or imperfect for real scenario comparison due to being in raster format.

By combining the rasters with the same format, some formulas can be used to perform simulations and geo spatial relations. To simulate fires, floods and any other geographic related event, topographic data regarding the measured altitude are important for a three dimensional view of the scene. Altitude is of major importance, because with it, multiple other can be extracted, such as slope, aspect, hillshade, color relief, terrain ruggedness index, topographic position index and roughness.

For fire specifically, fuel present, either in soil and canopy are important to calculate fire spread conditions, the distinction between for example short grass and tall trees is important because the fire does not progress the same in both types of vegetation. Fuel can be classified in dozens or hundreds of categories depending on the measured fire behaviour in each type.

For floods, water drainage info is important to calculate how long would it take for the water to vanish from a certain location, river flow and meteorological data to know the increase in water per time.

To identify each location, just the coordinates are not enough, some attributes are important to know what is in a certain place, either it being just simples forest zones, a road, a building or even variable information over time, such as temperature, wind, precipitation or even people and transport movement. The more precise the information is, the position it lays in should be preciser as well, strongly excluding the use of raster when processing information for complex structures or small ones. Complex structures because they cannot be represented as squares and the smaller they are the harder it is to be certain if the information is safe of the where it is located. For example, if raster position is used to identify the location of a firefighter just by simply knowing that he is inside square area up to 30x30(m) it may say that he may be close to the firetruck or 40m from it and that is a big deal in risk scenarios. Even for data like fuel, raster format may be inclusive because a area containing two or multiple fuel types with close occupied percentages is hard to be classified, and the borders of big masses of fuel shifted to incorrect locations. The scale is an important factor to measure the accuracy of the results, so sensible information that requires precision needs either really small scales or to be in vector format.

3.3 Simulation

Simulation is of major importance for the success of this project, however to create a simulation model from scratch would take most of the available time, so a good approach is to find tools able to simulate hazards based on user inputs and produce results that can be later compared with OSM data. The accuracy of the simulation will not be evaluated, although its results are important for the study in hands.

The quantity of inputs required and the role they take in the simulation should be considered, because the more inputs a program needs, the lower the usability gets, but the quality of the results may increase due to the details being treated by the simulation model.

Some options of possible approaches to produce simulations are the use of third-party external simulation software, use of previously existing models in software prepared to run simulations or the creation of new models. Due to the existence of already tested programs that can be used, the creation of new models would compete with such solutions, and the time required to produce a good replacement for those would be too much, so if a good simulation program is found, then it should be used, however for further long term updates, the improvement of the simulation tools should be upgraded to increase its results quality.

Optimally, the topographic inputs required for simulations should be in raster format, because those are the easiest to find and meteorological inputs should be the least complex possible, because the free sources are not that many and not that rich in information. The output can be in either vector or raster, however vector has more support functionalities at its disposal.

For this study, being the thesis about integrating features, more than one simulation should be used, for example, not only forest fires simulation, but flood simulation as well, to show that such solution can include most or even all simulations necessary for civil protection and crisis management in a single system.

3.4 Visualization

Simulation results in GIS format require mapping tools to display it according to its spatial reference system. Just by simply analyzing such data in the format it is stored in the database, not many visual conclusions can be drawn from it. Comparison of the results with base layers that represent a certain map location, like open street map or google maps base layers helps to visually identify what areas are affected.

One of the most known tool to view and manipulate GIS data is QGIS, and during this whole project it is used multiple times to crop initial data, verify the veracity of the simulation results, comparison of different layers and even creation of new spatial features. Overall, it is a really useful software to work with geographic data, even if it is not directly used in the developed solution.

Being this a web based solution, web display tools need to be used to show the data to the end user, like Leaflet or OpenLayers.

3.4.1 QGIS

QGIS can load and display geo referenced data in multiple formats and compare them. By loading various layers of GI, if such layers have a common SRS they will be overlapping, giving the option to compare different data sources that have only in common their geographic coordinates.

A Spatial Reference System is a system used to identify the types of coordinates used. Because the Earth is not flat and a single measure system is not in place to represent maps, many measure origins and scales can be used depending on what we want to measure. The most common systems used are EPSG:4326 and EPSG:3857. Being the first, World Geodetic System, a standard representation of the world with latitude and longitude and the latter, the Universal Transverse Mercator (UTM) coordinate system, divides the earth space into 6 zones and reprojects the coordinates, turning them from latitude and longitude degrees to metric distances.

After loading a layer using a certain SRS, calculations can be done with the info they contain and new layers generated using those outputs. The style of any layer can be altered for visualization purposes, such as color changes, transparency and many other options the user may which for.

Plugins are a key feature in QGIS, allowing the utility of the application to grow, due to addition of user created functionalities that use the resources QGIS provides.

Python Console is a good tool for developers, allowing the use of programming python commands or scripts to calculate GIS operations. Identification of certain attributes in desired locations, cross such informations between multiple layers, generation of new layers, etc.

QGIS also offers some useful tools to manipulate GIS data, like crop using coordinates, translate file formats, reproject to new reference systems, convert data from vector to raster and vice versa, etc.

3.4.2 Web Maps

There are a lot of web mapping services available to display cartography via web. Robert E Roth et al [RDS+13] studies multiple technologies for web mapping, giving us an idea of what options are available, what they can be used for and how is the user experience with them. The most easily found online for the task in hands are Leaflet and OpenLayers, two similar options in mapping web cartography that can be used to display geographic information in multiple formats, from simple images in raster (png, jpeg, tif), vector, GeoJSON or WMS.

3.4.2.1 Leaflet

Leaflet is an open-source Javascript library for web interactive maps. It is a light library, easy to install, understand and use. Works efficiently across all major desktop and mobile platforms, can be extended with lots of plugins and has a well-documented API.

3.4.2.2 OpenLayers

OpenLayers is also an open-source Javascript library, similar to Leaflet. Just like leaflet, it supports geographic information of all kinds to display map tiles, vector data and markers from a multiple source formats.

3.4.2.3 WMS

A Web Map Service is a server protocol that defines the format in which maps are provided over the web.

3.5 Web Server

The development of a web-based solution is important to simplify the use of the program, allowing the access of its functions by someone authorized for it over almost any device that can use internet connection. By doing so, a server should store the sensible code and provide all necessary utilities to the end user. This server should be in a safe place and have all security measures ready to prevent someone or something to use it as anything other than the purpose it was built for. Its services should be provided through a website and/or other software that could make use of it, depending on the people that require its use. The setup of the client should not be complex, allowing the simple access of new systems to the features it provides.

Overall, the server should be responsible to access the necessary data and store new one, treat this data to be used as simulation inputs, produce simulations and save the results, compare the simulation results with infrastructure data, create alerts and heatmaps based on the comparison, display the end results, allow the user to input necessary information and interact with the system in desired allowed ways.

3.5.1 Django

The selected web server development technology is Django Framework [FBC08], a python library that simplifies the creation of web servers. Some examples of simplifications that Django introduces are: creation of database schemas, addition and extraction of data from the database, URL parsing and others, but the main reason that made me opt to use Django is the possibility of using Python as the development language, simple and powerful.

3.5.2 GDAL/OGR

GDAL is a main feature in this work, being responsible to treat raster data. It is able to translate raster from multiple formats and process it in many desired ways. It is able to extract the information about a raster source to create data models that can be used in django and has a lot of functionalities regarding the treatment of such data. It is used in QGIS to treat the data, can also be used using command line and even has a Python API. OGR is like GDAL, but for vector data formats. [War08]

3.5.3 User Inputs

Some user inputs are required to generate the files necessary for the simulation. Such inputs should be analyzed, as there are multiple configuration possibilities for the simulation.

There is available data for the whole territory of Portugal, so it could be possible to give the user an option to select the desired location given that there is previously prepared data for each zone or a way to crop the data with the user desired coordinates, use of a single area for municipal use or even ask the user to collect the data for input themselves which opens a whole lot of possibilities for the user but does not ensure proper results, however it may be a solution for the lack of quality in buildings information.

Due to the unpredictability of weather data and the difficulty of measuring it for every location, this data could either be live data (which is not easy to get) or ask the user to input the desired values. Some info regarding the current or historic data for certain places could be displayed to help the user in choosing the values. There is also the possibility of using SNIRH stations to produce wind cartography using wind vectoring models like the ones used in FireStation [LCV02] Some parameters asked in FARSITE, like the distance resolution or time steps could be an option for the user or just use a default for all simulations.

After the user inputs every necessary values, the server should use the available programs to produce simulations. With the resulted simulations, calculations can be done to spot infrastructure and buildings affected by the fire over the simulation and even those who get to close to the fire perimeter that may get affected due to imperfections in fire spread simulations. In order to improve even more the quality of the results, multiple simulations could be done and an heat map created representing the probability of the fire spread to each location.

3.5.4 Operations after Simulation

Instead of showing the full extent of the fire after the simulated time, the user should be able to visualize the fire growth in a time based manner, so it could easily distinguish what area would be on fire first and prioritize response measures to priority places. To do that the simulation result should be filtered using time, dividing the simulation in multiple results, each one containing the fire growth locations for 1 hour time. Simple array lookups using the raster data and generation of new rasters using geodjango-raster utilities do the trick, creating new raster files. With those multiple files generated, there is only needed a way to display them overtime or display the ones the user asked for. An example for this is to give the user a slider that he can use to move between hours of simulation. If vector data is used instead, the filtering of per time values is simplified due to the use of CQL_filters in GeoServer provided data.

After simulations are complete, some calculus in the data should be performed to display useful information for civil protection and crisis management, such as residential areas too close to the fire, or even assumed to be consumed by the fire in the simulation. By identifying such areas, the authorities may later want to simulate with barriers protecting such places to realize the importance of protecting it and how the fire would behave if that area was covered by a fire barrier (soaking the soil, using combat measures or placing physical anti-fire barriers). A residential area may be considered in danger of being consumed by the fire if it is less than 50m from any fire point in the fire perimeter. Because farsite does not simulate over residential areas, when the fire perimeter encounters a soil whose fuel is residential it simply goes around it (kind of like water terrain), so every area close to the fire should be considered, being the fire points relative to the fire presence 1 hour into the simulation, 20h or even after its completion, however priority should be given to the first areas affected by the fire. The same should be done for infrastructure (roads). Authorities should be advised when the fire is to close a certain road, so some minutes before the fire encounters a road it should be closed to the public and alternative paths generated. Using the in danger zones (residential and infrastructure), the closest water supply zone should be identified, as well as the closest fire station and hospitals to help in crisis response for each zone. The area consumed in the less time factor and most fire intensity should be identified as well to further analyze zones where the fire will have more destructive power in order to avoid unexpected risk situations. Further possibilities should be analyzed to improve the quality of displayed information for civil protection operations.

3.6 Summary

The chapter starts with an architecture proposal of the end solution. A Development view describes the components of the system regarding the programmer view. Physical view lists all devices used to mount the system. Process view explains the possible flow of activities taken by the users and responses of the system to those. Finally an use cases diagram displays the main uses available to users.

The data section mention some types of data required for the study and possible formats that can be used. Simulation section provides a discussion relative to the use of simulation applications and the inputs required. Visualization address some functions of QGIS and possible web mapping services to be used.

To conclude the chapter, a section relative to the integration of the required functionalities using a web server. Some technologies to treat geographic data are explored and some ideas regarding what could be asked the user to perform simulations and what would be displayed to them after.

Chapter 4

Implementation

4.1 Data

Portugal public institutes provide most of the data required for the desired simulations. The necessary important data consist on elevation, slope, aspect, fuel, canopy cover, weather, wind, buildings, infrastructure, river flow and others. Next there will be a explanation on how to find such data, different examples of sources and the treatments it requires to be used in this project.

4.1.1 Elevation

Elevation data is available for the whole planet surface. It was collected by NASA's Shuttle Radar Topography Mission (2000) and made available to the public in 2015. It was filtered by José Alberto Gonçalves to contain only the data relative to Portuguese surface. This data was projected in PT-TM06 SRS and has a 25 meters raster resolution in Geotiff format. Fig. 4.1a

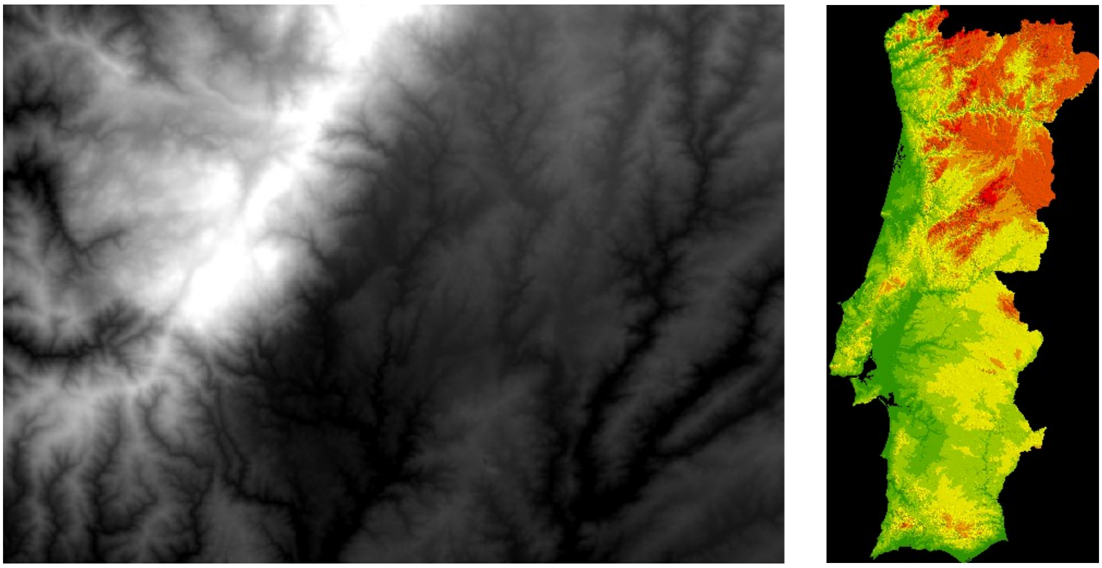
There are other sources where this data can be found, such as the digital terrain model (MDT) with 50m raster resolution that can be found, among others, in DGT geo spatial services provider. Fig. 4.1b

The desired format for this type of data is raster, and it can be found in GeoTiff, a raster format, however for Farsite simulations it should be in ArcGRID format (.asc), so it is required to crop the data with the coordinates of the study area and further conversion using *gdal_translate* command.

The lowest point in Portugal is in coast (0 m) and the highest is either Serra da Estrela (1993 m) for continental Portugal and Pico (2351 m) if islands are included. Most of northern region is mountainous, while south is mostly flat.

4.1.2 Slope

The elevation data can be used to generate slope data using QGIS Terrain Models Analysis (Raster -> Analysis -> DEM), providing the elevation file as input and the desired mode as slope. QGIS will use the GDAL command *gdaldem* to generate the desired terrain data. This data can be represented in either degrees or percentage. Fig. 4.2a



(a) Elevation raster data for Tondela Region ranging from black (lowest) to white (highest)

(b) Digital Terrain Model for Portugal

Figure 4.1: Elevation Data examples

Slope data represents how steep the terrain is. Values closer to 0 represents flat terrain, while higher values contain hills. This data is important to fire calculations, due to the behaviour fire has in different slope terrain, gaining speed when climbing and going slower in descent terrain.

4.1.3 Aspect

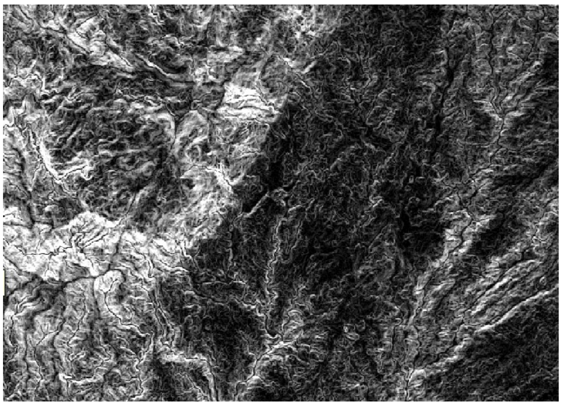
Just like the slope, this data can also be generated using the elevation data in QGIS. It represents the direction the terrain is facing in degrees. Fig. 4.2b

This data is useful to compare with weather data, due to the effect the sun and wind produce in terrain depending on the direction it is facing.

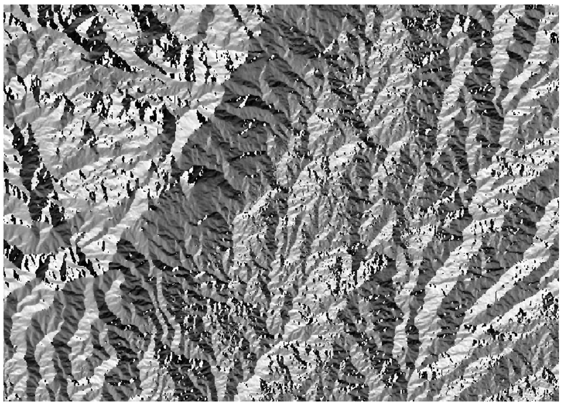
4.1.4 Fuel

The fuel present in all Portuguese surface is available in ICNF website (Fig. 4.3a).

ICNF provides models that distinguish the different types of fuel beds present in continental Portugal. This data is important due to the way fire progress in different fuel types. Farsite has its own code to treat fuel data, so ICNF also provides the data already prepared to be used by this software. The model uses the values in table 4.1. It is also possible to provide custom fuel models to Farsite using the desired values for fire spread calculation if the default values are not enough to represent all existing fuels. The data comes in ADF format, which is Arc/Info Binary Grid format, so to use this data in Farsite, conversion to ASC is needed, also using the *gdal_translate* command.



(a) Slope raster data in degrees for Tondela Region ranging from black (0) to white (25))



(b) Aspect raster data in degrees for Tondela Region ranging from black (0) to white (359)

Figure 4.2: Slope and Aspect Data Examples

Another example that can be used to represent the fuel is Corine land cover (CLC) from 2012, provided by DGT. CLC is vector cartography containing the use and occupation of the soil based in visual interpretation of satelite images. This type of data has more values than the fuel data from ICNF, however not all of it regards fuel, but also zones used to industry, buildings, airports, among others. Fig. 4.3b

4.1.5 Canopy

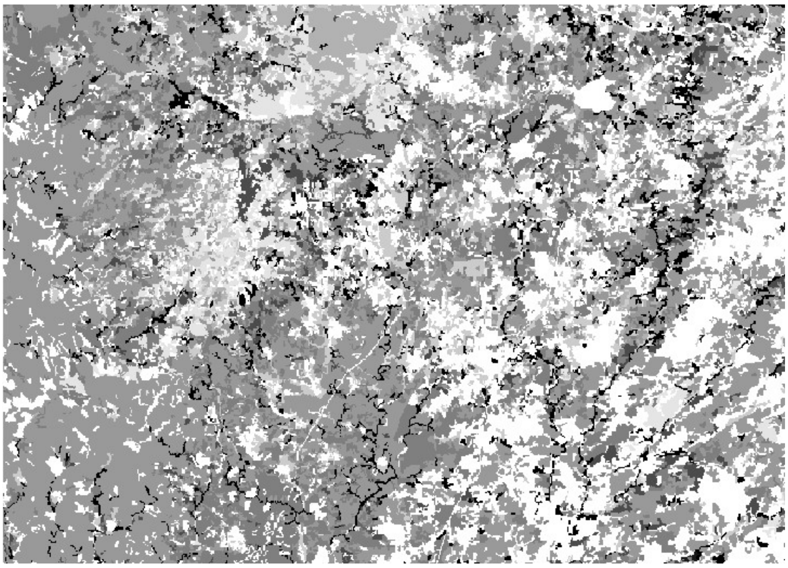
Canopy cover is available in iGeo in WMS format, Fig. 4.4b. It represents the percentage of forest cover in all Portuguese surface. To use this data, first it must be saved in raster format (GeoTiff). The saved raster has 4 bands describing the color of each pixel, which is not ideal, because Farsite requires a single band representing the percentage of canopy cover, so calculations are needed to transform the data to a single band. QGIS has a tool to perform such operation, and using the expression:

$$\frac{(band1 + band2 + band3)}{3} \times \frac{100}{band4}$$

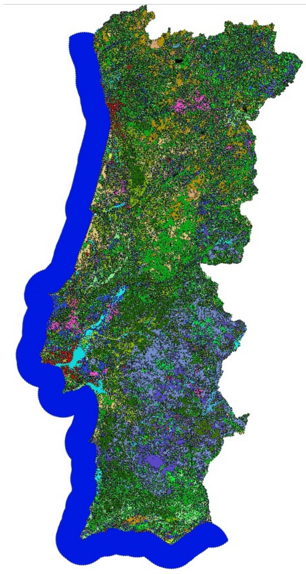
outputs the canopy cover in a single band representing the percentage, this one also in GeoTiff, which will then require a conversion to ASC format. Fig. 4.4a

Table 4.1: Farsite fuel model

1	2	3	4	5	6	7	8	9	10	11	12	13
Short Grass	Timber Grass	Tall Grass	Chaparral	Short Brush	Dormant Brush	Southern Rough	Closed Timber Litter	Hardwood Litter	Timber Litter	Light Slash	Medium Slash	Heavy Slash

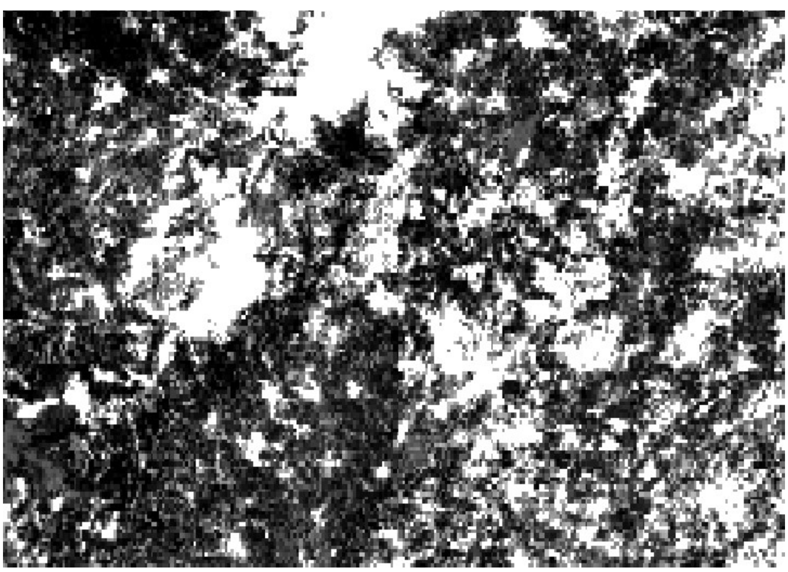


(a) Fuel raster data in FARSITE standard for Tondela Region



(b) Corine Land Cover

Figure 4.3: Fuel examples



(a) Canopy cover raster data for Tondela Region ranging from white (0%) to black (100%)

(b) Canopy cover for Continental Portugal

Figure 4.4: Canopy examples

Table 4.2: Weather inputs examples

Mon	Day	PPT	AM	PM	Tm	TM	HM	Hm	Elev
07	01	0	400	1500	16	32	20	2	200
07	02	0	500	1600	13	34	18	4	200
07	03	20	300	1500	21	28	40	20	200
07	04	0	400	1400	17	30	18	5	200
07	05	0	600	1300	21	36	27	7	200

4.1.6 Weather and Wind

This also can be generated, but if true values are desired, such values can be asked for in IPMA or from sensors of SNIRH.

For Farsite simulation purposes, the necessary weather inputs are relative to the month and day of occurrence, precipitation, morning and afternoon registration times for corresponding minimum and maximum temperatures and humidity and the Elevation of the located data. Table 4.2.

About the wind inputs, the required data also includes the month and day of observation, however this one also needs the hour and minutes, speed of the wind and direction, as well as the cloud cover. Table 4.3

Weather data entries are daily values, whereas wind needs inputs for every 4 hours.

4.1.7 Buildings, Infrastructure and Other

OpenStreetMaps provides geographic information of some data useful for civil protection and crisis management support, such as residential buildings locations, roads, railways, rivers, public places and buildings like hospitals or firefight headquarters. Although it may not be complete, it is a start and for this study it is assumed that this kind of data is up to date. Fig. 4.5

There are multiple sources where this data can be downloaded. OSM provides some guides and links of where to get it. An extraction that is constantly updated for the whole Portuguese surface can be found in geofabrik, a host for OSM data.

Table 4.3: Wind inputs examples

Mon	Day	hour,min	wind speed	wind direction	cloud cover
07	01	0000	03	000	00
07	01	0400	02	080	00
07	01	0800	00	100	00
07	01	1200	05	080	00
07	01	1600	00	090	00
07	01	2000	09	110	03

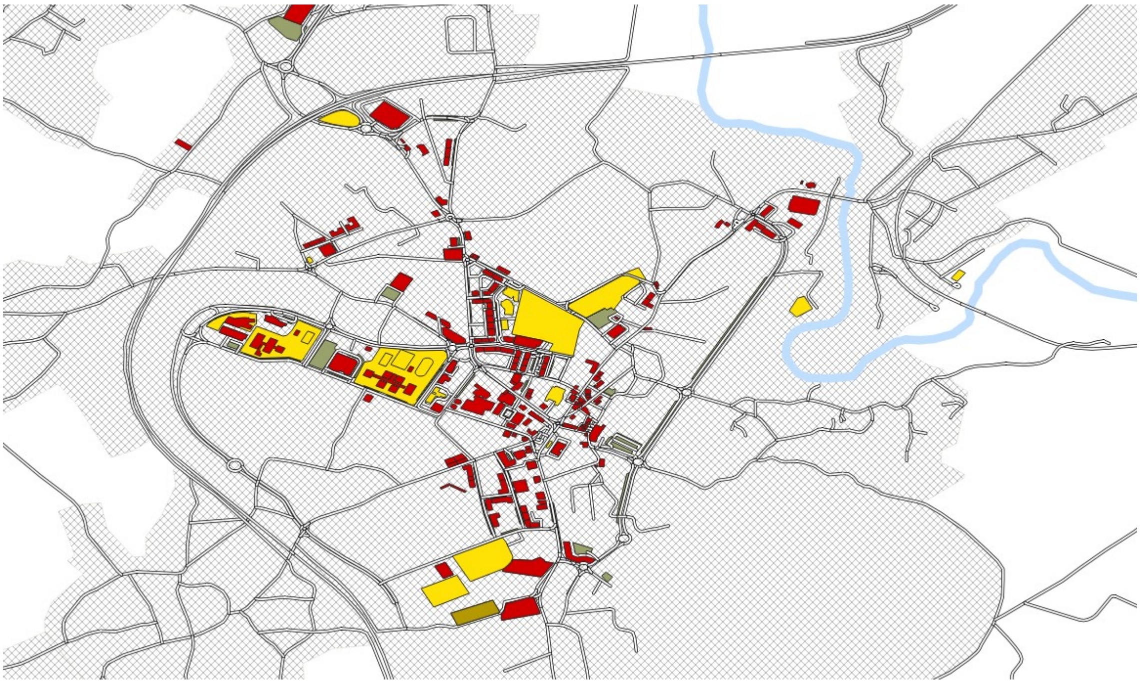


Figure 4.5: OpenStreetMap Data data for Tondela Center

In order to improve the results of alerts and increase the awareness of places in danger of being affected by hazards, this data should be improved. The admin should be able to add more features to it and even more data types. Some examples of data related to this that can be added are combat forces positions, concentration of population, addition of more information for each feature to display or even produce damage calculations. These data are therefore related to any information that the authorities need to compare with the results of the simulation.

4.1.8 Flow

Data relative to necessary river flood calculations are available in SNIRH, a system that records values relative to water using sensors spread through the whole territory. There are a lot of sensors recording that, however most data is either outdated or even not available for most of them. For this study, no data for flow was gathered, although it is known to be available for future use. For each selected location, the corresponding sensors should be selected regarding the data they have.

4.1.9 Crop Values

To be able to represent simulations for the whole Portuguese surface it is required to get data for it all. Although it could be done for the whole territory, for study purposes only a certain region is necessary and for that it is possible to crop the data for such location using the coordinates that define it using QGIS tools. Thus, when all the data is available for Portugal surface, crops should

Table 4.4: Tondela Crop values

SRS	North	South	West	East	cellsize	ncols	nrows
4326	40.640138889	40.450138888889	-8.300138888889	-7.95013888861	0.000277777778	1260	684
3857	4959406.261323042	4931572.478040015	-923967.234624572	-885005.4128157574	30.9221	1260	684

be done to avoid big computations.Because Tondela was selected as the study area, the data was cropped for values in Table 4.4.

Farsite needs topographic data in ASCII GRID (.asc), which is not the format of the gathered data. Files can be converted in QGIS, producing results with a structure of parameters on top and a value for every cell in the area.

The original format of cropped data in QGIS for the Tondela region was in EPSG:4326, a format that considers the cellsize to be in lat/long values. When using this format as input in Farsite it was noticeable that the simulation was not producing good results. Farsite uses either meters, kilometers or feet as a measure, so cellsize should be the distance of each cell in the chosen measurement system. Later I realized that Farsite uses the mercator SRS (3857) to measure distances, so a conversion of the data to EPSG:3857 would solve the data measure problems, being such reference system able to be used in all/almost all programs for this study.

To fully convert the data from the sourced format, it first needs to be converted to mercator crs and then translated to asc format. To convert the crs, use the save as option of a layer in QGIS and select the *"EPSG:3857 - WGS 84 / Pseudo Mercator"* as the desired crs, the desired extent to extract, which must be the same for all data types used and choose the resolution, by opting either in horizontal and vertical cell size or columns and rows. Farsite cannot use data composed of cells with different x and y size, each cell should be considered a square, so horizontal and vertical size should be the same. The result of such operation will output a tif file in EPSG:3857 with the extent and resolution provided. Now it must be converted to asc file format. This can be done in QGIS raster options (Raster -> Conversion -> Translate), which uses the *gdal_translate* command *(gdal_translate -of AAIGrid tif_inut_path asc_output_path)*, giving as output the so desired file for Farsite.

It may still be necessary to update the cellsize, because the extent and resoltuion may not be compatible, so it ends up giving a different, but close value for x and y size of each cell. This may be a problem, and so conversion to square size cells may be ideal, instead of having a different delta size for columns and rows. When cropping the original data, instead of selecting the number of columns and rows, the priority should be the size of each cell. To update these values, either compatible values for extent and resolution need to be used from the beginning, the *FORCE_CELLSIZE=TRUE* creation option used or the output asc file value for dx and dy replaced with a single cellsize. Using those last two options may distort a bit the data, so to improve simulation results, this should be taken into account.

4.2 Simulation

4.2.1 Farsite

Farsite can be used to simulate forest fires using input arcGRID files for topographic information and fuel, wind, weather and time variables to produce over time spatial fire propagation. Next, a short explanation on how to use FARSITE V4 program to produce simulations, as well as the linux version used to integrate it in the web server.

As explained before, FARSITE requires some specific data of a landscape, as well as weather data to provide useful simulations. Such data can be freely collected online from multiple sources, like explained in the previous section.

FARSITE uses data mostly in ArcGrid format, which specifies the coordinates origin, cellsize, number of columns and rows. With this, it calculates distances using metric or imperial measure system, which excludes EPSG:4326 as a valid spatial reference system, using this one lat/long degrees as a measure system. To work around this, as explained before, the data should be in EPSG:3857 coordinate reference system.

In order to produce simulations using the program application, the user is asked for complex inputs: Landscape file generated with Latitude, distance units, elevation ASCII (meters or feet), slope ASCII (degrees or percent), aspect ASCII (1-25 or degrees), fuel model ASCII (default farsite model, custom, convert or const), canopy cover ASCII (cat 0-4, percentage or const) and optional inputs for standHeight ASCII, crown Base Height, crown bulk density, duff loading ASCII and coarse woody ASCII (optional parameters are avoided for this study). Fuel Ajustments and fuel moistures (default values used). Weather file containing time related information for the minimum and maximum temperature, as well as the minimum and maximum humidity. Wind files containing the direction and speed of wind as well as precipitation for each measured time. Burn Period with the time desired for simulation (it must have measured weather and wind values in the previous files). Other optional files are fuel conversions, fuel custom models and coarse woody. These files are ignored, since they are not required, however the use of such input values may be important to improve the quality of results.

With all required input files, the user needs to chose the model parameters for simulation, such as the time step, visible time steps, perimeter and distance resolution:

- Time Step - Determine the fastest spreading point on the fire front and calculate the amount of time required to spread the distance resolution (including acceleration from its current state). This will be the new sub-timestep required to achieve the distance resolution if it is less than the original timestep or the time interval to the next wind observation.

- Visible Steps - Time between displayed lines of fire growth perimeter.

- Distance Resolution - Set the dynamic timestep to the sub-timestep.

- Perimeter Resolution - Calculate the fire growth for the sub-timestep.

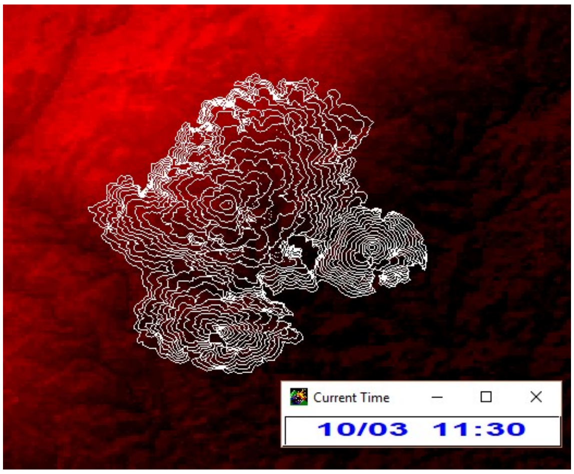


Figure 4.6: Farsite Simulation with 3 different ignition points, 1 day and an half after ignition

Input of start and end time of the simulation is also required, only then it becomes possible to initiate the simulation. The user can now insert ignitions, barriers and combat measures using the map provided by the program. With this being done, it becomes possible to start the simulation and the program calculates the spread of fire over time.

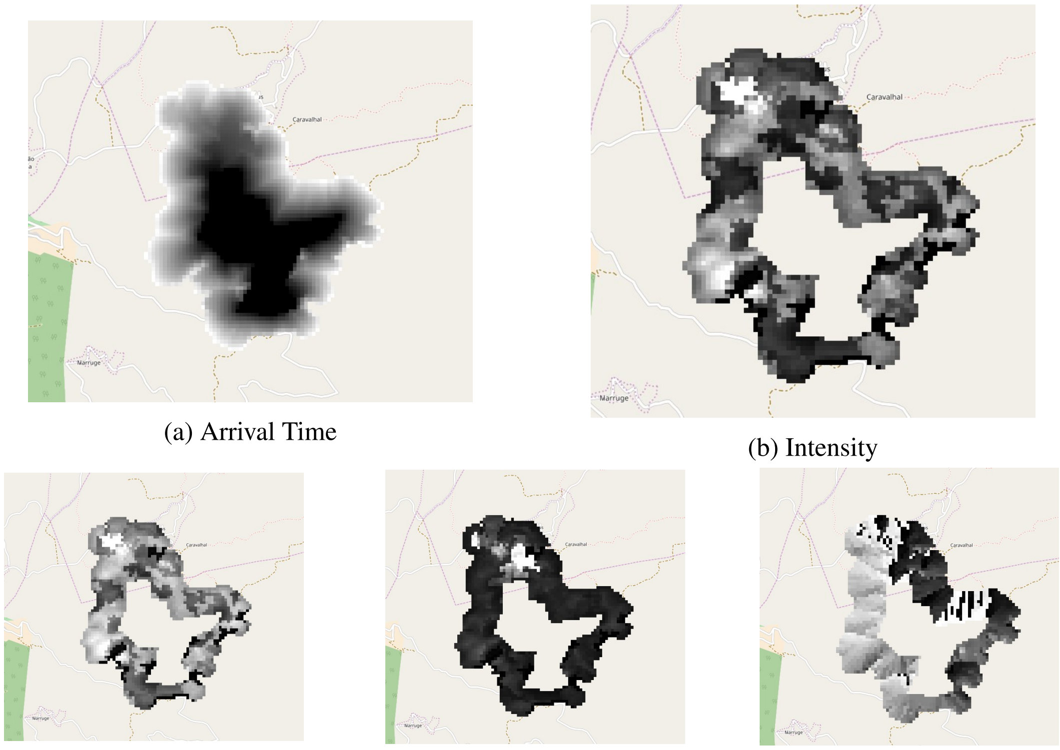
To get the simulation results other than just visual results in farsite 4.6, it is required to select the desired output formats, being this in either raster (ArcGRID) or vector format (shapefile), and may contain values for time of Arrival (hrs), fireline intensity (kW/m), flame length (m), rate of spread (m/min), heat/area (kj/m2), reaction intensity (kW/m2), crown fire activity (cat) or spread direction (az).

Fire.org provides a more complete user guide to help get through every necessary step of the simulation program.

FARSITE can be used with command line with the program TestFarsite [dsc16] using prepared files for landscape, input parameters, ignition and barrier vector files, outputting multiple raster files with the simulation result. Such input files need to be prepared before simulating and the path of each placed in a text file that will be used as a parameter when executing the program (Instructions). Landscape can be generated inside the program using the raster files for elevation, slope, aspect, canopy cover and fuel. The *.input* file contains information regarding the custom fuel, fuel moisture, parameters of simulation, weather and wind inputs and others. The ignition points and barriers are represented in shapefile format (.shp), so a file with the vector need to be previously prepared with points or polygons representing the ignition points or even already developed fire areas and the barriers location.

Creation of custom models for multiple study areas, like Tondela by gathering relevant data (elevation, fuel, canopy) and cropping it to the desired coordinates using QGIS.

Generate landscape files for farsite using its desktop program or find a way to do it in another way that could be implemented in the web server by asking the user for the inputs of data and further generation of landscape files. If such is not possible, the server should store landscape files



(a) Arrival Time

(b) Intensity

(c) Flame Length

(d) Spread Rate

(e) Spread Direction

Figure 4.7: Farsite simulation output examples

for every needed area.

Inputs file should be customized by the user by either uploading the file directly or generating it using user inputs mentioned before (times of simulation, timestep, weather and wind, ...).

Ignition and barriers files can be either directly inputed by the user or generated in the server, but that would require some way of geographical input by the user that would be converted into a shapefile that could be used by farsite. There is also the possibility of asking the user to upload the shapefiles himself, but that would require him to have some knowledge of GIS to generate shapefiles with points, lines or polygons containing the ignition points and barriers. Geodjango combined with leaflet can be used to input vectors directly to the database using the web maps of leaflet. Using that, geometric polygons data is inserted in the ignitions table. Those ignitions can be converted from PostgreSQL to shapefile format using *pgsql2shp* command. That is a necessary measure, taking into account that farsite requires those inputs in shapefile vector format.

When the server gets these files (landscape.lcp, inputs.input and ignition.shp) it can run simulations in farsite, outputting multiple files in ASCII GRID format for fire arrival time, crown fire, flame length, heat unit per area, ignitions, intensity, perimeters, spots, spread direction and spread rate (Fig. 4.7). The resulting data has the same geographic configuration parameters of the input data.

4.2.2 Flood Simulation

Flood simulation was left as a secondary objective for this thesis, but some study was done regarding it anyway. At first, some models were studied that could be used to perform flood simulations. Overall they seemed complex and the data they require may not be as easily found as it should be. Some of the viewed software that could be used to simulate are HEC-RAS v5.0.3 or TUFLOW, being the first free and the latter a paid version. Crayfish is a QGIS plugin that combines flood models to visualize animations regarding floods in the map.

Most precipitation and flow data necessary are not as easy to get as the necessary data for fire simulations. IPMA and SNIRH are options of where to get such data. IPMA provides it, but not freely, it need to be previously asked for, by filling a form with the necessary approvals from the responsible project managers and data providers and some payment is required too. SNIRH looks more viable, providing data for free from multiple sensors spread through the entire territory of Portugal, however most relevant data is outdated or even missing.

HEC-RAS is a program that uses multiple hydrology related models to perform flood risk mapping. Crayfish can be used with HEC-RAS models to animate the simulation in QGIS. Further read and experiment is required to know the possible output and how it can be used in web maps.

Input required data for HEC-RAS: Elevation (GIS Data), hydrographic steady/unsteady flow (excel format). An example of data from SNIRH.

To simulate in HEC-RAS, import elevation data, generate image, generate mesh in geometric data, remove error points, create upstream and downstream of river flow, import unsteady and/or steady flow data and only then simulate. I got stuck at importing flow data using some data for flow of the Tagus River in Santarém (SNIRH) that I could combine with the cropped elevation data, however an error shows up.

Due to the complexity of using such models, later I chose to develop my own simplified simulation model that could represent a flood. Even though this model may be completely wrong, overall it still provides results that resemble a flood result, which is the most important for this study.

This model was built in python, using as inputs only elevation data and river shapes from Open Street Maps. Using the river locations, it creates an array representing a raster with the location of it. It also requires the user to input a value for the flood level raise, indicating how much the river increases in height. The model creates another array representing the flood increase in the whole map and updates the river values with the input flood level raise, then runs through the whole array to update the flood value for the neighbours of each river cell and the neighbours of it, if it got flooded.

This model has some problems, such as not being able to run using big areas due to over iteration and the over flood caused by the fact river tend to descend along the way, so the lower points will be flooded more than they should. Despite such problems, the results tend to represent flood in lower areas near the river, which is similar to the impact floods have, and so can be used

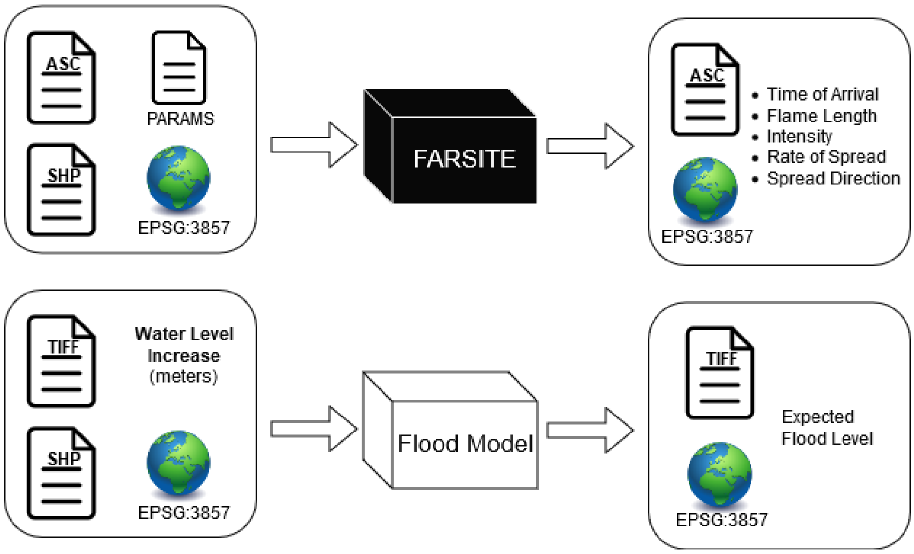


Figure 4.8: Simulation Diagram

as an example when comparing with infrastructure data. If this project is ever upgraded, then a better option needs to be used to simulate floods and this one discarded.

Overall, the inputs required for the simulation solutions and the respective outputs returned are explained in the diagram of Fig. 4.8.

4.3 Visualization

4.3.1 TIF conversion

ArcGRID is the format resulted from the simulations using Farsite, however such format is not supported by most web mapping services, and even those who should support them did not seem to work that well with it. So, to be able to use the resulting rasters in web, conversions should be made to a more supported format. A really good example is tiff, which is a heavier format, but can easily be used by leaflet and geoserver.

GDAL command to convert to tiff:

```
gdal_translate ArcGRID_input_path tiff_output_path
```

When converting the files, no information seems to be lost.

4.3.2 GeoServer

GeoServer is able to transform a source raster or vector file to a service that can be used in web mapping (WMS). To configure it, it needs to be started and all necessary commands are in the admin web page.

To provide the simulation results, a workspace needs to be created, as well as stores and layers. Each store has an associated path of the simulation result.

Layers require a style different from the original, because that one is only black for regions with no data and white for the others. Style can be modified using Styled Layer Descriptor (SLD), a language used to describe the appearance of map layers. It uses brackets similar to html to represent statements that distribute the appearance of the layer depending on its attributes.

To create multiple layers to display using geoserver's WMS, it could be done using the geoserver API, which would required some time to understand how it works. A workaround to this time consuming problem is to create all necessary stores and only alter the files they look for in the path they contain, however this may be a problem when too many services are needed or if the user wants to access past simulations, because only the most recent is saved over the previous one.

Two different approaches were used to display the results in GeoServer, one using the results in raster GeoTiff format and another using them in vector PostGIS format. GeoServer has limited functionalities to treat raster data, so the use of raster is more complex than vector, however when starting to implement the solution, raster seemed like the more viable option due to the simulation results being in raster. Probably the most annoying aspect of raster use in GeoServer is the impossibility of filtering the provided data using the cells data, whereas using vector allows the use of Common Query Language (CQL) filters, which filter the provided data regarding the properties it contain.

For this project, a single workspace was created, containing multiple stores, each containing a layer. When using raster, a store is necessary for each filtered hour, each containing the path for the raster representing the spread for that hour, while vector data only requires a store for each simulation (one for fire simulation results and other for flood). When defining a layer, the CRS and bounding box with the the coordinates that contain the data needs to be specified, as well as the styles that can be used by that layer. Fig. 4.9 briefly explains the technologies used to manipulate and display the data over the web.

4.3.3 Leaflet

Leaflet was the mapping library used to display the results in the web. The use of it is simple and there is a useful extensive documentation on how to use it online, as well as multiple plugins examples that can be integrated with it.

It is possible to create layers based on many data source formats, addition of controls and methods to interact with the data and a lot of more useful features to interact with geographic data. Layers can come from tile files, wms services, images, GeoJSON and many other formats. The ones used for this project were GeoJSON for infrastructure data and WMS for simulation results.

An example of javascript to add a WMS layer to a leaflet map:

```
{% load leaflet_tags %}
{% leaflet_js %}
{% leaflet_css %}
```

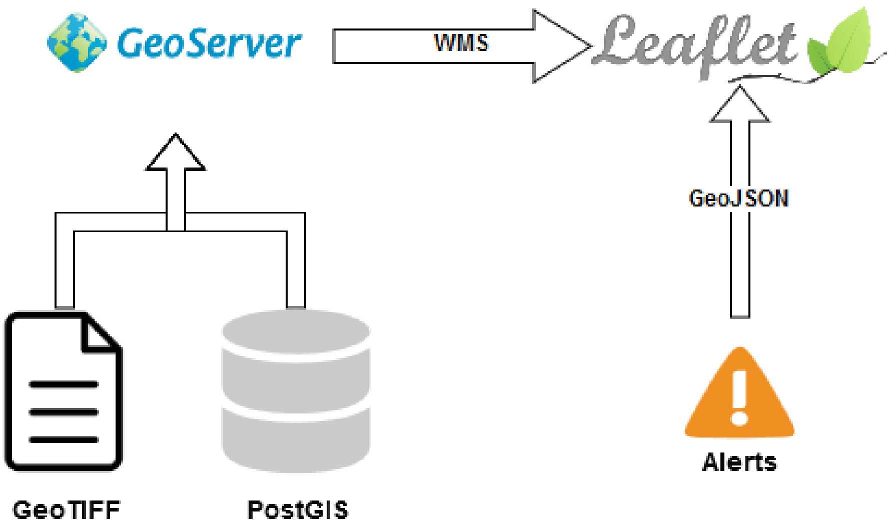


Figure 4.9: Visualization Diagram

```
{% leaflet_map "gis" %}

L.tileLayer.wms('http://localhost:8080/geoserver/cite/wms',{
  layers: 'civildefense:fire_simulation',
  format: 'image/png',
  transparent: true
}).addTo(map)
```

One plugin of Leaflet was also used to perform navigation routes in the map, as an example of interesting upgrades that leaflet offer for the upgrade of the system. It is able to calculate the route from a source, a destination and intermediate points on the map. The user is able to move those points as he uses the web map, to constantly update the route he desires to take (Leaflet routing machine).

4.4 Integration

It is clear now that the project has its basis defined to be able to provide useful information and task solving capabilities for civil protection and crisis management support, so it is now necessary to develop a solution able to integrate the previously mentioned functions in a single system, providing easy access and usability for those who want to make use of it.

As mentioned before, the opted solution is the development of a web server that provides over the web the option for its users to perform simulations of crisis, for them to be able to study how those events work in different scenarios, enabling the development of more accurate response measures, upgrading the civil protection aspect and even predict how currently happening events will behave in the near future, allowing the support of crisis management due to the reduction of unpredictability to which these crisis are generally associated.

Without a solution like this, for someone to perform a similar operation, the use of multiple previously installed software is necessary, some for simulation purposes, considering they even need to collect the data themselves, which is sometimes a difficult task itself and use those results in yet another software program to visualize and compare them with other data related to sensible objects that should be secured from catastrophic events. It is therefore a demanding task that needs trained professionals to know how to perform all those operations.

In this section, a description of the steps required to mount this solution, allowing the input and store of the necessary data, the production of simulations and subsequent crisis management analysis, all this at the distance of a web address, returning important knowledge in a matter of a few minutes or even seconds.

4.4.1 Web Server initialization

After a successful install of django framework, a new project needs to be started. Django has a command that shortcuts most of the work needed to initialize a web server, by simply running *"django-admin startproject projectname"*. This will create a structure of folders and files that will tell the framework how to behave. The created root folder will have the project name and any project modification will be performed inside it. Then, inside this folder there is the file manage.py, the file that needs to be executed when the user wants to interact with the server, for example to start it. Inside the root directory there will be folders for every used package, each containing a __init__.py file indicating that folder is indeed a package. Settings and configurations are defined in settings.py, which will usually contain information regarding keys, directory paths, installed apps, middleware, templates, database connections, static files configuration, global variables and many other options. One last file worth mentioning is urls.py, which contain the URL paths used to map connections between URL expressions and the views.

Now it is required to start a new app, which may be confusing to distinguish between those and projects, but overall, a project may contain a collection of configurations and apps (web applications), while an app can belong to multiple projects. Each app will have its own views file containing the functions responsible to treat the calls for certain urls paths and render a visual result in the form of templates to the end user. Before continuing, it is important to update the settings, by adding the necessary apps to the *installed_apps* list, add a path to the templates configuration, giving the server a way to know where to find the html pages, create a new database and add its configuration and access parameters to the file, add the static path, so the server know where to find new entries for those kind of files, add new paths that may be useful for future development and other configurations that may be important. This file usually requires some updates when new apps are added to the project, mainly at the begining of the development.

Examples of external applications used by this project include leaflet to treat and display geographical data in web maps, django GeoJSON to work with spatial data in json format, enabling the easy transfer of gegraphic information from views and templates and crispy forms to upgrade the visual quality of forms in django.

Some commands need to be taken into account when developing django projects, such as: *python manage.py runserver*, used to start the server, making it accessible in web browsers corresponding address, *python manage.py collectstatic*, necessary to be executed when new static files are included in the project, *python manage.py makemigrations*, that create a migration when changes are made to the models, *python manage.py migrate* to effectively push those changes to the database and *python manage.py test* to run the available tests for the installed apps.

4.4.2 Data

Django also facilitates by a lot the database interactions, enabling the creation of new tables, addition of new data, update of existing ones and extraction of it to be used by the program. Inside each app, there is a file named models.py, which contain classes representing the data tables used by the application, so by providing a new class to this file will automatically create a database schema, with all necessary statements and even an API for that database, enabling django to access the database tables as objects.

Each class will have at least variables that represent the columns of its associated database table. These variables will be django fields imported from *django.contrib.gis.db.models*. An example of a class, representing a table that contains, among others, geographical information:

```
class table_name(models.Model):
    id = models.AutoField(primary_key=True)
    name = models.CharField(max_length=20)
    number = models.IntegerField()
    geometry = models.PolygonField(srid=3857)
```

To push these changes to the used database, the commands makemigrations and migrate previously mentioned need to be executed, which will generate SQL equivalent code and execute it to produce the intended changes in the database. A new table is created with the name table_name and columns id, which will be auto incremented and used as the primary key, name, a text field with a restricted length, number, an integer field and geometry, a column containing vector information in Well-known binary (WKB) format.

If the data necessary to be used by the program is found already in shapefile format (for example, ignition shapefiles), then django has a command able to generate a GeoDjango model for data using the same format as those files, provided a name for the model (*python manage.py ogrinspect data_source model_name [options]*). This is especially useful when importing data for infrastructure and related, because such data is provided by Open Street Maps already in shapefile format. Using the option *–mapping* will return a mapping dictionary as well, to be used for importing data with LayerMapping utility. LayerMapping uses arguments for the model to insert the data on, a source of the data provided and the mapping dictionary.

The generated API now allows simple inserts and extractions. To use it, the created models need to be imported, and then multiple operations inside the class are provided, such as the following examples:

```
from .models import table_name

#create new row and save it to the database
row = table_name(name="title", number=1, geometry=polygon.ExportToWkt())
row.save()

#access the new row values
row.name

#access objects in the database
table_name.objects.all()
table_name.objects.get(id=1)
table_name.objects.filter(number__gte=1)
table_name.objects.filter(geometry__intersects=another_geometry)
```

Most web applications require an admin environment, where only authorized users can access to perform sensible updates to the database data, and for that django also simplifies the programmer life. Admin sections are usually just an interface where it is possible to add, change or delete content, so it ends up being almost the same for every web application that requires one. To simplify the development of web applications, django automates the creation of admin interfaces for models. The file admin.py, inside the app folder is responsible to dictate what models can be used in the admin interface. To access it, the server needs to be normally started, but instead of the defined urls in urls.py file, the address is *http://localhost:8000/admin* (if the server is in the local domain). In this interface, the admin will find lists with the existent database tables, inside of which will be displayed the data they contain listed. The admin is able to add or edit the data using automatically created forms or even delete it.

All data models used for this project are listed in Table 4.5, with the identification of the main features, the responsible to update such data and some observations regarding its usability. As it explains, most of the data can be inserted by the admin, which enables the improvement of much of the data overtime, allowing the admin to insert new objects for infrastructure, simulation parameters, required input files and geometries to be used by simulations. Landscapes and elevations require the admin to have previously prepared files to upload to the server, being the first a special type of file that can be generated in FARSITE desktop program and the latter a GeoTiff raster file. Both of these also have a column where the admin can insert a polygon representing the area they occupy in the map, which will be used to display for the user when choosing the simulation inputs, so he is able to know the location of it. Fire and flood simulation tables have rows representing a pixel of an affected zone and a value for time/danger level. The combination of all polygons render the complete simulation result area, so every time a new simulation is done, all rows are

Table 4.5: All Data models used

Model	Main Features	Edition	Observations
Barriers	Geometry	Admin; Load from shp	Draw polygons in a leaflet web map that represent barriers.
Custom fuels	Farsite Parameters	Admin	Number values representing a fuel model to be used by farsite.
Elevations	Tif path; Area	Admin	Previously prepared tif raster file upload to be used by flood simulations. Draw a polygon for the area to be represented in leaflet maps.
Fire Simulation	Polygon; Time	Automated	The collection of all features in this table represents the fire simulation result.
Flood Simulation	Polygon; Danger Level	Automated	Same as fire, but for floods.
Fuel Moistures	Farsite Parameters	Admin	Number values representing fuel moistures to be used by farsite
Ignitions	Geometry	Admin; Load from shp; Save simulation	Draw polygons in a leaflet web map that represent ignitions.
Landscapes	Landscape path; Area	Admin	Upload of previously prepared LCP file to be used by farsite. Draw a polygon for the area to be represented in leaflet maps.
Places	Geometry; Info	Admin; Load from shp	Draw polygons in a leaflet web map that represent a place. It contains extra information that may be useful for civil protection.
Rivers	Geometry; Info	Admin; Load from shp	Draw polygons in a leaflet web map that represent rivers. Used for flood simulations
Roads	Geometry; Info	Admin; Load from shp	Draw polygons in a leaflet web map that represent a road. It contains extra information that may be useful for civil protection.
Weather	Farsite Parameters	Admin	Dates and number values to be used by farsite.
Wind	Farsite Parameters	Admin	Dates and number values to be used by farsite.

replaced with new ones. This may be improved by assigning an identifier to the result, so instead of replacing older values with new ones, the search method used to get the simulation results must include the corresponding identifier. This may be a number, a title, anything that distinguishes it from polygons of other simulations.

4.4.3 Simulation

As previously mentioned, the software solution can be used to integrate multiple GIS-based simulation models, and the ones used for this are TestFARSITE and a simple flood related model. Both need the user to select some desired parameters that will influence how the model will behave. Most of these parameters are complex, so they need to be previously saved in the database, while others can be more flexible for the user to choose. Nevertheless the user still needs to control what are the inputs required for the situation he wants to simulate. To do this, different forms are provided for each kind of simulation.

For fire simulation, the user needs to select the desired landscape, ignitions and barriers, all these using a multiple choice field with its title in the option. These type of inputs, having a geometry field, can be showed in the map, so the user can know what are the options he has without the need to look anywhere else for what every option means, this way he can instantly see in the map what he did actually chose. Another important option the user needs to select are the dates of start and end of simulation. These ones will, besides setting the simulation times, also look in the database for the existent weather and wind values inside those dates and use them to perform the fire simulation, so when choosing dates it is important to have already stored weather records for the interval inside those. Other parameters, also required, but less important are time step, distance resolution and perimeter resolution, all integer fields with a limited range that define the time and distance used in calculations, spot ignition probability, delay and minimum distance, parameters required for the spot fire model used in farsite and farsite acceleration, a check box for the activation of the farsite acceleration formula. Of the 3 parameters groups, the last one is the most complex, so the used default parameters seem to be good for use in any simulation, while the 2 initials tend to vary more often when performing simulations.

Flood simulation only requires 2 user inputs, the elevations raster, in form of a multiple choice option, that like the first group of fire inputs, also has a geometric field to display for the user while he selects it and lastly the water increase level in the river water height, an integer field.

To perform the display of the geographic values in the map, the model objects are serialized to geojson format and passed in a dictionary inside the context of the render function, then its geometry extracted and added to the leaflet map using javascript. When the user selects a different option, there are functions responsible to alternate the layer visible in the map.

When the user completes the selection of parameters, by submitting the form, a POST request action is sent to the view with the necessary values. Those values are then used to prepare the necessary files and run the simulation.

Fire simulation software TestFARSITE is executed using python subprocess, which runs command line processes. To execute the program, the path to TestFARSITE executable and the path to a command text file are needed. The first depends on the installation path, and the latter is a file containing the path to the necessary input files (landscape, inputs, ignitions and barriers), output option (0 - both, 1 - ascii grid, 2 - FlamMap binary grid) and path to output the results. This command text file needs to be updated for every simulation and all files constructed with the given info. Landscape file is the path contained in the landscape object selected by the user, ignitions and barriers, being stored as polygons in the database, need to be first converted to shapefile format, so the command *pgsql2shp* needs to be used to create a new (.shp) file, being its path used in the command text file. The inputs file is more complex, as it contains all non spatial parameters required for the simulation in text format. A detailed explanation on how to fill this file is provided in firemod project repository, but overall, the required information that gets logged in this file are the parameters mentioned earlier about time, distances, spot and acceleration, as well as fuel moistures, custom fuels, weather and wind data extracted from the database acording to the start and end date provided, as well as the burn periods, which also depends on the dates.

Having the command file ready, the simulation can begin. The output result comes in ascii grid format, which is not ideal to be used by gdal, so a conversion to GeoTiff format is required, using *gdal_translate* command. The new tif file is opened with gdal, and its information saved to be queried. This information is composed mainly of array of values of the raster, statistics, extent, size of pixels and the no data value.

Flood simulation is done by a python class composed of functions that make use of the inputs and rivers geometry existent in the database. The elevation raster selected by the user is opened using gdal, and its information extracted. Two new arrays are created with the same shape as the one representing the elevation raster, one used to identify the river location and the other to save the flood results. The first one is filled with ones or zeros identifying a presence of a river by checking if a vector representing a pixel of the array in the correct coordinates intersect with any river object geometry (this could also be done by extracting the rivers inside the extent of the elevation raster, followed by a transformation from vector to raster with the same extent and size as it). Now with the raster ready, it becomes possible to run the simulation, that search for every pixel containing a river, setting the value selected by the user for the water level to the flood results array in the same coordinates, then search for its neighbours that are not rivers and compares the value of its height plus the water raise to the height of the neighbour. If the difference is positive, than the results array is updated to it and a new iteration is started using this new neighbour. There are some problems with this solution because a river spot may influence spots far away from it if it is positioned in an higher altitude, otherwise would not. This results in values of flood increase way higher than the input value for lower spots, so the interpretation of the results should be in quantitative danger of being affected, instead of actual water level increase.

Both simulations require the results to be saved somehow for later comparison with the OSM data. To do this, 2 different approaches were taken relative to the format. The first approach was to save the results in raster format, using gdal tools to convert an array to GeoTiff, creating a new file. GeoTiff files can be loaded directly to geoserver to be displayed using WMS and can also be opened in python using gdal to perform operations, however they lack support tools to filter, because the service provided by geoserver to raster files can not use CQL filters based on the raster attributes and the result had to be saved in file format and not directly to the database. Later I found more useful to save the result in polygon format, creating a model to the database. The new table would be composed of polygons, each created using the location of the pixel in the raster and the raster info. Every entry of this table will then be a geometry of a pixel with a value for time/flood danger associated.

4.4.4 Operations after simulation

Events like fires depend on factors that change over the course of time, some of which can be controlled, while others tend to be unpredictable. The unpredictable is what simulation try to predict, so the ones that can be controlled are adjusted to the best solution possible. It is important to track over time changes, instead of looking for the complete results all at once, allowing the possibility to move the controlled forces to a more desirable place. It is ideal for the user to have time frame control, so the results of the simulation need to be filtered regarding the time of arrival. Having the solution divided, multiple interesting information can be extracted regarding the course of action to take in an operation, like property or infrastructure that may be affected, people in danger, combat forces location and routes. To know the infrastructure and property that is affected, an intersection comparison between them and the simulation results returns the solution. People in danger may be viewed using gps location of single individuals or areas of concentration of people, it may be used like in risk cartography, using the resident population of a certain place, multiple approaches can be used, depending on the type of information sought. Combat forces location and routes should be allowed for the user to move and experiment, enabling a theater of operations simulation, after all, combat forces are not static over time.

Raster results can be filtered using python after loading the array values, however there is no simple way of comparing them directly with the vector values of the data stored for infrastructure. One possible approach is to convert the raster into vector and later compare them. If the results are saved in vector format, then the comparison can be instantly done, which reduces the runtime significantly. Other problem regarding raster is the fact GeoServer does not provide a way to filter raster services, like in vector formats using CQL filters. For this project both formats were used anyway. While raster is saved in GeoTiff format and uses multiple web service providers to display the filtered maps, vector does the same with a combination of polygons in a spatial database table that require a single web service and can be easily queried using either back-end operations and front-end filtering.

Using gdal tools, a raster information can be retrieved regarding its statistics, geographical extent and sizes, the value for no data locations and of course, the data array. To get the statistics, the function *band.GetStatistics(True, True)* returns a list with the minimum and maximum values, average and standard deviation. Raster configurations are returned using *GetGeoTransform()* with values for the origin coordinates of the map, pixel width and height and number of columns and rows. With those statistics and raster configurations, multiple spatial operations become possible in a way that the values of data inside the data array can be associated with spatial coordinates using simple calculations. The geographic data of a raster in array format contains a number of rows, each containing another number of columns, inside of wich is the raster value of that pixel. The raster of simulations from FARSITE contain a value for the time of arrival of fire in minutes for that pixel. In order to filter the simulation per hour, change the values that are not inside the range of the desired hour to the no data value and create a new raster file with the resulting data array.

If the user wants to see combination of the simulation result filters, all necessary files need to be created before rendering to the user, and this is a time costing process. Every time the user asks for a new hour of information regarding the result, a new layer is added/replaced, which could also be done by serving all layers first and giving the control option of what is visible. The opted solution was to provide a slider that instantly updates the visualization of the displayed results depending on the hour value in the slider. By moving the slider a javascript function is activated to add a new layer to the map depending on the appropriate filter to be used, which is a new service in case of raster usage or a new CQL filter to the used service for vectors.

When using the database infrastructure data, the approach taken was to only perform the data comparison in back-end operations, so another option is given to user hour related, so besides the slider, an integer input is provided that will perform a POST request asking for the affected data to be displayed. To identify areas that are in danger of being affected, comparison between the simulation raster and the infrastructure vector data is done to find features that are intersected

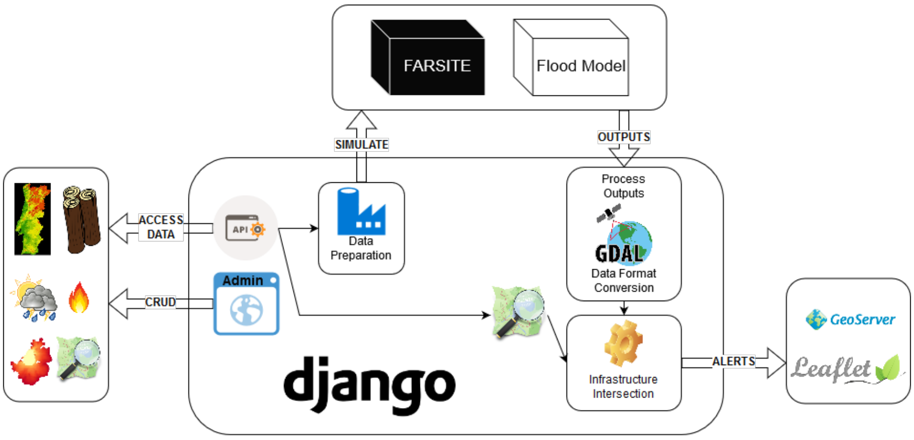


Figure 4.10: Integration Diagram

by the fire. OSM vector data comes in EPSG:4326 reference, so a coordinate transformation is needed to compare it with the simulation results, being this one in EPSG:3857. Comparison between raster and vector format is not fully developed, so to compare those two different formats, a good approach is to convert one of the data types into the other format and because raster data can be better represented as a polygon, then a vector as pixels, the simulation should be converted to vector. To perform such conversions, a vector requires points of the raster to form polygon shapes. Being each raster cell represented in a square format, to be able to convert it to vector, the coordinates of its vertices can be used to create a square polygon and each of those cell's resulting polygon can then be compared with the vector data for the infrastructure. The vector *Intersect()* function of the GDAL API can be used to verify if a polygon intersects another, returning true if it does. Having this, it becomes possible to filter what places, roads, buildings and other are affected by the fire growth. The resulting values are converted to json format and passed to the template responsible to render it in the leaflet web map using javascript. Having the affected data in json format, depending on what and how the user wants it displayed, a lot of possibilities are available, from a simple display in the map, to the use of pop ups, text alerts or any other desired way (Fig. 4.10).

A way to give the option of moving combat forces is to allow the save of a simulation state, so the input of barriers can be altered and new simulations performed. Currently the system is able to save the current hour selected by the user as a new ignition, creating a vector composed of the fire area previous to the time selected to save and adding a new ignition to the ignitions table. Although it may be improved, this already provides the option for a change in the operations settings, which is a good feature for civil protection and crisis management simulations.

4.5 Summary

Implementation chapter provides a view of the implementation path taken to develop the web GIS solution.

First it was required to find the necessary data and shape it to the formats used by the simulation programs. A description of where to find them and how to modify it is provided, so every data is correctly prepared to be used. Some figures are displayed to give an idea of what the data is representing.

Having the necessary data ready to be used, simulations can be performed. The simulation section explains the steps necessary to produce simulations using FARSITE desktop and command line programs, as well as the way the created flood model behaves.

Visualization section mentions the technologies used to display the results in web maps. It is explained the steps taken to store and provide spatial data using GeoServer and ways of displaying it using Leaflet.

Finally, the steps to integrate all components in a single web server using Django Framework. It is explained how the data is stored and accessed in a PostgreSQL database, what input forms are provided to the user and how simulations are executed. The simulation results are then used to compare with Open Street Maps data to verify what places and infrastructure may be in danger of being affected. The results are displayed to the user and the option to save a certain state is provided, so new simulations can be performed with slight changes to the input values, such as the ignition area and barriers placement.

Chapter 5

Results and Discussion

5.1 Case Study

Tondela region was selected as the case study area. It is located in Portugal center region (NUTS II) and sub-region Viseu Dão-Lafões (NUTS III). Tondela municipality has an area of about 370 km2 and 28 946 population according to 2011 census. A big portion of its terrain is composed of forestry, a big ammount of fuel that allows the spread of big fires that may get out of control, creating crisis scenarios that may be difficult to recover from.

To conduct a proper study, the necessary data needs to be prepared according to an approximate cut of the desired area. To simplify conversions, let's define the extent area by starting in an arbitrary integer point in mercator coordinates northwest of Tondela region. Let's assume this point as being (-923 967, 4 959 406). add a certain number of columns and rows with 30x30 size to represent the total area of Tondela. 950 rows and 1300 columns include all locations of the region of study, with the last point of the extent being (-884 967, 4 930 906).

Now that the coordinates are defined, the required data needs to be clipped. QGIS has great tools for that, as explained in this thesis.

Altitude files for Portugal are split in multiple areas, and Tondela happens to be split into two of those, so a merge between files n40_009_1arc_v3.asc and n40_008_1arc_v3.asc is needed using *gdal_merge* command. Crop the resulted tif (can not merge to asc) with the coordinates for Tondela. A conversion to mercator coordinates is now needed, being the source in WGS84 system. This may be done using the command *'gdalwarp -overwrite -s_srs EPSG:4326 -t_srs EPSG:3857 -of GTiff input_tif output_tif'*. Now a crop to the Tondela defined extent is required. The same command can be used to crop with the extent and resolution selected and also convert the result to the required asc output format (*'gdal_translate -tr 30 30 -projwin -923967.0 4959406.0 -884967.0 4930906.0 -of AAIGrid input_tif output_asc'*).

The number of columns is indeed correct, however the extent is adapted to the coordinates of the source raster initial pixel found closer to the provided coordinates, so the result data has the values of Table 5.1, which differs nearly 2,4m west and 26,5m north. The cellsize however takes the expected value of 30m size, which is the ideal for the simulation. Horizontal and vertical

Table 5.1: Tondela ArcGRID file parameters

ncols	1300
nrows	950
xllcorner	-923969.429880728130
yllcorner	4930932.500181087293
cellsize	30

value resolution should be equal to 30, which translates to 1300 columns and 950 rows. Generate DEM terrain for slope (*'gdaldem slope altitude_asc output_slope_asc -s 1.0 -of AAIGrid'*) and aspect (*'gdaldem aspect altitude_asc output_aspect_asc -of AAIGrid'*) using the returned file for elevation.

Convert fuel to tif and crop by saving the layer provided in adf format as a GeoTiff with the pretended extent (equal to the altitude extent) and cellsize. Convert the result to asc (*'gdal_translate -of AAIGrid input_tif output_asc'*). The resulting file has the same parameters of the previous files.

Translate the canopy using the calculator tool and the expression mentioned before for canopy extraction. Crop the data by saving as a new tif file with the desired exntent for Tondela. Translate the resulting tif to asc with the intended projection (gdal_translate -of AAIGrid input_tif output_asc).

Crop OSM. As mentioned before, OSM data can be download in Geofabrik downloads site, which provides extractions of continents, countries and regions constantly updated. Data was downloaded for the complete Portugal surface, so crops are required to extract only Tondela data. The complete information could be inserted in the database, however to avoid increasing the calculation times, only the study area will be used. The data comes in shapefile vector format with default CRS 4326. To extrat the required data, QGIS can use the save as function in the desired layer, giving as the desired CRS 3857 and the extent of Tondela. The selected data extracted regards buildings, places of interest, roads and places.

Create Landscape file using the result asc files for elevation, aspect, slope, canopy and fuel in Farsite desktop application. Add new entries in the database for landscape using the admin interface and load osm data also to the database, using layermapping to add new objects using the django models.

As the weather and wind data are concerned, the data selected to be used was the registered wind speed and direction and precipitation values in SNIRH station located in Varziela during the fires of June 2017. Weather data relative to temperature and humidity was not registered in SNIRH stations near Tondela. The closest station with such values is in Barragem de Castelo Burgães in Aveiro.

The quality of the results depends in the quality of the used data. While some of that data do not change much over time, such as topography, others are not easy to predict successfully, such as wind and it is even assumed that data on infrastructure and buildings are up to date, which often is not verified due to the complex process of collecting such data. The difference verified

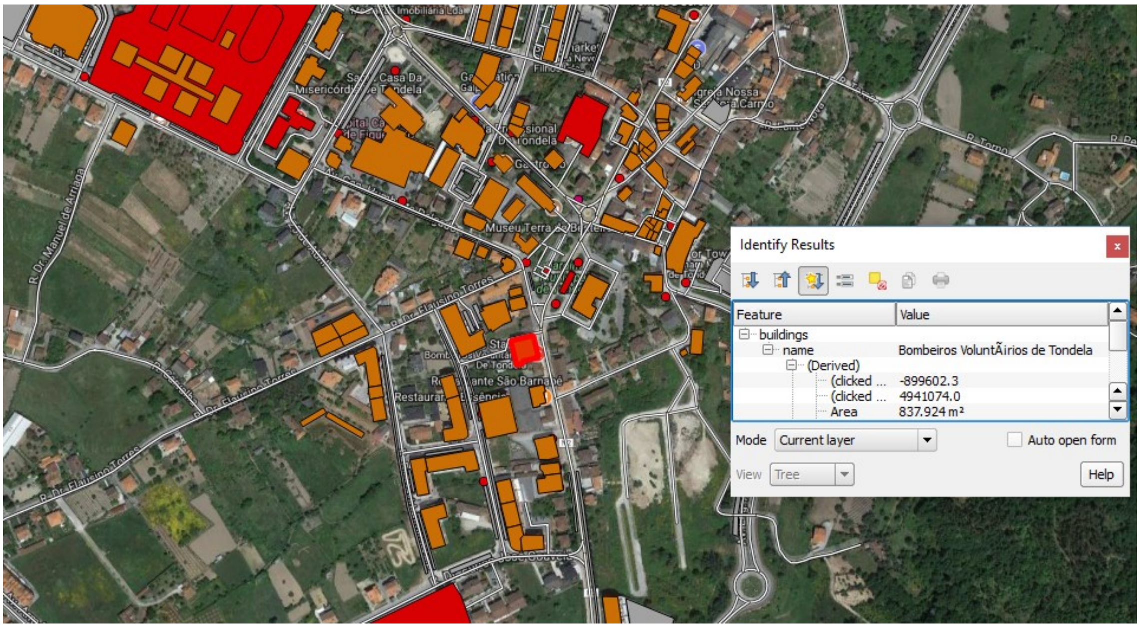


Figure 5.1: Comparison between Google satellite and Open Street Maps data

by comparing buildings data of OSM with satelite images from Google really shows the lack of features representing them in the OSM data (Fig. 5.1). However OSM has a layer for places, which includes residential areas with agglomerates of houses and others. This layer can be used to identify residences in danger.

Next a hypothetical situation will be analyzed, where fires are identified in some forest areas near Tondela. The possible destruction expected to be caused by those fires is showed by the simulation results, displaying villages and roads that would be affected by the progression of the flames. To explain why the use of this solution is important in preventing catastrophes, a theater of operations will be used in the simulation, in which combat measures are used as barriers to suppress the fire progress. The difference between the use or not of combat forces will be analyzed to explain the importance of defending some areas over others. This tool will then be useful to identify the best ways of spreading the forces over the defense zone, being it in an active fire operation or in preparation of possible future fires.

To simulate a new fire, the ignition point location is a major factor that influences how and where the fire will progress. Assume a new fire starts near Caramulo, more precisely near Múceres place, a residential area near a big forest. If a big fire triggers in such zone, a lot of buildings and roads will be affected, besides threatening the whole Caramulo mountain range.

Using the routing plugin, by identifying the firefight headquarters as the start location and the closest residential area to the ignition location as the destination, we can verify that it would take at least 20 min for the combat forces to reach the fire zone (Fig. 5.2). Considering the time firefighters would need to establish a perimeter, one hour after the fire is identified, a combat barrier would be ready to suppress the progression of the fire trough the residential zone of Múceres. To

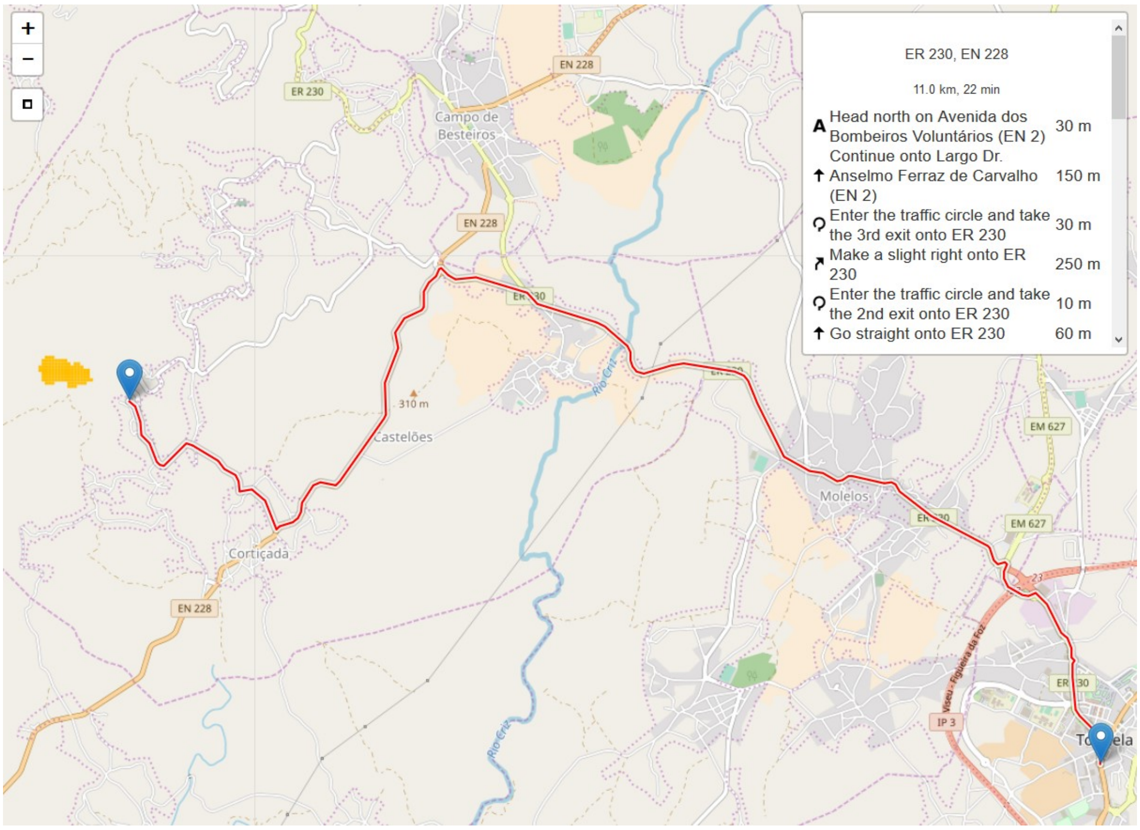
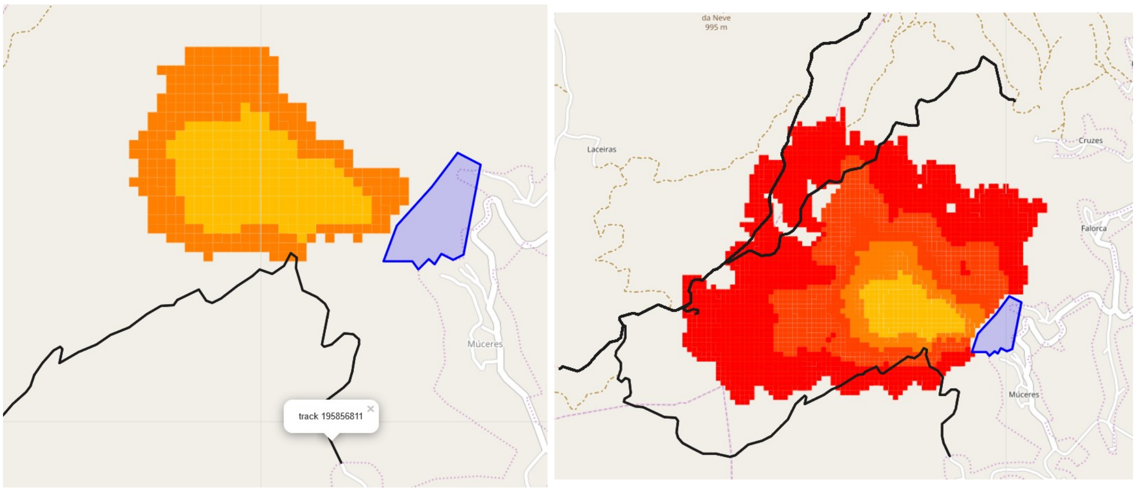


Figure 5.2: Ignition detected and firefighter's route

see how this would affect the fire, a barrier needs to be added to the simulation, covering the zone firefighters would be on.

During the second hour of fire progression authorities need to decide if the combat measures need to be increased in case the current situation is not under control. As verified in the simulation result, the fire reach the perimeter in this second hour, allowing the combat measures to avoid Múceres from being affected at first, even though a track that can be used to reach Caramulo is affected (Fig. 5.3a). The display of affected features of OSM data is presented in black, blue zones are barriers representing the combat measures and the fire progression is in a color range from yellow to red depending in the time value. If the fire reaches this track, the potential mobility of the firefighters to the mountain range top is reduced, decreasing the chances to control the fire. There are still other options to go around the fire perimeter, and being this track not a major concern in public transportation, its defense may be avoided, focusing instead all forces in the residential area of Múceres. If no more forces are assigned to the operation, fast forwarding the simulation to 10h after its start, a rapid expanse to west is noticed (Fig. 5.3b). One of the main reasons for this fast progression is the slope increase provided by the uphill of Caramulo in addition to the pile of fuel present in the area.

It is noticeable that this fire requires more forces present in the field to fight it, or else it may get easily out of control, considering the fire will continue its spread uphill and may even surround the



(a) 2nd hour after being detected

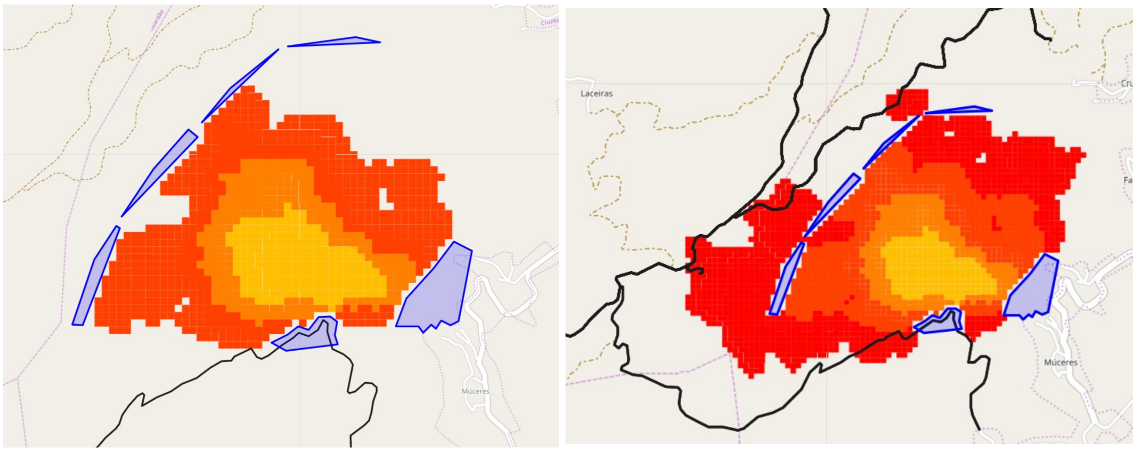
(b) 10 hours

Figure 5.3: Fire progression simulation results

defense area, threatening the nearby residential areas (Falorca, Cruzes and even Múceres itself). Let’s consider that an extended attack is requested to help the initial forces. By observing how the fire would progress, these new measures may be adapted to suppress specific targeted areas. Some of these areas may be protected for example by putting a new ground force in the first affected track and an aerial mean to reduce the fire progression uphill. To represent this new combat measures, a new barrier is added to cover the zone where the track is first affected and some thin barriers in the hill representing the aerial force passage.

The results of the new simulation show progress in the operation. The fire only reach the initial track after 5 hours (Fig. 5.4a), and the area consumed after 10 hours is extremely reduced in consequence of the aerial combat forces (Fig. 5.4b). Although improvements are verified, some zones are still severely affected, mainly the south location where a rapid growth still happens. It is important to mention that this zone is composed of mainly forest, so fire progression in the south is not a priority because residential areas are not in the way and the infrastructure present is not of major importance. Despite some success, the residential nearby areas remain in danger, being the fire spread expected to reach Falorca and Cruzes hamlets 20h into the simulation.

The further away from the ignition time, the less accurate the results will be, so the user is able to save a certain hour as a new ignition. In this case, the user may be interested in save the 5th hour, time in wich the fire reach the aerial area of operation, which may force a retreat to a more suitable location for this force to be effective and remain safe. At the same time, the ground forces located in Múceres may have been effective enough to force the fire to retreat, allowing them to join forces with the new allocated force in the track to push back the fire even more. Having the new ignition saved, the admin is able to edit it, and so remove all polygons that no longer truly represent the fire location and even add more in places it was not expected to be but were verified to actually be affected by the fire. New barriers can be added, and so perform a movement of



(a) 5 hours

(b) 10 hours

Figure 5.4: Fire simulation results with new combat measures

combat measures to new locations depending on the need.

Having made these changes, the user is now able to perform new simulations with new inputs. Consider it is found necessary to allocate new ground forces to nearby Falorca and Cruzes location, while the ones already in place join forces to make the fire retreat even more.

Thanks to this new introduced tactic to control the fire progression (new barriers), the fire is expected not to reach any residential area in the first day of combat, which will probably be enough to suppress the fire in danger zones. The difference is clear in Fig. 5.5, where the fire seems to get under control relative to residence protection.

The program is able to simulate multiple fires at the same time. If a new fire ignition is detected, a new polygon can be added to the ignition saved previously. Consider a new ignition is detected near some villages south from Múceres, approximately 4km of distance between the previous fire. This new ignition is in a critic area, too close to main roads, two villages (Tourigo and Barreiro de Besteiros) and an hamlet (Pousadas). Authorities need to respond fast to this threat or else critic infrastructure and human lives will be in danger. In situations like this, a proper response is important, even more when efforts are split into different fires. By exploring the results of this new fire simulation, it is evident a lot of critic areas are in danger, in a few hours the fire could get to important infrastructure, and even Tourigo village would be affected, so the program identifies this critical aspects that are intersected with the fire progression (Fig. 5.7), allowing the trigger of proper response. Having this information, response means can be introduced to the simulation to select the best possible approach and avoid loss of properties and even call for evacuation measures to save the lives of people if the response can not reach there in time.

Like mentioned before, the flood simulation model has some problems regarding the quality of results, however simulation can still be done and the affected places and roads identified so the proper civil protection measures can be put in place. The simulation result can be filtered using

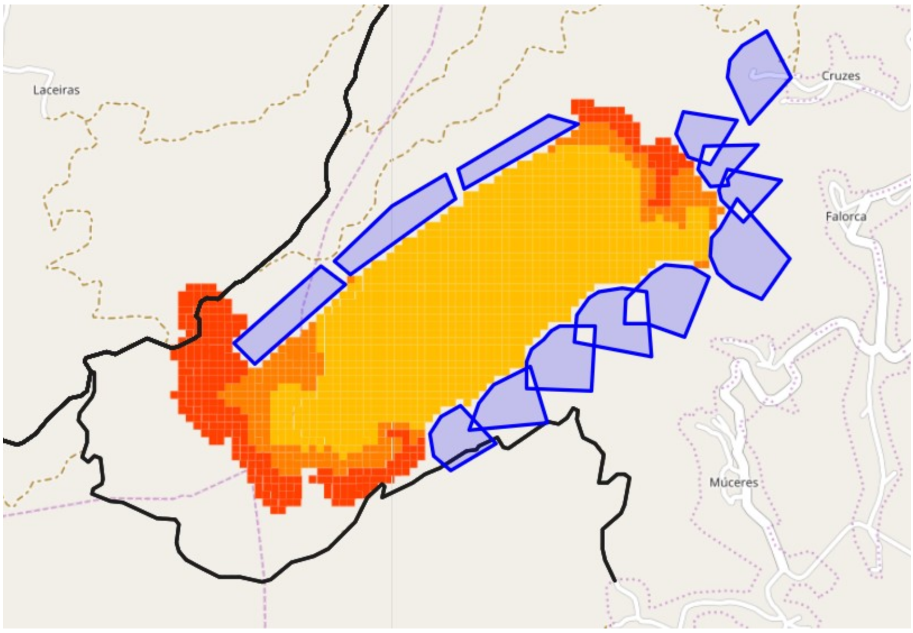
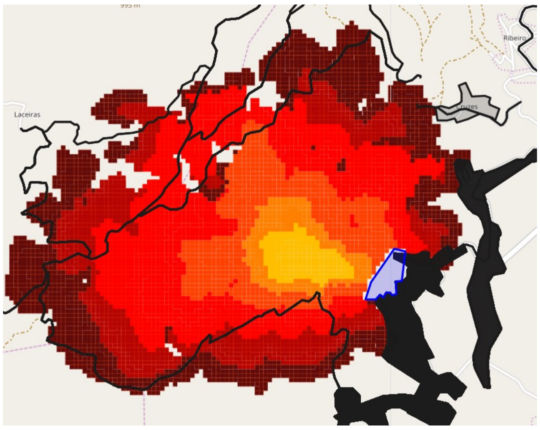
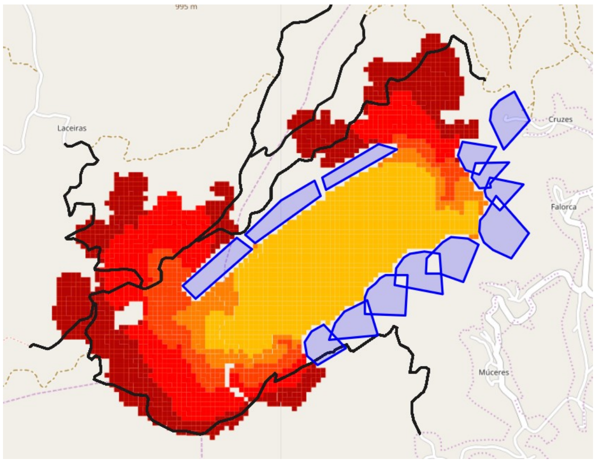


Figure 5.5: Fire simulation 10 hours after detected with changes to combat forces



(a) Initial ground forces



(b) Increased ground and aerial forces

Figure 5.6: Fire simulation comparison 20 hours after detection

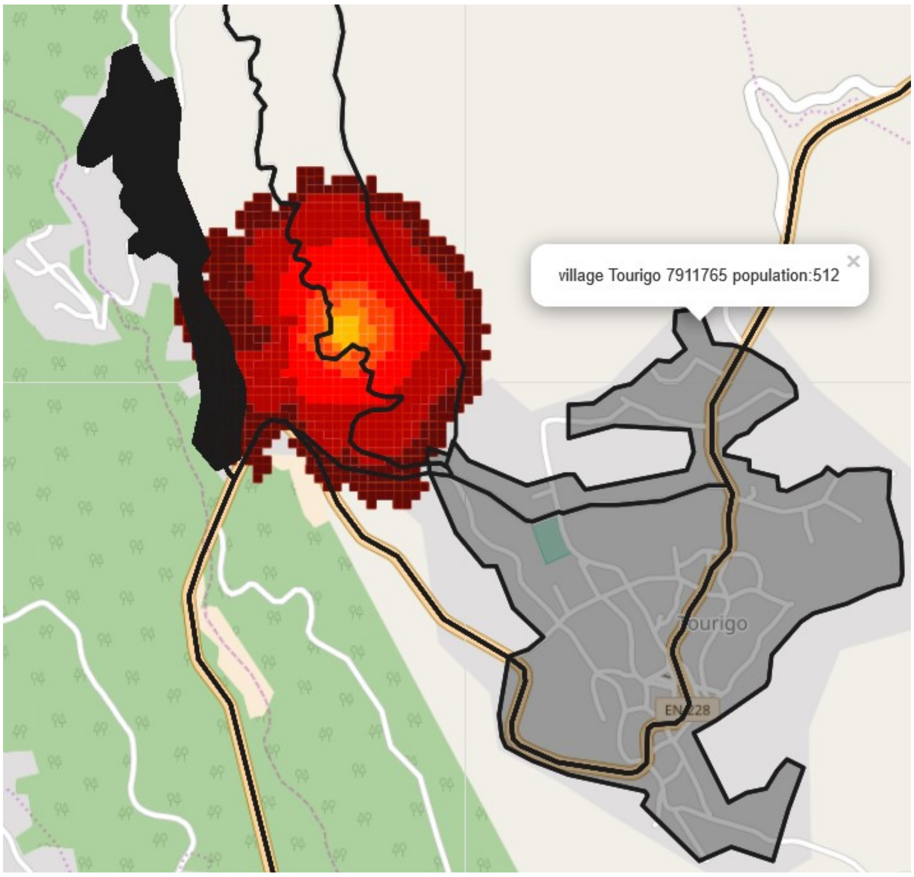


Figure 5.7: Areas affected by the new Tourigo fire

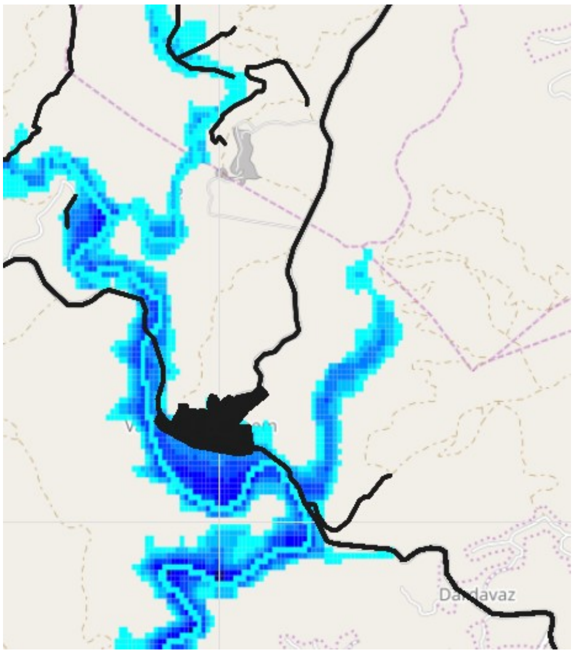


Figure 5.8: Areas affected by a flood simulation result

the results parameters, patterns identified to create heatmaps and alerts to affected zones. Figure 5.8 shows a visualization of the results using the visual interface provided to the user after the simulation is complete.

5.2 Useful Scenarios

Under certain situations, the use of a system of this kind can be crucial in emergency management. When the scale of the hazard requires a big operation to defend the population, the management of the geographical locations of the combat measures can be a difficult task. This system can be used to predict the growth of hazards and simulate the assignment of combat forces to the desired location in order to protect crucial zones that may be in danger of being affected.

Study scenarios are a kind of use that can be given for this, as it can simulate different scenarios customized by the user. Doing so, preparation of defense tactics may be based in simulations. The collection of multiple scenarios results may be important to help in decision making during actual operations. It also can be used to planning and land management when considering the construction of new buildings and infrastructures. Studies about how this new constructions would be in risk of being damaged by disaster events is a decisive factor in land management. Immobile defense forces placement can be analyzed, being this a good option for isolated places who may need a rapid intervention to protect them while new forces cannot be present. It can also be used to decide on the location of permanent strategic points to prevent major catastrophes from breaching in a short time. Supply zones placement may be also considered for nearby safe locations.

As a tool to help in crisis management support, this system can be useful to predict the behaviour of a disaster using verified real time values as inputs. Public institutions can provide the actual and predicted meteorological values and spatial area of the visualized occurrence identified by satellite images or even sightings of people present. Using this information, the responsible authorities may want to simulate the distribution of defense forces in the field and how they would be effective. When the combat measures are not enough for the total area in need of being rescued, the system can be important to identify what locations should be defended over others to reduce the total damage. It is then a deciding factor in choosing what areas should be evacuated, and those who should be reinforced.

During big scale operations, it can also be used as a storing tool to save the disposal of forces and spread of fire over time, allowing future analysis of how the approach to the crisis was and what could be improved.

Being accessible over the web, the system can be used by almost any device with internet connections, allowing its use by anyone. If it is provided to the common population, awareness of emergency situations behaviour may improve the response society has to such events, improving overall protection. If a new fire is detected, nearby population can use this to predict how long would it take for the fire to reach him/his property and infrastructure he may need to use to escape if it comes to that point.

Taking the simulated scenario of Caramulo fire as an example, if a fire starts in that mountain range, the fire would quickly climb the hill, spreading in all directions with great intensity and consuming everything at its path. Not only combat forces are required to reach the nearby population fast and in force, but also should delay its progression upwards. Sensible areas to fire progression can be identified by performing similar simulations in different zones. Should for example a immobile defense point be installed on top, in a strategic place that can counter the fire progression? Should the defense measures combat closer from the residences or push its position uphill to counter the fire? What would be the priority places to defend? When will the fire reach a critical road and when should it be closed? These and many other questions can be asked not only when preparing for risk seasons, but also during the defense operation. This system can be a good support in answering them.

There are some features that may be included in this project in the future to improve its utility and quality. These updates will be discussed later on what would be the approach to implement it and why would it be useful.

5.3 Difficulties Encountered

During the development of this project some technologies required more time to adapt to and some possible features proved too complex to integrate in the final solution using the given time. I had to study some tools and libraries I have never used before, which may have led to amateur techniques, some were even found out and properly replaced during the development, however there is so much to progress from here to improve the overall quality of the program.

The data search, collection and preparation was harder than what it seemed at first, which led to a delay in the time where it was expected to start simulations. Canopy was the most difficult type of data to get relative to topography, while weather related data turned out to be not as easy to find as expected, given there are institutions in place recording this data who do not freely share them or even the lack of enough recording sensors spread through the territory.

The understanding of how to correctly use FARSITE software took longer than expected as well. The program is able to perform good simulations, however its use is somewhere complex. The most difficult step was to really understand the correct data to be used for Portugal.

Many of the found useful software to simulate floods turned out to either be paid versions or expect complex data inputs. The integration of a proper flood simulation system would take some more weeks, time that could not be used for it. A workaround was explained earlier, where a simple solution was used to simulate floods, however this and other possible future simulation models need to be upgraded and better prepared to produce good simulation results in order to improve the quality of the civil protection.

When first preparing the visualization of simulation results, I expected leaflet and other web mapping tools to be able to directly load raster files to the map. This solution turned out to be inefficient and even not working for many situations. Then I found GeoServer, a web mapping service, enabling geographic data to turn into a service that can be easily loaded to leaflet using javascript commands. The use of this tool also required some time to understand, and even had to understand a styling language used by it to display the data.

Conversion of files were a headache. Some tools required the data in a certain format, while others in a completely different one. The coordinate reference system of the sourced data was mostly in EPSG:4326 while the one required by farsite and web maps is in EPSG:3857. During the whole process, many conversion functions were created and some even turned obsolete after some upgrades.

It was the first time I developed a web server in Python, using a framework I have never heard of before, so some adaptation was needed to configure and develop the server. Nonetheless Django turned out to be a useful framework and easy to adapt to.

This was my first experience with geographic data as well. The first approach to work with it was to use QGIS python script tool and later try to integrate its use in the web server, however there were some compatibility issues regarding the python version and PATHS used by Django and QGIS. After two or three days of changing software versions it ended up in a dead end. Latter on I found Django had a raster library to treat raster data, however this had too few solutions for the problem at hands. This library also turned out to be slow compared to the next solution, the use of GDAL and OGR libraries in python.

The comparison between the results and historical data of fires for Tondela was a feature I expected to include in this document, however most historical GIS data regarding fires for Portugal only display the total area consumed by fires. This is not ideal considering time based operations are important for this study. Historical ignition locations are rarely mentioned in such online data and the effect combat measures made to the development of such hazards is even harder to find documented. These scenarios can probably be obtained by directly contacting the proper responsible authorities, however what is in question for this thesis is not the quality of the simulation models, the test of those was already done in its development (excluding the flood model). It would be still interesting to compare a real theater of operations over time development with this simulation solution to see how exactly it can fit in an active operation as a decision support system.

5.4 Future Upgrades

5.4.1 Short Term

Simple upgrades that a single developer could make to the program in a few weeks work.

Save and Load simulation results. The simulation results are saved in a PostgreSQL table as polygons, each represented as a row. Every time the result is loaded using the respective web service, the whole table is selected, implying new results replace older ones. This process is good enough to analyze only one simulation at a time. On the other hand, if the user wants to visualize older simulations, a new simulation needs to be executed to represent it. The option of representing the simulation results as a single Multipolygon is not advisable, since it cannot store a time value for every pixel. As explained before, the use of raster format is not ideal as well. A possible solution is to add an identifier for every simulation in the used model and a filter for geoserver and every query that search for the simulation results in the server.

Prepare data for the whole surface of Portugal. This system is able to simulate and compare the results with any place in Earth surface, provided the necessary data to represent the desired location. The database used can include data for portions of land depending mostly on the geo coordinates used to cut the data. Such portions may include an area like the one used in the study case, smaller ones or even country size examples. The time required to simulate will vary depending on the size of the landscape, so the ideal would be to use exactly the minimum necessary area for every simulation. A good approach would be to automatically clip the area using user provided coordinates. Such can be done by extracting the coordinates values of a square inserted by the user on a leaflet map. Using those values, gdal tools could used to crop the data gathered for Portugal and the resulting data saved in the database and prepared to be used by the desired simulation models. If this seems unnecessary, a few landscapes should be previously prepared and saved in the database to better represent the whole necessary area to be used. Another problem with this type of solution is the need of a tool to generate some types of files, such as the landscape ones used by Farsite. However, if a new simulation model is used, this option may be simplified, implying the required input data is in formats easy to generate.

Complete the OSM data with missing information. The data provided by OpenStreetMaps may have a good enough representation of most Portugal places and most infrastructure, although it may be outdated or even completely missing for some parts. A lot of buildings are missing and isolated ones usually are not represented at all. This can be verified by comparing this data with satellite images. The lack of data will influence the results and so providing a bad advise for civil protection and crisis management. The developed tool can although be used to insert new data, improving the expected outcome. The more complete is the database the better. This means for every type of features the user may be interested in visualize and analyze in these simulations, either it being roads, railways, buildings, places, landmarks, enterprises, defense locations, water spots, gps real time and historical location of people or vehicles, critical infrastructure, events or basically any other thing that may be interesting to keep track of. Some of these inputs may be manually inserted by the admin/user or automatically inserted using an API.

Extract weather and wind information from the proper providers and save them to the database model. Currently only some necessary data for the case study was used, however this information should be available for any required date. Even the present date data and expected weather and wind values for the upcoming hours/days should be stored, so simulations can be ran to predict the evolution of active hazards. Some sources of such data were mentioned before, but its gather should be automated to facilitate the use of the system.

Collect historical ignitions and weather values. It may be of interest to compare historical events results with the provided simulation tool to verify its accuracy. It may also be used to simulate the outcome of different defense approaches to study and test new combat measures, therefore increase preparation to management a crisis. Weather values can be found using the previously mentioned sources, however ignitions can be trickier. Ignitions can be inserted by the admin, using a polygon to represent the shape of a fire when it was first detected (or for a certain point after it, depending on the user need). It would be ideal to save the representation of an historical fire in polygons format, storing the time of arrival value to visualize its spread over time. This can be stored in similar way to the simulation results and later be used to compare with new simulations.

Improve the flood simulation model. A simple flood model was created for this system, however it is not optimal, as stated before. Some solutions were explored during this thesis, however none was implemented. Further experiments and research of a good tool is important to better predict the outcome of a flood. The optimal solution would make use of river flow data, topography, weather data that influence the variance of water level, drain capacity to know how much water is removed and where. These may be enough to predict the over time water level prediction. The inclusion of defense measures (barriers and other types) may be interesting to calculate the effectiveness of a defense operation. The representation of the necessary data require a better resolution, because the collected raster data 30x30 resolution may be a poor representation for flood modeling. Small objects and buildings can also influence the outcome of a flood, so the model should also require this data. The inclusion of a time based value to the simulation results is of major importance to predict the over time effect of the flood in the landscape.

Host the server in a proper machine and get a domain to host the system. Establish access controls to define who have access to what. Only a certain type of users can have admin access to alter the database data using the site admin interface. Establish the accessibility of the site basic features, either it being for public domain or restrict its access for the responsible authorities. It may be necessary or at least advisable to change some settings of the framework to deploy the solution or even change the technologies used. An official database needs to be created and even the storing of some files updated.

Improve website styling and layer controls. Currently a bootstrap based style is being used to display the basic necessary inputs, control and results. A better front end is a must to improve the visual quality of the system. New and improved templates to provide a better visual and intuitive experience. The javascript functions used by them should be increased and improved as well to increase responsiveness and layer insertion to leaflet maps. Addition of controls to the maps, enabling the display and hide of layers and functions according to the user need. This will also allow the variation of base maps, possibly including satellite images to improve the space awareness. Other possible options for base maps are the topography related layers, to distinguish the presence of hills or the type of fuel present, important values that influence the simulation results. Some other information that can be pulled from the database may be considered to display to the user, such as the weather and wind values in the matching location or OSM data related info that are currently not being displayed but are nonetheless stored in the database.

Improve the option for the user to perform new simulations after small changes in the results page. Currently this is possible by saving a simulation result as an ignition, filtering it by the selected hour. This saved ignition can then be used to perform new simulations. If the user want to modify the combat measures location or even the landscape in case the fire gets proportions bigger than the previous one, new options need to be selected when performing a new simulation. One problem related to this approach is the removal of the time value for the new ignition, which will then be considered as the initial point of the fire. Another one is the inconvenience of creating new barriers to represent their new position and the need to perform a new simulation to get the results. An option solution is to allow the user the create new barriers or other features that will interact with the simulation directly in the visual page and an option to save those to directly perform a new simulation. Instead of simulating every time the user makes a change, the option to suspend or store the simulation states and continue in the desired time when the user updates a feature should be considered. This is possible to do using the Farsite desktop software despite not being available in the used command line program.

Use of combat measures of Farsite, instead of barriers. Sometimes combat forces soak the floor slowing the progression of fire. Barriers may not be the proper representation of the defense measures, and Farsite software provides options to use, such as aerial and ground forces. The modfarsite used for this project to allow the execution using python subprocess does not include an option to use these means. An approach to include them in the simulation parameters would increase the quality of the expected results. Barriers are represented in the simulation as impenetrable objects that stop the fire from reaching the inside of their area, however the defense measures used by authorities are not always like that. The defense measures should be more customizable to better represent all types of defense options available in order to better deploy the resources through the combat field.

5.4.2 Long Term

If the development of a professional solution based in this thesis is happening, what could be done to improve its functionality, usefulness and its overall value.

Add real time forces location. Create a system that keeps track of defense troops using a geo locator device. The purpose of this system would be to perform simulations using the real location of the combat measures. It is more useful for active operations, in which it would predict how effective would be the current deploy of the defenses and find unities that could be in danger. There should be a restrain into who can access this information. An API is required to be in place to handle the transfer of information between the new system and the current database. This could also be interesting to issue movement commands, so the forces receiving this information would know when and where to move. Using the simulation system, the possibility should be given to send an alert to the forces, informing them of danger possibility or to proceed to a new defense location. If a client is created to public use, considering it would receive the gps location of the users, an alert system could be put in place to inform its users if they would be in danger of being affected in the following hours, considering they would remain in the same place. Some interesting information that could be sent to these users would be the current fire area, the simulation results and escape routes.

Explore the use of new simulations for other type of hazards. Fires and floods are the more common in Portugal, however there are many other events that threat lives and property of society. Some of those can be predicted somehow using simulations, provided the appropriate models. Some examples of that are snowfalls, heat and cold waves, tsunamis, earthquakes, landslides or even technological hazards. Snowfalls increase the danger in transports. The identification of possible affected infrastructure prior to a critic time may be important to avoid accidents. Heat and cold waves simulation is useful to inform the population that may be in danger, so a proper protection can be prepared. Tsunamis usually cause a more catastrophic impact in coastal areas. Being one of the few hazards associated with huge amounts of deaths and destruction, it demands a big effort in preventing the damage caused by them. When a new tsunami is detected, a state of emergency is triggered in the nearby possibly affected places. It takes time to reach the coast, and during this time population needs to be informed and a damage mitigation plan is put in place. The improvement of the plan using simulation results may reduce significantly the loss of lives. Earthquakes strike fast so the simulation is not as important in real time events as it is in preventive studies. The detection of possible destruction caused by earthquakes is still a major concern so population can know how to proceed in case it happens. Landslides affect infrastructure and buildings, however they strike fast too, so only preventive simulations can be of use. Technological hazards, like transportation or industrial accidents can also be simulated. The effect a road accident may have in traffic is important not only to manage a proper response when it happens, but also to plan the construction of new infrastructure.

Add machine learning techniques to improve the overall simulation results and reduce the uncertainty. Learning techniques can be integrated in the system for various reasons. Some examples would be the interpretation of satellite images to create data, analysis of historical events to create new simulation models or even analysis of multiple simulation results to detect danger zones or patterns.

Build API for external services to use its technology and data. With the scaling of the solution, more applications can be created or updated to include some services provided by this system. To facilitate their integration, a specification of the required features is necessary to create a service provider. Those applications may be interested in accessing stored results, perform new simulations or provide inputs. Inputs provided by external apps may enrich the stored information regarding ignition points, areas on fire or in danger, geo located elements such as buildings, infrastructure or people. Other software programs may be interested in using the simulation techniques and results for purposes other than those used by the system. Overall the system has features that can be of use by many other applications, so its services should be made available somehow.

Automate its use to extract a valuable database of experiences. Like the collection of historical data, the collection of simulation results can be a knowledge source to look for when searching for information regarding hazards. A whole library storing simulation experiences may be useful to address when preparing defense measures. Instead of simulating every time of need, the use of previously gathered results may drastically reduce the effort required to find the proper solution. An automatic function could also be triggered under certain circumstances to activate the system. For example if a satellite images recognition is used to identify the start of a fire, the system could be automated to generate the shape of the fire as an ignition, get the required weather inputs and select the respective landscape to perform a fire simulation. All other subsequent functions could also be automated to alert necessary receivers. Using machine learning techniques, the disposal of defense measures could also be automated depending on the best results scenarios.

5.5 Summary

Results and discussion chapter introduces a study case relative to Tondela region. It starts with a description regarding the steps necessary to prepare the data to be used. Some simulations of a forest fire near Caramulo are executed and the results the user can see in the view page using the leaflet plugin are placed as images to show the expected fire growth. Some changes regarding combat measures and ignition area are made to address the impact different scenarios would make in the landscape and infrastructure. A flood result is also presented, so the main features of the program can be compared between simulations. After the case study, some scenarios are explained in which the use of this tool may be of interest to a proper civil protection and crisis management.

A section to mention the difficulties encountered to address some technologies, some set backs that may have delayed the development of the resulting solution and some problems to take into account when developing a system of this kind.

To conclude, some possible future upgrades to the system are explored to increase the utility and quality of the program. This section is divided in two, one for simple upgrades that could be made without much effort and the last for more complex ones that would require a bigger investment and the work of more than one person. Some of those solutions would expect the development of external applications that could make use of this system.

Chapter 6

Conclusion

The purpose of this dissertation was to develop a Geographic Information System to help in civil defense and crisis management suport using simulation techniques to predict the behaviour of hazards under certain conditions. The proposed solution is able provide over the web an application that simulates fires and floods using personalized inputs of topography, fuel, weather, wind and spatial events. The results of simulations are compared with infrastructure and places data from OpenStreetMaps to display what areas should be secured from an hazard event.

To explore the type of similar solutions existent by now, a literature review was conducted. Some simulation systems were found able to produce mostly fire and flood simulations. Those systems require simulation models to treat data and output the predicted over time behaviour of the hazard. Some of the models are mentioned and explained in the literature review, in order to better undestand what they do. What most of the found software encountered lacks is the ability to display the infrastructure and buildings hazards may affect, only displaying the simulation results over a base map. An intensive research for data that could be used was necessary to get the right information. The selection of what type of data to extract depended on what the models required and also some guides mentioned. DGT methodological guide provides a good insight on concepts to consider when producing risk cartography as well as some types of hazards to study and where to find relative information.

The open data that can be found online is enough to properly produce simulations for Portugal territory. Nevertheless, the data may be outdated in some cases, which may be responsible to some unoticed errors in the simulation results. Most of the data is not standardized, so some conversions are required. The necessary steps to treat it to a useful format are addressed so future similar solutions can be simplified regarding data preparation. Spatial data relative to infrastructure, buildings and others provided by OSM turned out to be incomplete. To solve this problem, the user is able to input new data to the database using the admin interface, allowing the enrichment of the information available for civil protection.

The simulation tools used for this project are FARSITE for fires and a simple flood model for floods. FARSITE is a powerful tool to simulate fire progression over a landscape, allowing the user to input the desired topography, fuel and weather data, as well as ignition locations and combat measures. Using the ignition location, multiple studies regarding the behaviour of fire in certain landscapes can be performed to produce risk cartography. By adding combat measures to the simulation, a whole theater of operations simulation becomes a possibility. The simulation results output not only the location of the fire with the associated time of arrival but also to other useful information like intensity and flame height. For study purposes only time of arrival was used, being an important factor in filtering the fire progression based on its presence at a certain hour.

To integrate the data collection, hazard simulation and results visualization a web server was built using Django framework for Python development. It connects to a PostgreSQL database, using PostGIS for geographic data support. The execution of simulations require the server to prepare the necessary data to input and transform the results into a desirable format to be displayed in a web map. Geoserver is used to provide a web mapping service that will be added as a layer to the leaflet web map. Depending on the hour asked by the user, the simulation results are compared with the infrastructure data. In case an object is in danger of being affected by the hazard, the object is passed as a GeoJSON to alert the user by displaying it in its geographical location and some text info that relates to it. The possibility of saving the simulation state in a certain hour is also provided, so some changes can be made to find the best possible approach to protect the elements in danger.

The study case scenario shows the utility such a GIS can provide to the authorities planning. The fact the effectiveness of the combat measures in combating hazards can be predicted, and the measured probable damage such events would cause is a good indicator mistakes can be avoided. During the development of the actual solution some interesting ideas emerged that could be implemented in the future. Some of those ideas are fairly simple to implement that will increase the quality of the solution. Others would require more effort and time to put into practice, but would enhance the utility it could be given and its overall value, maybe even allowing this system to be considered a must have in civil protection and crisis management.

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Appendix A

Appendix

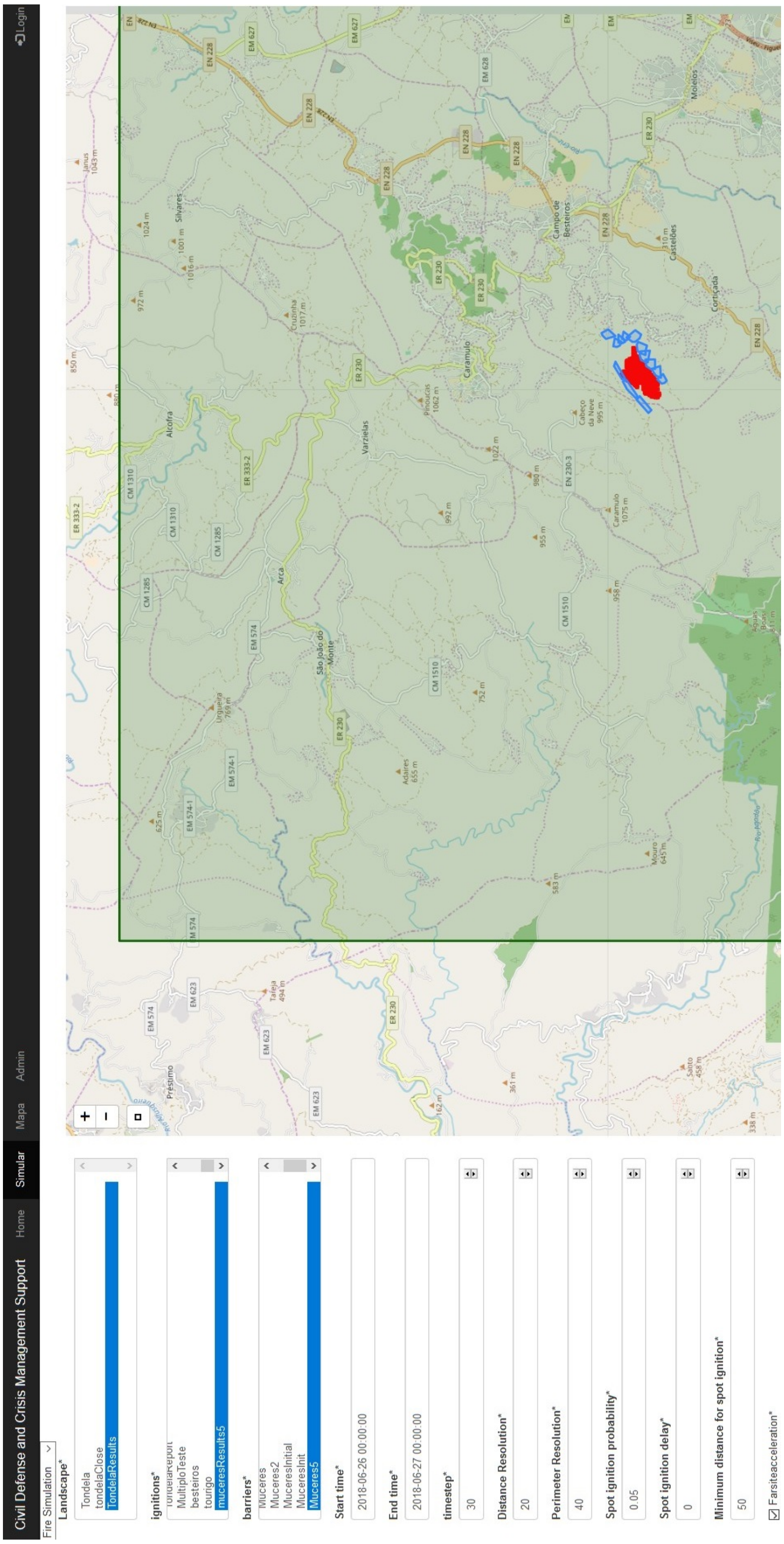

Figure A.1: Simulation interface

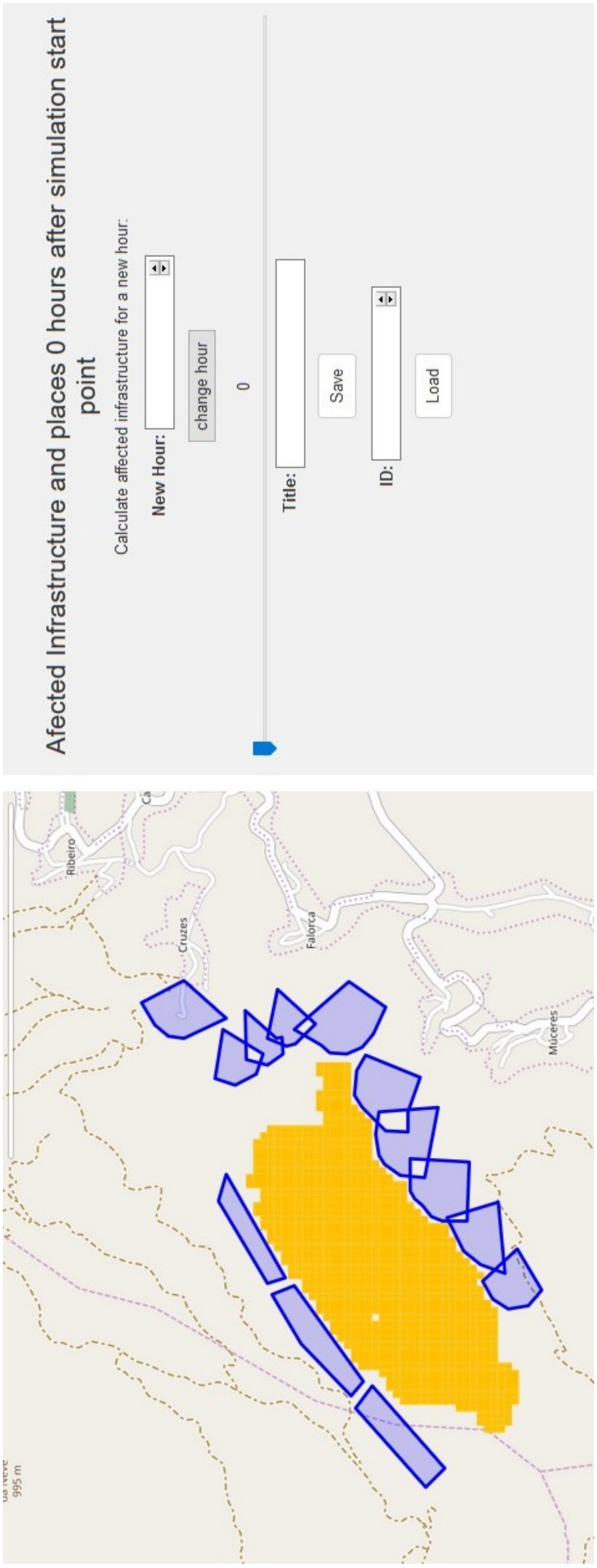

Figure A.2: View interface at 0h results

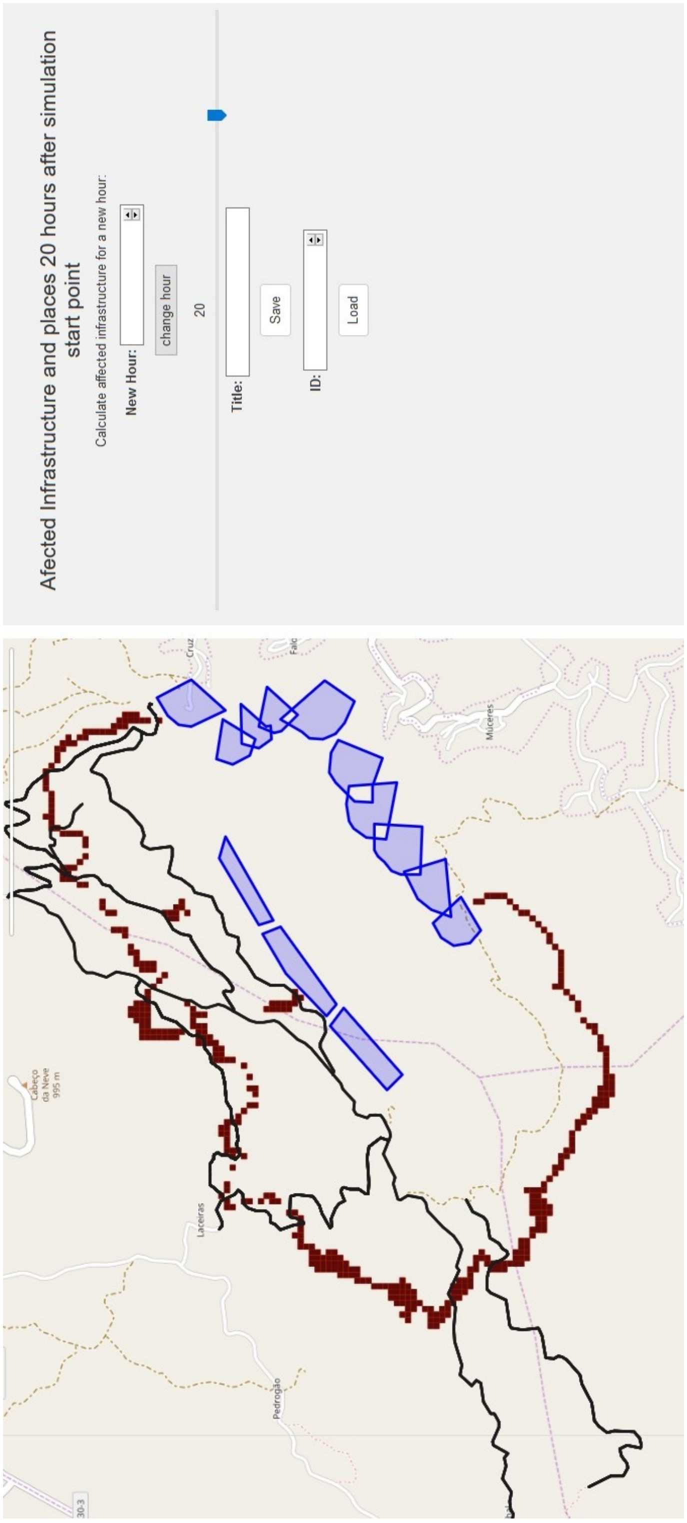

Figure A.3: View interface at 20h results