

# Semantic Enhancement of a Virtual Reality Simulation System for Fire Fighting

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**Abstract.** Fires disasters provoke great destruction of high valuable environments and economical losses, especially when they are located in urban areas. The usage of Virtual Reality Simulator to support the training process of fire fighters and managers has two main advantages: *i)* it supports the simulation of scenarios like big city fires that could not be simulated in the real world *ii)* it reduces the accident risks as users are trained to experience situations as ‘alike’ as possible to real fire. The success of the Virtual Reality Simulator depends on how close to reality the simulation process is; it also requires the integration of heterogeneous data sources like maps and cadastre. Both these aspects are met in this paper by a careful management of Semantics in the information system. Semantics are useful firstly to have a better model of the fire fighting process and a better adaptation of the simulation environment to the user profile. They are useful secondly to facilitate the integration of data from heterogeneous sources. This work discusses and presents some preliminary results about how Semantic can enhance Virtual Reality Simulators in the fire fighting context.

**Keywords:** Semantics, Virtual Reality, enhancement, Fire fighting, formalisation, ontology, real time, CityGML

## 1- Introduction

Virtual Reality simulators for fire fighting training are appropriate tools for presenting virtual and interactive scenarios impossible to be created in the real world. For example, a fire brigade cannot learn the practical aspects involved in a twelve-floor building fire emergency, since the variables involved cannot be re-created in a physical simulator. Only small and controlled drills can be performed within the security measures of professional training centres (see Fig. 1). The evolution of Virtual Reality simulators have been addressed by an increment of technical aspects like *i)* the graphic quality of the 3D

world rendered, *ii*) their screen resolution, *iii*) stereoscopic support, and *iv*) the addition of novel interaction devices, aiming to increase the users immersive experience. The aforementioned benefits make possible the development of very realistic simulations for the training of fire fighters.



**Fig. 1:** Aircraft Rescue and Fire Fighting Basic Training [23] [08].

Emergency Response field require access to information and knowledge that comes from different and, in many cases, heterogeneous sources, i.e., the terrain data could be provided by a Map Server provider, the roads and street information or the cadastral data could be provided by the local territorial authority, or even the status of the semaphores in a given area could come from traffic and urban designers [30]. Additionally, 3D models are becoming widely available and can be obtained from municipalities or other institutions, making the heterogeneity of sources a very tricky task to conceive [29]. The Emergency Response methodologies are region/country dependent, as they describe specific actors, processes and tasks, and also may have diverse terminology. In this respect, there is a broad understanding that the use of semantic technologies introduces valuable modelling tools and underlying languages, which is advantageous for the unification of the concepts and terms behind the terminology used in the heterogeneous data sources (on one hand) and the terminology of each Emergency Response region (on the other hand).

In simulation environments, the categorisation of user roles is a key element, since it is closely related to the users' perception of the 3D world. Within a described simulation scenario, the users have different interaction paradigms with the system, which depend on their roles in the Emergency Response process. If these roles are well-defined the immersive experiences can increase significantly, which will enhance the effectiveness of the training. The support for this behaviour can be realised by adding a Semantic Layer to the VR system. Eventually, the Semantic Layer will provide necessary information for two important processes: first the integration of data from various sources, second the adaptation of the simulation environment to the user profile.

This work will elaborate on some preliminary analysis about the possible semantic enhancements by adding a Semantic Layer in the VR Simulator. Some custom tests are shown in the corresponding section to help to understand the possibilities of the semantic enhancement of VR simulations.

## 2- State of the Art

### 2.1 The various meanings of semantics in geographical information systems

Semantics is the discipline that studies the meaning of things. The word originates from the Greek term *semantikos* that means “significant”. The word semantic in its modern form is considered to have first appeared in French as *sémantique* in Michel Bréal’s 1897 book, *Essai de sémantique* [03]. Semantic technologies constitute some of the most interesting technologies derived from the World Wide Web revolution. Constantly reviewed in different areas of knowledge (e.g. Linguistics), their greatest improvements of information technologies might still be yet to be discovered.

In the domain of Geographic Information, the word *Semantics* has been used frequently somehow to refer to the improvement of the information system by explicating more information, but with different interpretation of what semantics are in an information system. The remaining of this section reviews these different interpretations and their relevance in our context.

Very early, geographical data producers used the word semantics to refer to the part of geographical data that were related to the thematic properties of features and their attributes like a “number of lanes” for a road. In many virtual models, there are two sorts of data: the coordinates and the textures. Enriching such data with semantics can thus be interpreted as follows: making explicit, at the level of data, the features as well as their nature and properties. This is what is proposed in CityGML model [17]. The authors use semantics to denote properties different from spatial ones. They propose to integrate in CityGML semantics elements relevant to disaster management thanks to a taxonomy of classes that distinguishes between buildings, vegetation objects, water bodies, and transportation facilities like streets and railways. These objects are useful to support automated analysis like finding the quickest way to a building.

Another basic definition of semantics proposed by Kavouras et al [15] is the relationship between the data and the reality. Many works analyse how to represent this information, essentially in order to integrate heterogeneous data or in order to facilitate dataset discovery in catalogues. Most approaches consist in associating a real world feature type (also known as a category in an ontology) to a database feature type [16]. Mustiere et al. [22] and Abadie [01] propose a more precise representation of the relationship between a geographical database representation construct and a category of the real world. Their model tracks every choice made by the data producer to create the database structure and to populate it from his observation of the real world, like the decision to decompose the representation of a road into road segments or the decision not to put in the databases dead ends that are less than 20 m. long. This meaning of Semantics is much used in works related to the integration of heterogeneous databases, described in the next section. It is what we call *nature-oriented semantics*.

Kuhn has a different point of view on semantics, summarized in the following statement of the author: *meaning is the use* [18]. This is what we call the *value-oriented interpretation* of Semantics as compared to the preceding nature-oriented interpretation. An interesting work in this perspective is the proposal of the economist Gibson [11] to describe the word in terms of what activities are supported by the objects, i.e. the affordances: “The affordances of the environment are what it offers the animal, what it pro-

vides or furnishes, either for good or ill". Kuhn [19] extends upon this work and model affordances in Geographic Information Systems. Similarly, Jordan [14] proposes to use *affordances* as relevant descriptors for places: a place to rest, a place to have a drink, and so on. This meaning of semantics needs somehow to have a formal model of human activities to assess possible affordances of objects in these activities [05]. A formal model for fire fighting process is presented in section 2.3.

## **2.2 Formalising semantics to integrate heterogeneous data**

Generally, three kinds of data interoperability, namely system, syntax and structure, and semantic interoperability [24][02]. System refers to hardware, operating systems, and communications heterogeneity, such as communication protocols. Syntax and structure interoperability covers data representation, formatting, data models, spatial schemas heterogeneity. Semantic interoperability reflects the meanings of objects, terms, features, code, message or any other form of representation. While quite some progress is realised in solving heterogeneity of the first to groups, the semantic interoperability is the most challenging. With the development of Spatial Information Infrastructures (SII) the semantic interoperability is becoming a critical issue to be dealt with.

One of the formal approaches to describe semantics formally is ontology. Ontology in broad sense stands for the philosophical study of the nature of being, existence or reality. In theory, ontology is defined as an explicit and formal specification of a conceptualization [12]. Theoretically three kinds of ontology architecture can be distinguished [24][26]: global, peer-to-peer and hybrid ontology architecture.

Global ontology architecture assumes the existence of a single big ontology for the application field. All concepts and relations are well-defined by this ontology without referring to other ontologies. This architecture is suitable for the application domains where all parties have a common understanding and agreement.

Peer-to-peer ontology architecture refers to cases when several ontologies are used as the mappings between them are known. These ontologies could also form a new concept and a relation network as the global ontology architecture. This architecture is more flexible but it might happen that many abundant data may exist.

Hybrid ontology architecture is a combination of the above two. In this architecture, domain ontology is build and other specific ontologies refer to it. A commonly agreed definition and constraints of domain vocabulary are defined in the domain ontology.

Heterogeneity of geo-spatial data for emergency training may benefit of the second and the third approaches [28]. This means that a domain ontology for emergency response should be built, that further can be mapped to the ontology of users (having also domain ontology, such as domain ontology for fire-fighters, domain ontology for police, etc.) and ontology of data (such as ontology for topographic data sets, ontology for cadastre, etc's).

## **2.3 Formalisation of the fire-fighting process**

Emergency response procedures and the organisational structures may differ significantly per country. Some countries are exposed to earthquakes, others to flood and fires;

fire brigade and police might be the primarily responders in some countries, while in others civil protection centres or other governmental institutions may take the lead. In all cases, however, the local and national governments and the international organisations have legislations that prescribe work-flows and procedure for emergency response. Considering these documents and analyzing the work of the emergency responders, it is possible to specify what kind of data might be of primarily interest when performing a certain tasks [29]. The main components of this formal modelling are the actors, their tasks and the information they need to have at their disposal and usually, the language used is Unified Modelling Language (UML).

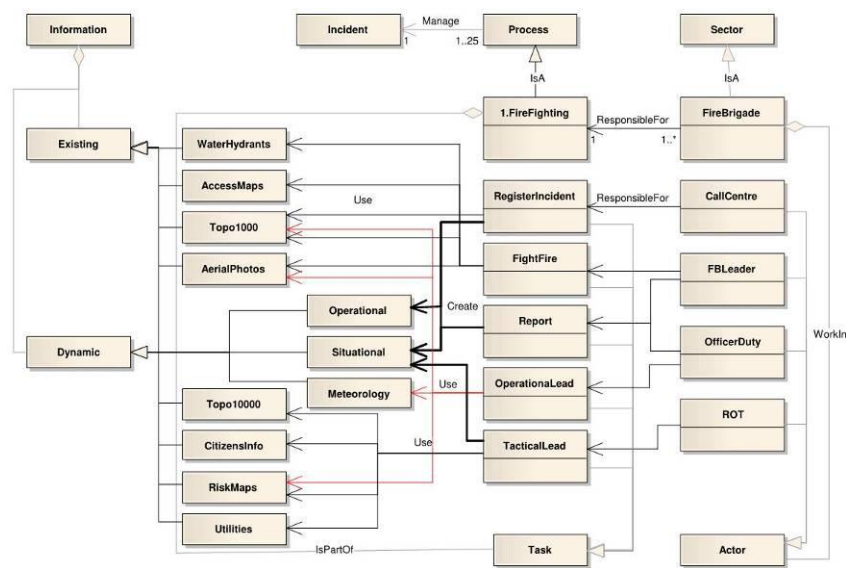


Fig. 2: UML diagram representing tasks, actor and information for Fire Fighting (from [31]).

The goal of extinguishing a fire is to prevent further damages on property and limit emission of dangerous substances. The workflow can be quite specific but has several common key elements as follows: the call centre receives the emergency call, registers the incident and informs the responsive fire brigade unit. The officer in duty (and the needed fire engines) moves to the area of the fire. On the way to the fire they examine various pieces of information such as different topographic maps, locations of water resources (open water and hydrants), the optimal route to the area, vulnerable objects in the area (available on risk maps), information about citizens, etc. If the fire covers a large area (as it often happens with forest fires), a regional operation team (ROT) is formed and coordinates the actions.

In this case the following actors can be distinguished: *CallCentre*, *FBleader* (of one fire engine), *OfficerDuty* and *ROT*. The most important identified tasks for providing/recording information are *RegisterIncident*, *FightFire*, *Report*, *OperationalLead* and *TacticalLead* (see Fig. 2). For example, the task of the operator in the call centre is to register the incident and inform the fire brigade sector. *FBleader* is responsible for the direct actions for fire extinguishing of one team. The officer on duty performs the overall

operational lead on the field. These two actors should be in regular contact report with *ROT*.

As it can be seen, the information needed for the involved processes differ with respect to the actors. Some of them (operator in the call centre, *Fbleader* & teams and the officer in duty) need large scale topographic maps (i.e. Topo1000, scale 1:1000). *ROT* (located in a command centre outside the dangerous area) needs small-scale map (Topo10000, scale 1:10000) and information about citizens, vulnerable objects (available through Risk Maps) and often utility maps (e.g. gas-pipe lines).

The process as described above can be further enhanced with actors, tasks and needed information for specific types of fires or scales and can be considered in the VR Simulator. The information provided by the VR simulator can be also adapted to the goal of the each specific training, e.g. for training of fire fighters on the field or for operational and tactical training of *ROT*.

### **3- Our proposed information model for a Semantic enhanced VR Simulator**

#### **3.1 Fire fighting simulator capabilities**

The VR system is aimed to help in the training or to improve the efficiency of the fire-workers (field agents, managers...). The common teaching procedure includes the theoretical content and some practical examples, all of them with *fake* fire and with strong limitations, as it is impossible to fire a forest or a 12-floor building only to teach how to fight it.

The presented simulation system is oriented to the fire fighting procedures, in forest and urban areas. Some approximated algorithms of the fire spread have been modelled and developed [20], as real-time nature (since the fire fighters and managers interact with the fire) limits the complexity of the methods. Therefore, we cannot use the very well known and accurate fire spread algorithms existing in the bibliography.

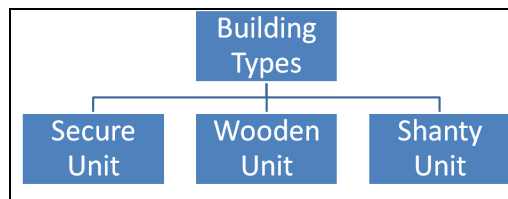
In order to be able to simulate how the fire spreads and to model the behaviour of the users, the simulator will be provided by passive data coming from different sources and dynamic events, not only including the user actions but also real-time changes in the weather conditions, for example.

The most important required information is the topographic information of the scenario where the fire simulation will be held, which includes the terrain itself (given as a Digital Elevation Map or DEM), the aerial imagery and the ground classification given by disjoint zones, coming from any available GIS system [09]. Although very detailed information would be great, having at least a rough classification based on *Water*, *Roads*, *Urban Areas* and *Forest Areas* is required.

The available topographic information is then pre-processed and sampled into the internal field representation, based on a squared grid of autonomous cells, each of them containing geometrical information, such as position, side size, elevation and slopes [27]. Also, per cell information, related to the fire spreading algorithms, is also stored. It includes the type of the cell, the amount of initial fuel and the burning rate depending on its type.

The weather conditions are also required by the fire spread algorithm, being the wind direction and speed the more important considered physical variable [27]. Although other parameters like humidity and global temperature are relevant for an accurate simulation, the wind speed and direction are considered the most influent variables.

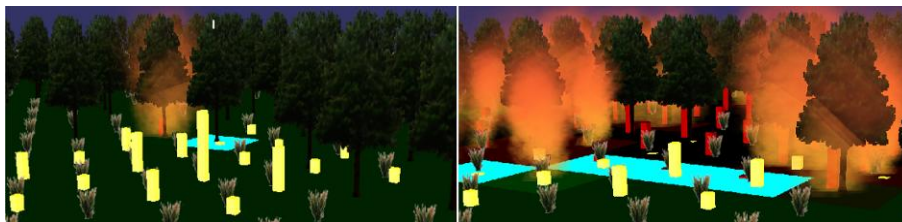
The simulator also deals with urban fires, so the fire spread algorithm includes the buildings concepts, adding the corresponding classifications and spreading rules [04]. The urban fire algorithm is an extension of the forest areas, and essentially, the algorithm works in the same way. A *Building* is sampled into squared cells, applying the corresponding building type, and also, the number of floors as a key element. For the building types, we have considered three main types; following the classification introduced by Iwami [13] (see Fig. 3).



**Fig. 3:** Different types of buildings considered in the simulator. The Secure Unit is harder to burn, and its final state is not destructive. The Wooden Unit and Shanty Unit are destructive fires, where the building burns totally and collapses. The Wooden Unit and Shanty Unit burns using different schemas [13].

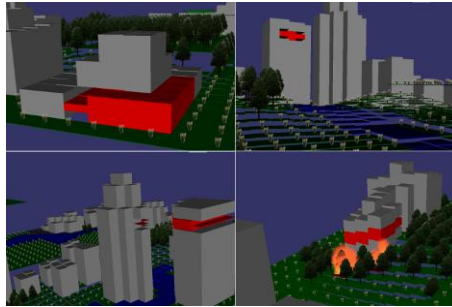
The introduction of buildings into the fire spread algorithm required the addition of a set of specific rules to deal with the peculiarities of the urban fire [20]. The fire evolution in buildings with several floors should be considered as 3D, as the fire tends to go upwards. Also, the radiation effect is stronger in higher floors, increasing the probability of fire spreading to near buildings. These rules are easily added to the fire spread algorithm, but the addition of the extinguishment support is more difficult to achieve.

In forest areas, the extinguishment support is simulated by adding the concept of *Water Quantity* to the cells. In fact, the water concept is an abstraction of any extinguisher agent. In runtime, any amount of water thrown to an active cell reduces its amount of fire (*FirePower*) (see Fig. 4) by a given quantity, depending on the type of the extinguisher agent.



**Fig. 4:** Extinguishment support in the simulator is based on the “throwing water” concept, where water cancels a determined amount of *FirePower*. The water disappear immediately if there is enough *FirePower*, or remains there as available water, which could be evaporated by the radiation effect coming from the neighbouring cells.

In urban areas, this algorithm is not easily scalable, as the building concept is much more complex than outside areas [25]. The real life procedures to deal with urban fires differ too much depending on the building, the surroundings, the available resources... In Fig. 5, some very different situations are shown. The extinguishment algorithm implemented for those situations are based on external water sources (water jets), thrown from large fire truck.



**Fig. 5:** Urban fire examples where the burning floors have been coloured in red to make them distinguishable from the rest. The urban fire can spread to adjacent floors (up, left), upwards and downwards (up, right), to neighbouring buildings (down, left) and to the surrounding terrain (down, right).

### 3.2 Geographical 2.5D and 3D data analysis

Classical 3D virtual models, comprising a Digital Elevation Model (DEM) and realistic textures are very useful for the user visualisation. Indeed, a great difference between virtual globes and maps is that the virtual globe is closer to the user experience of the real world than the map. These data can be provided by data producers or can be simulated if a specific landscape or atmosphere is required. Besides this terrain information, objects are necessary to perform some analysis as explained by Kolbe et al. [17] when they present CityGML relevance for disaster management.

We distinguish between 2D, 2.5D and 3D data. In 2D representation, coordinates are only planimetric. In 2.5D there is one altitude for each planimetric coordinate (like a DEM). In 3D it is possible to describe several points with different altitudes and the same planimetric coordinates, like on a wall or when a bridge crosses a river. From an algorithmic point of view, sometimes 2D data is more suitable than 3D. The calculation of solar radiation or wind effect at street level do not require the same accurate representation as the intervisibility problem, used to check if two objects (e.g., fireman and injured people) could see each other inside a building. This combination of 2.5D and 3D objects, as well as the combination of different levels of details of the data, leads to interoperability problems.

These problems become clearer when different heterogeneous data sources are used at the same time, for example, the terrain data, the buildings, the road networks and the water resources map (like hydrants, a very important element in the fire fighting process). Depending on the data resolution and scale, the hydrant location in the virtual world could not be precisely aligned with respect to the terrain data as it would be required in



the Virtual Reality Simulator. The solution for these situations is based in the utilisation of multi-resolution data, assuring the data quality, alignment and integration at a specific level. CityGML, with their well defined 5 LoD, is a very handy 3D data representation, allowing unifying multiple data sources at a given LoD.

One last important element regarding geographical data in the system is to support the unambiguous designation of objects and places in a way that is both machine readable and human readable. This is useful typically for firemen, civilians or the manager to communicate on the phone relevant information about the scene. Street names and addresses are the common human readable reference system for urban objects. But it might be useful to have other ones (for instance if a street name is destroyed or too far to read it). In most works, it is suggested to identify landmarks that can be used to reference things in a landscape. An interesting proposal is that of Morita's real scale map who defines objects in the real world (like a fire light) that, together with relationships like "5 steps from" compose a fully functional reference system [21]. An alternative way to solve this issue is to design identifiers for objects in the real worlds. This approach is investigated in the context of collaborative data and in the Semantic Web where people want to attach descriptors to a resource identified with a URI. Yet, these URIs are not that much human readable like for instance <http://data.ordnancesurvey.co.uk/id/50kGazetteer/16354>. In our context, Morita's proposal fits better in the Virtual Reality Simulator implementation.

#### 4- Exploiting the Semantic Layer in different scenarios

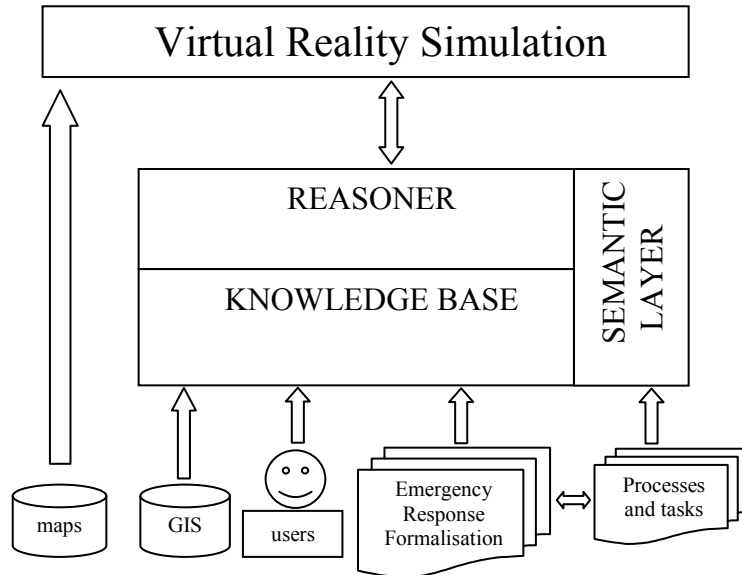
The utilisation of Semantic technologies is a key element to introduce semantic concepts into VR application. The fire fighting simulator, presented in Section 3, could benefit of an integration of the semantic knowledge embedded in the fire fighting process.

As it has been address in Section 2, the formalisation of the fire fighting process triggers the categorisation and representation of different entities, processes, tasks, subtasks and roles.

The utilisation of this categorisation into the VR simulators could enhance the possibilities and features of the VR fire fighting simulator. The relationship between both modules is directional, i.e., the Semantic Layer can send semantic information to the virtual world and, in the other hand, the results of the actions of users in the virtual world can be retrieved by the Semantic Layer for further utilisation.

Therefore, the Semantic Layer (see **Fig. 6**) takes all the relevant information, composed by the GIS information, the user categorisation and all terms and concepts of the Emergency Response procedures into a set of ontologies, where the reasoning would produce direct input signals for the Virtual Reality Simulator. These input data can be conceived as an asynchronous signalling system, triggering changes in the VR while the users are online.

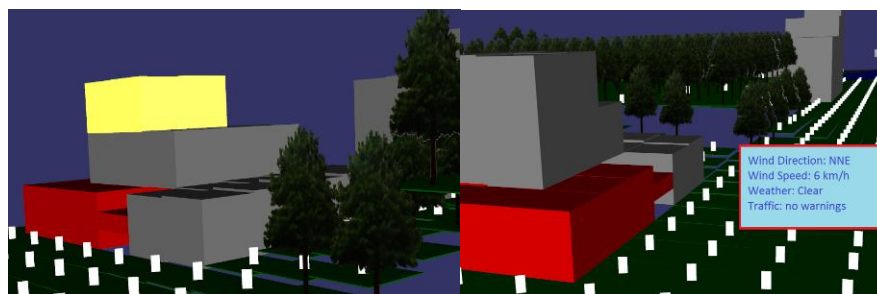
In this work, some very simplified scenarios and examples will be addressed, in order to preview how the VR simulations could benefit from the Semantic Layer. These examples have been chosen to fulfil a wide range of possible practical applications, but they should be understood as representative examples of a larger set of possibilities.



**Fig. 6:** The Semantic Layer manages the different kind of information that will be loaded into the VR simulation. The Processes and Tasks are the result of the formalisation of the Emergency Response procedures related to the fire fighting process. User categorisation is addressed by the existing roles in the processes and tasks. All this information plus all the relevant GIS information is used by the Semantic Layer to analyse and trigger all the semantic enhancements in the VR simulation. The cartographic information, 3D maps and static information of buildings are loaded directly by the VR simulation.

### Use case 1: Semantic Highlighting of VR elements

The Semantic Highlighting of specific elements is the simplest way to enhance the VR simulations, as it is easy to implement and to understand. In this case, the Semantic Layer triggers visual changes in the VR, whose main purpose is to highlight specific elements to be visually more distinguishable from the rest of the objects.



**Fig. 7:** Use Case 1. Left) Burning buildings (floors) have been highlighted in red, and the target floor in yellow. Right) Additional on-screen information is displayed, in this case, related to weather and traffic conditions.

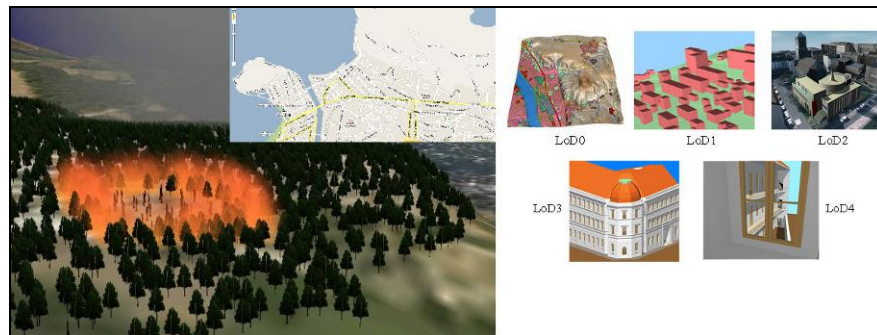
As an example in the fire fighting simulator, an agent field could receive relevant information to locate a targeted ignited floor of a burning building, by rendering it with a distinctive red colour (See Fig. 7, left). The Semantic Layer would provide to the VR system the specific floor (and building) to highlight. The Semantic Highlighting takes advantages of the applied identifiers to the VR objects, allowing linking a given object by some descriptor.

### Use case 2: Enhance VR setup using user profiles

The VR setup is usually designed and implemented to fulfil the usability requirements from the target users, as a result of the specification process in the early stages of development. But, even in the same group of users with the same role, different people would require specific modifications of the VR setup. Sometimes these modifications are only a matter of rearrangements in the GUI due to subjective reasons, but other times the modifications could be triggered from a semantic point of view.

If a user in the fire fighting management role is left-handed, the GUI (menus, toolbar, toolbox...) and mouse interaction behaviour could be adapted to improve the user experience, since it is quite normal to produce unique GUI layout for right and left-handed people.

For immersive setups where a first or third person view point is normally used, the users could improve the virtual experience if the avatar height is similar to their own height. The VR setup should be adapted or reconfigured using the semantic information. Normally, the key element is the user role, which triggers different kind of visualization and different data retrieval methodologies.



**Fig. 8:** Use Case 3. Left) Different resolution and types maps are used in the simulator. Right) The different LoD that CityGML proposes in the specification [07].

### Use case 3: VR elements replacement by user type

There are different elements which can be presented to the users in several ways. Even if the available hardware and software can handle with highly detailed 3D models and dense information, sometimes is preferable to use simplified models or impostors of the

data, to increase their understanding of the information and the final usability of the applications.

In the fire fighting process, the field agents and managers in the control centre have different needs of data resolutions. In one hand, field agents using immersive simulators, will require highly detailed representations of their surroundings, rendering buildings and fire as realistic as possible. In the other hand, managers would not require such complexity, and a combination of cartographic layered 2D maps and a simplified 3D aerial view will suffice for them (see Fig. 8 left).

The proposed behaviour require to replace virtual elements depending on the user role and needs, being the Semantic Layer the responsible to tell to the Virtual Reality Simulator this kind of information, instead of hardcoding the VR elements replacements in the Simulator. CityGML model has support for well specified Level of Details, which allow selecting between different resolutions with respect to the needs of the users. They can be seen as a key element in the whole system. While a LoD 4 or 5 will be used by immersive simulators (fire agents), the LoD 1, 2 and 3 would be enough for the manager role (see Fig. 8 right).

## 5- Conclusions and/or Discussion and future work

This paper has studied the relevance of Semantics in the context of Virtual Reality Simulators. Two kinds of enhancements are brought by Semantics.

Firstly, *nature-oriented* semantics can improve the integration of data from different sources. The combination of multiple heterogeneous data sources (formal specification, maps, municipalities' urban information...) is indeed a major problem from the acquisition point of view. Required semantics to solve this issue are based on domain ontologies that should be used to annotate the data. Besides, this information would also be used to access this information. We also propose to introduce a reference system that is usable not by a geodetic surveyor but by actors involved in the process, in a way similar to Morita's real scale map. This will facilitate the sharing of user comments and feed backs.

Second, *value-oriented* semantics, especially the modelling of the activities enhance the user experience. The proposed use cases in Section 4 show how Semantic Layer and Virtual Reality Simulator can be integrated to enhance the user experience. Uses cases 1 is more related to enhance the presentation of relevant information to the users. Use case 2 is a clear example of exploiting the user preferences or profile to modify how the 2D classical GUI or the equivalent 3D widgets can be adapted to fulfil the user needs. Finally, the use case 3 shows the ability of CityGML to deal with multiple LoD's, as users require different data resolutions depending on their roles [08] [09].

Besides, the proposed information system relies on three types of semantic models: a model of tasks to organise the session, a model of reference system to organise some communication of information between involved agents, and a model of user profiles.

In this research, CityGML is considered as a major information model for the representation of 3D urban objects. On the basis of our initial investigations we estimate that the following enrichments of the CityGML model are needed:

- Specific classes and/or attributes that will support the fire simulation algorithm like behaviours of specific type of floors.
- Enhanced material properties to be used as visualisation clues to adapt the representation to the user profile.

Future work will concentrate on developing of the semantic models and integrating them in the Semantic Layer of Virtual Reality Simulator.

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