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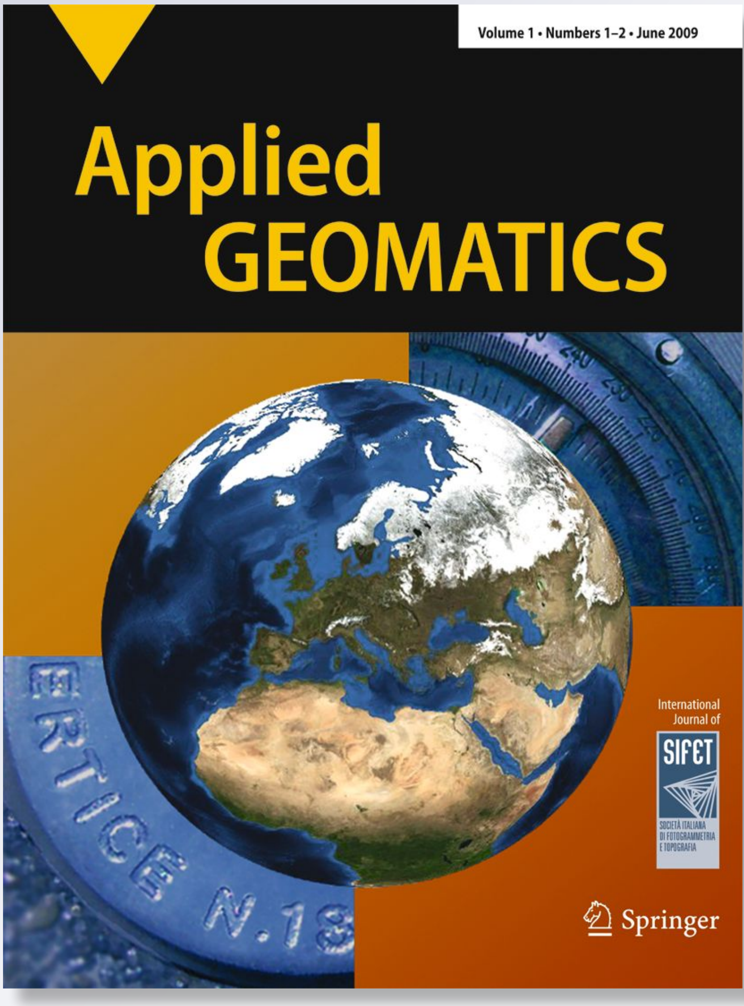

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ORIGINAL PAPER

Benefit of the integration of semantic 3D models in a fire-fighting VR simulator

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Abstract Virtual reality (VR) simulators have become a great tool for training purposes, especially for risky and uncertain situations such as today's widely extended driving or flying simulators. One of these cases is the fire-fighting simulators. The usage of a VR simulator to support the training process of fire fighters and managers has two main advantages. On one hand, it supports the simulation of complex scenarios like big cities, where a fire cannot be simulated in the real world; and on the other hand, fire-fighting VR simulators allow trainees to experience situations as close as possible to real fire events, thereby reducing the probability of accidents when they are going through training exercises with real fire. However, the success of the VR simulator depends on how close to reality the simulation process is, one of the most important aspects to ensure how realistic the scenarios shown in the training sessions are. This paper discusses how existing and dynamic 3D geoinformation can be loaded into a fire-fighting VR system and how the preservation of the semantic knowledge can benefit the user experience in the VR simulator. Semantic technologies are intended to help in the selection of information to get a seamless integration between the GIS data, the VR system and the tasks and users involved in the fire-fighting processes. The benefit of semantics is illustrated with some practical cases.

Keywords Semantics · Virtual reality · Fire fighting · Formalization · Real time · 3D models · CityGML

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Introduction

Virtual reality (VR) simulators for fire-fighting training are appropriate tools for presenting virtual and interactive scenarios, which are impossible to be created in the real world. For example, a fire brigade cannot learn the practical aspects involved in a 12-floor building fire emergency, since the variables involved cannot be recreated 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 VR simulators have been addressed by an array of technical aspects like (1) the graphic quality of the 3D world rendered, (2) their screen resolution, 3) stereoscopic support, and (4) 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.

For the trainees, it is important to practice their skills and tactics in the field under realistic conditions; however, this is nearly impossible in real life, where safety measures avoid these kinds of dangerous and destructive drills. That said, in VR systems, it is possible to have 3D models for existing zones in reality, including forest and urban areas.

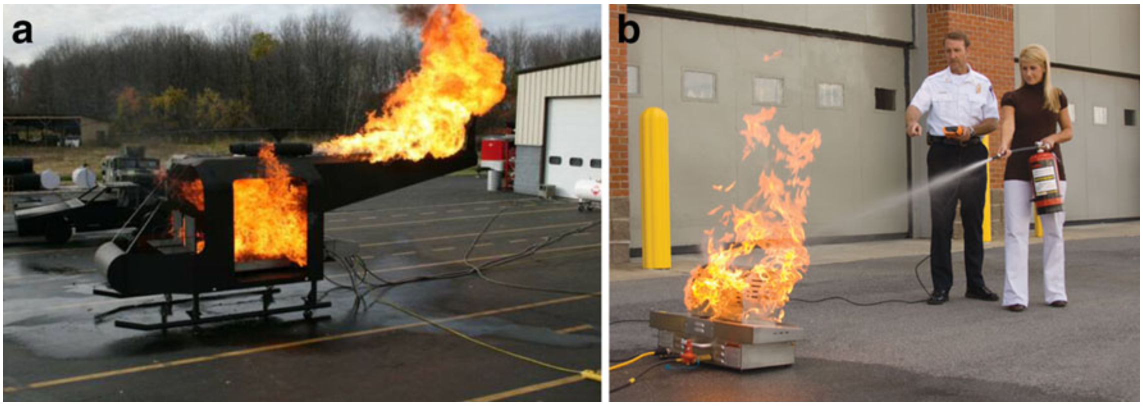

Fig. 1 Helicopter fire-fighting simulator (Kirila Fire 2011) and basic training with fire extinguisher (BullEx 2011)

The utilization of 3D models based on the real world has great advantages for the trainees and fire workers of a given station (Tanaka and Himoto 2006) where a 3D reconstruction of their area would be used to practice and learn different hypothetical situations, so they would be ready when a real emergency arises. Also, when a fire is detected in a given zone, the 2D and 3D data of the affected zone can be combined with real-time information coming from remote sensors. The resulting dataset can be used to plan and decide how available resources would be deployed in the field (Scawthorn 2008), helping in the decision-making process.

However, there are two major challenges in the integration of 2D/3D data into VR simulators: the heterogeneity of data and the different users that need different VR environments. In this paper we argue that data and user heterogeneity can be facilitated by semantic technologies and that this semantic integration can provide more realism and therefore better VR scenarios.

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 (in terms of quantity, quality and resolution of the data) and the terminology of each geographical zone.

The support for this behaviour can be realized also in gaming environment, i.e. by integrating semantics into the VR system, which will provide necessary information for two important processes: the integration of heterogeneous data sources and the adaptation of the simulation environment to the user profile, by filtering and reducing the data to their specific needs. This paper concentrates on the second aspect: retrieval of data.

The next section of this paper will present the main characteristics of the fire-fighting virtual simulator, including a comprehensive analysis of the data it requires to create the VR environment. Then, a brief description of semantic concepts is introduced, linked to the tasks and users involved in the fire-fighting process.

The main section of this work will elaborate on some preliminary analysis about the benefit of the utilization of semantic technologies in the fire-fighting virtual simulator. Initial implementations are shown in the corresponding section to help to understand the possibilities of the semantic enhancement of VR simulations. Finally, a brief summary of the mutual benefit between virtual simulations and semantics are described, followed by some key elements to be address in the future.

Fire-fighting simulator capabilities

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

The presented simulation system is oriented to fire-fighting procedures in forest and urban areas. Some approximated algorithms of the fire spread have been modelled and developed (Moreno et al. 2011), as real-time restriction limits the complexity of the methods (since the fire fighters and managers interact with the fire); therefore, we cannot use the very-well known and accurate fire-spread algorithms existing in the bibliography (Rothermel 1972, Finney 1998).

The fire-spread simulations take static data as input, and in runtime and iteratively, dynamic data is continuously generated or updated by the simulation itself (state of the fire spread) or by external modules (weather conditions; see Fig. 2). The most important static 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 model (DEM), the aerial imagery and the ground classification (land use), given by disjoint zones and normally coming from GIS systems (Dumond 2008). Although detailed information would be great, at least a rough classification

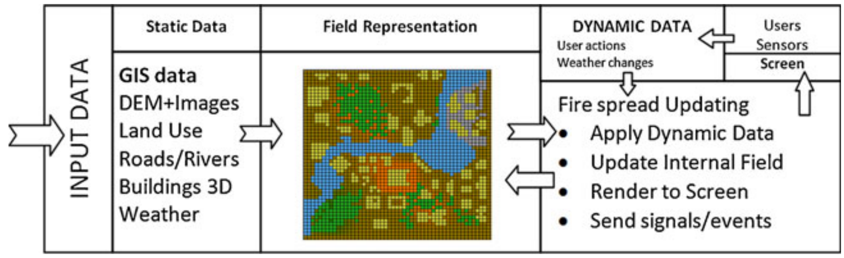

Fig. 2 Modular representation and data flow of fire-fighting simulator

based on water bodies (including sea, lakes and rivers), roads, urban areas and forest areas is required.

Other relevant data includes natural or artificial barriers (normally firewalls are not represented as roads); water piping system and the hydrants networks (in urban areas) and all the available information about the structure and composition of the buildings. The dynamic information is normally linked to the internal state of the simulator, and it represents all the variables calculated in runtime like the "fire power", i.e., the amount of fire at a given point; the amount of remaining fuel, since it could be partially burnt; or the remaining active extinguisher, thrown by a fire fighter during his virtual training.

The weather conditions are considered as dynamic data too, although the information comes from external modules. The weather conditions vary along the simulation time or can be changed manually by the training manager during the session.

Fire simulation in forests (wild land areas)

The available input information is then pre-processed and sampled into the internal field representation (Fig. 3a), based on a grid of autonomous cells, each of them containing geometrical information such as position, dimensions, elevation and slopes (Weise and Biging 1996). Some additional information related to the fire-spreading algorithms is also stored in each cell of the terrain, including the type of the cell, the amount of initial fuel and the burning rate, depending on its type, associated to the terrain typology and the existing fuel in each cell (Moreno et al. 2011).

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 (Weise and Biging 1996), as they modify the fire behaviour in a sensible way. The implementation of the radiation effect simulates how the fires spread across a barrier (river, road, firewall) if the wind conditions are favourable (Fig. 3b).

Fire simulation in buildings (urban areas)

The simulator also deals with urban fires, so the fire-spread algorithm includes the "building" concept, with the addition

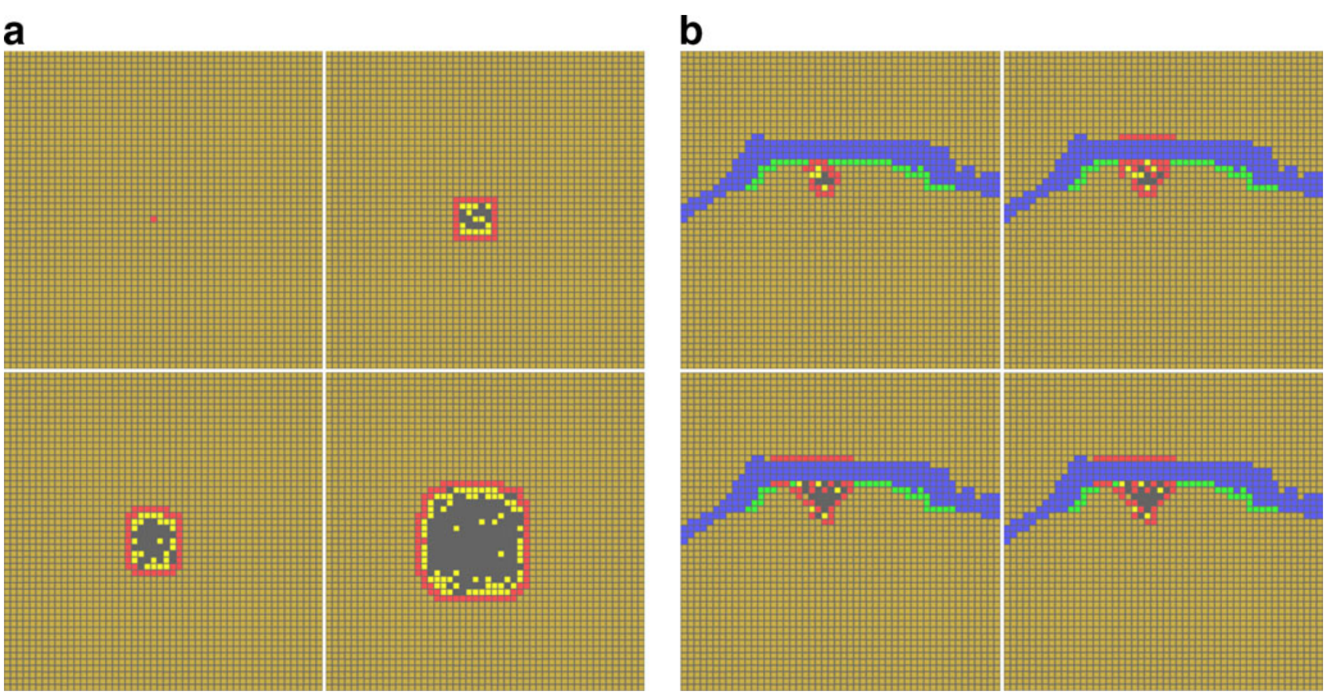

Fig. 3 The field is represented as a matrix of cells. **a** The fire spread in a flat terrain with no wind, so the achieved shape resembles a perfect circle. **b** How a fire can spread across a river in favorable flat terrain wind conditions

of the corresponding classifications and spreading rules (Breton and Duthen 2008). The urban fire algorithm is an extension of the one for forest areas, and essentially, the algorithm works in the same way. A building is sampled into squared cells, with each cell considered to be room of the building. The building type and the number of floors are key elements that are stored as information in the building data. For the building types, following the classification introduced by (Iwami et al. 2004; Fig. 4), we consider three main types: secure unit, wooden unit and shanty unit. The secure unit is harder to burn, and its final state is not destructive, while the wooden unit and shanty unit are linked to destructive fires, where the building burns totally and collapses. The wooden unit and shanty unit burns using different schemas, with a violent flashover in wooden units.

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 fires (Moreno et al. (2011)). Fire spread in the same floor is the most probable method of fire spread in building (Fig. 5a). However, the fire spread in buildings with several floors should be considered as 3D behaviour, as the fire tends to go upwards and less likely, downwards (Fig. 5b). Also, the radiation effect is stronger in higher floors, increasing the probability of the fire to be spread to the near buildings if the wind conditions are favourable (Fig. 5c). The fire-spread implementation for the urban areas is not independent from the algorithm in forest or wild land areas—a fire can spread from buildings to the surrounding area or vice versa (Fig. 5d).

Situation related to geo-information heterogeneity

As sketched previously, the creation of the internal representation of the field requires a diversity of input data (left side of Fig. 2). For any given region, a low resolution of the terrain is always available thanks to the data retrieved by the Shuttle Radar Topography Mission or the ASTER satellite. Despite this, national, regional and/or local authorities of the targeted region may possess updated and higher-resolution data for the DEM, normally including highly detailed aerial imagery. With this amount of data, a georeferenced 3D reconstruction of the region can be obtained, and hence, each

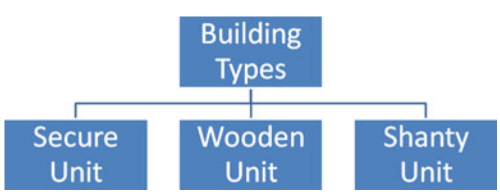

Fig. 4 Different types of buildings considered in the simulator (Iwami et al. 2004)

autonomous cell in the field will have access to its own elevation and the slopes with the neighbouring cells.

However, just 3D cartographic information of the region is not enough for the fire-fighting simulator. The land-use classification and the road network (including firewalls in mountains, which sometimes are not classified as proper roads or paths) should be obtained from GIS servers, possibly linked to administrative authorities such as the land-use classification maintained in the CORINE Land Cover dataset.

Going into further detailed GIS information, the land use could be complemented with information about the forest composition (trees, density, age, etc.) or the information about the buildings in urban areas (construction year, materials, dangerous facilities, etc.). Additional information for the fire-fighting scenario is also required to increase the realism of the results such as proper classification and location of the water resources in the considered region. The GIS can also provide detailed technical information about the hydrants in urban areas including water capacity, available pressure and maintenance information (fully functional or not).

OpenStreetMap provides free geographic data, contributed by anonymous internet users. Although focused on traditional GIS data (streets, roads, buildings), there are a number of proposed extensions including some related to emergencies, like ambulance stations, fire stations, water tanks, fire hydrants or emergency phones. In (OpenFireMap 2011), a preliminary prototype has been developed to show the location and metadata of fire stations and fire hydrants in Nuremberg (Germany; Fig. 6a). Similarly, in (DC Water 2011), a daily updated KML file (Google Earth) is published with the location and maintenance status of the fire hydrants in Washington, DC (Fig. 6b).

In summary, the fire-fighting simulator must deal with a high degree of heterogeneity of data, due to multiple data sources, different qualities, file formats and possibly, coordinate systems. There are European initiatives, like INSPIRE (2007), which try to improve the interoperability of information systems in Europe; as a currently ongoing work, it will take some time to be widely spread across Europe. Although one of the main problems is the lack of data or the difficulties to access to them (summary in Table 1), sometimes the excess of data is a major problem, due to the need to select or filter the information depending on the user role in the simulation.

From a conceptual point of view, the heterogeneity of the data can trigger a sensible loss of semantics, where the same concept is referrenced using different representations or different identifiers, leading to conflicts in the data. The utilization of traditional file formats oriented to geometry representations for visualization purposes includes a dramatic loss of semantics, reducing all available information to

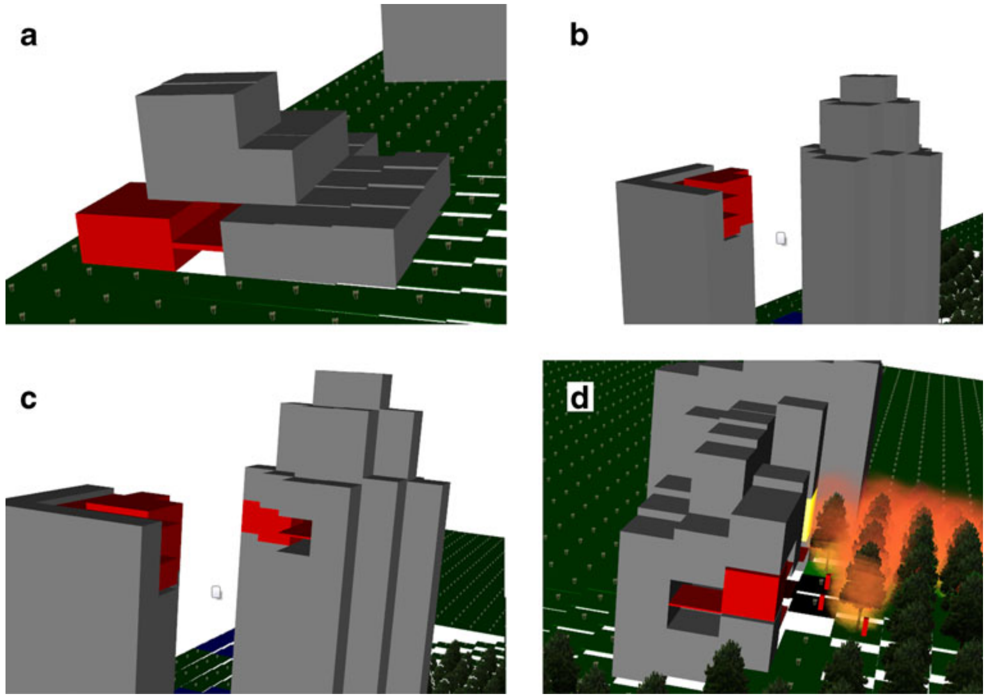

Fig. 5 Urban fire examples where the active fire spots have been marked with *circles* to make them distinguishable from the rest of the scene: **a** The urban fire can spread to adjacent floors, **b** upwards and downwards, **c** to neighbouring buildings and **d** to the surrounding terrain

geometric objects with no semantic distinction between a bunch of triangles representing a tree or a building. Ling et al. (2009) introduced a conceptual definition and a preliminary implementation of a middle-ware layer to deal with heterogeneous GIS data, given in a number of distinct file formats. However, the semantic preservation is not really guarantied, as only a data conversion method between file formats is considered. Thus, one of the major issues to be addresses for a scalable fire-fighting simulator is how the input data can be retrieved by the application, preserving the intrinsic semantics of the data.

Semantics and its use

In the domain of geographic Information, the word "semantics" has been used frequently to refer to the improvement of the information system by explicating more information, but with different interpretations of what semantics are in an information system (Kuhn 2005). The remainder 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

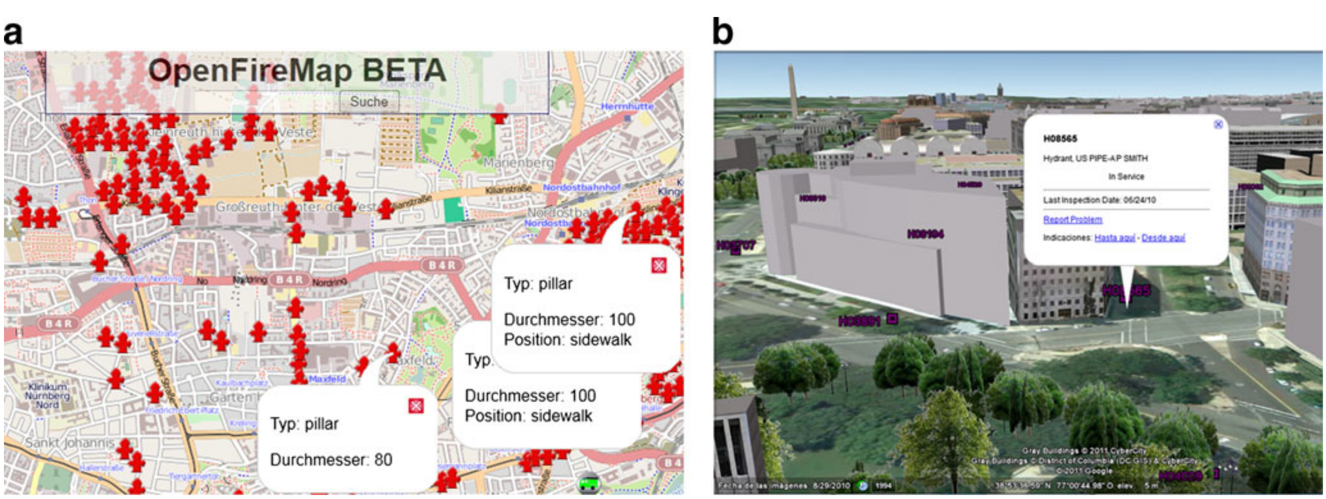

Fig. 6 (OpenFireMap 2011) shows the location of fire stations and fire hydrants in Nuremberg (Germany) using the OpenStreetMap database. DC Water (2011) provides a KML file with the fire hydrants location and operating status

Table 1 Summary of the some possible information providers for the VR fire-fighting simulator, adding some details about the data source

GIS data	Data sources	Details
Cartography	SRTM/ASTER	Low resolution
Regional aerial scans		High resolution: local
Imagery	–	False colour: height
	Regional aerial Imagery	High resolution in regions
Land Use	CORINE (Europe)	Highly detailed
Roads	OpenStreetMap	Collaborative community
	Commercial products: GPS	Highly detailed, updated
Buildings and 3D models	2D footprint extrusion	From land use type
	Scattered 3D city models	Some CityGML cities
Fire Hydrants	Subset in OSM	Some official websites
Firewall in mountains	Asking local authorities	Sometimes no digital info

related to the thematic properties of features and their attributes such as the 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 meaning and properties*. Several models and file formats, including VRML/X3D oriented to visualization of low-level primitives, or BIM (BIMS 2006) and CityGML models (Kolbe et al. 2005, CityGML Web 2011) with higher level of abstraction can be enhanced in this way.

BIMs are semantically rich, detailed models of buildings and other manmade constructions and can be used to enhance the types of rooms and buildings in the simulator. In the case of CityGML, the semantics can be used to denote properties different from spatial ones. We propose to integrate semantic elements relevant to disaster management and link them to the 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.

As stated before, BIM and CityGML are suitable file formats and representations with a high level of semantics, with explicit elements related to wild land and urban areas, and, thus, they can be used as part of the semantic approach to solve part of the heterogeneity problems in the input data. Another important use of semantics is the selection of data with respect to the context of the user. One way to achieve this objective is through the formalization of procedures, tasks and processes, where a clear relationship between objects, data and users can be defined and analysed (Fan and Zlatanova 2011).

Formalization of the fire-fighting process

The best way to formalization is studying and investigating the existing emergency response procedures. Local and national governments and the international organizations have legislations that prescribe workflows and procedures 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 primary interest when performing a certain tasks (Zlatanova 2008). 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).

In case of fire, the following actors can be distinguished (Fig. 8): CallCentre, FBleader (of one fire engine), OfficerDuty and ROT. The most important identified tasks for providing/recording information are RegisterInsident, FightFire, Report, OperationalLead and TacticalLead. 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 a team. The officer on duty performs the overall operational lead on the field. 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.

The information needed for the involved processes is as follows: The operator in the call centre, FBleader and teams and the officer on duty need large-scale topographic maps (e.g. Topo1000, scale 1:1000). ROT (located in a command centre outside the dangerous area) needs small-scale map (e.g. 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 in the preceding 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 also be adapted to the goal of each specific training, e.g. for training of fire fighters in the field or for operational and tactical training of ROT.

Solving data and user heterogeneity through semantics

The inherent heterogeneity of the data and users shown can be addressed using a combination of semantic technologies. The data, composed of the maps and the geoinformation must be matched into a single architecture or knowledge base. Marchese et al. (2008) presented some guidelines to solve semantic matching in heterogeneous data sources in the emergency response domain. Their work included the description of the necessary knowledge model, their relationships and the matching of the conceptual schemas.

Stoimenov et al. (2005) developed a solution based on ontologies to deal with heterogeneous data sources in the Emergency Response field. The solution relies in the Geo-Nis interoperability platform to integrate the system. For simplicity purposes, it is common to enclose all the semantic entities and relationship used to solve the heterogeneity in an independent layer (Stanimirovic et al. 2009). Their conceptualization of the semantic layer is located between the individual geoinformation communities and the data users, as the users are the ultimate consumers of the data.

In the case of VR simulations, we conceive this semantic middleware as a connector between the VR system and the data and users (Fig. 7). In this schema, the users and roles are modelled following the formalization of the fire-fighting processes and tasks, so they act as another data input to the VR simulator. As it has been addressed in the previous section, the formalization of the fire-fighting process triggers the categorization and representation of different entities, processes, tasks, subtasks and roles. A modification in the user roles, for example, due to changes at the organizational level, would modify the conceptualization of the entities in the semantic layer to allow the new user definition. Therefore, all the relevant information, composed by the GIS information, the user categorization and all terms and concepts of the emergency response procedures is stored and conceptualized in a set of ontologies within this "semantic layer", where the available reasoning methods will produce direct input connectivity with the VR simulator.

The processes and tasks shown in Fig. 8 are the result of the formalization of the emergency response procedures related to the fire-fighting process, while the user categorization is addressed by the existing roles in the processes and tasks. All this information plus all the relevant GIS data 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, but its selection is triggered by decisions made between the semantic layer and the GIS data.

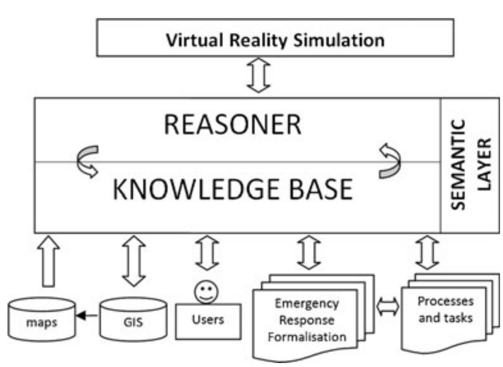

Fig. 7 The semantic layer manages the different kind of information that will be loaded into the VR simulation

Utilization of semantics improves user experience

The utilization of semantic technologies is a key element to increase the realism of the user experience. The fire-fighting simulator, presented previously, can benefit of an integration of the semantic knowledge embedded in the fire-fighting process.

Once the semantically enhanced data sources are loaded into the system, lot of queries can be performed in runtime. The queries related to geometrical issues, such as Euclidean distances, areas, volumes and visibility testing are easily answered even if only pure geometric data is present. More specific geo-functions like distances in urban areas, path finding using highways or retrieving the number of wooden buildings and their construction years in a given zone determined by GPS coordinates are also rather easily answered, but more semantic geo-information is required.

A quite typical concern when a fire emergency is detected is to determine how and where to deploy the fire trucks, which involves the utilization of route-finding algorithms, while including restrictions like forbidden areas (they could be on fire), closed roads, traffic jams or low visibility zones (smoke). The result of this algorithm will be the most suitable route to reach the affected zone, trying to avoid unnecessary risks and supplying the estimated arrival time. The solution can be presented to the users as an annotated path in a 2D map, a formatted text with step-by-step development (ready to be printed), or as a downloadable route for the fire truck GPS system, depending on the role of the users (manager or fire truck driver).

The deployment of the human and technical resources could be triggered or enhanced semantically. If there is available information about the water pipes, hydrants and pressure conditions in the affected zone (due to static data or via installed remote sensors), the selection of appropriate fire trucks, fire workers and their equipment will be better, reducing the probability of mistakes in such material selection tasks.

However, these described scenarios do not rely specifically on the VR system as they can be independent and non-VR related applications (text-based or web applications). In the following section, some initial implementation will be discussed, which demonstrates how VR simulations can benefit from semantic technologies. 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. For each use case, the benefit to the VR system will be described as a comparison of how the same results could be obtained without the semantic information available through the semantic Layer.

The first use case shows how relevant information can be highlighted for the users during a training session. The user

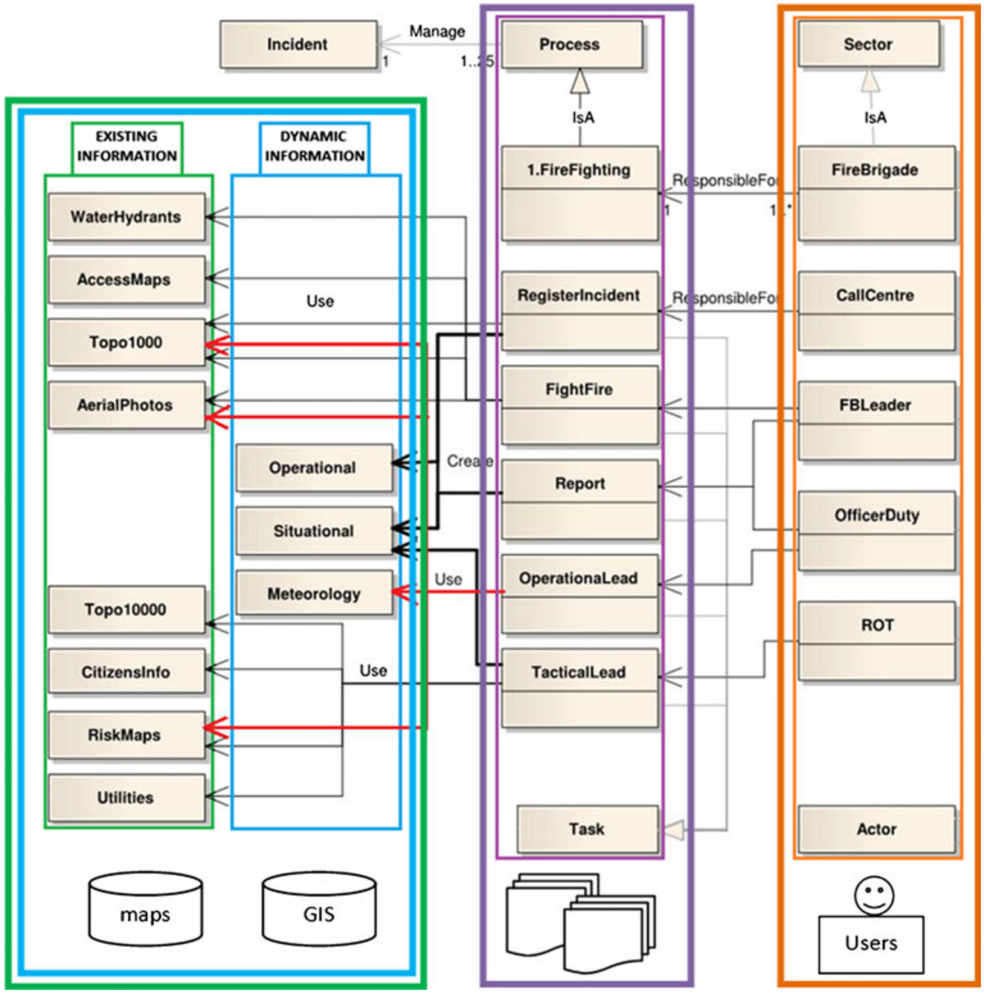

Fig. 8 The semantic categorization matches all the UML entities into the VR system

experience becomes enhanced by the seamless integration of the underlying and heterogeneous geo-information and the VR entities, allowing unique and non-ambiguous visual identification of graphical objects. In the second use case, we present how the user experience can also benefit from such integration by exploiting the user profile, history and preferences to adapt 2D/3D GUI following semantic approaches.

Usage case 3 addresses the ability of the semantic interoperability to deal with the adaptation of the available geo-information to the users, especially in urban areas, where CityGML and BIM are considered a reference conceptual model for the representation of 3D urban objects. The ability of handling multiple“ levels of details” is important, as users require different data resolutions depending on their roles (Dumond (2008)).

Usage 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 middleware 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.

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. 9a). The semantic layer provides the specific floor (and building) to highlight to the VR system. The semantic highlighting takes advantages of the applied identifiers to the VR objects, allowing the llinkage of a given object via a descriptor.

The semantic highlighting can also be used to provide visual clues to the fire truck drivers about the route from the fire station to the fire, like in GPS navigation devices. In this case, the virtual representation of the route could incorporate real-time information about the evolution of the fire, the traffic state or any other relevant information in a virtual head-up display.

The semantic queries can be triggered by the users as a result of a clicking action on the graphical viewport. The VR system converts this 2D click on the window into a 3D ray intersection, checking the objects it finds in its way. In a non-semantic VR system, this procedure returns the object ID of

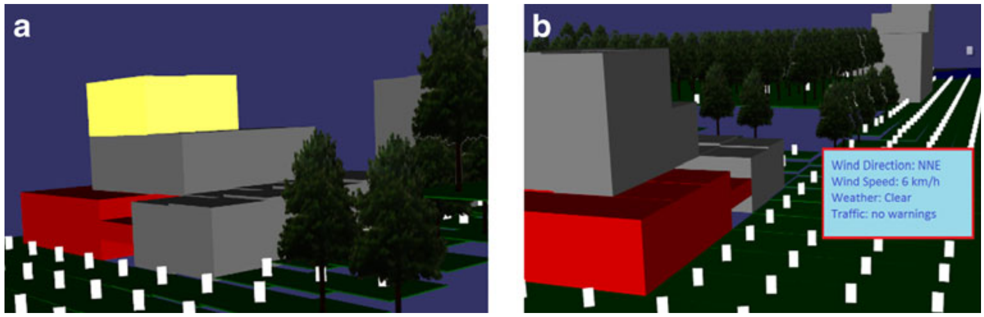

Fig. 9 Usage case 1. **a** Burning buildings (floors) have been highlighted in *red*, and the target floor in *yellow*. **b** Additional on-screen information is displayed, in this case, related to weather and traffic conditions

the currently displayed objects, which will not necessarily identify it is a building, a road or any other rich object. If the semantics of the virtual scene are preserved, the correct global identifier of the object will be retrieved, allowing further queries about its properties and relationships.

Usage case 2: enhance graphical interfaces using user roles

The user interfaces are 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. However, even in the same group of users with the same role, different people would require specific and personal modifications of the interface. Typical user interfaces or GUIs follows the WIMP interaction style, with Windows, Icons, Menus and Pointer devices. By contrast, the most typical user interface method for immersive VR simulations, known as head-up display (HUD), is based on adding virtual information on the foreground of the graphic output. Generally speaking, both GUI and HUD are basically non-configurable. So, if a user is left-handed, the GUI (menus, toolbars, toolboxes, etc.) and mouse interaction schemas cannot be adapted to improve the user experience. In the latest GUI toolkits, the addition of mobile panels allows a personalized customization of the GUI. In commercial games, the design of HUDs is normally focused on finding the best way to show information to the user but, without breaking the artistic integration between the HUD and the graphics coming from the game engine.

Recently, the games where a first or third person viewpoint is used are adding more customizable options, like the configuration of the avatar of the player. The users can select and edit multiple details, like gender, different colours for skin, hair, eyes, or the outfit. Sometimes, the users experience is better if the avatar height is similar to their own height.

Even if these customizations can be performed only with the information stored in the user profile, the user interface should be adapted or reconfigured using also the user role. For a semantically enhanced user experience, the key element is the user role, which triggers different kind of visualization modes and different data retrieval methodologies. The semantic layer will have access to the user profile as well as all the relevant information about the ongoing task, including the role; the role of a user is not unique as a user could have multiple roles in an emergency response process (see Fig. 10).

The semantic utilization of the user role to adapt traditional tools has been researched extensively by Toro et al. (2006) for virtual engineering applications, like CAD editors. Those

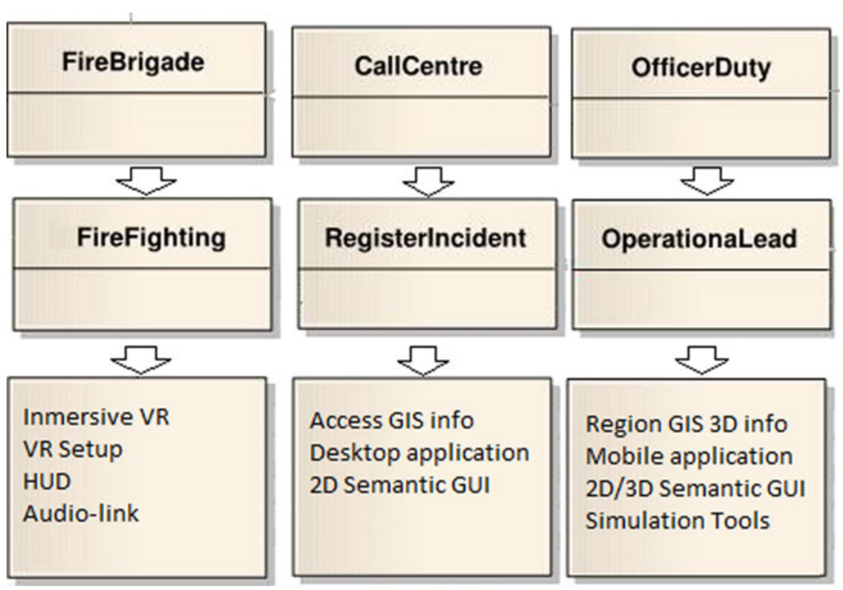

Fig. 10 Different GUI and HUD requirement for a selection of some user roles and an active task

semantic technologies can be extended to fire-fighting simulation systems, where GUIs and HUDs would be enhanced by the semantic technologies. The GUI layout and tool composition will be semantically adapted for a left-handed fire manager or for a fire brigade chief with a small screen size.

In immersive training sessions, the HUD presented to the trainees would take into account their roles and the specific tasks they are training, thereby personalising the displayed visual information. The HUD for a fire worker with a hose in front of a fire will provide information about the water pressure, the wind conditions and live audio with the officer to receive proper instructions. In a similar way, the officers in the field will have an adapted HUD or GUI for their task. A list of their assigned fire workers will be presented, but also a mini-map of the zone will be displayed, with a very basic representation of the field with 2D information mapped on it.

Usage 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 it is preferable to use simplified models or impostors of the data to increase understanding of the information and the final usability of the applications.

Traditional VR technologies provide a unique virtual representation of the scenarios and their objects. Even if multi-resolution objects or terrains are rendered, their ultimate goal is to get a better efficiency in the visualization, i.e., better frame rate in the simulation.

In the fire-fighting process, the field agents and managers in the control centre have different needs regarding data resolutions. On one hand, field agents using immersive simulators, will require highly detailed representations of their surroundings, rendering buildings and fire as realistic as possible. On 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. 11a).

The proposed behaviour requires replacing virtual elements depending on the user role and needs, with the Semantic Layerhaving the responsible to tell to the VR simulator this kind of information, instead of hardcoding the VR element replacements in the simulator. CityGML model supports a set of well-specified levels of detail (LoD), allowing the selection of different resolutions according to the needs of the users. 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. 11b). The semantic layer is responsible of triggering the algorithms to get the information from the users, decide which data should be collected from the maps and GIS distributed repositories and finally, adapt the information to be rendered or used in the VR application.

Conclusions and future work

Semantic technologies can be used to preserve semantics during the data acquisition process in VR systems, even if the input data comes from multiple and heterogeneous data sources. The fire-fighting process, as a subset of the emergency response management, requires a large amount of formalization related to the involved users, processes and tasks. Thus, to assure the inter-operability of data and users, the implementation of a semantic layer has to take into account the specific knowledge restrictions imposed by the legal regulations.

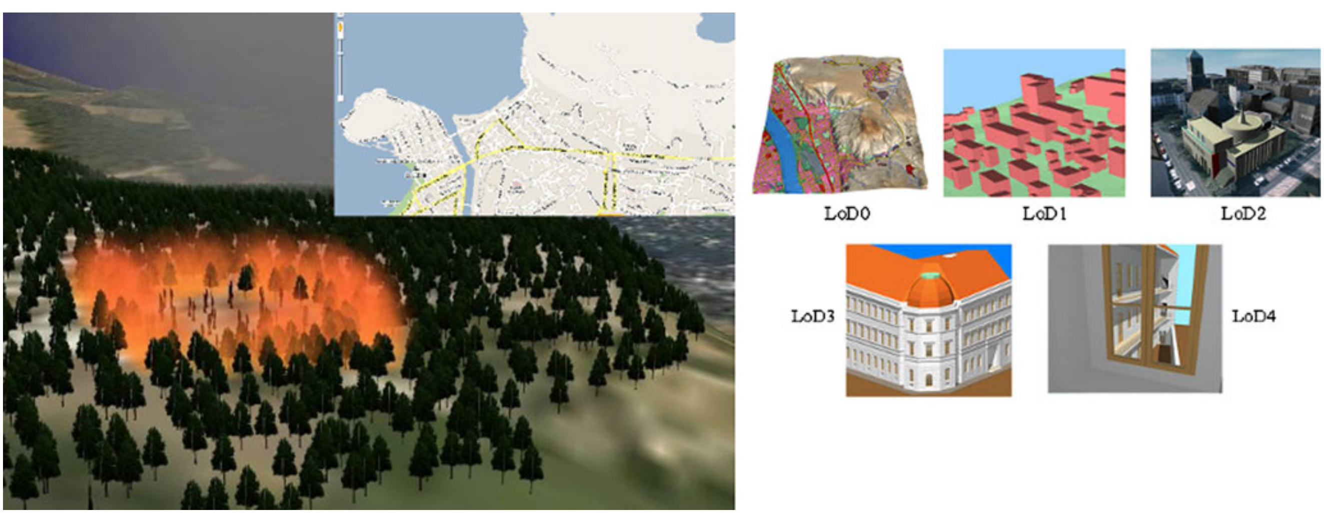

Fig. 11 Usage case 3: **a** Different resolution and types maps are used in the simulator. **b** The different LoD that CityGML proposes in the specification (CityGML Wiki 2011)

This paper has presented some initial research about the benefit of the integration of semantic technologies into a fire-fighting VR simulator. A conceptual semantic layer provides a solution for two main problems: the heterogeneity of the geo-information and the data filtering and adaptation to the user roles.

The implementation of the semantic layer can be based on previous research works, but an adaptation of generic architectures and software platforms should be done to fit the fire-fighting domain. A preliminary custom implementation of the semantic layer has been started, and its development will continue in the future. As shown in this paper, the integration of the semantic layer in the fire-fighting VR simulator enhances the user experience in several ways. Some preliminary and basic usage cases have been selected to show the potential uses of such integration. For each usage case, we have presented how the semantic knowledge is exploited to achieve innovative results, compared to the same scenario following a non-semantic approach.

Further research will focus on the modular decomposition of the semantic layer, including the algorithms involved in each of the major issues addressed in this work: heterogeneity of the data and the filtering or adaptation of the data to the user profile. The utilization of CityGML for storing intermediate states of the fire-fighting simulator, i.e., using CityGML as an output file format, will be considered as another research line. The extension mechanism of CityGML could be used to try storing the internal representation of the field and the dynamic values of the fire spread algorithm.

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References

BIM (2006) National BIM Standard Purpose, US National Institute of Building Sciences Facilities Information Council, BIM Committee. Retrieved from: http://www.buildingsmartalliance.org/client/assets/files/bsa/nbimspurpose.pdf. Accessed 31 August 2011

Breton T, Duthen Y (2008) Les simulations de propagation de feu en milieu urbain. hal-00287987, version 1 - 13 Jun 2008, Technical Report from Institut National Polytechnique de Toulousse (INPT). http://hal.archives-ouvertes.fr/hal-00287987/. Accessed 7 September 2012

Bullex Safety (2011) Bullex digital safety fire training programs. http://www.bullexsafety.com. Accessed 31 August 2011

CityGML(2011) Collaborative wiki with all relevant links and tools. http://www.citygmlwiki.org. Accessed 31 August 2011

CityGML(2011) Exchange and storage of virtual 3D city models http://www.citygml.org/. Accessed 31 August 2011

DC Water (2011) District of Columbia water and sewer authority. http://www.dcwater.com/hydrants/status.cfm. Accessed 31 August 2011

Dumond Y (2008) Forest fire growth modelling with geographical information fusion. 11th International Conference on Information Fusion. June 30–July 3, 2008, Cologne, Germany, pp 1–6

European Directive (2007) Directive 2007/2/EC of the European Parliament and of the council of 1 March 2007 establishing an infrastructure for spatial information in the European community (inspire). European Commission, Brussels

Fan Z, Zlatanova S (2011) Exploring ontologies for semantic interoperability of data in emergency response. Appl Geomatics 3(2):109–122

Finney M (1998) FARSITE: fire area simulator-model development and evaluation. Res Pap RMRS-RP-4, vol 1. USDA Forest Service, Rocky Mountain Research Station, Ogden, UT, 47 pp

Iwami T, Ohmiya Y, Hayashi Y, Kagiya K, Takahashi W, Naruse T (2004) Simulation of city fire. Fire Sci Technol 23(2):132–140

Kirila Fire (2011) Kirila Fire training facilities. http://www.kirilafire.info. Accessed 31 August 2011

Kolbe T, Grger G, Plmer L (2005) CityGML interoperable access to 3D city models. In: Oosterom ZSFF P (ed) Proceedings of the International Symposium on Geo-information for Disaster Management, Springer, Heidelberg

Kuhn W (2005) Geospatial semantics: why, of what, and how? J Data Semant Spec Issue Semant-Based Geogr Inf Syst 534:1–24

Ling Y, Zhou F, Wang X, Yang B (2009) Integration of heterogeneous geospatial data based on middleware technology. WASE Int Conf Inf Eng 2:314–317

Marchese M, Vaccari L, Shvaiko P, Pane J (2008) An application of approximate ontology matching in eResponse. In: Proceedings 5th International Conference on Information Systems for Crisis Response and Management (ISCRAM), Washington DC, USA, May 4–7 2008, pp 294–304

Moreno A, Segura A, Korchi A, Posada J, Otaegui O (2011) Interactive urban and forest fire simulation with extinguishment support. In: Advances in 3D geo information sciences, Lecture notes in geoinformation and cartography, Springer, Heidelberg, pp 131–148

OpenFireMap (2011) Using OpenStreetMap to show the location of fire stations and fire hydrant in Nuremberg. http://toolserver.org/~ti/ofm2/. Accessed 31 August 2011

Rothermel R (1972) A mathematical model for predicting fire spread in wildland fuel. Tech. Rep., USDA, Washington, DC

Scawthorn C (2008) Fire following earthquake, supplemental study for the shakeout scenario: the shakeout scenario. US Geological Survey and California Geological Survey, Pasadena, Tech. Rep., US Geol Surv Open File Rep 2008–1150, California Geological Survey Preliminary Report 2 version 1.0, US Geological Surv Circu 1324, California Geological Survey Special Report 207 version 1.0

Stanimirovic A, Bogdanovic M, Stoimenov L (2009) Data access layer generation for interoperable GIS environments. In: Proceedings of the 12th AGILE International Conference on GI Science, Hannover, Germany, June 2009

Stoimenov L, Predic B, Mihajlovic V, Stankovic M (2005) GIS interoperability platform for emergency management in local community environment. In: Proceedings of 8th AGILE Conference on GIScience, Estoril, Portugal, May 2005

Tanaka T, Himoto K (2006) Physics-based model of urban fire spread and mitigation of post-earthquake fire risk in historic cities. Abstr Ann Disaster Prev Res Inst Kyoto Univ (CD-ROM) 49:1–5

Toro C, Posada J, Termenón M, Oyarzun J, Falcón J, Gabrys B, Howlett R, Jain L (2006) Knowledge based tools to support the structural design process. Lect Notes Comput Sci 4251(679):686

Weise DR, Biging GS (1996) Effects of wind velocity and slope on flame properties. Can J For Res 26:1849–1858

Zlatanova S (2008) Sii for emergency response: the 3rd challenges. In: ISPRS Archives, the XXI ISPRS Congress, Part B4-TYC IV, Beijing, July 2008, pp 1631–1637