3D TECHNOLOGY FOR IMPROVING DISASTER MANAGEMENT: GEO-DBMS AND POSITIONING

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ABSTRACT:

An increasing number of disasters (natural and man-made) with a large number of victims and significant social and economical losses are observed in the last years. Although particular events can always be attributed to fate, it is improving the disaster management that have to contribute to decreasing damages and ensuring proper care for citizens in affected areas. Some of the lessons learned in the last several years give clear indications that the availability, management and presentation of geo-information play a critical role in disaster management.

The paper discusses requirements for a system supporting 'urban and urgent' disaster management. The aim of the system is to support facilitate the work of police forces, fire departments, ambulances and government coordinators in disaster situations. The (geo) information provision addresses important aspects such as data discovery (finding the needed information based on a user location and user profile defined on the-fly), data preparation (in a form appropriate for the requesting front-end) and data export (considering the state-of-the-art in standardisation).

The focus of the paper is on the required developments at a database level (or middleware) to be able to provide context-aware solutions assuming positioning (to determine the location part of the context) and communication (to exchange the context-aware information). Three important aspects are addressed: a) Integrated management of multimedia information (graphics, text, video, raster), b) Ontology and semantic translators, c) 3D positioning to cope with emergency situations.

1. INTRODUCTION

The terrorist attacks in the US and Spain, summer floods of 2002, fires and earthquakes of 2003 in Europe have tragically demonstrated, the whole disaster management sector needs extended and more sophisticated means for facing man-made, natural and industrial risks. This issue gains a high priority in the political agenda in many governments in Europe. New systems have to be developed that allow different service units to operate together (to understand each other) in any critical situation. The cooperation across different sectors, involved in disaster management such as the Health Sector, Police and Fire Brigade and civil protection, has to be extended beyond their specific services. They have to be open to cooperate, coordinate and understand other organisations and the information they may provide. The final goal is limiting the number of casualties by a) facilitating the work of the emergency services, making it safer and more efficient, and b) ensuring citizens (in the area of disaster and outside it) will receive high-quality care, on-time information and instructions.

Amongst all, geo-information is becoming a key issue in the achievement of these goals. Geo-information collections consisting of maps, images, plans and variety of schema's are already widely used in many of the Disaster Management Phases, e.g. Mitigation, Preparedness, Recovery (Zlatanova and Holweg 2004). The use of geo-information in the urgent (time-critical) Response phase is still limited. Several major problems can be considered:

- Most of the information available is designed, stored, and managed by organisations that normally have distinct authorizations. In normal circumstances these organisations operate independently of each other. They are only partly designed to work in a multidisciplinary environment, and their systems reflect this status with known limitations to their interoperability.
- Geo-data is managed by different systems (CAD, GIS, DBMS) in specific details, resolutions, object definition, schemas and formats. Exchange of data is based on creating a copy of data sets in a specific format that is readable by the systems of the other party. Preparations of such files may require days and storage space of several hundreds megabytes. This manner of work is definitely not appropriate for dealing with emergency situations.

The experience suggests that the real barriers are not lack of data or insufficient technical capabilities. The current development of Geo-Information Infrastructures (GII's) at several levels (national NCGI, European INSPIRE, etc.) based on open standards (OpenGIS, ISO TC211, OMG, W3C) further improves this situation. The bottlenecks are in most cases related to the 'information' about the information, i.e. finding the most appropriate data and making data available. The lack of interoperability, due to the explosion of many standards and developments, delays systems to be connected and updated without massive investments (often unaffordable for organisations). This results into a partial automation capable of dealing dedicated tasks but unable to deliver intelligence to multi-user groups.

This paper addresses the developments in geo-DBMS (with focus on the 3D and semantic aspects) to support Response phase in disaster management. Since providing appropriate information in the Response phase is highly related to the location of the rescue teams and/or citizens on the field, current and future possibilities for 3D positioning are discussed in detail. The paper concludes with important directions for research and development

2. THE USERS AND THE SYSTEM

Disaster management is an application that involves a very wide group of users. Figure 1 shows a categorisation of the users according to the environments they are working in (related to their tasks in the emergency operations). Two general categories of users can be distinguished, i.e. teams working in *wireless* environments, on the field (indoor or outdoor) and users working in *wired* environments (indoor) in management centres and related institutions (Zlatanova and Holweg, 2004). The users in wired environments can be subdivided further into users working in *VR* environments (controlling, analysing and managing), *Desktop* environments (advising on particular situations and occasions) and accessing information through the *Web* (wide audience, press, etc.). In the centres for coordination, various pieces of information have to be assembled for decision-making. In the field, the workers need information about the current situation and prognosis for the immediate development in their area. Moreover the field workers can collect information to be returned to the central for analysis and redistribution. These generalised activities impose a variety of requirements such as consistent information in any environment, search, analysis and processing of information on the Internet and distributed databases, real-time data update, routing outdoor working teams, individual and intuitive visualisation on different devices to support decision-taking.

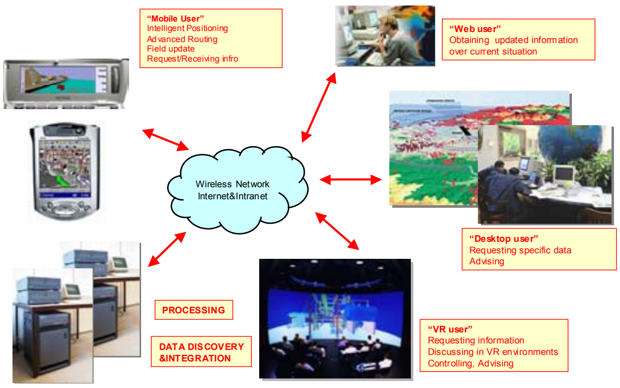

Figure 1: The users in a disaster management situation

3. GEO-DBMS FOR DISASTER MANAGEMENT

Most of the important data and information necessary for the support of such a system are spatially related; a geo-component is of special relevance. Amongst all the systems dealing with geo-information, DBMS are the fundamental componet.

3.1 State of the art in Geo-DBMS

The integrated architecture of storing geometric data and relationships together with administrative data in DBMS's is now getting mature. The importance of the integrated architecture was recognised by the industry and the OpenGIS consortium standardised the basic spatial types and functions (i.e. Simple Feature Specification, SFS) (OGC, 1999). ISO (ISO TC211, 2003) and OpenGIS agreed to harmonize their geo-information standards and specifications. Several commercial DBMSs are available with support for spatial data type: Ingres, Oracle, Informix or IBM DB2. In addition several heavily used non-commercial DBMS have geo-information support: PostgreSQL (with roots more than two decades ago) and MySQL (since the most recent version in 2004). Also more and more originally commercial CAD and GIS packages support the integrated architecture: ESRI, MapInfo, Intergraph or Bentley. Even one of the DBMSs (Oracle Spatial) has started supporting 2D topology in the most recent version (10g). Currently, the main attention is on 2D spatial data types, but 3D geometric objects can be maintained as well. Research on 3D has resulted in defining a 3D geometry data type (Stoter & van Oosterom, 2002, Arens et al., 2003). Recent experiments and benchmarking have clearly shown a significant progress in DBMS's performance (van Oosterom et al., 2002). Loading and querying spatial information is still more elaborate than semantic (attribute) data but the response time is compatible and can be tuned to meet requirements of disaster management where the response time is of critical importance (Zlatanova et al, 2003).

3.2 Current and future developments

Despite the progress shown within DBMSs developments, still a number of generic issues needs to be addressed in order to provide service to multi-risk management:

- Extending the management functionality into the third dimension is a research question of critical importance for fighting crisis situations in urban areas. For example, true three-dimensional data (instead of 2D maps), supplied directly to a fire brigade working in a dense built-up area will increase the possibilities for orientation and reduce time, which significantly improves the effectiveness and safety of rescue teams.
- Developing 3D models and frameworks for management of different topologies at database level and corresponding operations. This will allow extension of the spatial functionality to be able to perform 3D routing, generalisation, and adaptation of different types of data, and consistent field update of data. Some explicit examples of implementations related to mobile environments are map orientation, map generalisation, bounding box, route maps, map styles, and colouring. Some of this functionality can be provided as a generic set of operations at a database level.
- Frameworks for describing multidimensional spatial relationships, structures for maintenance of multiresolution, multidimensional and historic geo-data need further research. Investigating and developing multidimensional and multimedia data models for efficient organisation of large urban models, utilising and elaborating different international specifications including ISO, OpenGIS etc.
- Data update with newly collected data from the field can be very critical for both a) monitoring the disaster event and b) giving instructions to the involved people. From a database point of view, this process requires strict consistency rules for integration with existing models and immediate propagating the information to all the users. In this respect, extended models for maintenance of historic information (to be used also for prognosis and future scenarios) are becoming especially desirable.
- A major issue in disaster management is the presentation of the information. It has to be prepared in the best appropriate form. For example, navigation instructions to the closest exit can be presented as voice, text, simple graphics, animation or even 3D graphics. The time for delivering such formats differs significantly. The system has to be able to understand the context (type device,

emergency of situation, status of the device, etc.) and accordingly prepare the presentation. In this respect at database level, a variety of algorithms have to be developed: for generalisation and compression of graphics and images (with respect of the screen resolution), graphics-to-text (voice) conversion, etc.

- Semantic domain models (ontology based, see section 4) and translators between data from different sources and domains that is reasonable to be implemented at database level (see also next section).
- Preparation for distributed environments (open standards, shared GII within INSPIRE and NGII), which are composed of autonomous and heterogeneous components (based on agreed interface specifications).

3.3 3D data in large scale outdoor/indoor models

One aspect, different in Disaster Management compared to other applications of geo-information, is that the requirements for combined indoor (internal plans of buildings and construction) and outdoor (more traditional geo-information, such as topographic, utility and cadastral data) models. In general these models are large scale (1:500 or larger) and have a true 3D nature. The systems responsible for creating and managing these data sets are often quite different. For example CAD system are used for creating indoor models of buildings and constructions and GIS for outdoor geo-information. However, users in urgent disaster management situations need and expect seamless access to the information.

In order to realize this a number of problems have to be solved (van Oosterom et al., 2004). The first one is bridging the semantic gap between these different worlds (design versus surveying), this is discussed in section 4.2. Once an agreed model (covering aspects of the different world, CAD and GIS) is created, different views on this representation may be defined. The integrated GIS-CAD model is managed in a way that consistency is maintained (during updates or adding new data). The result will be that different applications may be used to perform specialized tasks. This also implies that different users may be working, at the same time, in different environments (or at different locations) with the same model. Similarly for both GIS and CAD worlds a gradual move from file based approaches to DBMS approaches has occurred in situations were the geo-information use has become more structural and by more than a single individual (owning the data).

Data management will benefit from well known advantages of DBMSs: multiple user support, transaction support, security and authorization, (spatial) data clustering and indexing, query optimizing, distributed architectures, support the concept of multiple views, maintaining integrity constraints (especially referential integrity, but also other types). In summary, 'island' automation is abandoned and society wide information management becomes a reality. The DBMS can be considered an implementation platform for an integrated model (with different views). However, when exchanging information (or using services from other sources), the structured exchange of information becomes an important issue. The UML (also see section 4.2) models are both the fundament for the storage data models (further described in the DDLs of the DBMS) and the exchange data models. The eXtensible Markup Language (XML) can be used for the models at class level (XML schema document 'xsd') containing the class descriptions and also for the data at the object instance level ('normal XML document with data 'xml'). XML documents also include the geometric aspect of objects (examples are LandXML, GML, X3D, etc.).

4. DATA INTEGRATION AND KNOWLEDGE DISCOVERY

The integration of multiple systems and databases is a common necessity in large organisations. For disaster management it is becoming a critical issue.

4.1 Problems in data integrations

There are three basic strategies for accessing data from multiple sources: centralization, federation and collaboration (dynamic integration). With centralization, a central data warehouse is created to contain a copy of all or part of the information stored in local database and managed by separate organizations (e.g.: a central database contains the data from Police and Municipality, copied from their respective databases). Frequent updates ensure currency of the central database. Federation strategies privilege access to multiple databases from a central location without need for creating a central database. This strategy is based on communication and connectivity, rather than content centralisation. However, federation assumes an overall model (or schema) of which the different distributed DBMS cover parts of the content. In the third strategy, dynamic collaboration, no such accepted overall (distributed) schema exits. This strategy is based on dynamic data discovery and use of the relevant sources. However, as the sources are heterogeneous 'translation services' (for example in mediators) are required for meaningful coupling and integration of the information in applications. There are pros-and-cons in all three solutions, but experience suggests that federation or dynamic collaboration of content have the largest chances of success.

In a case of emergency, 'mountains' of data (static & dynamic) are available and have to be analysed whether they are useful/necessary for the current scenario or not. Analysing such volumes of data clearly overwhelms the traditional manual methods of data analysis such as spreadsheets, ad-hoc queries and dedicated scripts. These methods can create informative reports from data but cannot analyse the contents of those reports to focus on important knowledge. There is an urgent need for new methods and tools that can intelligently and automatically transform data into information and, furthermore, synthesize knowledge. These methods and tools are the subject of the emerging field of knowledge discovery in databases. There are at least three distinct cases in which information may be lost when communicating between different language groups, and by analogy, between Information Communities:

- In the first case, definitions and concepts are shared but there is no common language between the two groups, or the groups share a common language but use dramatically different dialects. This problem is corrected through simple translation using a bi-directional mapping between the two languages. As long as the languages themselves are stable and there is a 1:1 relationship between relevant terms this mapping solution supports effective communication. For instance, if A and B want to talk about logistics and the overland transportation of goods and A refers to trucking and B knows the large vehicles as lorries, they can agree that the mapping of 'house' = 'building' will be used to communicate this concept.
- In the second, somewhat more abstract case, a stable base of definitions for terms is not shared between the communities. Correcting for this requires a direct mapping

of shared definitions plus a set of interpretations for terms that can't be mapped. Where there is a 1:M mapping of definitions between communities, generalization and a consequent loss of information will occur when mapping multiple, specific definitions to one more general definition.

- Finally, there is the case in which basic concepts are not shared between the communities, i.e., when the two communities have starkly different worldviews. For instance, consider the real world features ‘snow’ and ‘transportation systems’. Suppose one Information Community recognizes only the first, and the second recognizes only the second. Attempting to address the effects of snow on transportation systems would be difficult or impossible in either community.

4.2 Formal semantics

The discussion above clearly shows that an important key solving the discussed problems is capturing the semantics included in the different models. Implicit knowledge or nice pieces of natural text and tables are not sufficient for this purpose. A more formal approach, as developed in disciplines such as knowledge engineering, ontology and object-oriented modelling, is required. Based on this formal semantic approach it becomes possible to decide whether different domain models (or even models within one domain) are or can be harmonized. Also, spatial information handling by machines will become important, which makes the formal approach even more necessary. In the last decade important technology progress has been made in the discipline of knowledge engineering (UML, ontology, semantic web), which enables further knowledge formalization in a practical manner.

At this moment most spatial (both CAD and GIS) information is used relatively direct by humans, in the future also large parts of the information will (first) be processed by machine, especially in time-critical situations of disaster management (before communication again with humans). While a human (familiar within a specific domain) is capable of interpreting different concepts by using implicit context information (which domain is under concern, who did supply/produce the information, etc.), for a machine (or humans not familiar with the specific domain) it will be necessary to make this knowledge explicitly available. A large part of the formal structural knowledge concerning the concepts (objects being modelled) is captured in the relationships that an object has with other types of objects (specialization/generalization, part/whole, association), characteristics (attributes) and operations (methods, functions) belonging to the object class.

UML class diagrams are often used for this modelling (OMG, 2002, chapter 3, part 5). The use of UML class diagrams has become the ‘default’ approach when creating formal knowledge frameworks, but the graphic diagram has a limited semantic accuracy. Within UML a non-graphic language is provided for further modelling semantics (knowledge frameworks), i.e. the Object Constraint Language (OCL, see OMG, 2002, chapter 6, OMG, 2003). This can be used to specify conditions to which a valid model should adhere (constraints); such as invariants for classes and pre- and post-conditions for operations.

Besides UML (and OCL) there are also specific tools for handling (‘reasoning’) with formal concepts (semantics, ontology); e.g. translation the terms/concepts from one domain to the terms/concepts of another domain. Possible tools are OWL, the Web Ontology Language (W3C, 2004) or the new ODM (Ontology Definition Metamodel) development from the OMG of which the final adoption is expected November 2004.

4.3 Further research

Some of the most important issues to be considered in semantic/data discovery domain are:

- Integration of thematic, contingency and real-time data in preparation for knowledge discovery and emergency knowledge transaction processing.
- Developing context-aware engines and agents for query and analysis with respect to the type of the front-end and communication channels used.
- Investigation, adaptation and development of converters to well-known Web standards and formats.
- Developing knowledge-based systems for browsing and analysis in a distributed data environment.
- Investigating and developing intelligent semantic-based engines and corresponding translators for semantic search and analysis.

5. POSITIONING OF MOBILE WORKERS AND USERS

As mentioned in Section 2, highest requirements are coming from the mobile users and workers. To be able to discover the most appropriate information, the system may need 3D positions of the users. Furthermore the system has to be able to maintain continuous communication related to both rescue forces (police, ambulance, fire brigade) and citizens.

The required accuracy of the positioning may depend on the case and may vary from 100 meters (locating a hospital) up to 5 meters (locating and safe exit in a building with reduced visibility). The system should be able to detect what kind of situation appears and selectively decide on the preferred way of positioning and communication (depending on the availability of networks).

5.1 Positioning

Several possibilities for positioning can be considered: Global Navigation Satellite Systems (GNSS), telecom networks, WLAN or hybrids of them. All approaches have advantages and disadvantages (Zlatanova and Verbree 2003).

At the moment the only available relatively low-cost Global Navigation Satellite System devices offering 3D positioning and navigation capabilities are GPS devices. Although these devices are designed to track up to 12 satellites simultaneously, they receive in dense build-up areas not that easy the minimal 4 satellite single frequency signals necessary to determine a 3D-position. The configuration of these line-of-sights is not optimal either, limiting the accuracy to less than the 10 meters, which could be obtained with a clear view. At first sight, both accuracy and availability are not suitable for the rapid and precise positioning necessary for tracing ad tracking mobile workers and users within disaster management application. Furthermore, with a cold start, the receivers needs a certain start-up time to acquire the satellite almanac, necessary to know where to look for a certain satellite. Within buildings and other closed spaces the satellite signal is too weak to use. Finally, the receivers should be carried in such a way as the antenna is more or less positioned to the sky. All these limitations are no in favour of for using GPS as it is currently available.

However, all the mentioned limitations are to be solved within the near future or by a combination with other equipment. New GPS-satellites will use a stronger signal. The receivers will be assisted (AGPS) by terrestrial communication signals providing the satellite almanac data in forehand, which will reduce the start-up time for a first position fix. Pseudolites at the earth surface can resolve the limitation of a few visible satellites.

Another promising initiative is the European Navigation System Galileo. With Galileo the total available satellites will be doubled and consequently the chance to receive 4 or more of satellites simultaneously will be very high. A first simulation study (Verbree et al, 2004) proves this observation. Figure 2 shows a small part of the city of Delft modelled in 3D. Given the theoretical GPS constellation and the proposed Galileo constellation one can determine which satellites are visible from a certain position. It is known that for 3D positioning are needed either 4 GPS, or 4 Galileo, or 3 GPS and 2 Galileo, or 2 GPS and 3 Galileo satellites. As the position of the satellites changes during time, we have to determine the line-of-sight form the receiver to the satellites for a specific time during the day. The red lines indicate for a random time the reception of GPS satellite signal, the purple of the Galileo satellites. Adding Galileo satellites the availability and thus the usability of GNSS dramatically improves. Figure 3 shows a combined Galileo GPS positioning. The green dots indicate for a 90%-100% availability of GPS and Galileo satellites during a period of 24 hours. This figure indicates that even within the narrow streets of Delft the combination of GPS and Galileo will work very well.

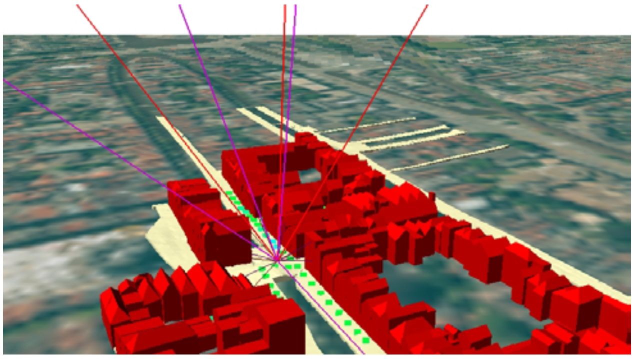

Figure 2: Simulation of GPS (red) and Galileo (purple) positioning

It is important to realize progress in telecommunications. The GPS/Galileo receivers will be miniaturized and integrated within devices like PDA's and cell-phones, creating a situation where the location of these devices is known prior accessing the disaster management system. This location awareness will reduce the input while specifying a certain location-based query.

The expectations of positioning based on telecom networks are high. In theory tele-communication networks can trace a mobile phone by range measurements, comparable to the principle behind GNNS. But where for example GPS is a global navigation system, telecom networks are not. Where GPS offers real 3D positions, telecom network cannot due to the configuration of the transmitters bounded at the earth surface. Where GPS offers a global accuracy of 10 meters or better, the accuracy of telecom networks corresponds in principle to the cell-size of the base-station, i.e. it is limited to 100-500 meters. Any claim to use triangulation between three or more base stations depends on an adjustment of the current situation and thus a large investment. The urban areas are again problematic. A mobile phone can be easily connected to a transmitter (e.g. on a high building) that is 2-3 km far way from the current position of the user.

Figure 3: Combined Galileo and GPS: positioning in narrow streets is possible (only two dark dots remain undetermined)

Telecom based 3D positioning offering the needed decameter accuracy or better is not foreseen. However, a number of hybrid systems, e.g. combination of mobile networks, GPS and additional information (i.e. postal code) are already in use. The progress in the WLAN offers another alternative to position a user in close ranges (30-40m). The general research question here is how to switch between different positioning systems to be able to provide accurate positioning at any time.

5.2 Communication

Another important aspect is the communication and practically this includes the interaction between the user and the whole system. Although third generation of wireless communication networks (UMTS) will improve the bandwidth and reduce bottlenecks that currently limit the amount of data that can be communicated, there will be a demand on reduction of the data, especially when thinking of communication on different networks (e.g. UMTS, GPRS). Nonetheless it will be more important to allow the user not just accessing data that are already part of the system, but also make sure these data are handled as effective as possible. Therefore it is necessary to allow them to update this data and to integrate new data sets. Here again the system has to support the user in acquiring the data, complete the data by using the available sensors, communicate them to the system, check the consistency, detect semantic dependencies to other existing data sets and integrate them and the dependencies into the system. These steps are necessary to enlarge the data pool of the system and make sure this data are able to be processed and analysed by the system. Nowadays systems usually do not support online update. All the described steps are done – often manually -in a post-processing process after the data is collected that introduces a large delay between the data collection and the data availability.

The privacy aspect is another topic when dealing with navigation and positioning devices. In general people do not like to be tracked and monitored, unless they are in danger themselves or have to obtain a position fix to help others. The type of positioning (global or telecom) has different nature. GNSS are passive devices, meaning the user have to approve transmitting their coordinates to the geo-mobility server. Telecom positioning can be initiated by the telecom operator regardless the wish of the user. This fact will be far more important in accepting and using GNNS in contradiction to location devices based on telecommunication systems. Some telecom operators claim a position accuracy of 100 meter or less, but as the status, the location and the operation of the 'space' segment (the transmitters) is not guaranteed (in contrast to GNSS), i.e. one can not trust the derived location of the user. Moreover without a clear business model needed to justify adjusting their ground stations and developing a kind of positioning service (in ordinary situations), telecom operator will not take the lead. However, in case of disaster management, telecom operators have to be prepared to use telecom positioning for alerting people in the affected area.

In general, we believe that developments in global positioning systems will reach a stage to be sufficient within the majority of situations in disaster management, especially when communicating with citizens. Further developments will be needed to allow receivers to be applied within buildings and other GNSS-hostile environments. A sort of hybrid systems have to be developed that will connect to a special kind of transmitters, WLAN and other short distance networks to provide the rescue teams with highly specialised services. As the kind of service needed to help people within buildings is more specific compared to outdoor applications the development of these short range-positioning tools will be driven by specialized vendors and operators.

6. CONCLUSIONS

In this paper we have concentrated on important aspects of a system for disaster management: 3D geo-data management and 3D positioning of the mobile user.

We expect that geo-information will have a critical impact on the first period of an emergency handling. This will be achieved by providing targeted information rapidly (having developed the models and frameworks as they are discussed in Sections 3 and 4) and by collecting relevant information from the filed that will assist coordinating rescue operations (maintaining historic models by keeping integrity and consistency, propagating information to all the users). Handling emergency will benefit from knowledge approaches, based on the extraction of information from multiple and distributed databases. These databases have to be based on federated and collaboration architecture (as discussed in Section 4) to provide the emergency sector with all insights that can be realistically obtained in support of life saving and protection of material assets. This will prevent that vital data will not be usable simply because of technical issues.

Accurate 3D positioning (as discussed in Section 5) will facilitate the logistics of emergency operations by providing 3D navigation capabilities in indoor and outdoor environments, which are unfamiliar to the rescuers. This will increase the net availability of resources for the core emergency tasks and limit the chaotic nature of emergency handling.

We firmly believe that a better utilisation of geo-information will contribute to better monitoring and fighting disasters, leading to shorter response times, focused and efficient emergency operations.

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