13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 3094

CONCEPT FOR AN INTEGRATED DISASTER MANAGEMENT TOOL

M. Markus[1], F. Fiedrich[1], J. Leebmann[2], C. Schweier[1], E. Steinle[2]

SUMMARY

In general, earthquake disasters in urban areas can hardly be handled by the operable disaster response teams of the affected region. An efficient and integrated disaster management could support their activities and help to limit human losses. Based on EQSIM, a damage estimation tool developed within the German Collaborative Research Centre 461: "*Strong Earthquakes, a Challenge for Geosciences and Civil Engineering*", the Disaster Management Tool (DMT) was developed. Its concept is presented in this article.

Main aspects of this DMT are fast and reliable damage and casualty estimation, use of up-to-date reconnaissance techniques such as damage detection based on airborne laserscanning data and the support of disaster management personnel with communication and information tools. The included decision support system will help to coordinate the allocation of the limited number of rescue personnel and machinery to enhance their overall efficiency. Onsite rescue operations will be supported by an expert system analyzing damage information acquired after the earthquake, combined with data about the buildings' construction and occupancy collected prior to the earthquake.

The DMT is developed for pre-event training and mitigation tasks and for post-event disaster management. For training purposes, actors in a disaster environment are simulated and connected to the DMT using a High Level Architecture (HLA) interface, an IEEE standard for distributed simulation.

INTRODUCTION

When urban areas are stricken by earthquake disasters and experience substantial destruction, in general the operable disaster response teams are overstrained. An efficient and integrated disaster management could support their activities and help to limit human losses. The Disaster Management Tool (DMT) is a multidisciplinary approach of the German Collaborative Research Centre 461: "*Strong Earthquakes, a Challenge for Geosciences and Civil Engineering*", to perform this task.

---

[1] Institute for Technology and Management in Construction, Karlsruhe University,
{fiedrich}{markus}{schweier}@tmb.uni-karlsruhe.de
[2] Institute for Photogrammetry and Remote Sensing, Karlsruhe University,
{leebmann}{steinle}@ipf.uni-karlsruhe.de

The Disaster Management Tool is a software system with up-to-date hardware supporting decision makers, surveillance and intervention teams during disaster response. The response actors can access basic data about building stock, residents and resources as well as dynamic data like seismic measurements, damage estimations, damage observations and damage detections. It assists decision makers as well as rescue team leaders with decision support and intelligent communication tools.

Real world data from a defined area in Bucharest, Romania, where strong earthquakes with average recurrence rates of 2 decades in the nearby Vrancea area occur quite periodically, was being used for model testing. The DMT is designed for earthquake disasters in Bucharest as a test case, but planned to be adaptable to urban areas in industrializing countries with various disaster types.

At the present stage of development, improvement of disaster response is the main objective of the tool. Given the disaster circle leading from mitigation and preparedness to disaster response, rehabilitation and reconstruction, the DMT can also be used for risk assessment using the damage estimation tool with expected seismic input. As well as for the task of preparedness using the damage estimations for disaster response training and to pre-assess the resources needed. In this paper the different components of DMT are described in brief. The stage of development and further goals will be expressed.

CONCEPT OF THE DISASTER MANAGEMENT TOOL

The Disaster Management Tool has three main functional parts. The first part comprises components for fast damage and casualty estimation, simulation of future progression of the disaster like fire propagation and consequences of decisions during exercises. It is named “simulation part”. The damage and casualty estimation based on seismic data is performed by the component EQSIM, which is in the most advanced stage of development within DMT (see [1]).

The second part encloses elements for decision support. Main components are a system for damage analysis based on airborne laserscanning, damage and casualty estimation based on building stock and residential data as well as the results of the damage analysis. An expert and information system supports rescue activities at collapsed buildings with case relevant advice and information from central database. A decision support tool for emergency operation centre members helps to assign the response resources in order to maximize the efficiency of response activities.

To integrate the operations on the different executive levels, the third functional part of the DMT provides means for the tasks of communication and information. The management information system conducts the aggregation, selection and distribution of information relevant for the specific actors of disaster response. A graphical user interface helps to visualize the mostly geographical related information. And a special augmented reality user interface helps analyzing the situation at rescue site to accelerate response activities.

The dynamic database is the central element of DMT. The different components use the common Oracle database to access static information like building stock or historical earthquake data. They also use it to store and exchange dynamic data like observation results from different sources or locations of rescue resources. Backup databases are filed on the local computers depending on the components in use. Figure 1 shows the concept of the DMT.

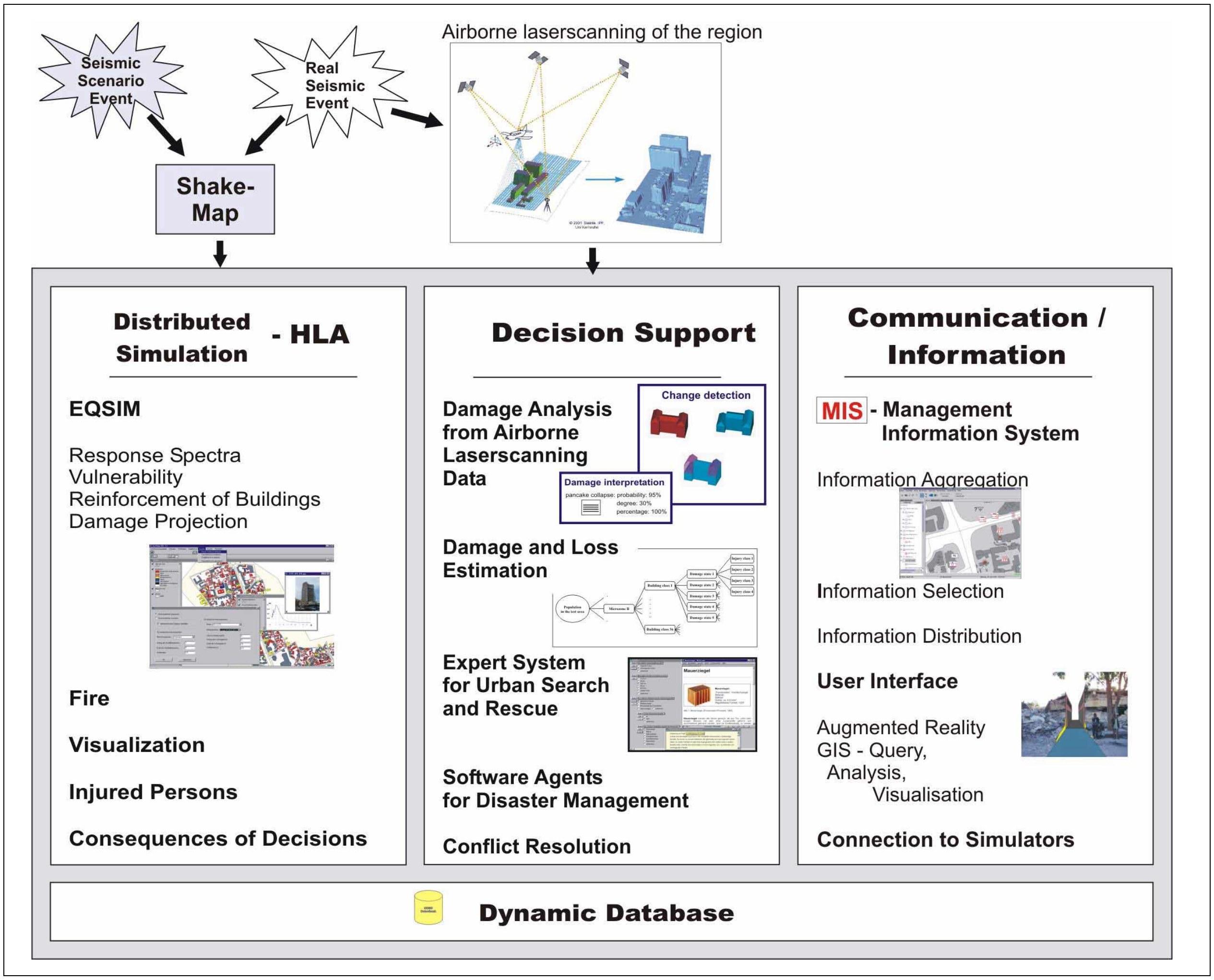

Figure 1: Concept of the Disaster Management Tool

SOFTWARE ARCHITECTURE

DMT uses an approach based on distributed computing over computer networks. It consists of components (figure2) that will be described in detail throughout this paper.

The EQSIM server program performs the calculation of the damage scenarios and implements the damage estimation methodology. Calculations are either requested of client programs where users can define scenarios based on the historical earthquake database, respectively defined earthquake parameters (such as location, magnitude and depth) or such requests arise from software agents, which may be used for decision support during disaster response. Field personnel may update the central database with observed damages that are input for a groundtruthing component of the server program to improve the scenario calculations.

The Management Information System (MIS) server controls the communication and information flow between users and with the database. It distributes new information to users with relevant responsibilities.

The Expert System Servers are located at or near to operation sites. The response teams use mobile computers or PDAs connected via wireless LAN to the servers to obtain case relevant data and advice. Input data from field personnel is sent by these devices to central database. Additional direct access to the database and use of MIS is possible for the field personnel.

During a simulated training exercise, all components are linked via a distributed simulation, which is based on the High Level Architecture (HLA). In this case, the field personnel and the response resources may be simulated by separate HLA-simulators. Figure 2 gives an overview of the possible application fields of the DMT.

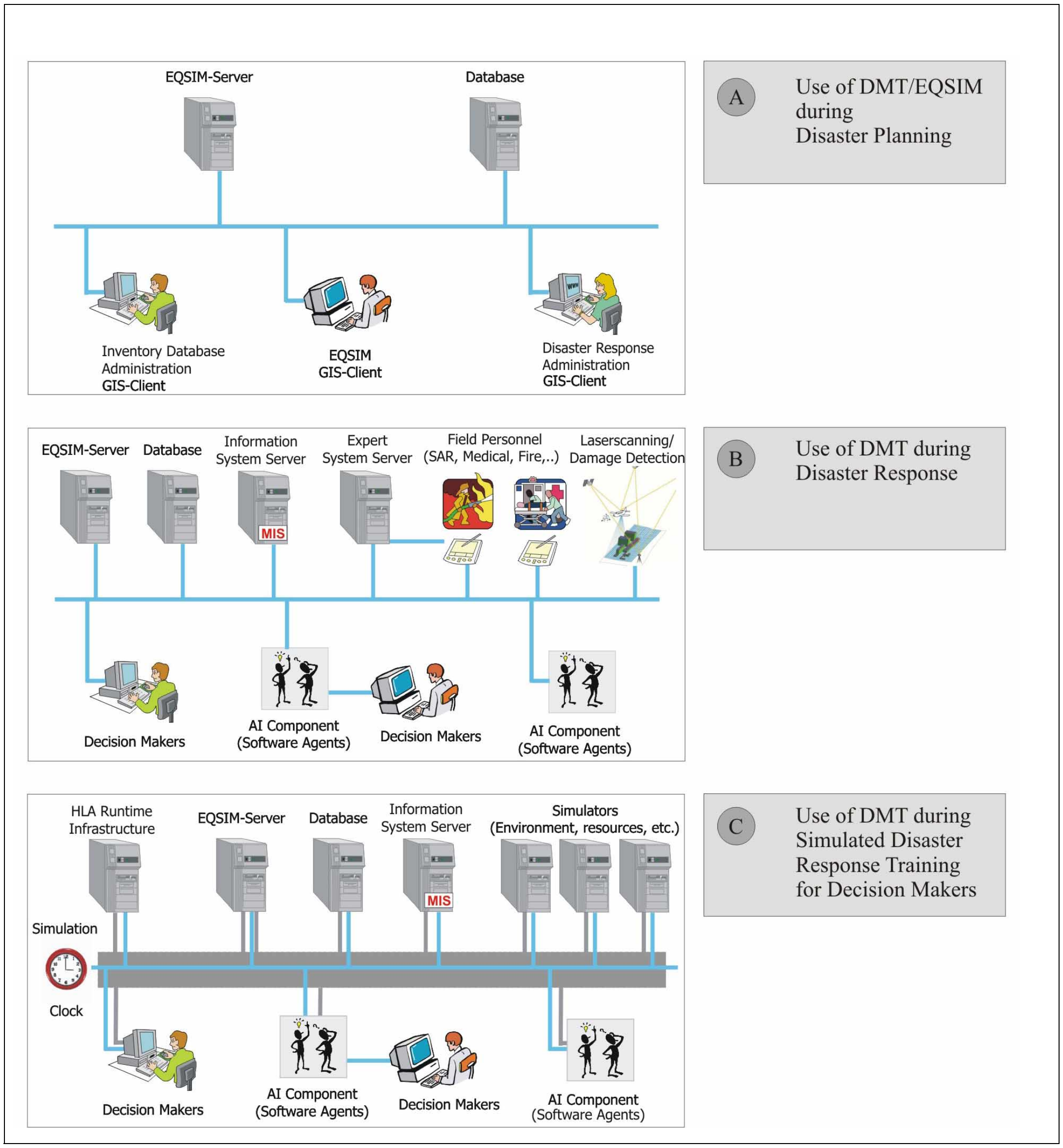

Figure 2: Possible applications of DMT and EQSIM

TEST AREA IN BUCHAREST

The Disaster Management Tool is designed for urban areas. Development and testing are carried out in Bucharest as a case study. An area of the city was defined for that data in a high-resolution were acquired, including detailed information for each single building. The test area is part of the downtown district, located between Piata Romana and Bodul Unirii, where most of the damages occurred during the last destructive earthquake in 1977 (Figure 3). The data collected for this test area are compiled in the central database, which is linked to the building layer and street layer of the DMT-GIS. The test area contains 1305 buildings with all kinds of occupancy. Supplementary, 763 small garages or stores were identified in this area that consist of one storey. After visual examination, no occupancy was assigned to these buildings.

The following compilation shows the essential building information within the database for each single building:

- Street and number
- Occupancy class
- Number of storeys/ basements
- year of construction
- type of construction
- construction details (floor type, storey height, balcony..)
- potential soft storey with different occupancy class
- number of flats/residents

Occupancy classes and construction types base on the ATC-14 Report [2] and the HAZUS methodology [3]. Supplementary to the 36 HAZUS classes of building structures, 14 European types, not common in the United States, were added. HAZUS construction types with only a few adaptations to European customs are marked with *.Construction data are necessary for damage estimation, damage recognition and planning of rescue operations.

As data sources served a list of expertises of highly vulnerable buildings from Romanian experts [4], building data including data of the buildings collapsed in Bucharest on March 4, 1977, acquired by the Technical University of Civil Engineering in Bucharest, a city map in 1:500 scale, results of the census in 1990, and the results of an inspection of the buildings in the test area. This inspection was necessary due to the different age and quality of the used data sources. Since the information are needed for each single building a questionnaire with instructions was developed for a visual inspection of single buildings. The whole building stock of the test area was inspected during three weeks with two teams consisting of 2-3 persons. At least one photography was taken of each building.

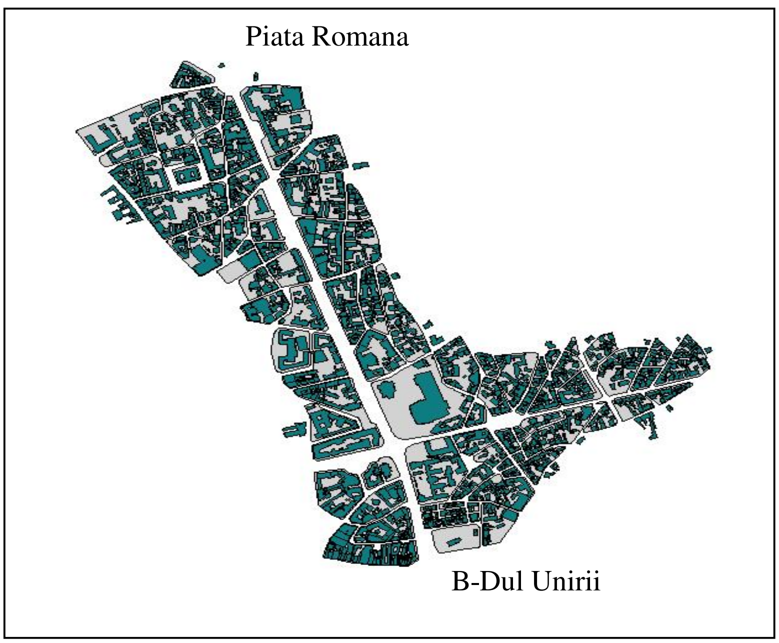

Figure 3. Test area in Bucharest

The building stock of the test area consists both of residential buildings and commercial buildings. The northern area is stamped by tall concrete frame buildings of more than 7 storeys. But also many low-rise historical buildings are included in the test area. Figure 4 shows the distribution of concrete buildings. The labels, derived from HAZUS typology and adapted to our needs, denote:

C1:	Concrete moment frame	L:	Low rise, 1-3 storeys
C2*:	Concrete shear walls (*: HAZUS type C2 extended to fit european constructions)	M:	4-7 storeys
		H:	8 and more storeys
		T:	21 and more Storeys
C3:	Concrete frame with unreinforced masonry shear walls		

Other construction types occurring in the test area are *wood* and *steel frame* buildings, *precast concrete*, *reinforced* and *unreinforced masonry* buildings. Altogether, 20 combinations of construction type and height range can be used to describe 97% of the test area building stock.

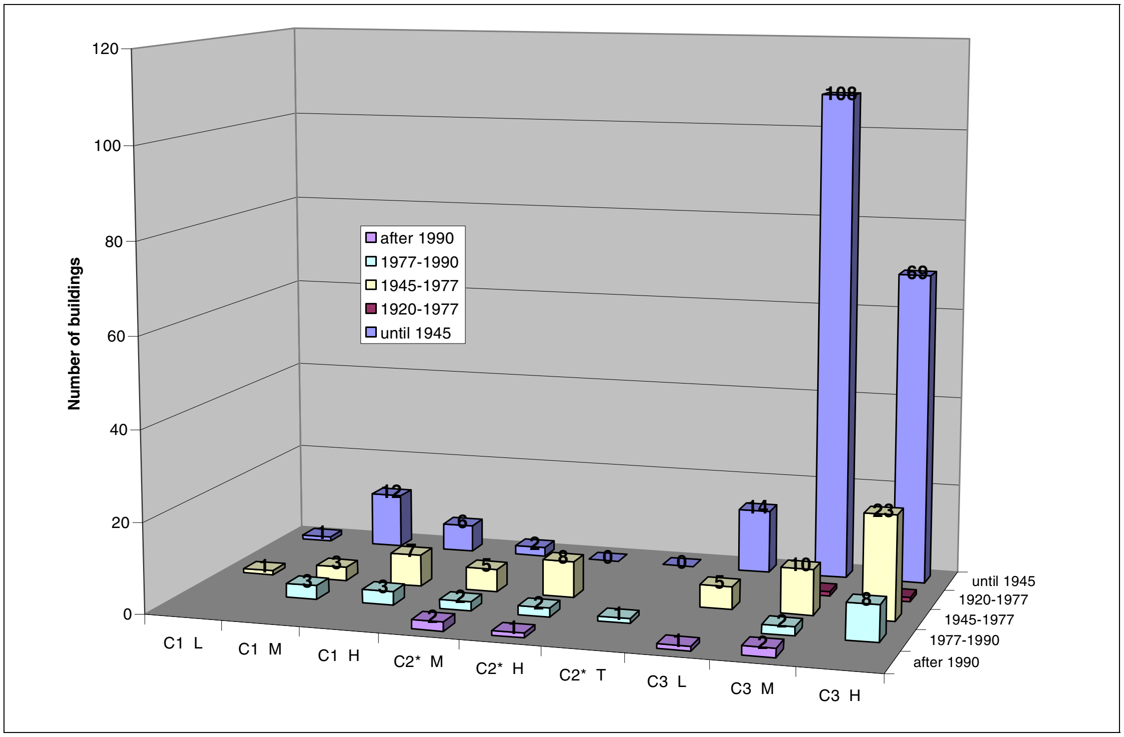

Figure 4. Different types of concrete buildings in the Bucharest test area, clustered by construction date

THE DATABASE

The central Oracle 9i database stores all relevant information. The database includes tables for different aspects of the damage estimation and information to be exchanged during disaster response. The tables are classified as following:

Static area information: information about the existing infrastructure and inventory of the test area. E.g., soil data based on microzonation or building details such as construction specifications and occupancy data.

Information about building behavior (EQSIM): capacity and fragility curves for all defined building types to calculate building damages using the capacity spectrum method.

Information for casualty estimation: these tables give the probabilities for different injury classes dependent on building type and damage class.

Earthquake related information: historical earthquake data including Vrancea earthquakes, based on the ROMPLUS catalogue [5] and available response spectra from recorded time histories.

Meta knowledge (EQSIM): this group of tables includes, among others, parameters for calculation of seismic response spectra and parameters for the used attenuation functions.

Scenario results (EQSIM): for scenario analysis all scenario results (e.g. damage and casualty probabilities on building level) are stored in different database tables.

Disaster response resources: personnel and material resources including fire brigades, specialized rescue teams, EMS teams, civil and military trucks, excavators etc.

Plans: the disaster response plans are related to activities and disaster response resources and support decision makers

Activities: including actions and actors to notify activities exchange information about new activities, e.g. observations

Observations: results of observations. Different observations from different actors about the same building are possible.

Because the database includes Meta knowledge about the damage estimation methodology, it is flexible to be used for other areas. Additionally, the impact of different available methods on the scenario results can be examined, making it in that way a valuable tool for researchers, too.

THE SIMULATION COMPONENT

The DMT can also be used in virtual disaster response training by the staff of Emergency Operation Centers (EOC). For this, EQSIM is embedded in a distributed simulation of the response activities after strong earthquakes. This simulation uses the High Level Architecture (HLA) as a common framework.

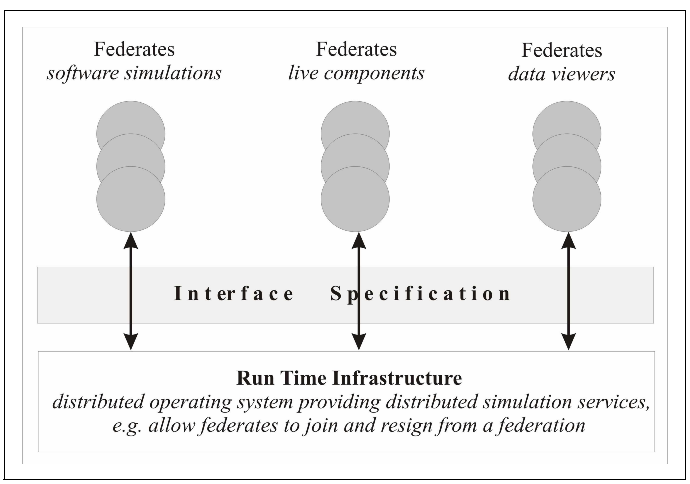

Figure 5: Main components of an HLA-based federation (after [9], p 212)

HLA was developed by the Defense Modeling and Simulation Office (DMSO) of Department of Defense (DoD) of the United States, with the main goal of building a platform for war gaming and training, taking into account interoperability and reuse of different simulation components. Since 2000, HLA is an Institute of Electrical and Electronics Engineers (IEEE) standard for distributed simulation systems. A distributed simulation using HLA is called a *federation*, and each single simulator in such a federation is referred to as a *federate*. A federate may be a simulation, live component (e.g., physical device or human operator) or data viewer. The federates interact via a central component which is called the *Run Time Infrastructure* (RTI). To enable this communication, each federate must implement a predefined HLA-interface (compare figure 5). Technical details about HLA can, for example, be found in the IEEE specifications [6], [7] and [8].

The EQSIM server program implements this interface as well. This allows other simulation components to send calculation requests to the server during a simulation-based exercise. In the simulation system, the disaster environment and the use of resources within the disaster environment can be simulated in real time. Simulated resources include SAR-Teams, ambulances, fire fighting units, recon units and heavy equipment resources for repair work of blocked roads and rescue operations.

To interact with the simulation, different elementary actions are defined. These actions can be used during a simulation by human operators, such as management-level personnel, to perform either predefined or improvised plans, based on the available actions. Additionally, a multiagent system can be linked to the simulation environment where the software agents (software agents are computational systems with goals, sensors, and effectors, which decide autonomously which actions to take, and when) use predefined flexible plans for their reasoning process. Because both the software agents and the computer interfaces for the human operators implement the HLA-interface, they can take advantage of the damage estimation tool EQSIM for the planning of the response activities, too.

CONCEPT OF RAPID DAMAGE DETECTION

One of the most important factors to plan an efficient use of SAR resources is the knowledge about the location, the extent and the characteristic of totally or partially collapsed buildings. Fast acquisition of such data is essential for rapid assessment of the needed rescue personnel and equipment. Within the CRC, a method based on airborne laserscanning is researched (compare e.g. Steinle & Vögtle, 2001 [10]) to rapidly obtain information about the damage situation of buildings in affected areas. This method will be briefly described in the following.

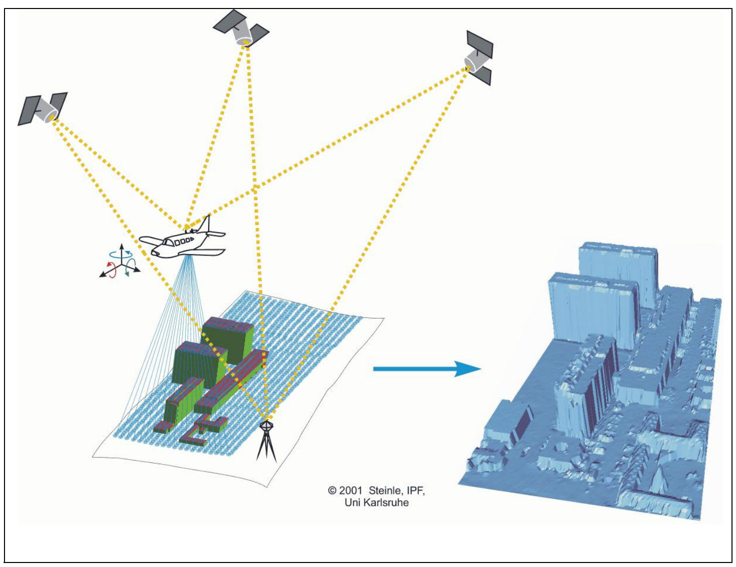

Figure 6: Principle of laserscanning

Laserscanning and building modeling

During the last decade, the laserscanning technology -an active airborne scanning technique- became an important and widely used technique for dense three-dimensional point measurements (see e.g. Ackermann, 1999 [10]). This technique allows producing height data sets, e.g. digital surface models (DSM) in an efficient and rapid way (see figure 6). Such models are a highly suitable base for the application of automatic procedures for the extraction and geometric modeling of buildings as 3D vector models (see Steinle and Vögtle, 2001 [11]).

Change detection and damage interpretation

The damage analysis is carried out by comparing building models extracted from post-earthquake laserscanning data with such stored as reference models for the endangered area in the DMT. Setting up the reference models is a kind of prerequisite measure and should be done regularly in the regarded areas to be sure to have a reliable base for the comparison.

Differences found in between the pre- and post-earthquake geometric models of the affected buildings are quantified in terms of change measures like volume differences, plane orientation change, height change or size alteration. These changes must be further analyzed and interpreted.

As urban environments are undergoing changes all the time, e.g. by construction activities (see Steinle & Bähr, 2002 [12] for details), and not only due to catastrophic events like earthquakes, it is necessary to rate the differences in buildings geometry. The changes identified as not being caused by normal urban modifications are further classified in damage types using a so-called damage catalogue. Principally, this is an archive storing observed damages at buildings of former earthquakes, but clustered and characterized according to the needs of the SAR organizations. This means that the separation of the types is done according to the rescue measures needed for saving victims from such collapsed structures. Each class is described in the catalogue with features that can be extracted from the buildings vector models. Therefore, automatic procedures can use this catalogue to identify the respective damage type at buildings based on the buildings models. As it can be difficult to find a total match between an observed building damage and the damage types stored in the catalogue, the most likely type will be assigned and the ratio of concordance will be given additionally.

At present, the automatic damage classification process is developed. The tests of this component are planned with laserscanning data of a military exercise area. Further adjustment with the damage catalogue will be necessary.

EXPERT AND INFORMATION SYSTEM FOR RESCUE OPERATION SUPPORT AND TRAINING

The technical personnel who is in charge of rescue operations after building collapse - in Germany mainly fire-brigades, the civil protection organization THW (Technisches Hilfswerk) and search groups from further organizations- rarely possess own experiences from similarly cases. However, the rescue of trapped victims from collapsed buildings requires a substantial technical, personnel and organizational effort (see [13]). During rescue activities, trapped victims are moreover at risk, when building elements are relocated or extracted, and when fine-grained building material trickles down on them leading to suffocation. Even rescue personnel are exposed to a substantial risk. After Tiedemann [14] more than 100 rescuers were killed during operations after a destructive earthquake in Mexico City 1985.

Figure 7: Screenshot of expert system data input

Standard procedures for rescue activities were designed in co-operating with the German Fire Protection federation (vfdb). For training and operation support, an expert and information system was created and tested with the THW [15]. It consists of the three components *on-line manual*, *expert system* and *computation component*. After integration into the DMT, communication with control personnel and data-exchange with the central database is possible. Local observations can be sent to database and construction details from database support rescue activities.

The on-line manual contains information about building types, construction components, rescue equipment and methodology. It consists of HTML and pdf documents with navigation support. It is useful for training and to easily access necessary knowledge during rescue activities. Thereof, the user gains access to the expert system where he enters information relating to a certain case (see figure 7). Context sensitive subsequent questions are posed by the expert system. To assist site inspection, building stock data from central database can be taken over. The diagnosis includes advice concerning the processed case and links to specific entries within the information system. Case-relevant checklists are printed and appropriate tools and methods are given. The expert system bases on the D3 Server System application [16], which is provided by the Department of Computer Science VI, University of Würzburg. The java-based application allows different users to simultaneously enter their observations for different cases using html forms.

With the third computing component, calculations of debris masses and masses of building materials such as steel profiles or concrete floors can be performed easily and reliable under operational conditions. This information can be used for strut dimensioning, crane selection and transportation calculations, again using this component.

The expert and information system is a server application that can be used at the rescue site through mobile computers and PDAs connected via wireless LAN. It was tested by professional users at model cases. Currently, the connection to DMT and its database is programmed. The functionality will be enhanced.

USER INTERFACES

Figure 8: Test equipment of the augmented reality user interface

The standard user interface for DMT users is a graphical user interface (GUI) with GIS functionality. The Management Information System and the EQSIM user utilize this GUI. A further user interface bases on augmented (AR) reality technology. An AR system overlays a virtual image and the real image of the scenery in real time. The AR system used here can be used in two variations: The one variation uses semitransparent displays (see Figure 8), the other variation uses a camera to perform the superposition. With GPS devices (used in differential mode) and inertial sensors the position and orientation of the user's head are measured. The measured position and orientation is used to superpose relevant data like residential use of the building or number of storeys before collapse using the ARS. But also geometric information can be directly overlaid. At collapsed buildings, the three dimensional view of the undamaged building can be superposed with the actual image of the building (see figure 10). The user can now directly compare the "real" view of the collapsed building with the view of the building before collapse in his spectacle. When going around the building, the user can repeat this comparison from different perspectives. This helps discovering areas with possible voids in the collapse structure or areas where trapped victims are possibly located following their initial locating. This technology, which is only possible with inventory data, can help the rescuers to search selectively and thus to accelerate the rescue process.

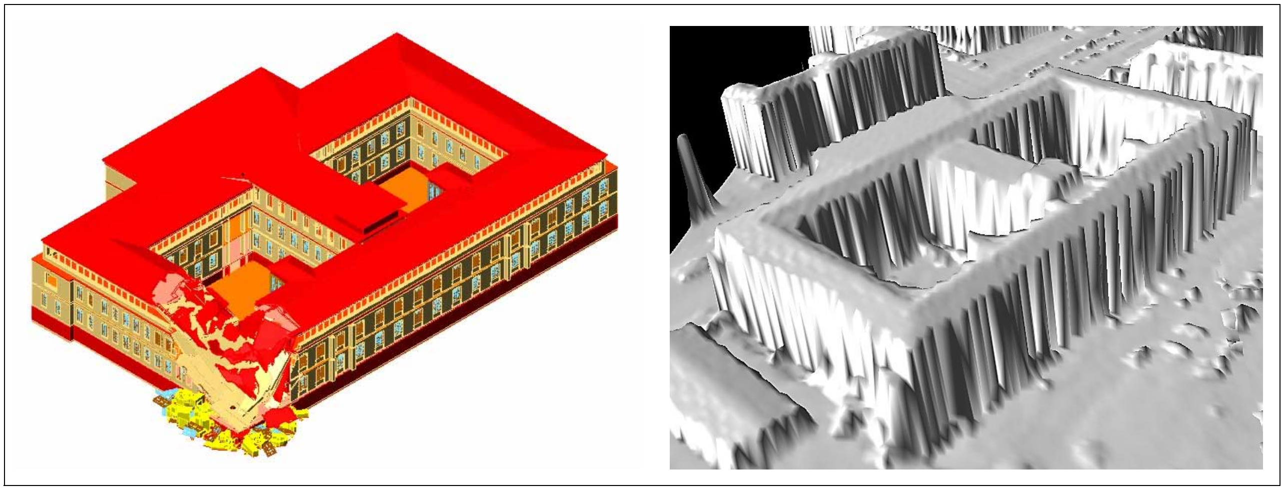

Figure 9: Modified fictive model of a collapsed building at University campus and Digital Surface Model (DSM) derived from airborne laserscanning of the same building (not collapsed)

First tests of the augmented reality user interface were performed at the university campus. Figure 9 and 10 shows the result of the test using a real not collapsed building from DSM and a model of the same building in a partially collapsed state (figure 9).

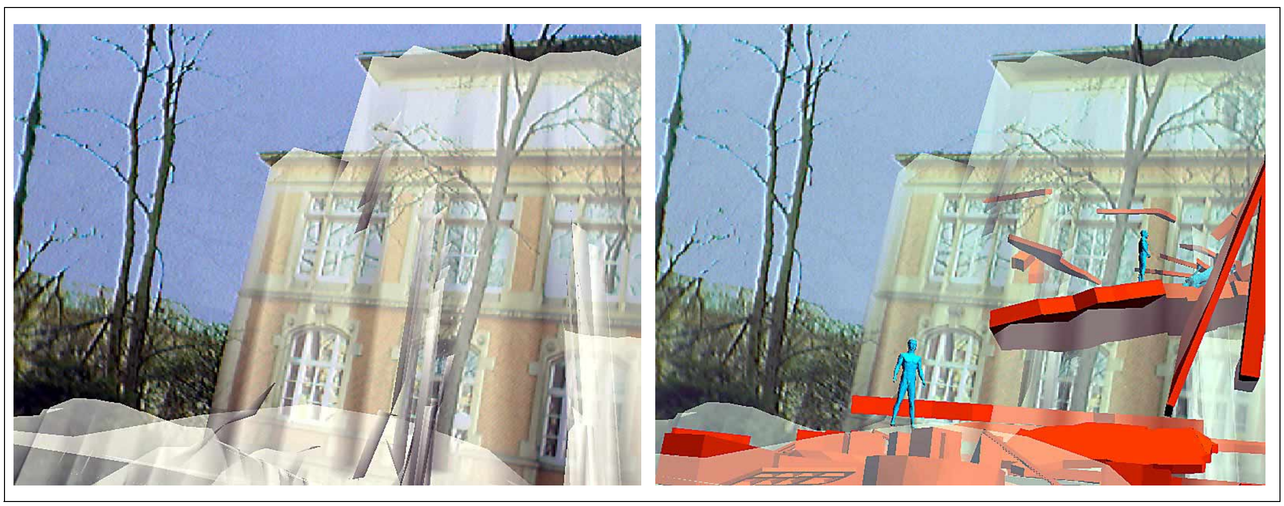

Figure 10 left: Superposition of the real view with DSM. Right: Additionally with damage model from figure 9 and virtual rescue team members

CONCLUSIONS AND FUTURE WORK

In this paper, the Disaster Management Tool was described as a promising tool for disaster response in an urban environment. The client-server architecture permits to use DMT simultaneously by different users. It can be applied for disaster planning, disaster response and for disaster response training.

The data acquisition of a test area in Bucharest and the collected data was described. The central database allows the users to avail steadily actualized data of the changing disaster environment. The database is necessary for data exchange between the DMT components like Management Information System and the Expert and Information System. For simulation of response activities, the distributed simulators, EQSIM and the user interfaces communicate in case of training based on a High Level Architecture (HLA) framework.

The concept of the rapid damage detection and interpretation component, which is using airborne laser-scanning technology, was given and the expert and information system supporting field personnel was described shortly. Then the augmented reality user interface and its planned application within DMT were introduced.

The first test of the whole DMT tool with local disaster management and response units in Bucharest is scheduled for October 2004. The exercise will be held on control center level and on onsite operation search and rescue level. At moment, the different components are adapted to DMT before the tests will be carried out under real conditions.

ACKNOWLEDGEMENTS

The research in this paper is part of different research projects within the Collaborative Research Center (CRC) *Strong Earthquakes: A Challenge for Geosciences and Civil Engineering*. It is funded by the German Science Foundation (DFG) and the state of Baden-Württemberg.

REFERENCES

1. Baur, M.; Bayraktrali, Y; Fiedrich, F.; Lungu, D. and Markus, M. (2001). EQSIM - A GIS-Based Damage Estimation Tool for Bucharest. In: Lungu, D. and Saito, T (Eds.): *Earthquake Hazard and Countermeasures for Existing Fragile Buildings*, Independent Film, Bucharest, 245-254.
2. Applied Technology Council (1987). Evaluation the Seismic Resistance of Existing Buildi.ngs, ATC 14 Report, Applied Technology Council, Redwood City, California.
3. National Institute of Building Sciences (1997). Earthquake Loss Estimation Methodology HAZUS. Technical Manual, Vol. I-III.
4. Monitorul Oficial al Romaniei, Partea I, Nr.516 bis (1999). Hotarare pentru aprobarea Normelor metodologice de aplicare a Ordonantei Guvernului nr. 20/1994 privind masuri pentru reducerea riscului seismic al constructiilor existente, 25.10.1999
5. Oncescu, M.C.; Marza, V.I; Rizescu, M. and Popa, M. (1999). The Romanian Earthquake Catalogue between 984-1997. In: *Vrancea Earthquakes*, Wenzel, F.; Lungu, D. and Novak, O. (Eds.), Kluwer Academic Publishers, Dordrecht, Netherlands, S. 43-47.
6. IEEE (2000). Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Framework and Rules, IEEE Standard No. 1516-2000.
7. IEEE (2000). Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Federate Interface Specification, IEEE Standard No. 1516.1-2000.
8. IEEE (2000). Standard for Modeling and Simulation (M&S) High Level Architecture (HLA) - Object Model Template (OMT) Specification, IEEE Standard No. 1516.2-2000.
9. Fujimoto, R.M. (2000). Parallel and Distributed Simulation Systems. *Wiley Series on Parallel and Distributed Computing 3.* John Wiley, New York
10. Ackermann, F. (1999). Airborne laser scanning – present status and future expectations. *ISPRS (International Society for Photogrammetry and Remote Sensing) Journal of Photogrammetry and Remote Sensing*, 54 (1999), pp. 64 - 67, 1999
11. Steinle, E. and Vögtle, T. (2001). Automated extraction and reconstruction of buildings in laser-scanning data for disaster management, in: Proceedings of the Workshop Monte Verita, Switzerland, 10-15 June 2001, Baltsavias, E. P., Gruen, A. and Van Gool, L. (eds.), *Automatic Extraction of Man-Made Objects from Aerial and Space Images (III)*, Balkema (Swets & Zeitlinger), Lisse, The Netherlands, p. 309 - 318

12. Steinle, E. and Bähr, H.-P. (2002). Detectability of urban changes from airborne laserscanning data, in: Navalgund, R. R., Nayak, S. R., Sudarshana, R., Nagaraja, R., Ravindran, S. (eds.): *Resource and environmental monitoring, ISPRS commission VII symposium*, Hyderabad, India, December 2002
13. Coburn, A. and Spence, R., (2002). Earthquake Protection, Second Edition, Chichester, England, John Wiley & Sons Ltd.
14. Tiedemann H. (1992): Earthquake and Volcanic Eruptions: A Handbook on Risk Assessment, Swiss Reinsurance Company, Zürich
15. Markus, M., Fiedrich, F., Gehbauer, F. and Hirschberger, S. (2000). Strong Earthquakes, Rapid Damage Assessment and Rescue Planning, in: Kowalski, K.M. and Trevits, M.A. (eds.): *Proc. of the 7th Annual Conference of the International Emergency Management Society: "Contingency, Emergency, Crisis, and Disaster Management: Emergency Management in the Third Millennium"*, Orlando, Florida, May 1999, pp. 369-378.
16. Puppe, F.,Bamberger, S., Iglezakis, I., Klügel, F., Kohlert, S., Reinhardt, B., Unglert, T., Wolber, M. (1997): Wissensbasierte Diagnose- und Informationssysteme mit dem Shell- Baukasten D3 – Handbuch, Lehrstuhl für künstliche Inteligenz und angewandte Informatik, Universität Würzburg