Chapter 6
EDIM: Earthquake Disaster Information System for the Marmara Region, Turkey

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Abstract The Istanbul Earthquake Early Warning and Rapid Response System has been established in the aftermath of the 1999 Kocaeli earthquake, and represents one of the few examples of operational earthquake warning systems in Europe. Several new methodologies and technologies have been developed in the 'environment' of this existing system in order to improve early warning but also validate methods and compare progress with the existing technology. Main improvements refer to testing and optimizing the existing system with a realistic catalogue of accelerograms, development of a self-organizing and distributed observational system in terms of hardware and communication software, and utilization of information technology. We thus improved the three relevant pillars of the early warning methodologies: Monitoring, warning, and communication.

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6.1 Introduction

The main objectives of EDIM were the enhancement of the existing Istanbul Earthquake Early Warning System (IEEWS) with a number of scientific and technological developments, which establish a transferable methodology and technology for early warning systems in general. The project focused on three topics: (1) analysis of and options for the improvement of the current IEEWS; (2) development of a self-organising sensor system and the exploration of its application potential to early warning and other items; (3) development of a geo-information infrastructure tuned to early warning purposes. These developments took place in the frame of the Istanbul system which allows testing the novel methodologies and studying their options for operational use. A critical condition for this was the close partnership with the Kandilli Observatory and Earthquake Research Institute (KOERI, Professor Mustafa Erdik).

EDIM is structured in three work packages dealing with real-time information from regional accelerometer networks (Work package A), the self-organising sensor system (Work package B); the geo-information infrastructure (Work package C). Project partners are the Karlsruhe Institute for Technology (KIT), Deutsches GeoForschungsZentrum Potsdam (GFZ), Humboldt Universität zu Berlin, Institut für Informatik, DELPHI Informationsmuster und Management GmbH, Potsdam, und lat/lon GmbH, Bonn.

6.2 Enhancement of the Current Early Warning System (KIT)

In order to study the performance of the current system and its expansion to the Marmara Sea region an accelerometric data set had to be generated. As the available strong motion data base in Western Turkey contains mostly events of the 1999 Kocaeli earthquake and subsequent aftershocks, and only few small magnitude events in the Marmara Sea appropriate data had to be synthesized. This data set consists of accelerograms for 280 earthquakes with magnitudes between 4.5 and 7.5 that are distributed in the Marmara Sea and the adjacent areas in a way that is compatible with historical seismicity. The accelerograms are simulated with FINSIM, which allows stochastic simulation of finite sources (Beresnev and Atkinson 1997). The program has been modified in order to include P-waves with special emphasis on the first few seconds which are relevant for early warning. A major effort has been made to make the synthesized data compatible with the observational data base. In addition we assured that the synthetic data fit the most recently developed attenuation relations for Western Turkey. Figure 6.1 shows the distribution of epicenters for the synthetic data set and also the location of the existing early warning stations (black triangles), as well as locations of early warning stations to be used in the future.

With this data base different options for warning systems could be evaluated. In a first step we studied the performance of the existing threshold based warning

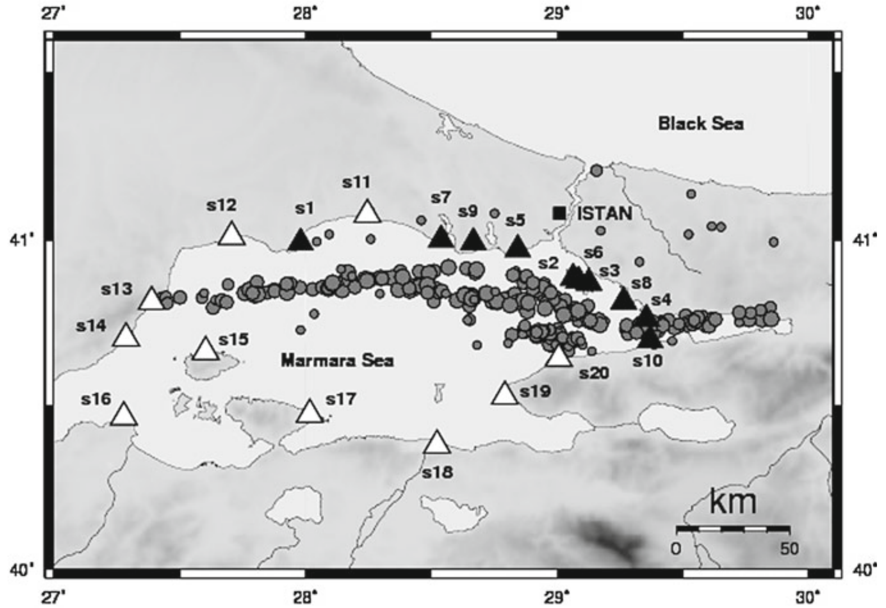

Fig. 6.1 Distributions of epicenters for the synthetic data set and location of the existing early warning stations (*black triangles*), as well as foreseen station locations (*white triangles*)

system. The IEEWS comprises 10 real-time three-component accelerometric sensors distributed along the shoreline of the Sea of Marmara (Fig. 6.1). The current system is based on three trigger thresholds that need to be exceeded at three or more sensors within 5 s before a warning is declared. The current thresholds are 0.02, 0.05 and 0.1 g, corresponding to warning class I, II, and III (Erdik et al. 2003). The current values have been chosen based on expert judgement without a clear quantitative relationship to the expected ground motion in Istanbul. In a first step we optimized these thresholds with the given station locations. For evaluation we used the criteria of properly classifying the events in three classes of ground motion in Istanbul and of the possibly shortest early warning time, with emphasis on the large events. For optimization a Genetic Algorithm has been used. The procedure is described in detail in Oth et al. (2010). It turns out that the trigger thresholds should be modified from the values given above to 0.03, 0.12 and 0.16 g. With this selection it is assured that all earthquakes which exceed a ground motion in Istanbul in excess of 0.12 g are classified as III and all smaller events are properly identified. The average warning time ranges between 5–6 s, but can as large as 20 s in certain cases. Another attempt has been made to optimize station locations and find optimum sites for ocean-based recording systems (ocean-bottom seismometer—OBS).

The early warning algorithm preSEIS, developed by Böse et al. (2008) had not been thoroughly tested before so that this became an important step in terms of evaluating its operational capacity. preSEIS is a neural network-based approach for early warning and has been compared with the ’virtual seismologist’ approach to Southern Californian data (Köhler et al. 2009a). In addition preSEIS has been tested with data of the Japanese K-NET network where 69 earthquakes in the magnitude range of 3.8–7.2 have been selected; 66 of those were used for training and 3 were tested for early warning. This real-date example provides very good performance values for preSEIS (Köhler 2010). preSEIS is used in the context of the IEEWS as a benchmark system, which is assumed to provide the best possible performance of an early warning system, against which different installations of instruments or other warning types such as the actual used threshold based method can be compared. With this approach the added value of the installation of additional stations could be studied. The additional foreseen installation would improve the early warning time by second to seconds. However, it requires a change in threshold values (Köhler et al. 2009b).

The availability of a high quality synthetic data set allows simulating scenario earthquakes such as the 1509 earthquake. This earthquake had a magnitude of 7.3 and caused severe damage in the Istanbul area. Presumably a 70 km long segment ruptured. Using the damage estimation service developed by DELPHI in the context of EDIM the damage that would occur on the nowadays building structure in Istanbul could be estimated for the scenarios.

6.3 The Self-Organizing Seismic Early Warning Information System (GFZ Potsdam)

The Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, as part of its commitment to the EDIM project and in cooperation with the Humboldt Universität zu Berlin (HUB), developed the Self-Organising Seismic Early Warning Information Network (SOSEWIN). SOSEWIN is a completely new generation of early warning systems, based on low-cost sensors (taken originally from the air-bag system of the car industry) that are connected and wireless communicating with each other in a decentralized people- centred and self-organizing observation- and warning network. The vision for the future is to integrate SOSEWIN into existing standard seismic early warning (EW) and seismological monitoring systems (Fig. 6.2).

Furthermore, dedicated software was developed with the primary goal of performing real-time seismological analysis for seismic EW (Fig. 6.3). Considering the early warning requirement of issuing ground-motion estimates as quickly as possible, the general scheme designed for real-time processing involves local, relatively simple, rapid, and robust analysis of data (Fig. 6.3). The SOSEWIN’s analyses of the earthquake’s initial *P* waves allow the event detection, as well as the estimation of parameters that allow some indication of the severity of the ground motion, and the epicentral area localization. Moreover, in cooperation with the HUB, a decentralized decision-making approach, which is termed ‘Alarming Protocol’ and where the information obtained by the single SOSEWIN nodes are combined and used for seismic early warning purposes, was developed (Fig. 6.3).

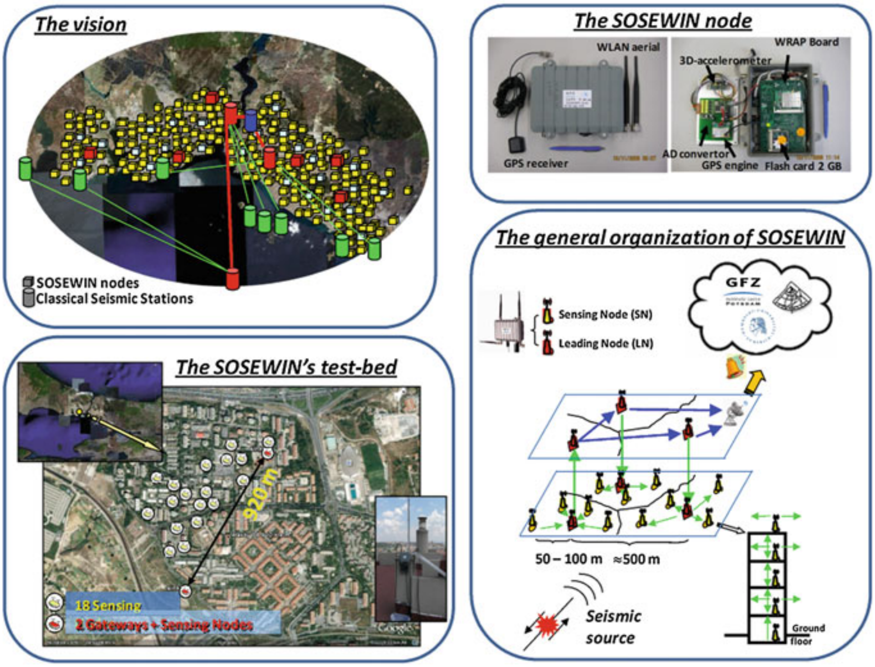

Fig. 6.2 Overview of the self-organizing seismic early warning information network (SOSEWIN)

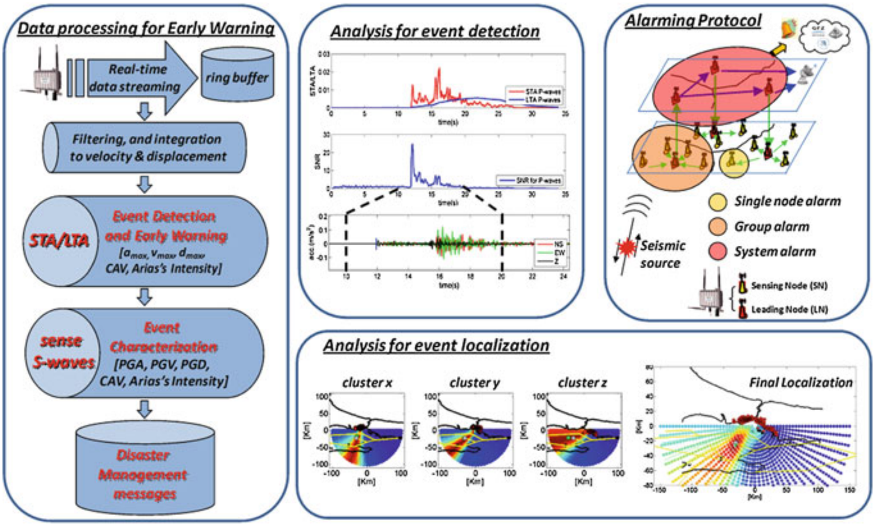

Fig. 6.3 Summary of the SOSEWIN's analyses

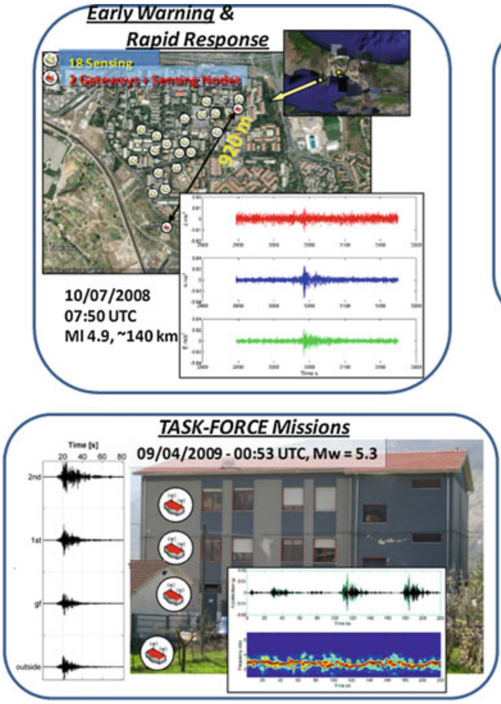

Fig. 6.4 Overview of the SOSEWIN applications

Besides the seismic early warning, the SOSEWIN system was successfully tested in the framework of: an Earthquake Task Force Mission following the L'Aquila (Italy) seismic sequence 2009 (Picozzi et al. 2009a), the monitoring of the vibration characteristics of the Fatih Sultan Mehmet Bridge in Istanbul (Turkey) (Picozzi et al. 2010), and the study of the subsoil characteristics which affect the ground motion during earthquakes (Picozzi et al. 2009b), (Fig. 6.4).

Finally, it is worth to mention that the SOSEWIN system already attracted the attention of both the scientific community and the industry. In fact, we were contacted both by a company of the oil-industry whether a commercial product is available which can be used in site early warning (e.g. refinery), and by international colleagues for future cooperation on this approach in seismic early warning for Megacities (e.g. China). Hence, this was the trigger that the GFZ Potsdam and the HU Berlin agreed to develop a concept for a commercial SOSEWIN-product with focus on seismological early warning. Indeed, in cooperation with a company we are planning to further develop the hardware and software as technology transfer from within the GEOTECHNOLOGIEN program to a commercial application.

6.4 Infrastructure of Self-Organizing Sensor Systems (HU, Computer Science Department)

The Self-Organizing Seismic Early Warning Information Network (SOSEWIN), which has been developed within the EDIM project, is technically a decentralised, wireless mesh sensor network, made up of low-cost components, with a special seismological application that supports earthquake early warning and rapid response tasks. The contribution of HUB was the development of the system software for the sensor nodes and the Alarming Protocol responsible for cooperatively detecting and distributing alarms throughout the network (Fig. 6.5).

- The basic operating system with self-organising routing software. A Linux operating system Pen WRT (OpenWRT 2010) was configured and for wireless communication capabilities a self-organising mesh network routing protocol (olsrd 2010) was identified.
- The integration of the acceleration sensors (coupled with GPS) into the system. A self-written data-provider is able to deliver the sensor's data to a Seedlink server, the Alarming Protocol or with its plug-in architecture to any other conceivable processing software.
- The developed Alarming Protocol, which is responsible for a collaborative decision within the network about an earthquake event and the distribution of an alarm message. Following a model-based development approach, the Alarming Protocol is based on common structure and behavioural models. The Alarming Protocol is defined using a formal description language (SDL in addition with ASN.1/UML/C++) (Ahrens et al. 2009). Using such a formal model, code for

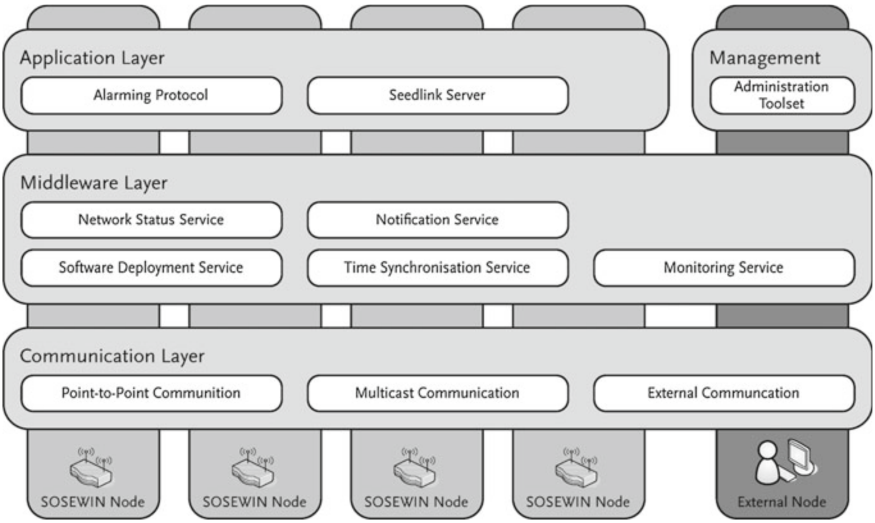

Fig. 6.5 An overview of the current SOSEWIN layer architecture with several services

the target hardware platform (sensor nodes) and for different kinds of simulators supporting different experiment scenarios (including the system's environment) is generated.

- Self-written components realizing the several network middleware services. The Network Status Service allows external users to access the network topology with link qualities for management purposes. An administrator can update the software easily via the Software Deployment Service remotely. The Notification Service allows external users to register for receiving earthquake or other imaginable alarms. For example, such a user is the web service infrastructure developed by lat/lon in WP C2. The Time Synchronisation Service allows nodes without receiving a GPS signal to synchronize their clocks to other nodes having a GPS connection.

In cooperation with the Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences and the kind support by our Turkish partner, KOERI, 20 SOSEWIN nodes were deployed in 2008 in the Ataköy area of Istanbul as a real-world installation. 18 nodes were deployed at the rooftops of 13-story buildings. Additionally two nodes have the role of internet gateways (DSL connections) at different places. Till the end of the project, this installation has been running for nearly two years. After learning the first lessons, this period was nearly without outage for one and a half year. During the last winter some nodes broke down and may need on-site-maintenance now (most likely due to the problems of a long-time outdoor deployment of such hardware). Nevertheless, the remaining network is still operable and providing data, which proofs the robustness and self-organizing idea of such a network.

Our model-based development and experimentation approach (Fischer et al. 2009) allows us to observe the behaviour of the Alarming Protocol model in different execution environments (several simulators, a virtual network or the Ataköy installation) and improve the same model by these different observations. For that, a complex toolchain was set up, managed by a self-developed Experiment Management System (EMS) in addition to a Geographic Information System (GIS). All tools are integrated in our GIS-based Development and Administration Framework for Wireless Sensor Networks GAFA4WSN (GAF4WSN Framework 2010). With this infrastructure, large networks with thousands of nodes can be simulated in their behaviour, visualized and evaluated. It allows also monitoring and administrating the prototype SOSEWIN installed in Istanbul.

Together with the development of the Alarming Protocol, different types of simulators have been developed, which focus on different aspects of the system, completely integrated into the EMS:

- A simulator based on the ODEMx framework (ODEMx 2011). Simulations with this simulator mainly focus on the validation and evaluation of the alarming protocol. For simplification, it abstracts just to the application level and contains only a very simplified network-stack model.
- A simulator based on the ns-3 framework (The ns-3 network simulator 2010). This simulator focuses on the wireless networking part with its challenges and yields results about warning times in a more realistic network model. Results

obtained from experiments done with increasing network size (up to 255 nodes) show that the difference between system alarm and first p-wave detection time does not depend on the size of the network. Thus, increasing the number of nodes will lead to a better coverage of an area without having a substantial effect on the performance of the alarming protocol.
- An emulation of a SOSEWIN network with virtualized nodes that runs exactly the same software as it is deployed on the real sensor nodes, but allows larger number of nodes and faster testing than deploying software on the real nodes.

Several experiments with different synthetic earthquakes and different distances to the sensor network were done with 8 nodes of the SOSEWIN prototype in Istanbul. The mean alarming delay (the time between the first P-wave arriving at the network and the emerged system alarm) averages 1.9 s (min: 0.56 s, max: 4.8 s). The evaluation has shown that the most time was consumed for the communication between the nodes, which was quite slow due to the fact that, as already mentioned, several nodes broke down. This caused several weak links between the nodes. Another reason was the small number of only three cluster heads in the Alarming Protocol, which means that all cluster heads have to emerge a group alarm in order to generate a system alarm. But several experiments with alarming delays around and in less than 1.0 s proof the potential of the SOSEWIN early warning system, especially for large and denser network installations.

6.5 Development of a Dynamic Geoinformation-Infrastructure (DELPHI IMM GmbH, Potsdam)

The aim of the project is to improve and enhance the existing Istanbul Earthquake Early Warning System (IEEWS) in different ways. As part of the EDIM project our working package deals with the provision of earthquake information to users. In the field of disaster management a lot of earthquake information must be collected, analyzed and published long before (planning period), short time before (early warning) and short time after an earthquake happened (rapid response). For every period it is necessary to provide all important information to planning authorities as well as to decision-makers. We decide for a mediation system (web portal) to provide quickly earthquake information to many special user groups. We focus on information about building damage due to earthquake which could be a serious problem for the rapidly growing Megacity Istanbul which is less than 10 km away from the Marmara Fault. Therefore, it is an interface to working packages A and B by using for example the geophysical result as input for calculating the impact on population (Fig. 6.6).

The mediation system consists basically of a MapClient with typical MapClient functions for navigation and layer configuration. Beyond these functions, the EDIM mediation system offers special useful tools improving the earthquake interpretation.

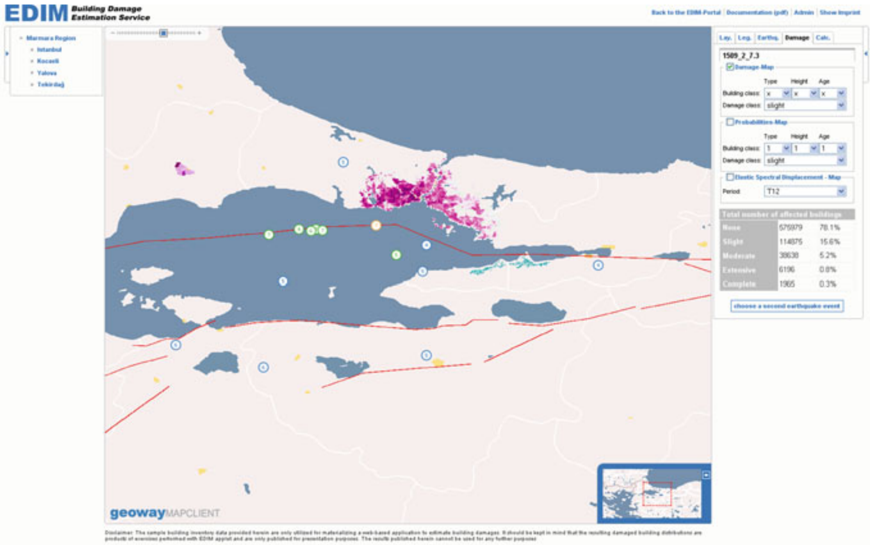

Fig. 6.6 EDIM mediation system

For example, visualized earthquakes can be filtered according to date or magnitude. Building damage information can represent each building class, damage class and moreover it can be filtered according to particular building properties, i.e. only multi-story buildings were taken into account. Two earthquake events can then be compared regarding visual and statistical differentiations.

In addition to this map representation, the mediation system integrates an online service for estimating building damage in order to produce very quickly new information layer. Consequently, a rapid assessment of damage distribution or cost estimations of past earthquakes can be done. Another field of application having emerged during the project term is the use of the system as a validation tool for synthetically computed earthquake scenarios. A performance-based procedure (FEMA356) is used, which was adopted to Istanbul by KOERI (Kandilli Observatory and Earthquake Research Institute, Bogazici University, Istanbul, Turkey). KOERI gave input for software requirements by providing and validating the implemented calculation method. Results were presented several times to KOERI and AKOM (Centre of Disaster Management) in Istanbul during the project term.

Earthquake information and building inventory are required as input for the service DES (Building Damage Estimation Service). A checking verifies the technical and structural input data quality since DES needs a special kind of data quality like data format, cell size and associating index. On the one hand DES has been required to be transferable to other regions, at least for the greater Marmara region. On the other hand, the building damage estimation service can only be performed for the Istanbul building classification as only the behaviour of all these building types is known.

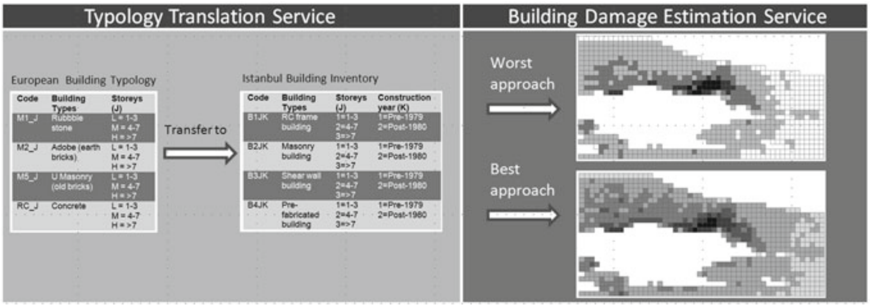

Fig. 6.7 Using semantic interoperability for classification mapping

For this aspect of reuse data or services, a 'typology translation service' has to be interconnected between input and DES in order to establish semantic interoperability. The typology translation service' matches a source data classification to a target data classification. Figure 6.7 shows the European Building Typology in contrast to the Istanbul Building Inventory.

Some object types of the source data classification have an ambiguous matching to the target data classification compared to others which have not. For this reason we propose a best and worst approach. This approach is based on a vulnerability matrix for all combinations of building class and damage class. The most vulnerable adequate object type—taking only similar object types into account—serves as matching point for the worst method and in contrast to the least vulnerable object type for the best method. Heterogeneous earthquake data is supported as input as well. In conclusion, the building damage estimation service (plus further services) gives not only an assessment of the impact on buildings due to earthquakes but also handles heterogeneous input datasets from different data sources, different authorities or collected by different measurements. Therefore, it is a precondition that a defined minimum of information in the dataset is available.

As Istanbul is a rapid growing metropolitan area it could be very interesting to get a new collection of its building inventory. The last data collection refers to 2000. Our idea to tackle this problem was to acquire geographic datasets on our own by classifying earth observation data which provide rapid mapping and topical information. We opt for TerraSAR-X sensor regarding independency of sunlight and cloud cover as well as providing high-resolution radar images maximum in two days. A TerraSAR-X scene for the centre of Istanbul was offered from the company Infoterra Germany, thanks to them, as basis for the extraction of input parameters for DES and a land cover classification according to MOLAND (Fig. 6.8). Reflection of radar data are dominated by surface roughness and surface material. Reflection could be a hint of the building material. The radar phenomenon of the reflection shade can be used to extract building heights. The phenomena of foreshortening and layover have to be considered by interpretation of radar shades.

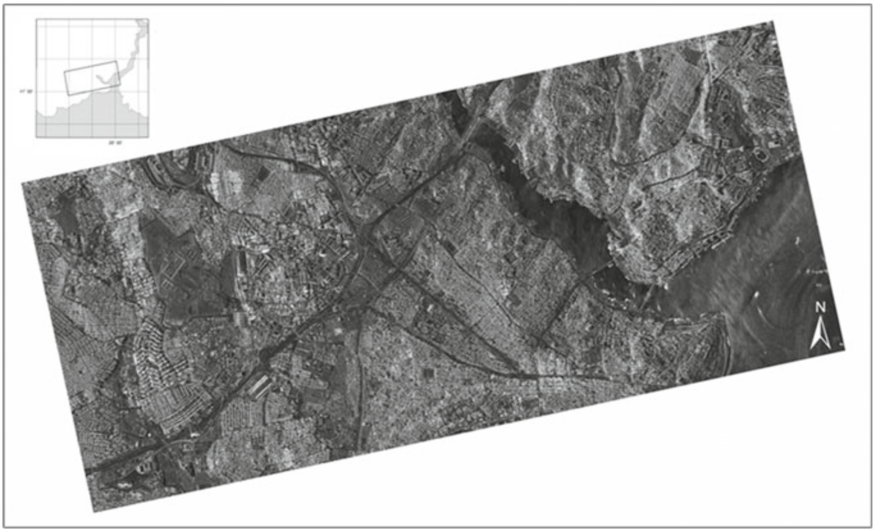

Fig. 6.8 TerraSAR-X sensor data for the centre of Istanbul; © 2008 Astrium Services / Inforterra GmbH

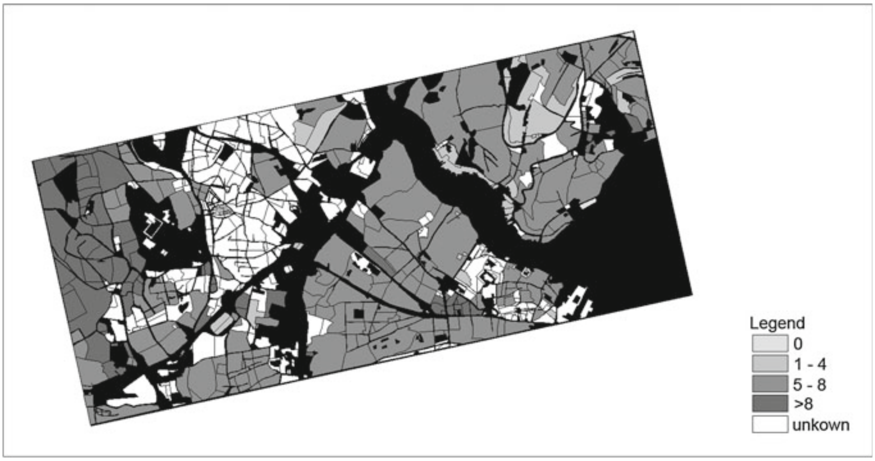

Fig. 6.9 Derivation of building heights (storeys) based on TerraSAR-X sensor data

The height derivation for the city of Istanbul was limited because of high-density area, hilly terrain and a lack of homogenous buildings (Fig. 6.9). The problem of hilly terrains could be solved with satellite TanDEM-X. Together with the almost identical radar satellite TerraSAR-X it will form a high-precision radar interferometer.

6.6 Conclusions

The integration of strong motion seismology, sensor system hard- and software development, and geoinformation real-time management tools prove a successful concept in making seismic early warning a novel technology with high potential for scientific and technological innovation, disaster mitigation, and many spin-offs for other fields. EDIM can serve as a model for further developments in the field of early warning on a global scale.

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