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DEVELOPMENT OF A GIS-ORIENTED DATABASE FOR THE PRE- AND POST-EARTHQUAKE ASSESSMENT OF BUILDINGS

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ABSTRACT

The paper presents a comprehensive strategy for rapid visual inspection of buildings and optimal prioritization of strengthening or remedial actions that are necessary prior to, or after, an earthquake event, respectively. Based on the FEMA procedures and the experience gained in the framework of building assessment in Greece, a building inventory and ranking algorithm is created for the case of the city of Düzce, in Turkey, a city strongly damaged during the devastating 1999 earthquake. Moreover, a multi-functional computer tool is developed for the management, evaluation, processing and archiving of the data stock gathered during the pre / post earthquake assessment process. The database core is reflected in real time onto a multi-layered GIS platform offering quick visualization of the spatial distribution of the pre-earthquake building condition, as well as of damage after an earthquake. As a pilot study, the data acquired on site are wirelessly synchronized with the use of a Personal Digital Assistant (PDA) contributing to the reduction of the time required for information gathering. By applying the proposed strategy and using the GIS-oriented database for the case for the case of a city already hit by a strong earthquake, the local authorities are equipped with a decision-making and risk management tool that is currently installed, tested and operating in real conditions.

Introduction

The August 17, 1999 Kocaeli earthquake, of magnitude 7.4, is one of the most destructive events ever to strike Turkey. This earthquake, also known as Izmit earthquake, occurred at 03:02 local time with epicenter at 40.702° N., 29.987° E., that is, about 11 kilometers (7 miles), southeast of the city of Izmit. On November 12, another major earthquake of 7.2 magnitude occurred 70 km east of Adapazari at 18:57 local time, resulting to heavy losses in the city of Düzce and affecting a population of more than 150,000, as well as causing heavy damage to more than 800 buildings (Ansal et al., 1999, Durakal, 2000, Youd et al, 2000). Since 2002 and within the framework of the European Union Research Project entitled "Marmara Earthquake Rehabilitation Project" (Europeaid/112976/D/G/TR) an effort was made to develop a computer-based risk management scheme for the city of Düzce built on a GIS-oriented database. The aim

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was to electronically organize, couple and visualise all data related to three principal engineering procedures that were already, or would be implemented in the particular city:

a) the *Pre-earthquake Assessment* of buildings in the city, which is aimed at evaluating the safety level of public buildings against the maximum expected seismic action, and the prioritization of strengthening activities in order to assure the serviceability of critical facilities after a major earthquake event.

b) the *Post-earthquake Inspection* of buildings, which allows the local and central authorities to obtain a quick but detailed statistical overview of potential damage (in terms of spatial distribution, degree, and total number of buildings associated with a particular damage level), thus assisting in organizing the required remedial and recovery measures.

c) the *Management of the 1999 Earthquake Damage Data* for buildings in the city, as a reference point for the two procedures described above.

Clearly, apart from the computational framework of the aforementioned procedures, the core engine is inevitably the building evaluation process to be followed as related to the (pre / post) earthquake assessment methodology adopted, and the corresponding 'scoring' algorithm. Based on international experience, as reflected in ATC-13 (1985) and ATC-38 (2003), which primarily refer to California building types, UNDP/UNIDO (1985) for the Balkan countries, the FEMA 154-ATC 21 (2002) and the FEMA 310 (1998) documents for rapid visual screening, as well as on the long established experience in assessment of buildings in Greece (Penelis & Kappos, 1997, Kappos, 1997, Stylianidis et al., 2003a, Stylianidis et al., 2003b) and Turkey (Spence et al., 2002, Ansal, 2003), a comprehensive methodology was set up, considering the particular requirements of the target area (seismotectonic environment, legislative and administrative framework, and building typology).

Furthermore, an attempt was made to utilize existing state-of-the-art knowledge in Information Technologies (IT) to reach the following three main goals:

a) Reduce the time required to gather information and share it with the authorities. This effort is inspired by the track-beating ATC-20i (2003) approach which incorporates a Personal Digital Assistant (PDA) as a means to eliminate the time spent in filling-in and processing the post-earthquake inspection forms (only), but is extended herein for the case of a joint management of the pre- and post-earthquake assessment procedures. Moreover, this is achieved through a unique database, handling both assessment procedures.
b) Visualize in space and in (real) time all the data related to the evaluation process though a GIS connection, an effort that FEMA154 (2002) considers as 'beyond its scope'.
c) Enhance the reliability of collected data with the implementation of internal logical error checks based on an expert system that attempts to spot out potential conceptual controversies of the data as they are input in the system.

The computer tool developed in this context is essentially a multi-purpose decision making scheme that is capable of significantly increasing the effectiveness of earthquake assessment process. It is also noted here that this tool is already implemented in the city of Düzce where the know-how transfer has been completed. The main aspects of the methodology adopted, as well as the GIS-oriented database architecture are presented in the following.

Overview of the methodology for pre / post earthquake assessment

Pre-earthquake Rapid Visual Inspection (RVI) is normally carried out on important and/or public buildings, and aims at assessing their seismic capacity and setting priorities for strengthening/upgrading schemes. In general, ranking of building is performed on the basis of qualitative, and some times, quantitative criteria, which involve the period of construction (or seismic code used), the structural system, the level of seismic hazard (or the seismic zone according to existing codes), the regularity of the building in plan and elevation, the existence of short columns, as well as the regularity of the infill distribution. The lower the building score, the more inferior the anticipated seismic performance of the building is, and thus the priority of strengthening is higher. For the case of the city of Düzce, a simplified standard form was prepared for data collection, mainly based on the forms proposed in the Istanbul Master-plan study (Ansal et al., 2003). Both the hardcopy Pre-earthquake Inspection Form (sheet) and the electronic database record consist of five sections distinguished according to the nature of the information they refer to. More specifically, Section A contains the building identification data, Section B the building's technical characteristics, Section C the relevant seismological and geotechnical data, Section D the data related to the structural system, while Section E summarizes the structural characteristics of the building that affect its seismic performance. With respect to the structural system in particular, different typologies have been adopted based on the Turkish and Greek experience, which have resulted to the area-specific updated structural typology matrix summarized in Table 1. The developed rating scheme ('scores') is summarized in Table 2; this scheme can also be used in most other areas of Turkey.

The adopted Post-Earthquake Quick Inspection Form on the other hand, is based on the one issued by the Turkish Ministry of Public Works and Settlement – General Directorate of Disaster Affairs (1999). It is based on a coupled system of 12 qualitative and quantitative criteria for ranking the structures on the scale of 'Inspected' (or 'checked'), 'Limited Entry', and 'Unsafe', for two main categories of damage (structural and non-structural). For both cases, the most unfavorable ranking among the structural and non-structural section, is taken into consideration. For instance, according to this procedure, if the structure is characterized as 'limited entry' according to 11 criteria, but ranked as 'unsafe' depending on a single criterion that is related to its structural performance, then it is considered as 'unsafe' as a whole. This approach is in fact very similar to that of the US guidelines, in particular ATC-20 (2005), which also prescribes rapid and detailed evaluation procedures for ranking buildings as 'Inspected' (green placard), 'Restricted use' (yellow placard) or 'Unsafe' (red placard). It is also interesting to note that the severeness of column damage is assessed for the most heavily damaged story and depends on the percentage of columns that have exhibited a particular level of damage. In case that damage is clearly very heavy or remarkable inclination of a story is observed or the structure is offset from its foundation, the building is directly characterized as unsafe and the detailed assessment procedure is omitted. In general, it can be stated that the aforementioned quick inspection form, although simple at its rationale, is slightly more complex than the one used in Greece, issued by the Earthquake Planning and Protection Organization (Ministry of Public Works, 1997) during the preliminary assessment of buildings following a strong earthquake. This form is also filled out after a qualitative visual inspection by trained engineers, and offers a quick overview of the extent of damage, before applying the more detailed and qualitative second level assessment, to decide on the structural integrity of buildings.

Figure 1: Building damage from the November 1999, Ms=7.2 earthquake (PEER, 2000).

Table 1: Proposed building typology matrix for the area of Düzce

	structural type	Structure's description	Seismic Code
REINFORCED CONCRETE	RC1	Reinforced concrete building (Beam-Column framed system)	pre 1975
	RC2	Reinforced concrete building (columns and some concrete shear walls)	pre 1975
	RC3	Reinforced concrete dual building (columns and adequate concrete shear walls having an area ≥0.5% the total area of floors)	pre 1975
	RC4	Reinforced concrete building (Beam-Column framed system)	post 1975 – pre 1998
	RC5	Reinforced concrete dual building (Beam-Column framed system)	post 1975 – pre 1998
	RC6	Reinforced concrete building (Beam-Column framed system)	post 1998
	RC7a	Reinforced concrete dual building (frames and concrete shear walls)	post 1998
	RC7b	Reinforced concrete box/tube or cell system (tunnel formwork system	post 1998
PRE-CAST	PR1	Prefabricated reinforced concrete frame building	
	PR2	Prefabricated reinforced concrete shear wall building	
MASONRY	URM1	Unreinforced masonry buildings, mainly in hewn stone, without diaphragms at floor levels or belts	
	URM2	Unreinforced masonry buildings with diaphragms at floor levels	
	CM	Unreinforced masonry buildings with R/C diaphragms at floor levels and R/C belts	
	RM	Reinforced masonry buildings with R/C diaphragm at floor levels and R/C belts	
	SM	Unreinforced masonry buildings strengthened with belts, diaphragms and one-sided or two sided R/C jackets appropriately connected to the masonry and resting on adequate foundations	
STEEL	ST1	Single storey instudial builidngs	a) pre 1975, b) post 1975-pre 1998, c) post 1998, d) DIN or other foreign codes
	ST2	Multi storey buildings consisting of 3D steel frames with or without vertically-oriented inclined steel braces	a)pre 1975, b) post 1975-pre 1998 c) post 1998, d) DIN or other foreign codes

Table 2: Proposed rating scheme (scores) for the pre-earthquake assessment of buildings

Material	Structural type	Initial score	Seismic Zone Factor according to Turkish Seismic Zonation				Soil Factor according to Turkish Code categorization			
			I	II	III	IV	Z1	Z2	Z3	Z4
REINFORCED CONCRETE	RC1	+3.0	-1.5	-1.0	-0.5	0	0	-0.3	-0.6	-0.8
	RC2	+3.5	-1.5	-1.0	-0.5	0	0	-0.3	-0.6	-0.8
	RC3	+4.0	-1.5	-1.0	-0.5	0	0	-0.3	-0.6	-0.8
	RC4	+4.0	-1.5	-1.0	-0.5	0	0	-0.3	-0.6	-0.8
	RC5	+4.0	-1.5	-1.0	-0.5	0	0	-0.3	-0.6	-0.8
	RC6	+5.0	-1.0	-0.5	-0.5	0	0	-0.3	-0.6	-0.8
	RC7a	+5.0	-1.0	-0.5	-0.5	0	0	-0.3	-0.6	-0.8
	RC7b	+5.5	-1.0	-0.5	-0.5	0	0	-0.3	-0.6	-0.8
PRECAST	PR1	+2.0	-1.0	-0.5	-0.5	0	0	-0.3	-0.6	-0.8
	PR2	+3.5	-1.5	-1.0	-0.5	0	0	-0.3	-0.6	-0.8
MASONRY	URM1	+2.5	-1.5	-1.0	-0.5	0	0	-0.3	-0.6	-0.8
	URM2	+3.0	-1.0	-0.5	-0.5	0	0	-0.3	-0.6	-0.8
	CM	+3.5	-1.0	-0.5	-0.5	0	0	-0.3	-0.6	-0.8
	RM	+4.0	-1.0	-0.5	-0.5	0	0	-0.3	-0.6	-0.8
	SM	+3.5	-1.0	-0.5	-0.5	0	0	-0.3	-0.6	-0.8
STEEL	ST1	+7.0	-1.0	-0.5	-0.5	0	0	-0.3	-0.6	-0.8
	ST2	+4.0	-1.0	-0.5	-0.5	0	0	-0.3	-0.6	-0.8

	Structural Vulnerability Scoring Parameters											
	No seismic code applied	Modification of use	Damaged by a previous quake	Inadequate maintenance	Pounding possibility	Soft Storey	Irregular infills	High rise building	Irregularity in height	Irregularity in plan	Possibility of torsion	Short columns
	XAK	AX	PE	KK	KR	PILO	TOI	MY	MK	OMK	STRE	KY
RC1	-0.5	-0.5	-1.0	-0.5	-0.5	-1.5	-0.5	-1.0	-1.0	-1.0	-0.5	-0.5
RC2	-0.5	-0.5	-1.0	-0.5	-0.5	-1.5	-0.5	-1.0	-1.0	-1.0	-0.5	-0.5
RC3	0	-0.5	-1.0	-0.5	-0.5	-1.0	0	-1.0	-1.0	-1.0	-0.5	-0.5
RC4	0	-0.5	-0.5	-0.5	-0.5	-1.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
RC5	0	-0.5	-0.5	-0.5	-0.5	-1.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
RC6	0	-0.5	-0.5	-0.5	-0.5	-1.5	0	-0.5	-0.5	-0.5	-0.5	-0.5
RC7a	0	-0.5	-0.5	-0.5	0	-1.5	0	-0.5	-0.5	-0.5	-0.5	-0.5
RC7b	0	-0.5	-0.5	-0.5	0	-1.5	0	-0.5	-0.5	-0.5	-0.5	-0.5
PR1	0	-0.5	-1.0	-0.5	-0.5	-1.5	0	-0.5	-1.0	-1.0	-1.0	-0.5
PR2	0	-0.5	-1.0	-0.5	-0.5	0	0	-0.5	-1.0	-1.0	-1.0	-0.5
URM1	-0.5	-0.5	-0.5	-0.5	-0.5	0	0	-0.5	-0.5	-1.0	-1.0	-0.5
URM2	-0.5	-0.5	-0.5	-0.5	-0.5	0	0	-0.5	-0.5	-1.0	-1.0	-0.5
CM	-0.5	-0.5	-0.5	-0.5	-0.5	0	0	-0.5	-0.5	-1.0	-1.0	-0.5
RM	-0.5	-0.5	-0.5	-0.5	-0.5	0	0	-1.0	-0.5	-1.0	-1.0	-0.5
SM	-0.5	-0.5	-0.5	-0.5	-0.5	0	0	-1.0	-0.5	-1.0	-1.0	-0.5
ST1	-0.5	-0.5	-0.5	-0.5	-0.5	0	0	0	-0.5	-0.5	-1.0	-0.5
ST2	-0.5	-0.5	-0.5	-0.5	-0.5	0	0	0	-0.5	-0.5	-1.0	-0.5

Overview of the GIS-oriented Database

Scope and goals

Having established the strategy for assessing the structural integrity of buildings prior to and after an earthquake event, a coupled GIS and database environment was developed for the electronic management of all collected data. The key idea was to develop a database that would offer more than a storage tank. Its scope was to closely simulate the (pre / post earthquake) quick inspection forms through an appropriate database interface (ideally filled out on-site, using a PDA), automatically compute the building scores, and finally rank and classify the buildings according to the adopted methodology. Moreover, it was aimed to establish a unique relation between the 1999 earthquake damage data for buildings (inclusive of retrofitting schemes and associated costs), their current vulnerability and their expected performance in a future strong earthquake. As a final step, the input data as well as the derived pre/post-earthquake assessment results should be synchronized and visualized on a GIS platform, thus allowing the statistical processing of data and the visualization of its spatial distribution. As mentioned earlier, the wireless data transmission was first suggested in the ATC20i (2003) document, while an advanced GIS representation of various assessment and seismic hazard data has been presented in Turkey in the Istanbul Earthquake Master Plan (Ansal, 2003), and Early Warning System (Erdik et al, 2003), as well as in other countries (e.g. O'Rourke et al., 2001). The database presented herein additionally aims at integrating the pre/post-earthquake assessment data, their visualization on GIS, and the expert system for rating/scoring that is specifically developed for the city of Düzce, all into a comprehensive computer framework.

Database Architecture

The system developed has to be installed at an operating server located either in an administration building or, in case of an earthquake, on a portable computer to control the data flow during a field campaign. Depending on the expertise of the local engineers responsible for assessing the buildings and the available hardware, either the quick inspections forms are filled out in hardcopy form or a PDA is used for direct data input. The database is built using Microsoft Access and is internally programmed using the Visual Basic for Applications (VBA) programming language and Structured Query Language (SQL) for particular data filtering. The former is also used for structuring a framework of logical checks that eliminate the possibility of inconsistent data input. This engine prevents particular combinations of vulnerability observations and building types, inconsistent geometrical characteristics, typing and numbering errors, etc. The data are recorded into three relational tables (for pre- and post-earthquake assessment, and building common profile) consisting of a large number (102) of data fields. An appropriate interface has also been designed for displaying the interactive quick inspections forms, as can be seen in Figure 2. A switchboard is used to facilitate navigation between the available forms and the main modules for data reporting, charting, printing and saving. The electronic database automatically provides all the statistics of the data while it communicates directly with a GIS environment (Figure 3) for visualization of the assessment results in space, implemented using MapInfo (2001) software and specific workspaces. The system was developed on the particular database and GIS software combination based on the tools already available in the city of Düzce and the end-user particular requirements, but can easily be adapted to other packages.

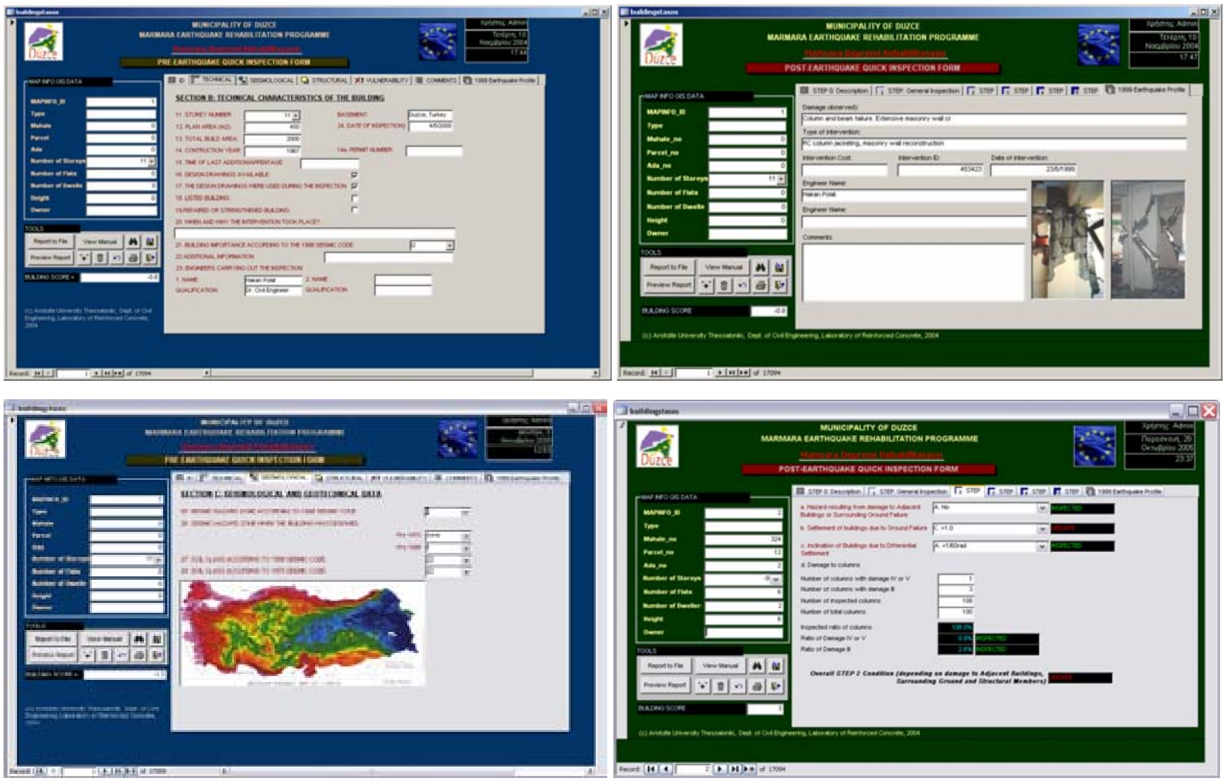

Figure 2: Electronic pre- and post-earthquake quick inspection form

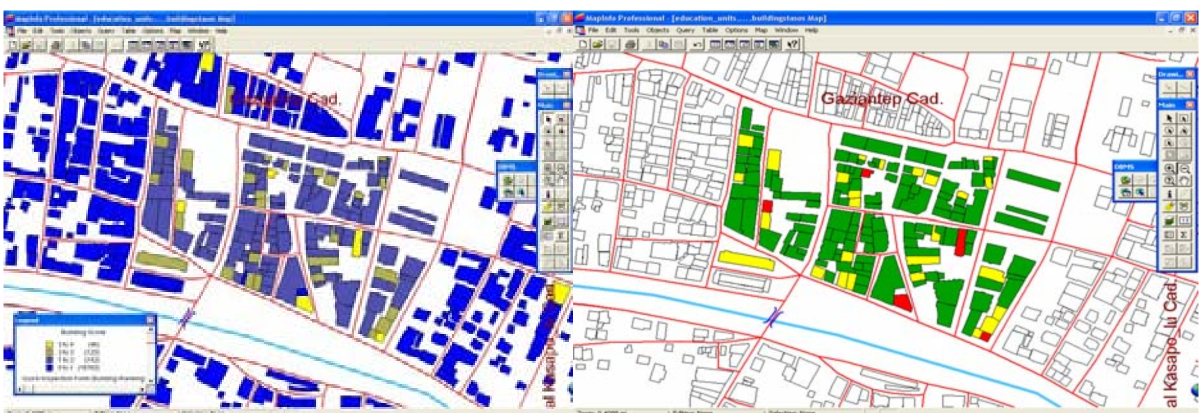

Figure 3: Automatic visualization on a GIS of the spatial distribution of the pre-earthquake building scores (left) and the post-earthquake (right) damage evaluation (green, yellow, and red placards)

A common (mdb) file is used for both the database and the GIS, in order to avoid import and export procedures for data exchange and allow the two components to interact directly, thus immediately reflecting all database changes onto the GIS and vice-versa (i.e. data flow is both ways). The tool is provided with setup files, for ensuring the installation of all the components into the appropriate folders, as well as an accessible on demand user's manual. The tool supports easy-to-use built-in (selective or global) printing facilities, storage and export to alternative types of files (Excel spreadsheet, MS document, Rich-Text Files), for further processing and archiving. The overall system structure is illustrated in Figure 4.

Direct Synchronization with a Personal Digital Assistant hand-held application

Another feature of the coupled database and GIS environment is that it can be fully synchronized with a PDA, either using a Bluetooth protocol or remotely through a GSM/GPRS connection. In this way, not only the data can be made available on the field, but they can also be modified or improved on site. In the particular case of the city of Düzce, pre-assessment and post assessment structural data for 17096 buildings have been transferred to the PDA (Pocket pc) using the Data on the Run (Biomobility, 2004) Microsoft Access emulator to overcome the lack of Pocket Access software. It is notable that at the time that the field demonstration took place (i.e. spring 2004) higher bandwidth 3G networks were not operating in the area of application, hence a connection was established using a remote Ipaq pocket pc (with Microsoft Windows Mobile 2003 operating system) and the modem of a common Nokia 6210i cell phone activated on a Bluetooth protocol and connected to the available service provided. It is clear, that as the phone and the PDA devices have been nowadays integrated into a unique cell phone (i.e. an Ipaq 6315 or a 3G mini laptop is more than adequate), the data transmission is significantly improved and will be even more efficient in the near future. As a result, it is considered that the wireless connection of the core GIS-based database with a remote hand-held device on the field is not only feasible but a very promising solution towards speeding up of the data gathering process.

Advantages of the adopted approach

The overall approach and aforementioned coupled GIS-database environment has a number of technical, functional and management advantages, which are summarized below. In particular, the database system developed:

- Implements the Pre- and Post-earthquake procedures developed by Greek and Turkish experts, as well as by the local authorities, which were further tailored to the particular characteristics of the target area.
- Maximizes the benefit to the Düzce local authorities by developing modules on software platforms that are already available and operative at the municipality level. This benefit is further strengthened by the systematic training of the Düzce municipality team on the use of the new software tools developed.
- Makes full use of the digital background prepared by the Municipality of Düzce containing a total of over 17000 buildings.
- Allows for import of new buildings (in particular those in the new quarters of the city, built after the 1999 earthquake) or removal of buildings that have collapsed or been demolished; there is no practical limit in the building number to be stored.
- Allows for the auto-correction of potential mistakes and inconsistencies that may occur during the on-site filling out of the quick inspection forms, since it automatically calculates the corresponding damage-related ranking (for post-earthquake assessment) or the building score (for pre-earthquake assessment), at each step of the methodology.
- Most of the fields are ‘locked’ and only pre-selected answers can be used, while numerical calculations are performed internally, hence minimizing human error.
- The information related to the performance of buildings during the 1999 earthquake is visible through both the pre- and the post-earthquake forms. Moreover, the data regarding the building identity is common between all forms and has to be entered only once.
- There is no actual need to import/export data between the Database and the GIS platform.

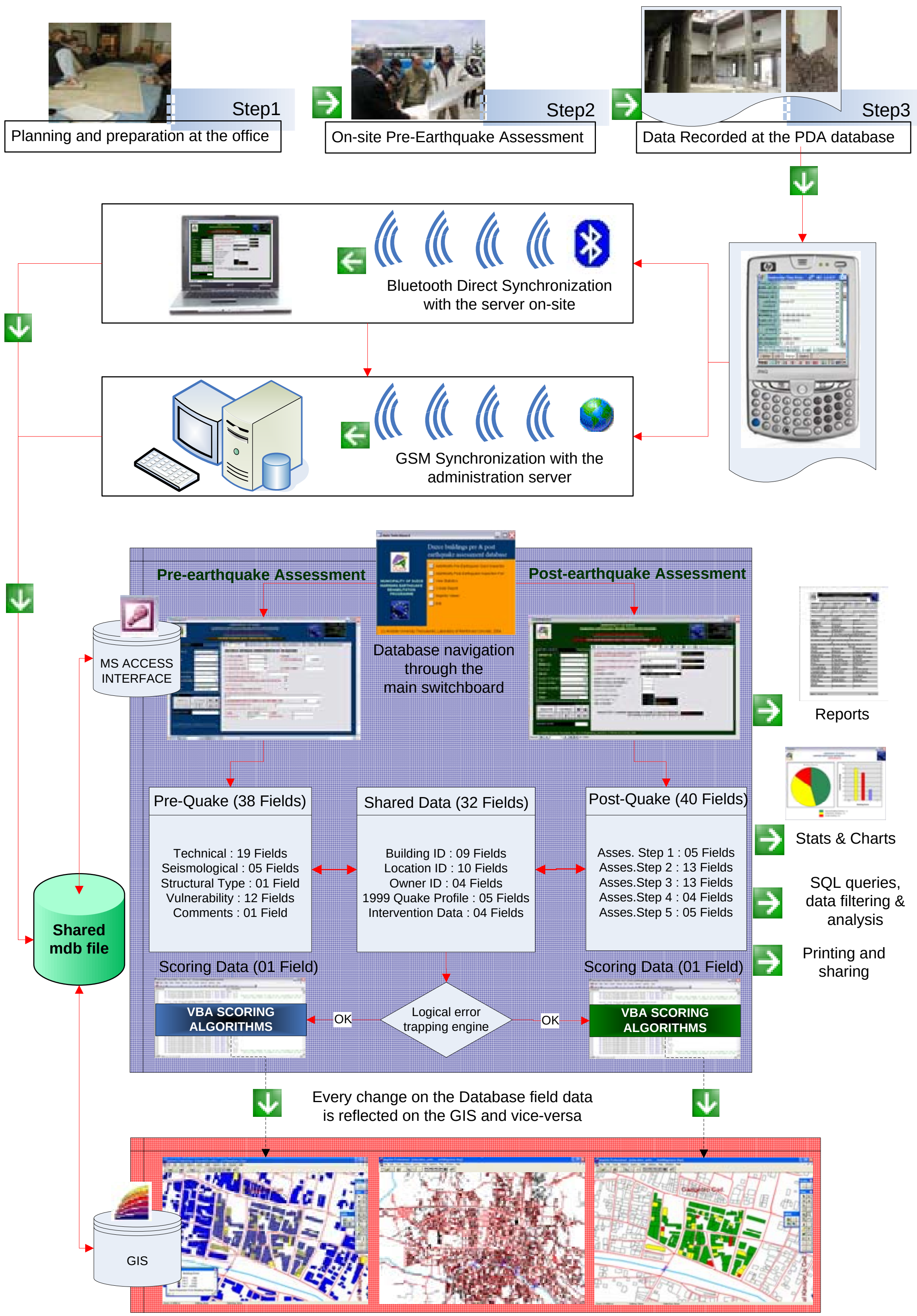

Figure 4: Process for data management, and structure of the GIS-based database.

- All building score algorithms developed are dynamic and can be updated in the future.
- Since all the calculations (including the rating process) are performed automatically, there is no need for the engineers to fill out the post-earthquake quick inspection form, and calculate themselves the corresponding numbers (for instance the percentage of damaged columns or the building score), thus, reducing the time required to complete the form on-site.
- In case it is desired, some users may have limited access to the database (i.e. being able to add information without being allowed to browse the existing records).
- An open source code is used that allows for easy-to-perform translation into Turkish or any other language if the need arises.
- Both the overall assessment strategy and the computer tools have been implemented and tested in real conditions during seminars and demonstration applications in the city of Düzce.
- The archiving and management process is continuous and extends prior and after an earthquake event. Moreover, in case of an earthquake, direct comparison can be made with respect to the (pre-earthquake) scoring and the actual behavior during the earthquake, offering vital information towards the optimization of the ranking scheme.
- The applicability of the procedure and tool described is highlighted by the fact that within 2005, pre-earthquake assessment data has already been gathered and electronically archived by the Düzce city authorities for a stock of 1400 buildings in 5 neighborhoods (mahalles).

Conclusions

The multi-functional computer tool presented herein is an effort to enhance management, evaluation, processing and archiving of data gathered during the pre- and post-earthquake assessment process. Its database capabilities and the integrated communication with a GIS platform, together with the remote data update using PDA devices, can be considered as a step forward with respect to the use of information technologies in risk and crisis management. It is hoped that the computer framework developed, has not only offered a useful Rapid Information System and a decision-making tool to the local authorities of the city of Düzce, but could also be adapted for implementation in other earthquake-prone areas.

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