PHOTOGRAMMETRY, VIRTUAL REALITY AND GIS FOR EARTHQUAKE DAMAGES EVALUATION

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ABSTRACT

A correct classification of the intensity of an earthquake relies on a precise evaluation and localisation of the damages, mainly those occurred in buildings and artificial structures.

In support of this critical operation some approaches were used by the authors, in the framework of researches carried out by the Italian National Group for Defense against Earthquakes (GNDT). These approaches were applied both for historical earthquakes and for the currents, like the last major Italian event occurred in Umbria and Marche countries in the 1997 autumn.

In the paper some experiences are exposed, where integration of Photogrammetry, Virtual Reality photography and Geographical Information Systems played an interesting role towards an accurate knowledge and estimation of the damages.

During the last seismic event, this kind of information was distributed and made public by using World Wide Web resources in a very short time; some considerations are presented below.

1. INTRODUCTION

For more than ten years a GNDT research unit (UR) has been operating within the DISTART Dept. at Bologna University and has conducted multi-disciplinary researches on earthquakes. The two products that represent the activity of this RU are the «Progetto Finalizzato Geodinamico» catalogue, published by CNR in 1985 under the supervision of D. Postpischl (Postpischl, 1985), and, more recently, the NT4.1 (Camassi and Stucchi, 1997), published by the GNDT, to which this RU has contributed to a large extent.

Within the last few years several historical analyses of earthquakes in the regions of Emilia and Veneto have been conducted and great efforts have been dedicated to the revision and parameterisation of the database (DOM4.1) of the observed intensities (Monachesi and Stucchi, 1997), which contains all the basic data obtained from the historical analysis.

Both the database DOM4.1 and the catalogue NT4.1 are currently distributed via Internet.

Within this context GIS technologies have been used for the analysis, representation and elaboration of historical seismological data, leading to the development of specific applications.

The recourse to the use of GIS techniques has been motivated by several considerations:

- an analysis of databases that relies only on their textual information is not adequate to yield a complete, exhaustive and correct outline of the events being examined;
- a study enforced by tools for geographical analysis allows to achieve a more synoptic view of the phenomena and to highlight aspects specific to the administrative, geographical and historical organisation, otherwise not evident;
- GISs allow procedures for the analysis and query of databases through techniques specifically devised for spatial data;
- it is possible to obtain an integration with different levels of information available for the same area; this facilitates at the same time a higher degree of "communication" with other fields of scientific research and with activities for geographical and urban planning;
- it is possible to carry out analysis at different levels of spatial and temporal scale.

Together with GIS approach, other experiences were carried out to provide a better knowledge and documentation about damages, specially using photogrammetry and virtual reality tools.

2. MULTI-SCALE GIS APPLICATIONS FOR MACROSEISMIC DATA ANALYSIS

Within the UR a desktop GIS system, MapInfo Professional, on Windows and Macintosh platforms, has been adopted; using the programming language MapBasic several specific applications have been then developed for the analysis and representation of historical seismological data.

The standard applications include programs for the management and query of the database with the plotting of data referring to single earthquakes, the selection and representation of the maximum observed intensities and the retrieval and display of historical site series (Bitelli et al., 1994; Bitelli and Camassi, 1996); an example, related to Perugia site, is showed in figure 1.

A more complex level have been achieved by the development of GIS applications dedicated to the analysis and representation of earthquakes at different geographical scales. The case presented here refers to the Santa Sofia earthquake of November 10, 1918 that has affected the Higher Forlì Apennine, among the provinces of Florence, Arezzo and Forlì. The most severe damages were felt in the villages of Santa Sofia, Galeata and Mortano, where several partial falls and about ten casualties were reported.

The GIS application for this event allows one to navigate among different joined databases, from the representation of the earthquake at a regional scale - in which (fig. 2) the available macroseismic observations are displayed on a background with the DTM - down to a province and town scale. The latter is illustrated in detail in the next paragraph and is based on raster maps obtained by scanning contemporary cadastral maps.

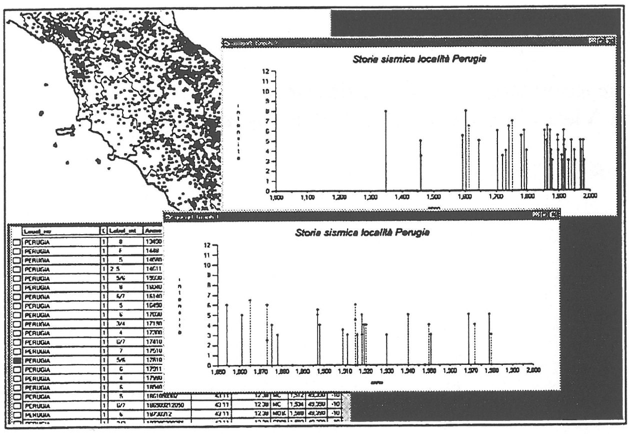


Figure 1 – Interactive query of the database of the Macroseismic Observations and display of the maximum observed intensities and historical seismic site series

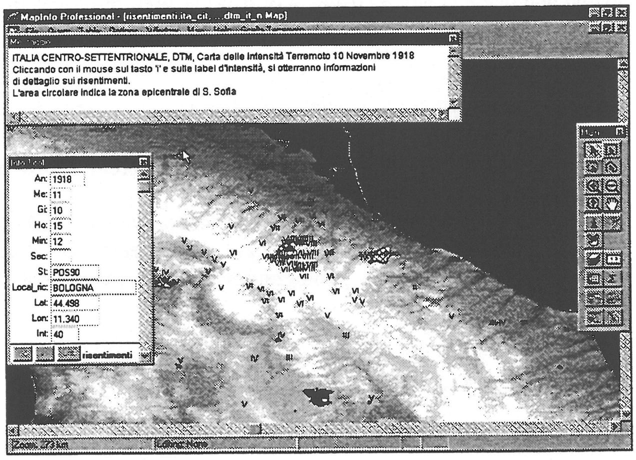


Figure 2 - Representation at a regional scale of the macroseismic information for the earthquake of November 10, 1918. By simply clicking the mouse the detailed information can be visualised and it is possible to move down to a more detailed scale

For some buildings information about the damages was available; these buildings have been digitised on the raster map and related data entered into the GIS (fig. 3). This information is very heterogeneous: it includes newspaper and scientific reports (seismic bulletins), technical surveys carried out by the Genio Civile engineers, which confirm the condition of the buildings or the remedial measures needed for the rebuilding, photographs, etc.

It is worth pointing out that the each scale of representation has, by its own structure, a different information content; it refers to a different conceptual and physical context, allowing at its best an interpretation of the attributes from a general level to a more detailed one. This kind of approach is obtained through an automatic query of the databases of interest depending on the actual scale of the map being displayed.

3. DESCRIPTION AND ANALYSIS OF THE DAMAGES AT THE LEVEL OF SINGLE BUILDINGS

The seismological research attempts to collate, for a historical earthquake, the most detailed description of the earthquake effects on the buildings. It is therefore very useful to have at one's disposal information on the damages of each single building, particularly when information on the building structure is also available.

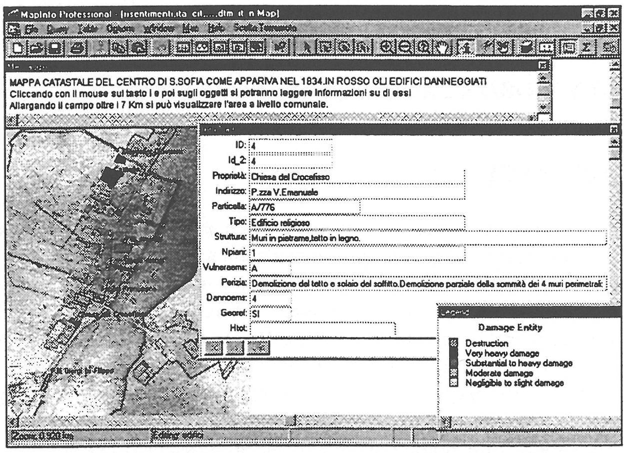


Figure 3 - Representation at a town scale of the 10 November 1918 earthquake damages: from the cadastral map it is possible to move down to the display of single buildings, showing textual data, planimetric maps, photographs, etc.

In the framework of the researches carried out, some different approaches have been followed for the study and description of the damages at the level of single buildings.

A first methodology is the use textual information obtained through the historical search.

The historical documentation usually provides very generic textual descriptions of the damages, normally related to a whole area or single important buildings, such as churches. Only in rare and fortunate cases it is possible to obtain technical surveys on single houses, describing the damages occurred and the rebuilding measures needed.

This information is often not enough for a precise definition of the damage and has to be enriched by other data with a higher or different information content. A more accurate use of the interpretative tools is one of the reasons for which a precise description of the damage details is required. For instance, the use of the EMS-92 scale (Grünthal, 1992) requires information on the vulnerability and type of damage (fig.4); this kind of data is not usually found in the textual sources.

A better description could be achieved with photographs or other objective representations of the building conditions (Lombardini and Minghetti., 1982). The availability of photographic documentation is limited to earthquakes of the last 150 years. Different photogrammetric techniques can be adopted to provide a metric usage of historical photographs (Fregonese and Guerra, 1994); they clearly require the knowledge of metric characteristics on objects that generally are no longer available, or have been transformed to such a degree that it is not always possible to collect data necessary to realise the external orientation.

3.1.3 Classification of damage

Note: the way in which a building deforms under earthquake loading depends on the building type. As a broad categorisation one can group together masonry buildings and buildings of reinforced concrete.

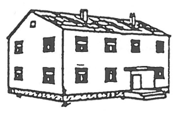
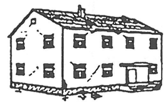
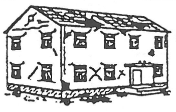
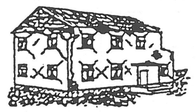
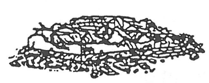
Table 2: Classification of damage to masonry buildings	
	Grade 1: **Negligible to slight damage (no structural damage)** hair-line cracks in very few walls; fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases only.
	Grade 2: **Moderate damage (slight structural damage, moderate non-structural damage)** cracks in many walls; fall of fairly large pieces of plaster; parts of chimneys fall down.
	Grade 3: **Substantial to heavy damage (moderate structural damage, heavy non-structural damage)** large and extensive cracks in most walls; pantiles or slates slip off. Chimneys are broken at the roof line; failure of individual non-structural elements.
	Grade 4: **Very heavy damage (heavy structural damage, very heavy non-structural damage).** serious failure of walls; partial structural failure.
	Grade 5: **Destruction (very heavy structural damage)** total or near total collapse.

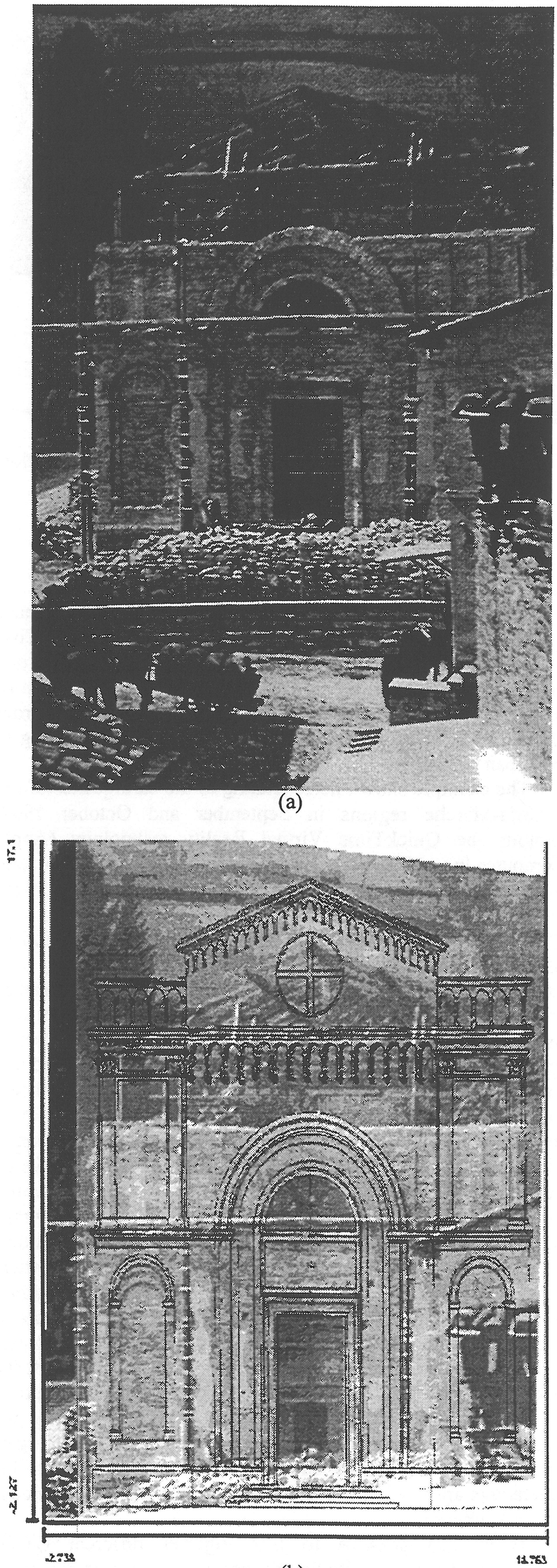
Figure 4 - Classification of damage to masonry buildings according to the EMS-92 scale

For the Santa Sofia earthquake, a research has been performed which has lead to the collection of wide historical iconographic documentation, mainly constituted by postcards or photographs (Guerrini, 1996). Besides these, Genio Civile surveys have been found in the State Archive in Forlì along with cadastral base maps.

A photogrammetric elaboration was carried out for instance for the church of Santa Lucia, in S. Sofia, which does not exists anymore. The church vaults collapsed while a religious service was being carried out and caused several deaths and many casualties.

An interesting image of this building in the aftermath of the quake was found and scanned (fig. 5a). The definition of several control elements on which to perform a photogrammetric elaboration, even if clearly of low accuracy, has been possible thanks to the retrieval of a plan drawn during the building project stage, since in the photogram neither the church nor other surrounding buildings were visible anymore. Using the co-ordinates of several control points obtained from the plan, a digital rectification of the facade has been carried out, whose result can be seen in figure 5b.

An interesting way of using the results of such a technique within the GIS application described earlier is shown in fig. 6: the rectified image, with superimposed reference data for a practical metrical use, can be visualised together with the alphanumerical information collected for the church through historical searches. The figure shows how it is possible to realise interactive measurements on the rectified image in order to obtain distances, areas and so forth.



(a)

(b)

Figure 5 - (a) The church of Santa Lucia after the earthquake; (b) image after digital rectification, with superimposed original vectorised data from the plan drawing.

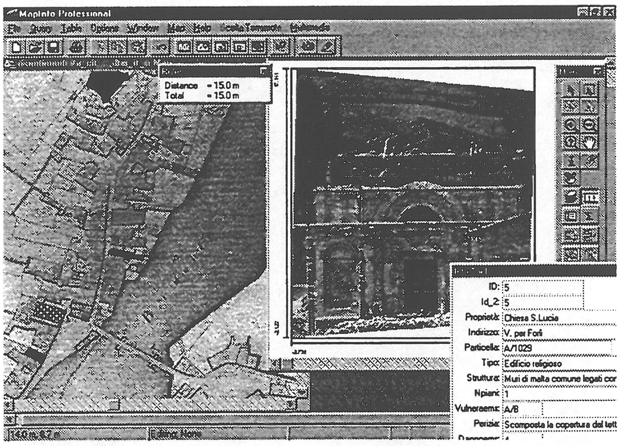


Figure 6 - Integration of the rectified image in a GIS application

4. VIRTUAL REALITY APPLICATIONS

Soon after the recent earthquakes, a preliminary macroseismic survey has been carried out, for purposes of Civil Protection; this task has also lead to the collection of a broad photographic documentation. On this occasion the collection of some panoramic photographic views was decided upon, in order to achieve a correct definition of the damage to the building in the urban context.

The example shown here, relating to the earthquakes of the Umbria-Marche regions in September and October 1997, exploits the QuickTime Virtual Reality technology (Apple Computer Inc., 1996) and allows one to define more accurately the damages on the single building preventing any loss in the necessary contextual elements.

The QuickTime VR (QTVR) is an important extension of the Apple QuickTime format for the interactive display and exploration of scenes, consisting of panoramic movies derived from photographs, assembled by using specific software available on Macintosh platform. The system allows the user to enter and explore the scene. The photographs are organised and handled to simulate a realistic image: in particular, the concept of panoramic view is used, in which the user can make use of an extended 360° view, without interruptions. The panoramic movie can be obtained by stitching together photographs which cover, shot by shot, the entire 360° span: to create a natural effect, the software blends the seams between photos and wraps the image onto a cilinder. To prevent perspective deformations, at the time of acquisition, the lens must rotate around a vertical axis, with its centre of rotation in the internal nodal point. Alternatively, you can directly manipulate a «virtual object» to create the effect that the observer is not moving while the object is moving; in this case, the images of the object must be acquired from all positions in the 360° span around the object.

The user can freely explore the final model, with the possibility of choosing the observation direction, of lowering or raising the visual field and of zooming in and out; this interactive application is guaranteed whether you use the mouse or the keyboard.

It is also possible to link together different QTVR panoramas or objects movies by using sub-areas of the scene (hot-links), allowing the user to navigate along paths of any complexity. The entire process is described in figure 7. Specific plug-ins allow the user to access QTVR scenes through common Internet browsers.

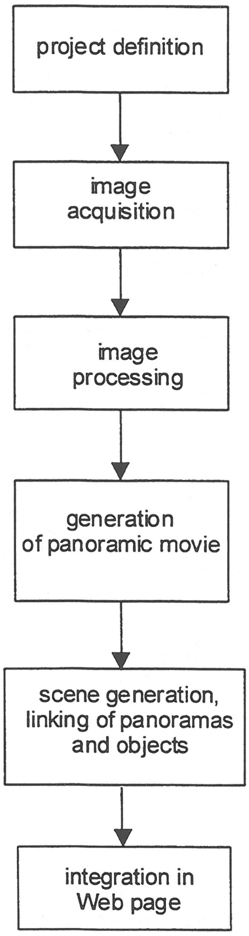


Figure 7 – The QTVR authoring process

After the earthquake, several QTVR surveys were carried out in villages of the epicentral area (Annifo, Cesi, Arvello, Sellano, etc.). The scenes were made available in Internet few days after the main shock (Camassi et al., 1997).

In figure 8 the Web home page for Annifo site is showed; the sequence of images reveals here very different damage levels, due, clearly, to the different levels of vulnerability. The damage to the Church, which can be seen clearly by 'navigating' and zooming onto some parts, is strongly influenced by fairly recent re-structuring work (a reinforced concrete ceiling not fixed to the bearing walls in dry masonry) which accentuated the seismic vulnerability of the building instead of reducing it.

The same situation can be noted in figure 9, where heavy damage has been probably caused both by structural problems in the building and by inappropriate rebuilding works.

The delineation of damage scenarios through this technology allows one to perform a very effective, even if complex, analysis of the different local consequences of the seismic quakes, and is an excellent means for the diffusion of scientific data.

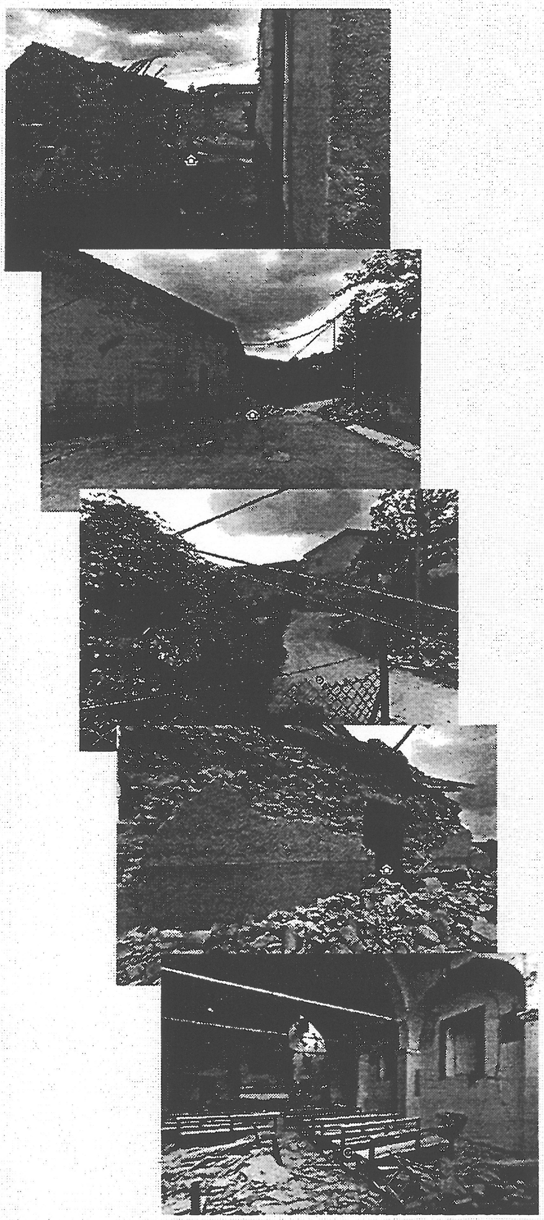


Figure 8 – Screenshots from the movie showing the damages to the Annifo Church, now definitively destroyed by the aftershocks. Note how the heavy concrete ceiling has remained intact but has greatly damaged the walls

5. THE DISSEMINATION OF SEISMOLOGICAL AND HISTORICAL DATA THROUGH THE INTERNET

Soon after the recent earthquakes in the Umbria and Marche regions, some of these applications have been used to make available through the Internet, almost in real time, macroseismic survey data and a considerable amount of elaboration of the historical seismicity of the area (GNDT, 1997). This application has met with a great interest and has represented a simulation of a possible way to make available seismological data to the scientific community. It is worth noting that the availability in the Internet of data of this kind is unfortunately very limited.

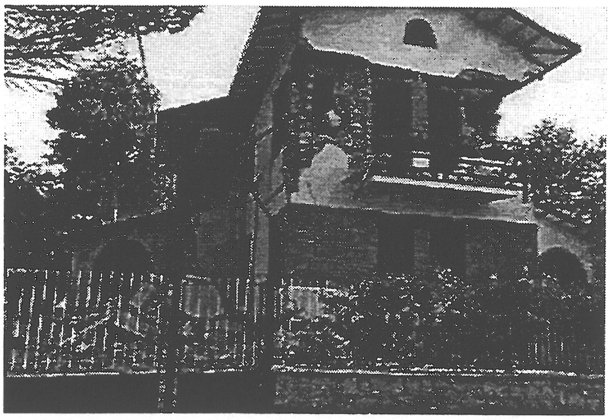


Figure 9 - Example of damage to a building in Cesi (Serravalle di Chienti). Note how recent rebuilding works have greatly affected the structure by the lack of adequate reinforcements of the brick walls

6. CONCLUSIONS

The knowledge gained within the last few years in the analysis and elaboration of historic-seismological data, both at a regional and detailed scale, has shown that best results can be achieved when multidisciplinary approaches and multiple techniques have been utilised. In this paper, with reference to both historical earthquakes and the recent seismic event in Umbria and Marche regions, several integrated applications of the use of GIS technologies, photogrammetry and virtual reality techniques for the study of information on building damages have been presented.

These experiences can receive a validation with important scientific and divulge implications if this body of information is made available, in real time, through the Internet.

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