State of the art on Remote Sensing for vulnerability and damage assessment on urban context

by

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Abstract

Major disasters across the world are more and more reported due to the consequences of their impact in terms of human, physical and economical losses. In the event of a natural disaster such as an earthquake, we are interesting both in the analysis of the severe urban area before and after the event by using airborne and space-borne imagery.

A damage assessment from such images can assist in providing loss estimates to benefit the federal government, the insurance industry, researchers, engineers and the residents of high-risk areas. In such cases, we are interesting for fast and effective and reliable results that represent the damage of the most affected areas. Very high resolution images are particularly well adapted to damage assessment methodology in urban areas and they allow a building based analysis. In the literature we can find several applications on post earthquake damage assessment and even more algorithms and numerous methods related to damage assessment by using remote sensing techniques that have been proposed by the Geoscience and Remote Sensing (GRS) community ([26, 51, 82, 42]).

Assessment of vulnerability is also of interest, and it can provide an important guide such as a broad spatial information basis for decision-makers to develop mitigation strategies, also it can help to raise public awareness of risks in the forefront of an expected disaster [100]. Seismic risk in an urban area is closely related to the structure, material and dimension of buildings and their mutual distances. Hence it is important to study the plan, elevation and structure of buildings for evaluating seismic vulnerability of urban areas. Building inventory can be obtained by field surveys. However, a large amount of time and effort is required. Thus an easier method to develop building inventory is of a major interest. Airborne remote sensing can be an effective solution for the development of inventory since it can provide high-resolution images of the earth's surface and most of the individual buildings and therefore part of the buildings such their roof can be identified in the images. ([111, 106])

Remote sensing has proved its usefulness for the crisis mitigation through situation reports such as for damage assessment through hazards. What is important to mention is that in the task of assessing directly the vulnerability by using remote sensing techniques is that there is not a lot of research work that can be found in the literature and the task is an open research area, trying to define and state the problem. In this work we will present a state of the art on remote sensing technologies for seismic evaluation in urban environment. In the frame work of URBASIS project our main scope is concentrating on the:

- Analysis of seismic vulnerability in urban areas (pre-earthquake)
- Analysis of the damage caused by an earthquake by using different techniques such as change detection (post-earthquake)
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Chapter 1

Pre-earthquake event: Vulnerability assessment on urban context by using Remote sensing technology

1.1 Introduction

Our main goal in this very first chapter is to present what has been done in the literature for assessing the vulnerability in urban context by using Remote Sensing techniques. The ultimate objective of our work is focusing in analyzing very high resolution (VHR) remote sensing data for the development of methodologies that can derive attributes from the urban content closely related to the vulnerability (vulnerability indicators- VI) either in individual buildings or in homogeneous areas in the case of an earthquake. The end scope is to provide a vulnerability map, such as a map that assess the vulnerability in agreement with the geotechnical analysis, as a decision support system for disaster and risk management. Summarizing, we are interesting in finding in the literature what has be done so far in the area of seismic vulnerability assessment in an urban content by using innovative techniques such as Remote Sensing (RS) and especially by using very high resolution images (VHR).

As a first step we are interesting in estimating the Seismic Vulnerability (SV). To be more precisely we are interesting in those indicators by a remote sensing perspective of view that could possibly identify directly the vulnerability of a building. Due to the very high level of resolution of about 15 cm provided by air-borne imagery we have access to very detailed characteristics of buildings and urban objects. In the literature, the characterization of the roof of the buildings has been used, [106, 76, 100] to identify the risk and the vulnerable of the a building either directly by RS or with some indirect methodologies in the case of an earthquake. However, the high level of details of VHR image requires new developments and we will try to focused on presenting different methodologies in the literature that they rather based on object image analysis instead of pixel image analysis taking in advantage the high detailed resolution of VHR images [14].

Vulnerability, is a very complex concept and several engineers and researchers in the seismic risk domain have been tried to define it and measure it. From a civil engineering point of view, Guéguen et al [48] supported that the aim of the seismic vulnerability assessment is to estimate the seismic performance of buildings. This estimate can be used (1) to assess the damage caused by an earthquake scenario, (2) to evaluate the direct costs which would result from it, (3) to contribute to the pre and post seismic assessment of the loss distribution in an urban area and last but not least (4) to identify before the
earthquake the most vulnerable buildings, in this work they developed a vulnerability assessment based on in-situ data before the earthquake. They focused in moderate-to-low seismic hazard regions to assess vulnerability for identifying before the earthquake the most vulnerable buildings which could benefit from being strengthened. The large scale assessment of building vulnerability can be used by municipal and government agencies in order to prepare for earthquakes, plan emergency response measures and mitigate risks.

The Understanding Risk community [57] that incorporate knowledge from several different fields and not only from civil engineers, developed a more generic framework for seismic risk assessment capturing different modules and not only focusing on the vulnerability of buildings.

What is important to understand in this survey, is the capabilities and the potentials of RS technology under the umbrella of seismic risk analysis. Due to the availability of VHR resolution in the detail of some cm in radar and optical technology we have access to very detailed characteristics of buildings and urban objects as shown from figure 1.1. The higher the resolution the more detail we can access. (Figure 1.1 is from Daniele’s Ehrlich presentation on Earth Observation exposure on Understanding Risk Forum community [80]). Therefore, Due to this detailed representation of the urban morphology on buildings, directly meaning, VHR imagery in urban context is more connected to physical vulnerability. In the following of this chapter we present a survey that focused on the the capabilities of VHR imagery on physical vulnerability.

On the following of this section, we will see in a glance the idea of vulnerability under the umbrella of seismic risk assessment in urban areas following by an introduction of the contribution of RS (1.1.1). In section 1.1.2 we connect the extremely increase in resolution in the last years with the urban land cover maps for vulnerability. Finally in section 1.1.3 we distinguish three different methodologies that arise from the survey focusing either on empirical approaches and field work (In-situ data), either only on RS technology, or by combining In-situ and RS data.

Different image processing techniques that have been used for assessing the seismic risk are presenting in section 1.2. Both techniques are focusing in a local scale (individual buildings) and urban scale (homogeneous buildings). As a first step we are interesting in the meaningful objects that can be extracted and help in the vulnerability assessment and for the vulnerability indicators that can be extracted directly from RS imagery, in section 1.2.1 we present the different characteristics that can be extracted in a local scale and in section 1.2.3 the characteristics that are more related to assessing the vulnerability in an urban scale. In section 1.2.2 we are presenting techniques for extracting geometrical characteristics of buildings, such as shape, roof etc. A short description on different ways of extracting road network is also presented in section 1.2.4. After is following a survey in section 1.3 on classification and image processing techniques on determined of an urban land cover map especially by using different vulnerability indicators extracted from RS. Next a comparison is presenting in section 1.3.5 between optical and radar sensors for land cover classification. Finally in section 1.4 we briefly discuss on the contribution, the limitation and future work on RS technology for seismic risk evaluation.

### 1.1.1 Understanding Seismic Risk and Vulnerability

Understanding **seismic risk** in a more general framework is definitely a necessary first step towards to vulnerability earthquake and damage assessment. In the case of assessing vulnerability, before we start focusing on the contribution of remote sensing technology on that research area, it will be interesting to have the whole view of the puzzle of seismic
Figure 1.1: Fine resolution provides more detail. The availability of VHR resolution in the detail of some cm in radar and optical technology allows us to have access to very detailed characteristics of buildings and urban objects as shown from the figure. Therefore by using VHR imagery for assessing vulnerability in urban context it makes more sense to focus our survey on the capabilities of this imagery for assessing the physical vulnerability and extracting building characteristics. Figure from the website of Understanding Risk Forum community [80].
The need of the earthquake risk information to become available was carried out from the Organization of Economic Cooperation and Development’s (OECD) Global Science Forum for the development of open source risk assessment tools. Based on this need the Global Earthquake Model (GEM) was developed to define seismic risk as the product of hazard, seismic vulnerability (the probability of loss given a level of ground shaking), exposure (the elements at risk—mainly buildings, critical infrastructure and people) [57]. The model includes a socio-economic impact module in addition to hazard and risk (exposure, vulnerability) modules. Figure 1.2 from [57] presents the integration of the three modules within a common infrastructure that models seismic risk assessment.

Therefore in the framework of the GEM seismic risk analysis is focusing in the following three modules:

- **Hazard module**
  It calculates harmonised probabilities of earthquake occurrence and resulting shaking at any given location

- **Risk module**
  It calculates damage and direct losses resulting from this damage such as fatalities, injuries and cost of repair. Damage due to strong ground shaking is calculated by combining building vulnerability (physical), population vulnerability (social) and exposure. At this module a future development on remote-sensing data collection techniques for classification, monitoring building inventory and thus building and homogeneous areas vulnerability assessment will be of our interest. For the moment we are focusing on a survey that enclose already published works on this subject, and will presented in the following of this report.

- **Socio-economic impact module**
  This module can provide tools and indices for estimating the impact from earthquakes on the economy and society, concentrating in particular on indirect losses, whereas indicators such as living conditions, economic development and location of the household can be assessed on the scale of a building, building block, an administrative neighborhood or city district.

In the following survey we will present works from the last 10 years that have been published on the above modules by remote sensing, and we will try to show the importance of RS for seismic RISK evaluation.

More works can be found on Risk the Module, one example is the one of Valero’s et al [106] that focused on the roof of the buildings, and as we will less work has been done on the socio-economic impact module, one example is Ebert et al [36] where they present an object based methodology on VHR imagery for urban social vulnerability. Some other researchers tried to combine all the different modules in a more general framework such as Taubenbock et al in his recent work (2008) [101].

Seismic vulnerability either by remote sensing or other technology is therefore a puzzle-piece that could be critical for minimizing loss of life, physical damage, social and economic disorganization due to earthquakes, by leading to better buildings construction, land use planning for sustainable development, improved emergency response, protection and prevention of critical infrastructures.

In figure 1.3, Taubenbock et al [100] showed in a table the several dimensions contributing in a holistic perspective on vulnerability. The focus is on the physical dimension
as example for the contribution of remote sensing to the general framework, therefore in this table is displayed only a part of a holistic framework focusing on the capabilities of the remote sensing.

The assessment of vulnerability can provide useful direction and guide.

The use of satellite imagery and the increasingly resolution analysis is becoming increasingly important for risk assessment and tools are developing that can capture and transfer high-resolution imagery for the exposure and consequences databases.

A few research works have been published for the purposes of the dissemination of the potentials and capabilities of remote sensing as a tool for seismic risk assessment focusing on pre earthquake imagery. On the following subsection we present what are the capabilities of RS for assessing vulnerability form a few publication that can be found in the literature.

The last years, since 2006 there is an interest on using RS as a tool for seismic risk and vulnerability assessment. Several european projects and international communities are taking an effort for the development of innovative techniques by using RS. Some of active research programs released are mentioned bellow:

- Group of Earth Observation: Work Plan Sub-Task DI-09-01a Vulnerability Mapping and Risk Assessment. The EUCENTRE participate in this task for the contribution in remote sensing and seismic risk management to initiate and foster research -within GEO- aimed at large-scale, rough determination of seismic vulnerability based principally on Earth Observation data 2009-2011.


- Understanding Risk (UR) community: Extraction of Exposure Information from Earth observation.
1.1.2 When spatial analysis moves a level higher

It is important to understand what can we do with the increment of resolution in imagery and how to use it so the seismic risk evaluation can benefit of it. In figure 1.4 we summarize the evolution of this increment in resolution corresponding with the evolution of different land cover/land use classification map. We introducing in somehow an interesting subject of remote sensing to deal with assessing vulnerability in building and homogeneous areas by using classification techniques. The main advantage is the usage of VHR and the utilities that can offer.

Very high resolution imagery the last decade has offer to the society the opportunity of creating Urban land and cover use maps under new considerations. Every single building with VHR is now available and detailed classification maps can be produced as seen in figure 1.4 either in a single building base or in homogeneous areas. What is important is Remote sensing to understand is how to define the interested classes for urban areas that could be used in agreement with two different tasks:

- The increment of the resolution and
Figure 1.4: When spatial analysis moves a level higher. How can we map urban built up areas with VHR.
• Vulnerability assessment in individual buildings and homogeneous areas.

What should be also considered will be tried to understand from presenting a survey in this work, is if there is a legend or a classification scene for urban areas that could be used. There is also the question of what imagery to use and we will also try to include this question in our survey. Land use classification can be done in four different levels as described [80] by Inderjit Claire according to the available resolution of the imagery. Level 1 is the classification in a country scale assessments by using 30-50 m of spatial resolution imagery, level 2 classification is when the assessment is done in a city scale which are more dense around 5 m resolution imagery, level 3 is when we are interested in cluster of buildings (group of buildings) that have similar characteristics which can be found in dense cities and uses 2.5 to 1 m imagery and at the end level 4 in a resolution less that 1 m is at the individual scale of buildings representation and 3D information and can be used to classify buildings according to their height. The higher the resolution is the higher the detail we can get for describing and classifying different features in an urban environment. A lot more information is available by very high resolution imagery in a detailed representation in individual buildings, such as the height and the type of the roof.

Also it will present different feature extraction techniques that have been used to extract meaningful objects from VHR imagery such as object oriented techniques (semi-automatic/automatic extracted of footprints) that allows efficient segmentation. Even if there is an interest in global and continental scale, we will focused our bibliography research in a city scale and what has been done in individual buildings and in homogeneous areas.

1.1.3 Methodology and beyond RS

Firstly we are interesting for the potentials of using very high resolution data in the context of vulnerability of buildings. RS can be an excellent tool for extracting roofs [106] and detecting objects in the complex content of urban areas and it can exploit the great potentials of the enormous increment of the images spatial resolution the later years. The innovations on image processing techniques and the methodologies are indisputably rising up by meaning that there is no doubt for the promising development from the scientific remote sensing society to the challenge of using VHR data. On the other hand we cannot expect from RS data only to offer the ultimate solution for a direct fast extraction of all necessary vulnerability parameters. Also there is not a potential from RS to substitute existing, available, and up-to-data GIS data [76]. However, as already mentioned this study is interesting in presenting the different techniques that have been used in the literature on the variety information that can be extracted from high-resolution satellite data, thus making them a useful additional tool regarding the analysis and monitoring urban areas. An interesting approach is also the development of methodologies that can combine in-situ and remote sensing data.

In figure 1.5 we summarize the three different approaches for assessing the vulnerability as follows:

• RS- Stand alone: Methodology based on the potential of VHR imagery in the context of vulnerability-related building parameters. Meaning extracting building attributes related to seismic vulnerability directly from RS data.

• Based on in-situ data: Methodology based on empirical approaches and field work. (We are not interesting in the development of this methodology in this work).
Beyond RS: Methodology based on the integration of RS and in-situ data for the seismic vulnerability estimation.

From now on, in the following of this chapter we are interesting in presenting the methodologies that can be provided by utilize remote sensing data. We are interesting in the potentials and capabilities of VHR remote sensing data and also what has be done in the development of image processing techniques that take advantages of the use of VHR remote sensing data. Based on the above we are interesting on the methodologies based on VHR remote sensing data. Also since there is not a lot of work that has be done we are interesting in the development of methodologies that can combine in-situ and remote sensing data.

1.2 Image processing techniques: RS a piece of the puzzle towards to Vulnerability assessment

Remote sensing capabilities and potentials.

Assessing the vulnerability in a complex system such as urban areas is a complicated procedure. Vulnerability of a hazard can be defined by a mixture of different components including physical, demographic, social, economic, ecological and political aspects. All of them can contribute by adding up the holistic conceptual idea of vulnerability. Taubenbock and his co-workers [101] were interested to identify the capabilities of remote sensing in the conceptual idea of vulnerability. Their results shows the principal capabilities of remote sensing contribution to the identification of physical and demographic aspects of vulnerability, as well as providing indicators for the spatial distribution of natural hazards. Aspects of social, economic or political indicators represent limitations of remote sensing for an assessment complying with the holistic risk framework. Mueller et. al [76] in a previews work, also investigate the potential of high resolution satellite data in the context of vulnerability, from their results they conclude that RS can help existing empirical methods for assessing vulnerability-related building parameters (physical indicators) in the context of earthquake events. They emphasize the potentials and the contribution of RS, such as for extracting meaningful information, as a useful tool regarding the analysis for monitoring of urban areas and also the support that they can provide to vulnerability assessment.

In this section we want to present different image processing techniques used by different researcher for assessing the seismic vulnerability. From the literature there is no straight forward methodology that is used from remote sensing technology to assess the vulnerability. But there are different image processing techniques that have been used in the literature and they could be useful for understanding the usage of RS for assessing the vulnerability in urban structures and also for identifying areas of homogeneous buildings and thus creating vulnerability maps.

We identified two different categories for assessing the vulnerability. The first one is on individual scale and the other one is on homogeneous areas. In figure 1.6 we see that vulnerability assessment can be done in two different scales.

On the development of vulnerability map for individual buildings, the classification might be vary from simple discrimination between gable and flat roofs [106] to much more sophisticated classification schemes between wooden and multi-storied buildings [114] based on height, area of the buildings and color and texture analysis.

On the development of homogeneous areas where the areas can be composed by buildings that shared common characteristics based on different features such as roof type,
Figure 1.5: Availability of data from different sources (either remote sensing data or in-situ) allows the development of different strategies for assessing the vulnerability. One approach is by using directly and only remote sensing technology, another approach is by using empirical approaches. The other way is by incorporating RS and in-situ data in a more general framework. The potential of very high-resolution satellite data in the context of vulnerability of buildings and the combination of in-situ data with remote sensing data is a way of major interest for investigating and developing methodologies for assessing the vulnerability.
shape of the building, relative distance between buildings (dense or sparse areas).

Before moving to the classification techniques and the presentation of different vulnerability maps from the literature, it is important to understand, what is needed to extracted from RS for this final step and how can RS extract this information. At a second step for creating the vulnerability map we can see how RS can use this information to create the maps.

From the framework proposed by Taubenbock and his team, [101] and from a different studies [76, 100, 114, 98] that have been focused on the potential of remote sensing technology in the sense of the context of vulnerability of buildings and for mapping seismic vulnerability, we can easily see that for assessing vulnerability directly in the sense of remote sensing is closely relevant with assessing physical vulnerability. Vulnerability indicators that can be defined with physical vulnerability indicators can be found that are related with the (roof type, number of structures, structure types, built-up density, building height, building material and construction type, building age, urbanization rate, sealed areas, open spaces, etc.). Research by Yamazaki, Caliskan, Taubenkok and their co-workers [114, 21, 101] used a combined methodology for assessing the vulnerability by combining in-situ and remote sensing data. As already mentioned, few studies can be found in the literature that are focusing in the remote sensing potentials for estimating the vulnerability and assessing the risk [106, 76, 101].

A presentation of different building characteristics derived from RS in the literature will present here. We will try to explain also the meaning of each physical parameter in respect to the seismic risk and their vulnerability. In any case we assume that the footprints of the buildings have been extracted, and in this case we are not considering of the image processing techniques that can be used to extract them efficiently. In a field survey studies focusing in earthquakes, need to have information about the buildings where the people live. Hence in that case, all individual buildings are need to be closely observed and traced on a field map and the building details, i.e. use of the building, floor-height, shape, attachment, age, material used (floor, wall, roof), structural bands, building conditions (wall cracks, floor cracks-settlements, wall-floor dampness), existence of soft storey and upper partial floors, etc. and afterwards recorded in a designed format. A case study is examined by Kumar Jimee [58] in a metropolitan city in Nepal for assessing seismic vulnerability focusing on buildings. Unfortunately, databases and field work of a variety of recent earthquakes or for low-moderate risk areas do not always exist. Therefore methods that take under considerations data field surveys or depending on existing databases of building inventory by field work in the case of fast seismic risk assessment (vulnerability) fail miserably due to their computational costs and other time consuming aspects. Satellite images offer as mentioned already an alternative way that looks promising and preferable. The capabilities of RS have been under consideration by Mueller in a recent work in 2006 [76] by Polli [83] and Taubenbock [101]. In all cases the authors focused mostly in building characteristic parameters with the exception of Taubenbock, where he also examined the population density during the night and day.

1.2.1 Individual Scale: Extracting characteristics related with physical Vulnerability

Building Height

Information about the building height is essential for the vulnerability and has been used from several study cases.
Figure 1.6: Capabilities of VHR imagery. Summarizing the potential of Optical, SAR, Lidar imagery in the spatial and spectral domain and the contribution of digital elevation models in the context of vulnerability for individual buildings and homogeneous areas in an urban scale.
• Three dimension information can be derived by a pair of stereo images. Stereoscopy uses binocular vision to produce overlapping photographs or other perspective views of an area. We can use these stereo images from air or space craft to determine the height of buildings or other objects through the apparent difference in the position of the eye vectors of the image from the satellite. Furthermore, after the stereo images are processed, the images are subsequently submitted to orthorectification, which is the process of removing distortion in these images due to tilted sensor and terrain elevation. Stereoscopy is more expensive method for measuring building heights than LIDAR systems and the quality of the information is weather dependent. Lee et al describe in their publication [61] a methodology through stereo matching based on epipolarity and scene geometry for a precise three dimensional information.

• Extension of shadows of the buildings can be also used to derive information about the height of the extracted objects. Borzi et all [15], use a simplifies method by using nadiral or near-nadiral images. They traced the height of the objects from the length of their shadow by knowing the geometry of the acquisition and the zenith angle of the sun.

• LIDAR data can also help for generating information about the buildings height. The advantage of LIDAR is that it provides very high-resolution models, both for horizontal and vertical accuracy. In addition, LIDAR provides better building shape characterization due to the lack of shadowing and layover effects [47] inherent to other techniques such as InSAR. Consequently, the data quality allows for fine and relevant feature extraction.

• Interferometric Synthetic Aperture Radar (InSAR) can use two or more Synthetic Aperture Radar (SAR) images, from airborne or space sensors. The elevation can be determined by analyzing differences in the phase of the waves returning to the instrument. InSAR data suffers from multiple scatterings off building geometries, shadowing effects leading to an underestimation of the actual building spatial distribution, and layover effects such as erroneous line-of-sight distance leading to an overestimation of the building height [47]. This is due to the low spatial resolution of InSAR data for urban areas. However, the resolution is improving in new generations of radar sensors, approaching a spatial resolution of 1 m. In the future, TanDEM-X (TerraSAR-X add-on for digital elevation measurements) will orbit in close formation with TerraSAR-X, scheduled to be launched in 2009 [2]. This unique twin satellite constellation will allow for an unprecedented accuracy, coverage and quality of DEMs. The main advantage of InSAR methods is that the elevation of each pixel can be determined independently, unlike in stereoscopic DEM where individual pixels are combined. However, InSAR is highly sensitive to sensor motion and speckle (granularity in the image).

Building Age

The age of buildings is another determining factor that indicate the strength of the building and therefore their vulnerability. This parameter can be obtained by comparison of temporal remote sensing pictures. By using high spatial resolution pictures taken over time it is possible to compare the pictures to locate new building mass. In figure 1.7 they use a pair of Land sat images to detect the urban growth from where the building age can be estimated. Taubenbock et al [100] used a series of Landsat data from the years 1975, 1987 and 2000 to assess the age of the buildings by using change detection.
Building material

Multi-spectral characteristics show the difference if reflectance from the materials on the earth surface. Many researchers have been already proposed algorithms to classify the features on the earth surface in the fields of natural environmental mapping, such as for forests and agriculture lands. However a few works have been focused on urban context and in built environment mapping and particularly on the identification of the roof’s surface material.

All materials have a spectral signature that is unique and determined by the chemical composition of the material. Spectral imaging utilizes sensors which record the reflectance of light in different wavelength bands such as the visible and infrared (IR) spectrum. From the retrieved data set it is possible to approximate a curve indicating the reflectance as a function of the wavelength, this is recognized as the spectral signature. An example that illustrate the spectra of roofs with different materials is shown in figure 1.8(b) and in figure 1.8(a).

Spectral imaging is divided in two categories: Multi-spectral that offers high spatial resolution, but low spectral resolution and Hyperspectral that offers high spectral resolution, but low spatial resolution.

Urban building inventory requires both very high spatial resolution to distinguish between the meaningful objects in an urban context and high spectral resolution to separate materials with almost similar spectral signatures. Hyperspectral imaging is the only technology which can provide the required spectral resolution. Current hyperspectral satellites do not have a high enough spatial resolution to provide good classification of materials. Dell Acqua et al [33] stress the importance to use the context for a more accurate mapping and they note some of the limitations of using VHR hyperspectral, which is that VHR in the spectral sense sometimes carries too much information, since it differentiates covers made by the same material but with different age or illumination conditions.

Roessener and her co-workers [86] presented a new approach for analyzing airborne hyperspectral data (Digital Airborne Imaging Spectrometer- DAIS) that combines advantages of classification with linear spectral unmixing based on a pixel-oriented procedure for end member selection. The results and their comparison with standard spectral classification methods show that the new pixel- and context-based approach enables reasonable material-oriented differentiation of urban surfaces. Segl et al. [90] extended this work by the fusion of spectral and shape features using DAIS data in reflective and thermal wave-
length ranges (Segl et al., 2003) allowing a better differentiation between roof materials. The limitations from these studies mainly occurred due to the rather large pixel size (6 m) and the relatively low signal-to-noise ratio (SNR) of the DAIS data resulting in a high percentage of mixed pixels and a limited representation of spectral features [54]. Heiden et al. (2001) [53] hyperspectral HyMap data of higher spatial resolution and of high SNR were used allowing the identification of less pronounced spectral features. This way, a wider range of materials consisting of 79 spectrally distinct classes could be identified. Successful identification of surface materials in hyperspectral image data requires detailed knowledge about the spectral characteristics of urban surfaces. The highest number of spectrally distinct materials and the greatest variability can be found for roof materials. This is caused by the wide range of available roofing materials and varying orientations of the roofs towards the sun and the sensor [54].

1.2.2 Extraction of building geometrical characteristics

Concluding to the above we are interesting in the investigation of a general methodology framework for assessing the vulnerability in an urban environment. This section attempts to understand the objects in an urban space characterization and the potential of VHR remote sensing data and DEM. Therefore we are interesting in describing different methodologies for the extraction of image objects and especially meaningful objects that can be related to the seismic vulnerability. As we already mentioned, estimating the nature of the roof of every building is a significant parameter for assessing the vulnerability, therefore extracting building information and particularly roofs is of our interest. In various application and not only in the case of vulnerability assessment, VHR and image processing techniques for their processing can be a useful supporting tool with the potential of buildings inventory.

Automatic rooftop detection and localization in aerial images has been an active research topic in the last two decades [109]. Several work has be done to built to achieve this goal ([68, 79, 89]).
Figure 1.9: (a) Example of structures that can be extracted from a VHR remote sensing image (with spatial resolution 0.25 m airborne image from the city of Grenoble). Structural information can be: large, small, rectangular, square, sophisticated structure, circular, textured, dark, long, thin, e.t.c. And on the right end side (b) Examples as can be seen from aerial images in the work of Wang et al [109] of commonly seen rectilinear and gable rooftops. There are big differences in both shape and appearance. They also share three types of quadrilateral parts (rectangle, right trapezoid, isosceles trapezoid), which are highlighted with different color.

Different methodologies combine different data beyond a single VHR image and they exploit information also from digital elevation model (DEM) as a pre segmentation ([68, 79, 60]). Some operators can also be derived by using morphological and advanced morphological operators ([23, 62]).

Feng and his co-workers in their recent work [39] review methods of building extraction using high-resolution images.

Wang et al [109] emphasize that roof segmentation especially from a single aerial image is not a trivial task and it remains a very challenging topic. They notice two reasons for that: The first is because of the complexity that is creating from the surroundings around the buildings create many false positives and noise when using simple detectors like edge detectors and second rooftops of different structural styles have large variances in both shape and appearance, which makes it impossible to build a simple shape model to account for all variabilities. The Figure 1.9(b) helps visualize some of these challenges.

Different techniques have been used in the literature either for building extraction or for several features that can help for the identification and differentiation of the roof and they can be divided based on the data modality, on the data fusion of the data, on region based techniques, on morphological operators and on using directly commercial softwares such as eCognition [1] and BREC [44]:

Object-based image analysis

Most of the recent studies on application of remote sensing for building extraction, are using object-based image analysis methods. Object-based image analysis has become an alternative approach in remote sensing analysis, especially for the automatic building extraction from very high resolution satellite imagery (Ikonons at 1m, Quickbird at 0.6m, Orbview-3 at 1m, Worldview-1 at 0.5m, GeoEye-1 at 0.41m, Worldview-2 at 0.46m). Pixel-based and traditional image approaches have been defeated with the increment of the resolution. Blansche and Strobl [14] discussed the advantages of object-based over the
pixel-based image analysis. In pixel based image analysis, meaningful information such as object shape, area, orientation, relative position etc cannot be included. OBIA is the new trend in image analysis and it has been applied not only in VHR imagery but also in coarser spatial resolution imagery. An excellent survey on object-based image analysis in a wide spectrum of applications but not only for object extraction is given by Blanschke [13]

- Based on the data

  Roof detection has been studied for several decades, one of the big challenge is its structure and appearance diversity. Wang and his co-worker [109], present a grammatical framework to account for these diversities and a multiple way compositional algorithm to extract rooftops from only aerial image this framework can handle rooftops with big shape/appearance variance in a global optimal way.

- Based on Data Fusion between remote sensing data

  Valero et al.[106] in order to estimate the nature of the roof of every building and, in particular, to make the difference between flat roofs and gable ones used VHR panchromatic data, and an accurate DEM. On the same work Valero et. al extracted two skeleton mixed features by developing the fusion of these two modalities. Based on these features the classification between the two considered classes becomes a simple linearly separable problem. However, they also approached the classification by using just one feature, from DEM data effectively by making a new classification replacing the pattern gable roof for all triangular roofs. Therefore, classification can be more general and then more effective to perform a flat roofs isolation. A generalization for triangular roofs is also presented but with some limitations due to the irregular geometry of the surfaces in hipped roofs and due to the existence of dormer windows that protrude in many triangular roofs.

  Another study in the literature by using data fusion with DEM but this time with hyperspectral data has be done by Madhok and Landgrebe [65]. This paper describes an experimental study where using a fusion of two essentially different types of data proves significantly superior to the individual use of either one or the other. The task is to identify and accurately delineate building roof-tops in a flightline of hyperspectral data. They used gradient-based algorithms on the DEM data and they show that its use alone is not sufficient to sharply delineate building boundaries. However, building roof-tops in this urban scene are constructed of different materials and are in various states of condition and illumination. This and the fact that, in some cases, the material used in roof-tops is spectrally similar to that used in streets and parking areas make this a challenging classification problem, even for hyperspectral data. In conclusion Madhok et al in their work prove that combining hyperspectral and DEM data can substantially sharpen the identification of building boundaries, reduce classification error, and lessen dependence on the analyst for classifier construction.

  Sohn and his coworkers [93] present a new approach for automatic extraction of building footprints in a combination of the IKONOS imagery with pan-sharpened multi-spectral bands and the low-sampled (0.1 points/m2) airborne laser scanning data. Laser scanning data where used to recognized an isolated building object in 3D object space cluster laser. All the member points of the cluster were similarly attributed as building points by investigating the height property of laser points and the normalized difference vegetation indices (NDVI) driven from IKONOS imagery.
As modeling cues, rectilinear lines around building outlines collected by either data-driven or model-driven manner were integrated in order to compensate the weakness of both methods. Finally, a full description of building outlines was accomplished by merging convex polygons, which were obtained as a building region was hierarchically divided by the extracted lines using the Binary Space Partitioning (BSP) tree. The system performance was evaluated by objective evaluation metrics and the detection percentage of 90.1% (the correctness) and the overall quality of 80.5% [93].

- Based on Morphological Operators

Benediktsson et al [10] in a work for Remote Sensing Images from urban areas use image processing techniques based on Morphological Transformations for feature extraction. First, in order to build a differential morphological profile that records image structural information they use geodesic opening and closing operations of different sizes, afterwards feature extraction or feature selection is applied. Both discriminant analysis feature extraction and decision boundary feature extraction are investigated in the second step along with a simple feature selection based on picking the largest indexes of the differential morphological profiles. Furthermore, the use a neural network to classify the extracted features.

Lefevre et al [62] proposed a new methodology for building extraction in VHR images without any ancillary data by using advanced morphological operators. They concluded that mathematical morphology offers sine image processing tools that can be successfully used to solve urban remote sensing issues such as building detection in VHR images. The methodology they proposed is based on a bidimensional granulometry in the filtering step. This morphological profile helps to define automatically the structuring elements used in the adaptive hit or miss transform. Additionally they proposed a clustering method to convert the input greylevel image into binary images avoids to determine the binarization threshold empirically. The fusion of the clusters also enables to take buildings with complex roofs into account.

- Segmentation and Building extraction by using commercial softwares

eCognition

The eCognition software is an object-oriented image classification software. The concept of eCognition is that an image is not represented in single pixels, but in meaningful image objects and their mutual relationship. eCognition classifies the image objects extracted in a previous image segmentation step, rather than classifies the single pixels directly. After image segmentation, a lot of additional attributes such as shape and texture which contained in image objects can be used for classification. Hierarchical object classification strategy is adopted to extract building features. In this classification, high resolution imagery, the feature height from both returns and the ground mask are used in the segmentation process. In order to produce highly homogeneous segments, weights are required for image layers. The weights can be assigned differently to different layers according to their importance or suitability for the segmentation result. The higher the weight is given, the more of its information will be used during the segmentation process. And the layers which do not contain the information intended for representation by the image objects should be given little or no weight. At the first level, only the multispectral
high-resolution images are used to classify vegetation surface and impervious surface which including roads and buildings [14].

BREC: the Built-up area RECognition tool

The BREC software developed by the Remote sensing group at the university of Pavia and is presented by Gamba et al [44]. The software allows detecting the characteristics of built up areas at different scales from urban extend delineation to individual building recognition, depending on the spatial resolution of the data and the data.

1.2.3 Urban scale: Extracting physical vulnerability characteristics based on Urban Contextual information

Information in the urban context that characterize the position of a buildings can be provided very useful for the evaluation of the vulnerability of the buildings. Distance to adjacent building, the distance to open space, the location of the building (Rural, Urban) or the usage of the building (Residential, Commercial, Industrial, Public, e.t.c) have been used in the literature by Taubenbock et al [101]. As we will see in the section 1.3 this kind of information can be distributed by the urban land cover classification which allows further analysis to urban space to detect the spatial distribution of vulnerability. These parameters can be well observed by satellite images. Once the individual buildings are identified in an image, then the position, and the distance to other buildings can be directly measured in the image [76]. On the other hand we can identified also the location of the building, by meaning the type of the area that it is located (rural, urban, open space) by a quick overview of the image. Mueller et al also point that different urban structure types can be identified in VHR satellite images based on the height of the buildings, the arrangement of the buildings and other assumptions and classified to block development, ribbon development, high-rise buildings and exclusive residential areas. In the latest publication point out that the availability of context information is one of the biggest advantage of remote sensing data for visual inspection of a study area. They also note that the position of a building in relation to other buildings or objects affects its behavior in the case of an earthquake

1.2.4 Road network extraction

Extracting the road network is not essential to the evaluation of seismic risk and especially vulnerability, but in several studies has been used as a complementary information to improve knowledge of the area of the interest and also it can be provided really useful to the management due to earthquakes for faster accessibility to the most vulnerable or damaged areas. Borzi et al [15], used a road network extraction in their study for assessing the vulnerability in an industrial area. The method that they used is based on a preliminary extraction of linear homogeneous areas which represent clues of road stretch, followed by stepwise elimination of false positives based on geometric rules, regularization and merge of segments by presuming that belongs to different section of the same street. In figure 1.11 is shown the road network as extracted by Borzi et al.

Hazarika et al. [52] discussed different resolutions and accuracies, from a regional perspective, for multispectral optical sensors that can be used for extracting information regarding road networks. In the report of DREAM [2] They conclude that using Landsat
images allows detecting roads wider than 15 m. Other higher resolution spaceborne sensors are proposed for detecting more narrow roads. In the particular case of detecting bridges, there is no operational direct extraction method from sensor images. A common method is to benefit from two kinds of data already extracted: the road network and the river network. A bridge can indeed be defined as a structure dividing a water body into two parts and that is connected to a road network. From the road and river networks, bridges can be identified in the frame of a GIS (Geographical Information System) by superimposing the water layer and the road layer [24]. The resolution of the images is depending on the size of the objects that need to be detected, Landsat data in lower resolution can be used estimate to identify main roads, main rivers and, as a result, main bridges. Higher spatial resolution images could be also useful for more detailed analysis in risk-prone areas.

For a more detailed explanation on this topic, there is a survey on automatic road extraction for GIS update from aerial and satellite imagery by Mena [71]. The work includes main approaches on general methods of road network extraction and reconstruction, road tracking methods, morphological analysis, dynamic programming and snakes, methods multi-scale and multi-resolution, stereoscopic and multi-temporal analysis, hyperspectral experiments, and other techniques for road extraction. Likewise, other approaches related in any way with the road extraction topic are also considered. Between them different papers on segmentation, vectorization, optimization, evaluation, semantic nets and neural networks, fusion techniques, fuzzy logic, and other methods are discussed.

Tupin [102] et all use SAR images and propose a two-step algorithm for almost unsupervised detection of linear structures, in particular, main axes in road networks. Firstly, they extracted linear features from the speckle radar image, which are treated as road-
segment candidates. Secondly, they identify the real roads among the segment candidates by defining a Markov random field (MRF) on a set of segments, which introduces contextual knowledge about the shape of road objects.

1.3 Determination of Urban Vulnerability maps by using Remote sensing

Detailed information about the Land cover of urban areas can help in the assessment of vulnerability and seismic risk management. Because of the large variety of disasters and related impacts, and also because of the variety of the available resolution of satellite images as introduced in section 1.1.2, in the literature several classification techniques can be found for land cover and land use maps. The different classification maps can be found application both to local (individual buildings) and urban scales (homogeneous areas) with most of the application appearing in the urban scales. As already introduced in section 1.1.2 the increasing spatial resolution of imagery has lead to a more detailed map that represent urban morphology and more sophisticated methods and automatic methods to classify objects rather than pixels. Different map can be created according to the size of the area that we are interesting and corresponding to the availability of the spatial resolution from level 1 to level 4 (see section 1.1.2). At a first step it is necessary to discriminate between large areas such as cities, forests and crops, while being able to extract from images the rivers as well as the main transportation axes, what we say land cover classification. At a second step information such as area of each building or distance between buildings can also be determined and classified.

1.3.1 Introduction to land cover/ land use classification

Geographical information in the form of maps is an important topic in many remote sensing applications. As already mentioned above, obtaining a map of seismic vulnerability with the agreement of geotechnical analysis is the main goal of this application. Classi-
Classification techniques can be used for the identification of areas of homogeneous buildings (residential, commercial, parks, open spaces, etc).

In this survey, we are not interesting for presenting in detail the satellite remote sensing classification techniques, instead we will introduce the concept of image classification and present different classification techniques that have been used in the application of vulnerability assessment in urban areas both in individual buildings and homogeneous areas in sections 1.3.2 and 1.3.3 respectively. In addition, we want to emphasize the great capabilities of remote sensing for mapping highly structured urban landscapes area-wide and up-to-date. The increment especially in spatial domain has lead to new classification techniques requirements for classifying very small-scale structures.

Land cover/land use mapping in urban areas have been relying on data coming from many different sensors, but most of the recent efforts are related to very high resolution (VHR) in both the spatial and the spectral domain and they are focusing in object based classification ([96, 31]). In a more general way classification can be performed several ways, e.g., supervised or unsupervised, parametric or nonparametric, and on whether spatial information is used or not.

An excellent survey of image classification methods and techniques for improving classification performance is presented by Lu and Weng [64]. Classification approaches in general can be grouped as supervised and unsupervised based in whether training samples are used or not. In supervised classification approaches land cover classes are defined. Training samples are used based on the availability of sufficient reference data. The signatures generated from the training samples are used to train the classifier to classify the numerical (spectral, spatial etc) data into a thematic map. Examples of classifiers are Support Vector Machines, Maximum Likelihood, Minimum distance, artificial neural network, decision tree classifier. As far as unsupervised classifications are concerned, the extraction process is fully managed by clustering-based algorithms. Numerically similar pixels are automatically grouped based on the statistical information inherent in the image. Even if the process does not in theory require any human intervention, the analyst usually has to define prerequisite sets of classes and parameters in order to help the algorithm to deliver an accurate classification.

One more categorization on the wide area of the classification approaches can be based on whether parameters such as mean vector or covariance matrix are used on and therefore taxonomy into parametric and non parametric classifiers. In parametric classifiers a gaussian distribution is assumed, and the parameters are usually generated from training samples. Some of the major drawbacks pointed out by Lu and Weng [64] in their survey, is that when landscape is complex they produce noisy results and they are not flexible in the integration of ancillary data, spatial and contextual attributes into a classification procedure. (Some examples are Maximum likelihood and linear discriminant analysis classifiers). On the other hand in non parametric classifiers they do not employ any statistical parameters to calculate class separation and they recommended when ancillary data need to incorporate into a classification procedure. Some examples are Artificial Neural Network, Decision Tree Classifier, Support Vector Machines.

Particularly in urban land cover classification, the main challenge arises from the spectral and spatial heterogeneity from very high resolution remote sensing imagery [96]. Taubenbock et al [96] in order to characterize the complex highly structured urban environments they proposed an object oriented classification approach with shape parameters and neighborhood relations providing an additional analysis apart from spectral information.

Furthermore, in the literature object oriented approaches are gaining a lot of inter-
est and they are most popular in several applications that utilize very high resolution imagery. On this account Taubenbock and Roth [99] for example, proposed an object oriented approach focusing on the spatial capabilities of the sensors for an accurate classification result of highly structured and heterogeneous urban morphologies. Under the assumption that typical urban objects, like houses, streets or open spaces correspond in any urban area, they developed a shape centered classification approach. With subject to the particular urban area, the user can select the scale parameter, for the starting classification procedure. By using an implemented segmentation, the hierarchical top-down classification concept allows modular use of the provided thematic classes. The multi-stage fuzzy logic based classification approach enables class allocation solely for segments with sufficient memberships.

However, the classification algorithms remain today a significant and complex area of research in order to achieve sufficient levels of accuracy. The area of classification gain a lot of interest in the research community and it could stand alone as a subject for development and investigation. Commercial softwares are also recommended. Many existing software solutions like Environment for Visualizing Images (ENVI) software ([4], ITT Visual Information Solution, 2008), or the Earth Resources Data Analysis System (ERDAS) environment ([3], ERDAS, Inc., 2009) allows for performing land cover classifications. The eCognition software also mentioned in section 1.2.2, ([1]) is especially cited in many papers for object based classification approaches.

1.3.2 Relevant- Vulnerability map for individual buildings

At the individual scale, information of the height can play an important role for determining the vulnerable of individual buildings. Polli et al [84] extracted volumetric data on tanks and chimneys from satellite images to assess seismic vulnerability and classify the structures by risk class in a 3D representation of the area (figure 1.13 (a)). Another example of assessing the vulnerability in individual buildings and classify the structures by a risk class is the one that classify between gable and flat by Valero et al [106] see figure 1.13 (b).

Yamazaki et all [114] classify individual buildings based on a classification methodology by using combination of the following information: 3D data acquisition, analysis on color, texture and coverage area of each building. In more detail, with respect to the building properties, Yamazaki et all consider the following items. The number of stories is estimated based on the building height evaluated by stereo matching. Based on their heights, the buildings are firstly categorized into two groups: one or two-storied houses, apartment buildings, and multi-storied reinforced concrete or steel-framed buildings. Based on the result of color and texture analysis and the evaluated building area, the buildings are classified into three groups: detached houses, apartment buildings and multi-

![Figure 1.12: Building classification based on height, color, texture and building coverage area proposed by Yamazaki et. al. Figure from [114].](image-url)
Figure 1.13: Classification of individual buildings in different risk classes. In (a) buildings are representing in 3D and they are classifying according to volumetric data (Figure from [84]). In (b) the vulnerable classes are based on the type of the roof (Figure from [106]). In (c) the buildings are classified based on a classification methodology by using a combination of the following information: 3D data acquisition, analysis on color, texture and coverage area of each building (Figure from [114]).

storied buildings. In addition, these buildings are also classified into two categories: wooden and non-wooden buildings with regard to the structural type. The flow the proposed building classification is shown in figure 1.12. Results after applied an aerial photo are shown in figure 1.13 (c).

1.3.3 Relevant- Vulnerability map for homogeneous areas

At the urban scale, different land cover parameters have been used from Taubenbock et al [101] to assess the vulnerability by combining parameters such as: build up density, distances between buildings or open space, night time population distribution. Using very high resolution images it is more usual to use land use classification, rather than land cover. In this section we will present the different approaches that has been used the for building urban land cover map based on seismic risk assessment. As we already mentioned in the introduction, the analysis at the scale of the city, including identification of areas of homogeneous buildings (downtown, historical, residential, commercial areas,
Figure 1.14: Built-up density zones compared to the original IKONOS imagery. An accuracy assessment of the homogeneous density zones is difficult because of the lack of a standard norm. Therefore the accuracy has been assessed by a comparison of the calculated zones to a digitized layer with visual allocation of homogeneous density zones. The overall accuracy result was 82% reported by Taubenbock et al [96] (Figure from [96]).

e.t.c. is a part of the methodology for assessing vulnerability in homogeneous areas in different vulnerability classes, based on different characteristics.

Taubenbock et al [96] proposed an object oriented approach to derive a thematic land cover classification. The classification methodology, is predominantly based on shape and neighborhood related features and it is exemplified by the extraction of roads with a region-growing rule base. The approach follows the assumption that objects representing real world structures correspond in any urban area. The urban land cover classification is used to compute a spatial distribution of built-up densities within the city and to map homogeneous zones or structures of urban morphology. The result of their classification approach is shown in figure 1.14 and the overall accuracy of their methodology was 82%.

The challenge of classifying urban land cover from high resolution remote sensing data arises from the spectral and spatial heterogeneity of such imagery. The frequent alternation and coexistence of built-up structures, vegetation, bare soil or water areas and the heterogeneity of the objects themselves (for example roads with cars) result in distinct spectral variation within these areas of literal homogenous land cover classes. Due to the spectral heterogeneity, the classification approach proposed by Taubenbock et al [96], was developed under the premise of mostly avoiding spectral classification features. Based on the generated objects - ideally representing all the real world structures in urban areas - a region-growing algorithm implemented for a very high fuzzy classification probability. This classification approach was predominantly based on shape features. The only spectral feature used in this classification process was the NDVI. All remaining features were shape-related and neighborhood-related attributes. Thus, easy transferability for urban land cover classification can be achieved with a few adjustments due to different spectral values.

Furthermore, the result of the derived land cover classification of an urban area has been used for a computation of density zones to deliver additional information for city
planning. Based on the prior land cover classification a moving window approach has been implemented. The window calculates the rates of pixels being classified as built-up, vegetation, water, shadow and infrastructure in the distance of 20 and 200 meters to each side of the middle pixel. The near neighborhood and the 400 pixel surrounding density value calculation have their theoretical background in a more flexible approach to classify homogenous density zones in consideration of near neighborhoods to detect transition zones and to embed the zone in respect to the whole structure of the quarter. Figure 1.14 shows an allocation of four different density zones, high dense, dense, loose dense and open spaces calculated from the land cover classification result. The three built-up density zones act as homogeneous zones in an urban environment. The paper was not published as an application for seismic risk assessment but for spatial structuring in urban environments.

In another publication on physical vulnerability assessment Taubenbock et al [97], used five different physical vulnerability indicators. Based on a land cover object oriented classification (a region growing algorithm was implemented for a very high fuzzy classification probability.) the five indicators had been used to allocate homogeneous areas within the urban area of Istanbul. Object-oriented classification methods classify homogeneous regions, or image objects. The classification rules in different homogeneous areas are vary and based on similarities rules like size, orientation, location, shape, configuration, colour, material, texture and function. A similar work is also presented in [21]. Figure 1.15 (a) shows the assessed vulnerability for a final vulnerability analysis map, which is the spatial distribution of three vulnerability levels computed from the weighted specific vulnerabilities presented in figure 1.17 (b).

The five different indicators that they examined where:

1. Built up density
2. Building alignment
3. Road width
4. Open spaces
5. Location (distance to major road)

For every zone indicated in figure 1.15 the parameters of the physical and demographic vulnerability indicators derived from solely remote sensing considered known and contribute to an overall vulnerability assessment in urban homogeneous areas.
Figure 1.15: Vulnerability assessment zones. In figure (a) the results for vulnerability assessment zones are presented ([21, 97]) and show the vulnerability distribution within the highly structured urbanized area of Uskudar in Istanbul. Highly dense built up areas with its highest population concentration, narrow and complex road network and the long distance to open spaces indicate higher vulnerability areas. In figure (b) an example of homogeneously distributed vulnerability zones generated by social vulnerability indicators such as night population, [21].
According to the GEM reported in section 1.1.1 Understanding Risk and Vulnerability, socio-economic impact module can provide tools and indices for estimating the impact from earthquakes on the economy and society. Ebert and Kerle [36] used a combination of VHR satellite data, a digital elevation model, a LIDAR normalized digital surface model, a set of different GIS data, census data and scattered ground truth information to assess urban social vulnerability focusing on landslide and flood hazards. However, indicators for social vulnerability do not necessarily relate to a certain hazard, but so express a lack of resilience to cope with natural hazards in a more general way [36].

As in the assessment of physical vulnerability some of the indicators used in social vulnerability are the same and object oriented image analysis techniques are applying, e.g. the position of the building in relation to the hazard zone, roof types, slope position, building heights, road conditions, texture. The novelty in their publication is the use of image-based contextual, object oriented analysis. Spectral, spatial, contextual, and texture information had been used for the class description for a land use/land cover map with accuracy of 89.1 % with the usage of a digital surface model and 84.3 % without. A digital terrain model was used to calculate the slope position to which the image objects were associated. For individual building scale the used census data, but for homogeneous areas they used remote sensing data (slope, road conditions, building density, roof size, material, distance to neighboring building, size and distribution of green houses, commercial and industrial development, distance to city center (rural, urban)).

1.3.4 Quantifying Vulnerability

In this subsection we would like to present different ways found in the literature for quantifying vulnerability. There are very few works on assessing vulnerability values either on buildings or areas. Some examples are explained below:

- Combining different data layer Taubenbock et al [100], quantify spatial vulnerability and present a methodology to display vulnerability by means of an n-dimensional coordinate system., where the axes are described by the selected indicators (slope angle, building vulnerability, accessibility) - different data layers. Each indicator is
Figure 1.17: Quantifying vulnerability. In (a) Methodology proposed by Taubenbock et al [100]. In this figure the combination of the various information layers is presenting, and shows different locations within the district of Zeytinburnu. For example the location indicated by the blue line shows a building with a direct neighborhood to the inner city highway and a 400 meter distance to a large open space and a slope angle of 12 degree. This information (from the data layers) is converted to vulnerability values resulting in a high building vulnerability of 0.85, a slope angle vulnerability of 0.9 and a low vulnerability of 0.15 due to the high accessibility. The length of the resulting vector describes the degree of vulnerability for the specific variables and the direction determines the main influencing factors. In (b) a weighted vulnerability assessment approach is developed for combining several vulnerability indicators (build up density, building alignment, road width, open spaces, closeness to major roads), which enables to calculate the total vulnerability level of an area, the methodology has presented by Caliskan et al in one of the earliest work [21].

- Weighted vulnerability assessment In one of the earliest work Caliskan et al [21], proposed a weighted vulnerability assessment approach is developed for combining several vulnerability indicators (build up density, building alignment, road width, open spaces, closeness to major roads), which enables to calculate the total vulnerability level of an area. The description of the method is presented in figure 1.17 (b)
1.3.5 General comparison between optical and radar sensors for urban classification and seismic vulnerability assessment

Optical sensors have traditionally been employed for land cover determination [87] due to the availability on highest resolution, use of multispectral images that allows the discrimination between different materials and the visual interpretation of optical images. Limitations of optical sensors appears to be the advantage of radars, which is that optical sensors cannot provide any data during the night or in case of bad weather, where radars can acquire images at any time, independently of weather or environmental conditions.

However, some studies for example Corr et al. used an airborne E-SAR image (2 m spatial resolution in the range direction and 0.6 m in the azimuth direction) for the classification of an urban area. They concluded it was necessary to derive additional features from the data, on shape and size, to resolve ambiguities between some land cover classes, and for improving the discrimination of buildings. For this purpose, radar imagery stands as a good complement to optical imagery.

In addition to the all weather capabilities, SAR conveys the greatest amount of information about structural as well as dielectric properties of the urban materials [32]. However optical sensors seems to be preferable in urban areas especially in building inventory and land use classification or in automatic feature extraction, where objects tend to cluster and show almost no more structure, the problems of radar imaging appear not to be overcome for urban characterization. VHR optical imagery on the other hand appeared to open new opportunities for detailed mapping and analysis of urban land use either by using spatial or texture metrics [55].

For seismic vulnerability assessment a very few works has be done by using SAR images. Aoki, Matsuoka and Yamazaki investigated the relationship between structures and backscattering characteristics using airborne SAR. They evaluate the detailed polarization characteristics by using the polarization signature if representative areas such as residential and commercial, they suggested that VV polarization intensity has a relation with building height. They also used a field survey to confirm their results on the characteristics of the buildings in each area. In comparison with SAR, optical sensors seems to be more attracted by researchers in the area of seismic vulnerability assessment application as already mentioned in the previous section, with preferences in VHR imagery [84].

1.4 Conclusion and discussion

In conclusion to the above, we would like to address the interest in two directions. Firstly, summarizing the potentials of RS and secondly recommend where to head according to the lack of published works.

So far in this report, we have seen what are the capabilities of remote sensing reported from different authors either limited in physical vulnerability assessment of the buildings (e.x roof type, age, material, size, shape, number of buildings [76], volume [84]. Publications exist based from simple roof indicators for direct physical vulnerability assessment [106] to more complicated risk assessments counting together different physical capabilities (based on spatial, color and texture analysis) in an hierarchical classification scheme [114]. The capabilities of RS in vulnerability assessment are extended from physical vulnerability assessments to a more general framework counting also demographical indicators that are more related with location factors (e.x Accessibility, built up density [97], distances, inclination of slope (DEM) [100]) and socio-economic indicators that
encounter the percentage of population living in high risk zone (e.g., population distribution) [98].

Also, emphasize should be done on the contribution of digital elevation models DEM and the joint processing of remote sensing data and (DEM) since it has already proven to be a crucial parameter for removing ambiguities in the case of characterizing vulnerability indicators in buildings such as the type of the roof. There is also a need of investigating what has been done in the area of optimal fusion of these data due to the importance of the contribution DEM.

On the classification task the interest should be focused on the spatial organization of the identified buildings and their respective heights and how the can be used to extract more accurate results, and on the scale of the city, including identification of areas of homogeneous buildings. Several work have been on proposing methodologies for classifying homogeneous areas.

Looking in the literature and the published papers in the sphere of vulnerability assessment by using RS and the amalgam of the different indicators that can be extracted (physical, demographical, socio-economic indicators), we conclude that the capabilities of RS are reported not limited but promising and they can stand alone for specific vulnerability assessment purposes.

If we expected from RS to contribute in a more generic way, then we should expected in the future to see more works focusing on the integration of RS and in-situ data. In a more futuristic framework and by taking in account ground truth evaluations for the developed applications on the assessment of seismic vulnerability, we expected that RS can offer and remarkably contribute more and more for vulnerability assessment due to the aforementioned capabilities and the increment of the spatial resolution of VHR.

Some of the areas that appeared to be from less to at all developed are the following:

- Need for Quantifying Vulnerability.
- There is also a need to evaluate the results of Assessing Vulnerability, based for example on some in-situ measurements.
- Need of more generic methodologies that can integrate data from RS technology and in-situ data for the seismic vulnerability on buildings or urban areas.
Chapter 2

Post-earthquake damage assessment on urban context by using Remote sensing technology

2.1 Introduction

Remote sensing techniques are gaining increasing interest for detecting urban damage and other surface changes due to the earthquakes. Remote sensing technology can provide information about the physical aspect of the damage (number of damaged buildings or infrastructure, level of damage, etc.) in urban areas. For this purpose, optical, radar images and Digital Elevation Models (DEM) can be useful tools for this application thanks to their very high resolution and the well-defined perception of the buildings. Also the feasibility of frequent revisit times of the sensor is an additional advantage. The above information extracted by remote sensing sensors can be extremely useful and important if the information can be provided in sufficient timeliness and efficient representatively [27]. Remote sensing technology in post-earthquake damage assessment has been applied in different earthquake study cases such as to the Hyogoken-Nambu earthquake (Kobe) in 1995 ([111, 66]), the Chi-Chi (Taiwan) in 1999 [95], the Kocaeli (Turkey) in 1999 ([37, 103]), the Izmit (Turkey) in 1999 ([11, 46]), the Gujarat (India) in 2001 [6], the Bam (Iran) in 2003 ([26, 27, 11, 115]) , Boumerdes (Algeria) in 2003 [26], the Central Java Yogyakarta (Indonesia) [75], the Sichuan (China) in 2008 ([63, 19]), the Wenchuan Earthquake, Sichuan province in May 2008 [91].

Although many studies on post-earthquake damage assessment have been carried out, there is still not a straightforward methodology. In the area of change detection in remote sensing images a lot of research has been done in and it’s been proved through different publications that it can be adapted efficiently for generating damage detection tools with the aim of producing damage maps. Automatic damage classification with several levels of damage, which goes beyond a simple binary representation has also gained a lot of interest in the area of earthquake damage assessment. One of the main challenges is the contribution of elevation information from Digital Elevation Model (DEM) in addition with the remote sensing data. This situation creates limitations to some extend in the application of remote sensing technology for damage assessment as most of the remote sensing data (optical satellite imagery, airborne and multi-spectral scanners) give a vertical view of the ground surface. That is why information about the height are important contribution for damage assessment. For that purposes data fusion techniques can be
generate to integrate sufficiently multiple data sets for urban area characterization. It can be one of the key factors for developing methodology for the improvement of damage assessment.

In addition to the above, characteristics of earthquakes and urban morphology are also important determinants for the appropriate data and methodology selection for post-earthquake damage assessment applications, as each settlement (in terms of building size, density, etc.) [73] and earthquake (in terms of magnitude, extent of affected area, etc.) [82] has its own specific characteristic. Moreover, the challenge for the post-earthquake damage assessment is not only related to the nature of the earthquake itself and the urban areas, but is also related to the data requirement, data availability and use of optimum methodology.

According to the trend of the last in the contribution for post-earthquake damage assessment by remote sensing technology we will present in this work a state of the art focusing in the methodology. In section 2.2 we are presenting how urban areas can sensed remotely by emphasizing the importance of the detailed characterization on a building and area scale can be provided, in section 2.3 a review of the available data sources that can be used is present. Limitations, advantages and disadvantages of each element will be emphasized. In section 2.4 a need of using multiple sensor and the importance of integrating different remote sensing is presenting and we continue with the methodologies for assessing post-earthquake damage in section 2.5, in this section we also include previous post-earthquake damage assessment studies.

2.2 Urban Areas and Remote Sensing

Sensing cities remotely is not new. Aerial photography has been prominent in military reconnaissance as well in civil use for most of the twentieth century [73]. Urban remote sensing applications are more dependent on the resolution of images therefore the use of satellite imagery has increased with the technological improvement in the resolution of the satellite imagery. It is surprisingly that it is only relatively recently at the start of the third millennium, that the spatial resolution of satellite sensors has increased to the extent that accurate urban classification can be performed ([73, 110]).

Donnay et al. [35] examine the development of satellite imagery for urban studies in three stages (three generation of satellite sensors). In table 2.1 we present the three generations of satellite sensor, (modified from [73, 35]).

The first generation of remote sensors had limitations for detailed urban analysis. The second generation instruments presented on table 2.1, although providing significantly finer spatial resolution than Landsat MMS were not more accurate for urban classification [73]. For the third generation, for a spatial resolution of around 5m or finer, enables relatively accurate urban classification. The development of the third generation satellite sensors has attracted considerable interest from the remote sensing community ([23, 70],[30, 40]). The scale of the third generation satellites corresponds to the scale of urban planning projects at tactical level [85]. On the other hand, slow processing, high storage capacity, and cost of the data are some of the major problems of working with this new generation imagery [81]. Other possibilities for urban remote sensing application are laser scanning and radar. Synthetic aperture radar (SAR) can be used irrespective of sunlight and weather conditions, hence this feature is highly effective in damage surveys when optical remote sensing, such as multi-spectral scanning and aerial photography, is difficult [111]. As they are active sensor systems, they have capability of taking images also at night.
Three generations of satellite sensor. (Modified from [73, 35])

<table>
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<tr>
<th>1st Landsat Multi-spectral Scanning System (MMS)</th>
<th>Operation Year</th>
<th>Spatial Resolution</th>
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<td></td>
<td>70's-80's</td>
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<th>2nd Landsat Thematic Mapper (TM)</th>
<th>Operation Year</th>
<th>Spatial Resolution</th>
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<td>1970s-80s</td>
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<th>2nd SPOT HRV instrument</th>
<th>Operation Year</th>
<th>Spatial Resolution</th>
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<td></td>
<td>1980's</td>
<td>20m multi-spectral sensor</td>
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<td>10m panchromatic sensor</td>
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<th>3rd IKONOS</th>
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<td></td>
<td>1999s</td>
<td>4m multi-spectral sensor</td>
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<td></td>
<td>1m panchromatic sensor</td>
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<th>3rd Quickbird</th>
<th>Operation Year</th>
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<tr>
<td></td>
<td>2001s</td>
<td>2.4m multi-spectral sensor</td>
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<td></td>
<td></td>
<td>60cm panchromatic sensor</td>
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Table 2.1: Development of the use of satellite imagery for urban studies in three stages. Some of the sensors are included in each generation on the table.

To study urban areas by using remote sensed data differs from studying the natural environment. As already pointed remotely sensed imagery data from satellites and airborne platforms have become important tools to grasp damage distribution due to natural disasters. To assess the building damage is a challenging task because of the different characteristics of the settlements all over the world. Aerial television imagery and photography are very useful to observe buildings and infrastructures with high resolution. Thus automated detection of damage is possible using only post-event images or both pre- and post-event images. Use of airborne SAR is also highlighted for 3D urban modeling. Yamazaki et. al. [111], review recent developments and applications, notably, remote sensing and GIS, from the viewpoint of risk assessment and post-event disaster management in urban environments.

Before assessing the damage on the building it is mandatory to classify and identify the context in urban areas. In table 2.2 we are presenting an example of some possible attributes that can be identified in urban areas from very high resolution remote sensing sensors on a building scale and on an area scale. First of all, as urban land use classes, include detailed information about buildings, transport networks, business, parks, shadows and variety of mixed uses, to study and analyze urban context requires higher resolution. Moreover, the size, densities and the contrasts of urban areas around the world are not the same [110], so it is difficult to decide on the appropriate spatial resolution for all urban areas. Characteristics of the urban areas decide on the appropriate spatial resolution for the specific urban area. On the other hand, higher resolution doesn’t always mean improvement in classification accuracy [23]. To achieve a more accurate classification, additional information may be needed, especially in the context of complex natural
Various methods incorporating contextual, structural, or perceptual information have been proposed ([41, 105]).

Furthermore, the selection of the resolution is much more dependent on the objective of the project. The building sizes, densities, the contrast of the urban environments and the objective of the project are the main determinants of the spatial resolution. Therefore, to select appropriate data for post-earthquake is relevant and requires prior knowledge about the settlement characteristics.

### 2.3 Satellite remote sensing data for urban damage assessment

In the case of earthquakes, high spatial resolution of the image, high temporal frequency of the sensor and capability of the quick response time are the main requirements for the urban damage assessment. Moreover, Digital Elevation Models (DEM) and 3D characteristic of the damage can contribute and is considered as another important requirement for the data selection. To assess the damage, there is a need for prior knowledge about the damage characteristic of specific area. Damages to buildings are usually described based on damage classes. European Macroseismic Scale (EMS) propose a pattern to classify damaged buildings. Building damage can therefore been classified according to European Macroseismic Scale (EMS) 1998, which includes a substantial to heavy damage state (Level 3), very heavy damage state (Level 4), and destruction damage state (Level 5).

Figure 2.1 and table 2.3 gives examples of damage pattern according to the EMS-98 damage levels [9].

To choose the optimum data for urban damage assessment, it is important to know the data types with their different characteristics, as all of them have different spatial,
spectral and temporal resolution. Parameters for data selection are consideration of area coverage, urgency, weather and spatial resolution of images [111]. Main differentiation comes from the type of platform and type of the sensors. Here, sensor types will be examined in two different platforms: airborne and space-borne.

Figure 2.2 derived from [111] shows various platforms and sensors used for remote sensing. The platform and sensors is selecting by considering the area to be covered, resolution of images, which are both closely related also weather and time conditions. If we want to get images over a large area, satellite imagery may be the most suitable tool although its resolution is in the order of several ten meters and return period is several weeks for commonly available earth observation satellites. On the contrary, aerial video and photography from helicopters and light planes can be obtained much faster with higher resolution despite the fact that the area to cover is much small. Regarding sensors on board platforms, synthetic aperture radar (SAR) can be used irrespective of sunlight and weather conditions, hence this feature is highly effective in damage surveys when optical remote sensing, such as multi-spectral scanning and aerial photography, are not the appropriate.

### 2.3.1 Airborne remote sensing technology

- **Aerial photography**

  The Airborne remote sensing is one of the promising data source to grasp damage information at an early stage of the disaster due to the high spatial resolution.
To obtain detailed inventory and to collect damage data of building environment use possible by using airborne remote sensing as they are very useful to observe buildings and infrastructure in urban areas [111]. Conventional aerial photos small format aerial photos, multi-spectral scanners, laser, airborne SAR and aerial video imagery are the main types of this data sources. On the other hand, because of the higher spatial resolution, the coverage area of the airborne sensors is limited and there is a need of different captures to cover a bigger area of interest. The main advantage of airborne imagery is that aircraft can react in a short time period after an earthquake, if the conditions permits. Conventional aerial photos allow high spatial resolution and stereo photos allows deriving information regarding the height in the other hand there is a lack of multi-spectral information and they cost. The high resolution of the aerial imagery is do high that it creates an advantage compared to space-borne imagery. However acquisition process can be long, as it might sometimes require long logistic preparation time. Turker et all [103] used two set of stereo images to assess the damage in the case of the Kocaeli earthquake in Turkey and to detect damaged buildings. Also Zhu and his co-workers [120] used a panchromatic image of the airborne digital camera UCD with spatial resolution 0.2 m and the corresponding 3D building data covering the same area are used to perform automatic change detection between extracted features from high resolution images and edge features derived from 3D building data to obtain damage information.

- **Airborne Laser scanning (ALS)**

LASER stands for Light amplification by stimulated emission of radiation. Laser scanning data provide the height of the ground objects, which can be used for developing models to extract the man-made features in a complex urban environment. Using the height variation along the periphery of objects present in the data, Dash et all [29], proposed a method based on standard deviation to distinguish between tree and buildings.

Airborne laser scanning (ALS) is becoming well used in research and commercial areas and gaining interest especially in the field of mapping and monitoring environmental and urban planning especially development of 3D city models [50], disaster management [94]. Laser scanning data is mostly used to characterize the type and the extent of damage by extracting the buildings and other man-made objects and comparing their status in pre and post disaster data, therefore it is helpful to produce a near real time damage model ([94]). ALS data can be used for two purposes: First to generate a model depicting the buildings of the area by using the post disaster data and comparing with the pre disaster database to find the damage model. The model should convey information about the type, shape and other related information of the building which could be proved useful for accessing the damage. Second to find the shortest possible path for the relief and rescue teams to reach the needy as many of the roads get blocked by rubble and debris [29].

Murakami et all in their study study [77] utilized the laser scanning technology to detect the change in the buildings in the city of Minakami, Japan, where they conducted that building chances could be produced without omission errors by using ALS. This hint that it can provide important information for earthquake damage assessment. However it is important to keep in mind that not all the damage type is resulted in change in the building height. On the other hand the main disadvantage of using laser data is that they have blind characteristic, since it gives information only about the height. It could be effective only by integrating other
data sources such as aerial photography, Acquisition of DSM data and optical imagery at the same time is an important tool for automated generation of ortho-images [77]. Another drawback of using ALS is the high cost and complex image processing and it is not widely used.

- Airborne radar

Airborne radar is not widely used either. One of the reasons for this is high cost of the technologies used in data acquisition. Airborne SAR image The airborne SAR is able to provide full polarization information. The polarization characteristics can help for the identification of detailed surface conditions of objects because they differ according to the factors such as the building material and the density of city blocks. If the structures on the basis of their areas and heights can be identified from the polarization characteristics, the results can be used in seismic damage assessments [111].

Airborne multi-spectral scanners can also overcome the limitations of the aerial photography in terms of spectral resolution and digital format. Cost is one of the limitations for both resolutions. Mitomi et al. [74], used airborne multi-spectral scanner to assess the damaged areas after the 1995 Hyogoken-Nambu, Kobe earthquake.

In conclusion airborne technology is more suitable to obtain detailed inventory and to collect damage data of building environment. SAR imagery is one of the most promising techniques in this objective, and aerial imagery are particularly useful in the early post-disaster damage detection as well as in the collection of inventory data in the ordinary period.

2.3.2 Space-borne remote sensing technology

Space-borne remote sensing are superior to airborne sensors if we are interested to cover large areas. In contrast to aerial imagery satellite imagery offers information at regional scale. Therefore, satellite imagery can be useful for damage detection in large scale natural disasters.

- Optical satellite imagery

In optical sensors (i.e. passive sensors) their images can give information about the reflected energy of objects. The main drawback of optical sensors is that they depend on the cloud coverage and they can be affected by the seasonal and atmospheric conditions like snow, smoke, also they can operate only during the daylight. In urban damage assessment the main assumption about the value of the damaged structures (post earthquake image) is that it can be higher compared to the (pre earthquake image) because of the collapse of the buildings [118] and so based on the obtained frequency distributions of the differences in the optical sensor values, which showed significant changes in the reflectance due to the earthquake disaster they can abstracted the estimated damaged area. Therefore changes in the reflectance values of damage structures is used to assess areas, although there are several external factors, which can create changes as well, such as seasonal and atmospheric changes. In addition not all the damage levels can be detect by only taking into account the reflectance values of the damage buildings, as some of the damage types, such as pancake collapse, do not create change in the reflectance value of the buildings. In
the literature there are several studies focusing in the urban damage assessment by using different spatial resolution, medium (Landsat TM (30m)), Landsat ETM+ (15m), SPOT HRV MSS (20m) AND pan (10m) and very high resolution of satellite images (IRS 1C & 1D (5.8m), Ikonos (1m), Quickbird PAN (0.67m), BREST (1m) ) are used respectively by ([11, 34, 88, 19] and [20] and [25, 5]).

The availability of higher resolution images such as Quickbird and Ikonos in the last years allows the interpretation of damage of each building block or even in each individual building, rather than the overall damage distribution and damage extent [115].

As already mentioned above the main disadvantage of optical imagery is that they depend on the atmospheric conditions and comparing images under different atmospheric conditions is difficult. While some of the satellites have steerable characteristic which allows data acquisition almost every day, most of the orbital satellite sensors fail to fulfill the rapid response requirement for damage assessment application. Limitation on the temporal resolution of the remote sensing technology can restrict the functionality if the real time disaster monitoring applications. On the other hand, currently meteorically satellites, such as DMSP, can operate in real time monitoring if weather related disasters. However, their spatial resolution is very low for assessing damage in urban areas. The solution of this problem is the imagery, such as SPOT which can select scenes from broad field of view and increase the temporal resolution of the sensor [107].

However, another problem that is arising by using very high resolution images is that they also introduce higher internal variability and noise within each land-cover class. Therefore, the pixel-based algorithms fail in handling them and there is a need of and developing and performing new methodologies.

- Radar satellite imagery

Capability of SAR satellite imagery has been demonstrated for damage detection in large-scale damage detection. They give information about surface roughness and surface moisture. The typical spatial resolution of space-borne SAR image is 5 to 100 m. Their main advantage is that they can overcome the weather limitations of optical imagery, since they can penetrate haze, clouds and smoke. Being active sensor, they do not depend on sunlight. Those characteristics are highly effective in damage surveys. Synthetic Aperture Radar (SAR) records the backscattering intensity if the earth surface. The basic assumption for damage assessment of using radar imagery is that change in the roughness due to collapse of buildings can be resulted with change in the backscattering intensity [67].

SAR data have been predominantly used in change monitoring because of their sensitivity to characteristics of the earth's surface, such as geometric structure, surface roughness, and moisture content. Another major distinction of space-borne SAR from optical sensors, besides weather and sunlight independence, is the possibility to extract the height information of a target area through interferometric SAR (InSAR). InSAR makes use of the phase information contained in the backscattered echoes of the returning signal. By combining two SAR images of the same area but acquired from slightly different positions (different viewing angles), it is possible to measure the phase differences across the common overlapping area and depict them in an interferogram, which can be used to extract height information [8].
Some of the cases that Radar SAR images were used for the identification of damaged areas were in the Gujarat India earthquake [118] and in the case of the Chi-Chi Taiwan earthquake in 1999 [95] ERS-2 SAR data. However analyzing radar data is a difficult task and it can be an exhausting research task to stand alone. These difficulties of analyzing radar data in urban areas create limitations for the applications.

2.4 Data Integration

We are interesting to look in the literature different methodologies of integrating multiple remote sensing data and how this research can help and improve the damage detection in urban areas after natural disasters such as earthquakes.

The methodology of the damage assessment can be vary depending on the study case and the type of the sensor. In the literature, there are several research that focused in the use of one type of sensor, ([75, 6, 17, 27, 34]). On the other hand the increasing availability of large amounts of data suitable for urban applications demands the development of adequate algorithms and procedures for their (semi-) automatic characterization.

Due to the availability of different data sources techniques particularly suited for multiple data sets analysis in the urban areas are also developed ([11, 19, 45]). Many sensor types (optical, thermal, laser, SAR) are considered, and particular attention is given to satellite data analysis. The very first challenge posed by such large amounts of data is the establishment of suitable application-driven criteria for usable data selection. An associated challenge is the development of automatic or semi-automatic techniques capable of extracting vector layers from raster data, in order to integrate them in a Geographic Information System (GIS). As a matter of fact, the use of remotely sensed information in geographic application is increasing, and not withstanding the fact that urban applications often require data at the finest ground resolutions, many interesting characterizations are feasible using even lesser resolution data from existing sensors (Figure 2.3). There is a big confident [42] that the use of multiple data sets for characterizing an urban area will be one of the key factors.

If anyone is interesting further on the integration of multi-sensor or a multi-resolution fusion techniques suited for urban areas can find more details on the survey [42].

In the case of integrating multiple data sets for rapid damage assessment after natural disasters such as earthquakes the advantages of the different sensors can utilize to combine and produce better results. Brunner et. all [19], proposed a novel method for assessing the structural status of individual rectangular buildings in an urban setting affected by a catastrophic event using pre-event VHR optical and post-event detected VHR SAR imagery. The building information extracted from VHR optical imagery and the acquisition parameters of the post-event VHR SAR scene are used to simulate the expected SAR signature of the building in the post-event SAR scene. Then, the similarity between the simulated SAR data and the actual SAR data is computed. Similarity suggests no change and that a building is likely to be intact, whereas dissimilarity suggests the opposite. Bigman with his team [11] used two study cases the 1999 Izmit (Turkey) and the the 2003 Bam (Iran) earthquakes where they investigate the capability to detect urban changes and classify them, by combining two tandem images and comparing their results by using optical and SAR data.

One other possible integration of data in the area of damage assessment is the joint use of remotely sensed and GIS data, a big research topic where many approaches may be found [46].
The joint use of these two sources of information will provide a better understanding of the urban scene and allow a faster characterization of the damage patterns, extensions and possibly levels. Gamba and his co-workers [46] integrate remotely sensed and GIS data for two different cases for the Golcuk (Turkey) and Bam (Iran) earthquakes for two different fusion cases, the first one is the combination of multi-temporal SAR and land use map and the second case is by integrating VHR imagery and building inventory with the use of GIS.

2.5 Methodology for damage assessment including previous studies

In the following section we divide the damage assessment methodology in two categories: Qualitative and quantitative. Our main interest will focused in quantitative damage assessment which can be done by developing computer and digital image processing in comparison with the qualitative damage assessment which can been done easily by visual interpretation of the image.

2.5.1 Qualitative damage assessment

An easy way to assess damage assessment is by visual inspection of the image. Assessing the damage by photo interpretation can be done with two different techniques a mono temporal technique, based in an image taken after the event, and a multi temporal technique, where a before event scene is compared with an after event scene [28]. The main drawback by using this technique is that a large temporal gap between images can leads
to the impossibility of damage detection for the new buildings appeared on the after event scene. Also this method can be costly and extremely time consuming. However in [28] they use photo interpretation for damage detection for the case of the Bhuj earthquake. Another study for damage interpretation by using aerial photographs is done by [78] where they try to interpret the damage in a wooden building area and was found to be effective for identifying collapsed and severely damaged buildings.

Visual interpretation was used in [113] in the case of the strong earthquake that hit the city of Bam in southeast Iran in 2003. They used Quickbird pre-event and post-event images and then a visual damage interpretation based on the European Macroseismic Scale (EMS-98) was carried out building by building, comparing the pre-event and post-event images.

Concluding, we can say that visual interpretation of pre- and post-crisis very high-resolution satellite imagery is the most straightforward method for discriminating and assessing structural damage and assessing. However, the feasibility of using visual interpretation alone diminishes in the cases of large and dense urban settlements and spatial resolutions in the range of 2 m to 3 meters and larger. Visual interpretation can be further complicated at spatial resolutions greater than 1 m if accompanied by shadow formation and differences in sensor and solar conditions between the pre- and post-conflict images [5].

2.5.2 Quantitative damage assessment

In order to focus our interest in the image processing techniques we are presenting a survey on the methodology for assessing post earthquake damage in urban areas. In this section we will try to present different techniques in the literature that exploit the capability of very high-resolution VHR satellite imagery.

Damage estimation can be considered mainly from two aspects- change detection and damage classification. Damage in urban areas is defining the level of damage on buildings, debris of the buildings, roads and other objects that can affected by an earthquake and captured by remote sensing imagery, object damage can be identified and classified by applying change detection algorithms to pre- and post-earthquake image pairs. While change detection is a way to find the most relevant changes and omitting the non-relevant ones, damage classification is used to categorize damage into different qualitative states. Both aspects are of interest for post-disaster analysis.

There is also the need of the extraction of objects such as buildings, roads that need to be identify as damaged or not. This task cooperate image processing techniques such as segmentation and object identification and we will also consider by briefly presenting this task in this report. However it is a very interesting and not trivial task, the reader can find a survey on exploiting objects from VHR satellite imagery from [68].

By an observation in the literature and for the change detection task in damage assessment we can divide the methodology approaches in a pixel-based, object-based.

- Pixel -based approaches: In pixel-based approaches, images are processed as they are, and the registration is the very first result to acquire. Then traditional change detection methodology can be apply to assess the damage.

- Object -based approaches: In object-based approaches, usually an image is firstly divided in meaningful regions. The main idea is that the damage is assessing not in the image directly but in meaningful regions, so there is a need before assessing
the damage to extract/classify the meaningful regions that we will be interest to assess the damage. The classification in this case might follows the change detection techniques or performed on a prior step.

With the use of very high resolution images (VHR) (i.e., 1 m or smaller) space-borne and airborne, the amount of detail that can be detected increases by a factor of 100 when the resolution improves from 10 m to 1 m, so that individual buildings, houses, human activity and tents can be recognized in a VHR satellite image [3]. There is a trend in the scientific society to use object based approaches with the VHR satellite images to overcome problems that pixel based approaches utilize with VHR data, that is why we emphasize on the methodology based on objects.

Summarizing, all the above image techniques can be implemented in an automatic damage assessment methodology:

1. **Image registration**

   Image registration is the process of overlaying two or more images of the same scene taken at different times, from different viewpoints, and/or by different sensors. It geometrically aligns two images the reference and sensed images. Image registration is a crucial step in all image analysis tasks in which the final information is gained from the combination of various data sources like in image fusion and change detection. In [121], Zitova et al. present a review of recent as well as classic image registration methods. Chesnel et al. in [25] they perform an methodology focused on the buildings solely through an object-oriented analysis. They present an original object oriented approach to register the images based on correlation. Also, they emphasize that pixel-based methods are more sensitive to these problems and show higher false-alarm rates. Analysis of the full images at a pixel level may not allow to distinguish damage from other changes. That is why recently, more attention is given to region-based methods with VHR images, reducing a part of the problems quoted above.

   **Previous studies**

   In [25], Chesnel et. all emphasize the relative influence of errors particularly in registration of building roofs. They choose a region-based approach with VHR-images to face the difficulties of dealing with VHR images and to overcome the sensitivity of the pixel-based methods where analysis in this case might not allow to distinguish damage from other changes. Finally, a solution to the problem of registration of building roofs is well defined by taking into account the conditions of the image acquisition and it is based on correlation. The less the damage on the buildings, the better the registration. The roof registration is particularly efficient for the buildings of EMS damage grade 0 and 3, but in damage assessment grade 3 the detection of the damage is less reliable [113], [116].

2. Define the object of interest **(Segmentation in order to obtain meaningful region/objects, representing buildings)**

   Since polygons are the principal geometric features in urban areas, it is possible to consider building as objects, identified in a map or in a satellite image. Extracting meaningful region/objects/polygons, representing buildings can be performed by
image processing and more specifically by segmentation techniques. Segmentation means the grouping of neighboring pixels into regions (or segments) based on similarity criteria (digital number, texture). Image objects in remotely sensed imagery are often homogenous and can be delineated by segmentation. Thus, the number of elements as a basis for a following image classification is enormously reduced. The quality of classification is directly affected by segmentation quality. Hence quality assessment of segmentation is in the focus of this evaluation of different presently available segmentation software. In [69] an overview and a comparison of different segmentation programs for high resolution remote sensing is performed and the quality of the individual segmentation results is evaluated based on pan-sharpened multi-spectral IKONOS data. If the reader is interested in this study, a study of four algorithms from the two main groups of segmentation algorithms (boundary based and region-based) is well presented for remote sensing applications in [22].

Previous studies

The buildings extraction from one single panchromatic image is not an easy task. Many objects in the imaged scene can be confused because they have very close radiance values: cars with some buildings, shadow with some asphalt roads, soil with some kinds of roofs and so on. In the case where there is no multi-spectral data available, a contextual analysis is needed to extract geometrical information of objects/classes within the images [27]. Land cover mapping in urban areas have been relying on data coming from many different sensors, but most of the recent efforts are related to very high resolution (VHR) in both the spatial and the spectral domain [45]. With VHR data, urban objects may be recognized as distinct blocks, and algorithms based on per-object segmentation rather than per-pixel classification are feasible. Complex multiscale frameworks have been developed in time for combining all these features and improving VHR image segmentation in urban areas [45]. The aim of many of the more recent algorithms is indeed to jointly consider area-based geometrical and spectral/texture properties in order to recognize objects in the original VHR image. Objects are spatial clusters of pixels meant to be consistently homogeneous with respect to the chosen features and characterized by a set of geometrical, i.e., shape, properties. For this case [45], an adaptive Markov random field (MRF) procedure is proposed.

3. Calculation of change detection index

Change detection is a process of identifying differences in the state of an object or phenomenon by observing it at different points in time [92]. Change detection has been used in a broad range of applications including urban and disaster studies. Changes are identified by comparing pixel by pixel two images that are acquired on the same geographical area at two different times. The comparison can be carried out according to a difference operator (this is the typical case of multi-spectral images) or a ratio/log-ratio operator (as usually done in a SAR image), [16] as well as with more complex strategies based on context-sensitive dissimilarity measures that are computed between statistical distributions. The resulting difference/ratio image is then analyzed according to either automatic thresholding algorithms, or complex context-sensitive and multi-scale algorithms to generate the final change-detection map.
In order to perform effective damage inventory, developing proper change-detection techniques for the in of major importance for the automatic analysis of remote-sensing images and for the the accuracy of the damage assessment. In the literature, many techniques have been proposed for change detection in both optical and synthetic aperture radar (SAR) remote-sensing data. For a detailed review that focus on the problem of change detection in remote sensing images in natural disasters the reader can run into the recent work of Habib et. all in the paper [51].

4. Classify the image by performing automatic damage classification algorithms.

Once the above steps of the methodology have been conducted then an automated damage classification can be performed on the damage images, either on pixel based approaches or on object based approaches. A survey for spectral and spatial methods for the classification of urban remote sensing data can be found in [38].

2.5.3 Previous studies for post earthquake damage assessment

In this part previous post earthquake assessment will be examined according to use of different data sources: Optical imagery, Radar imagery and Multi-source imagery. As an introduction we are trying to emphasize the necessity of object based methodologies over pixel based methodologies.

In post earthquake damage assessment, there is a not lot of use of pixel based approaches (pixel wise change detection algorithms) for high resolution images. Pixel values of two images taken at different times are used for example to produce land cover change maps. Accuracy of this method is depending on the selection of the threshold value, which identifies the limit of the change or no change values [117].

Al-Khudhairy et. all in [5] investigated four different types of temporal pixel-based change detection methods: standardized and un-standardized principal component analysis and calibrated (radiometrically corrected) and un-calibrated (radiometrically uncorrected) image differencing. The authors show that areas of structural change can be detected in the second PC and the higher ones (PCs 6 and 8).

Another application that utilizes the pixel based approach is the one conducted by Bitelli et.al [12]. For the change detection the difference between pre- and post-event images is computing and highlights the changes in brightness as a percent that exceed a user-specified threshold. This method permits to identify large damaged areas but lots of false alarms still remain. The results can be refined using a decision tree and considering other variables (such as ISODATA unsupervised classification and NDVI).

Image differencing and image rationing are the mostly applied to post earthquake damage assessment studies ([5, 118, 37, 104, 12]).

In conclusion, in change detection applications traditional pixel-based classification approaches have been widely used to characterize different types of image features involving agricultural, forest, and environmental monitoring. These methods are based on the concept that semantic information is represented in single pixels and are well suited for non-complex image scenes (e.g. spectrally homogeneous object classes) [5]. It is not surprisingly that these methods are not well fitted in the case of applications involving the characterization of man-made structures and other heterogeneous features in urban environments [49]. The main reason being that urban objects are distinguished better through their spatial (i.e. texture, form, area) rather than spectral reflectance properties [119]. Additionally, traditional pixel-based classification methods cannot differentiate
easily between object features that display high spectral overlap, such as, building roofs from pavements that are constructed using similar material [59]. Therefore, traditional classification methods based on single-pixel based analysis are no longer applicable to extract information from high-resolution satellite images, since a single pixel can not represent integral individual objects. From the spectral viewpoint, roofs of buildings consist of different materials of, such as brick, asphalt, various metal materials, etc [34].

Furthermore, in applications where VHR satellite imagery is used, it is necessary to expand the object feature base to include spatial characteristics in addition to spectral ones. Object-oriented segmentation and classification approaches [108] for change detection offer possibilities to overcome these problems. [5].

Walter in [108] introduced a change detection approach based on an object-based supervised classification by which the accuracy of change detection is about 77 %. This method interprets the structure of each object from the existing GIS database to obtain training samples of objects rather than traditional single pixel. Classification of remote sensing data no longer depends on the threshold, but rely on spectrum, texture, normalized difference vegetation index (NDVI), etc.

- Optical imagery

Turker and San in [104] used two Spot images acquired before and after the Kocaeli earthquake. The images were corrected geometrically and radiometrically, multispectral and panchromatic bands were merged. Damage detection was detected by subtracting the near infrared band of the merged images. For the accuracy assessment aerial photos were also used for ground truth data. The overall accuracy of the change map was found to be 83 %. In the same earthquake case Yusuf et al. in [118] the pre- and post-earthquake optical images with multi-spectral bands are compare by their spectral responses by calculating the differences in the sample area. The estimated damaged area was abstracted on a pixel unit based on the obtained frequency distributions of the differences, with a significant increase in reflectance due to the earthquake disaster. For the accuracy of the results a classification method used for estimating damaged area based on training data with aerial photographs taken after the earthquake and the damage distribution estimated from SAR images.

Al-Khudhairy et. al in [5] are focusing on structural damage assessments from Ikonos data for two different cases of Fyrom and West bank incursions. They investigating different traditional change detection techniques with (e-Cognition) an object-oriented image classification software. The used the pre-conflict to guide classification of the pixel-based change detection analysis. Afterwards they examine the feasibility of using mathematical morphological operators to automatically identify likely structurally damaged zones in dense urban settings. Their results showed that object-oriented segmentation and classification systems facilitate the interpretation of change detection results derived from very high-resolution (1 m and 2 m) optical satellite data. Also they showed that object based classification techniques enhance quantitative analysis of traditional pixel-based change detection. Additionally, their results suggest that mathematical morphological methods are a potential new avenue for automatically extracting likely damaged zones from very high-resolution satellite imagery in the aftermath of disasters.

Chesnel et. al in [25] proposed a method to assess damage on buildings in an urban area using a pair of very high resolution images Quickbird and Ikonos, with respectively a spatial resolution of 60cm and 1m on the case of Bam (Iran) earthquake. In order to classify efficiently and rapidly the buildings in several damage grades
using SVM along with a small training set, Chesnell et al calculate the correlation coefficient by considering that the correlation coefficient decreases as the damage degree increases. The classification performances were equal to 75%. The results in [25] shows that having a database of the footprint of the buildings before a disaster can lead to a reliable damage assessment with very high resolution images.

In [27], a classification procedure has been applied to Quickbird panchromatic image very high resolution optical images in order to maoe damage at building scale in the Bam earthquake case. They got into account the geometrical shape of objects within a panchromatic image due to the limitation of using a single band to classify such complex scene in urban areas. Morphological profiles from the original panchromatic images taken before and after the earthquake have been carried out in order to classify buildings in the scene. The classification has been done with the aim to cancel false alarms in the change detection process caused by shadow or other temporary objects like cars or recovery tents. For this purpose, the open and close morphological operators have been applied and the derived profiles have been used as inputs to an unsupervised classifier in order to extract the entire map of buildings before and after the earthquake. Comparing the pixel belonging to each building before and after the earthquake, a damage level at single building scale (ratio between the number of pixels after and before the earthquake forming the single object) has been extracted. Finally, in order to validate the obtained results, a ground-based damage map provided by ground survey has been done.

Yamazaki and Matsuoka in [115] they proposed a new context based detection approach for the case of Bam earthquake focusing on damaged buildings. They used a Quickbird image acquired over the damaged area and they used edge-based textures, multi-spectral gray level and morphological-based spatial resolution in order to describe the context.

In [112] Yamazaki et. al a visual inspection of building damage was carried out for the 2003 Algeria earthquake by using QuickBird pre-event and post-event pansharpened images. A total 1,399 buildings were classified into five damage levels of European Micro-seismic Scale. The results from the different interpreters were reasonably close for collapsed buildings but the difference becomes larger for smaller damage levels. The locations of refugee tents in the two post-event images were also identified. Their results indicate that high resolution satellite images can provide quite useful information to emergency management after natural disasters.

André et. al in [6] used an Ikonos image acquired two days after the Bhuj earthquake in India. They proposed a new methodology based on the detection of morphological anomalies on building boundaries. They used roughness and compact ratio in order to increase the accuracy of the method. The image processing method was based on the comparison between the convex hulls of the building and their actual shape after the earthquake.

Miura et. al in [75], used QuickBird optical high resolution satellite images to identify and detect areas covered with bricks (damaged buildings) and the areas covered with roof tiles (undamaged buildings) for the Central Java earthquake. Based on the field survey for the spectral reflectance of surface materials, the image classification technique (maximum likelihood ) is applied to post-earthquake QuickBird images to detect the damage. The distribution of the building damage is evaluated by computing Damage Index (DI) from the classified images.
The optical images presently available from space at resolution in the order of meter or better are certainly one of the most suitable tools to perform damage assessment.

- Radar imagery

Among the sensors on board satellites, synthetic aperture radar (SAR) is one of the most powerful tools for monitoring changes in the earth's surface, and can be used for 24 hours continuously without being influenced by weather condition. SAR systems can image and detect the extent of building damage through clouds and smoke. This feature is quite useful and effective for post-disaster damage assessment, especially when optical remote sensing or a field survey for broad areas is unattainable [67]. At this part we are presenting some of the previous studies in the literature that have been carried out by using SAR and radar imagery.

In [95], ERS-2 SAR data were used to detect damage in the case of the 1999 Chi-chi earthquake. Two SAR pre earthquake images were used and one post earthquake. Urban damage was detected by using coherence information obtained from InSAR technology. They conclude that a good interferometric condition was essential to detect urban damages caused by building collapse.

Huyck et al in [56] used ERS-SAR imagery in the Kiacaeli earthquake. SAR intensity, image correlation, coherence and cross power information were used to detect post-earthquake damage.

Matsuoka et al in [67] performed a feasibility study on backscattering characteristics of damaged areas in the 1995 Hyogoken-Nanbu (Kobe), Japan, earthquake by using the pre and post-event ERS images, revealing that the backscattering coefficient and intensity correlation between the two attained values were significantly lowered in hard-hit areas. The spatial resolution of the used operated satellites was fairly coarse, i.e., roughly 30 meters, it was difficult to identify the backscattering characteristics of individual buildings. However, it was possible to detect the groups of damaged buildings. In order to extract the extent of building damage in an area, they consider aggregated information such as average, texture, and correlation within a local window. In this study, they introduce the characteristic changes in the backscattering coefficient for extensively damaged areas using a GIS data set. The effects of pixel window size and SAR speckle noise were examined in evaluating building damage, using the difference in the backscattering coefficient and spatial correlation between the pre and post-event images. Finally, they proposed an automated method to detect hard-hit areas using SAR intensity images after speckle noise reduction.

Gamba et al [43] propose a joint approach of feature-level and pixel based approaches to address the change detection problem from synthetic aperture radar (SAR) images. The problem is addressed for the case of Bam earthquake. The approach is based on the extraction and comparison of linear features from multiple SAR images, to confirm pixel-based changes. Though simple, the methodology proves to be effective, irrespectively of misregistration errors due to re-projection problems or difference in the sensor's viewing geometry, which are common in multi temporal SAR images. The procedure is validated through synthetic examples, but also two real change-detection situations, using airborne and satellite SAR.

Synthetic Aperture Radar (SAR) has significant advantages in disaster monitoring that are all weather, independent of illumination imaging capabilities and strong stereoscopic sense. SAR technology looks promising and can be a significant tool
for damage assessment. In order to use VHR SAR to analyze dense urban areas (e.g., inner parts of cities), future work should focus on the analysis and the modeling of the effects of neighboring objects on the SAR signature of buildings leading to the definition of more generic building detection and reconstruction methods [18]. However, processing and analysis SAR images still confront by some difficulties.

- Multi-source sensor imagery

The combination of Synthetic Aperture Radar (SAR) data and optical images is a promising and suitable approach. In this part we will present some of the previous studies that has been done in the field of damage earthquake assessment and utilize the combination of different remote sensing sources.

Brunner in [18], emphasize that the best combination of imagery for rapid damage assessment is space borne VHR optical for the pre-event imagery and space borne VHR SAR for post-event imagery. However, it is difficult to compare them directly in a change detection approach because both types of data have entirely different radiometric and physical image formation characteristics. This challenge was addressed in [72], by statistically relating the two different observations in order to use a classical change detector, and was tested on a medium resolution SPOT-XS and ERS image pair.

In [11] Bigmani et al for the the 1999 Izmit (Turkey) earthquake investigate the capability to detect urban changes and classify them. They used two ERS tandem pairs and two panchromatic images collected by IRS before and after the earthquake. In both test areas, and in spite of the inhomogeneous data set they developed a pixel-by-pixel change detection where satellite data are used for test and training. Afterwards, a comparison between satellite data and the ground truth has been proposed to state the reliability of the method. In order to perform a pixel-by-pixel classification, each selected region has been divided into test and training pixels. A maximum likelihood criterion were used for the classification by assuming a Gaussian distribution of the available features. Different combinations of features were forming for the multi parameter data set and compared in order to understand which of them most contribute to the discrimination of changes. The relatively poor contribution of the SAR alone was apparent from this comparison, that could of course be slightly improved using more sophisticated SAR classification algorithms. However, the contribution of the SAR in addition to the optical data is also evident. The InSAR coherence was determine the best classification results, even better than the addition of all SAR features that probably suffers from the increasing dimension of a noisy feature vector. They also study the capabilities to detect different levels of damages using optical images and InSAR techniques. The observed results were encouraging and showed the relation between the intensity correlation of SAR data and the damage level.

Brunner et all in [19] present a novel method that detects buildings destroyed in an earthquake using pre-event VHR optical and post-event detected VHR SAR imagery. First, the 3-D parameters of a building are estimated from the pre-event optical imagery. Second, the building information and the acquisition parameters of the VHR SAR scene are used to predict the expected signature of the building in the post-event SAR scene assuming that it is not affected by the event. Third, the similarity between the predicted image and the actual SAR image is analyzed. If the similarity is high, the building is likely to be still intact, while a low similarity
indicates that the building is destroyed. A similarity threshold is used to classify the individual buildings. They demonstrate the feasibility and the effectiveness of the proposed method for a subset of the town of Yingxiu, China, which was heavily damaged in the Sichuan earthquake of May 12, 2008. For the experiment they used QuickBird pre-event optical imagery, and TerraSAR-X and COSMO-SkyMed post-event SAR data. Post-event QuickBird and WorldView-1 imagery as well as ground photography were used as reference data. [18]

2.6 Conclusion and Discussion

In this chapter, we tried to examine different aspects and highlight the hot issues that concerned by the Remote sensing society especially for the task of post earthquake damage assessment. We were considered data requirements and methodologies issues. We were convinced that post-earthquake damage assessment is a challenging task and there are significant limitation for data and methodology. These limitations can be summarized as:

- Increase of spatial resolution up to some cm where existing algorithms designed for medium to high spatial resolution are defeated by the extreme complexity of the images. Need of new algorithms for assessing damage assessment for VHR images.
- Different characteristics of sensors, in terms of spatial, spectral and temporal resolution.
- Different ancillary data, DEM, GIS, in-situ data. Need of optimal fusion with VHR imagery for efficient assessment of damage.
- Lack of revisit time of satellites.
- Lack of straight forward damage assessment methodology
- 3D characteristic if the building damage
- Restrictions of change detection methodology in most of the cases- requirement for pre-disaster image and analysis.
- Cost of the very high spatial resolution data.
- Working in urban areas- different morphology of the urban areas.

In conclusion, there is a need for further research, that can overcome these limitations and create more practical and efficient methodologies for post-earthquake damage assessment. A promising solution could be provided by integrated different data, as using different sensor sources and different kind of data such as DEM and GIS in a combination could enrich and detailed damage assessed tools for earthquakes. Especially integration of space-born and airborne imagery may be important when the disaster is widespread. Satellite imagery can provide information about the region or even about the buildings but its vertical viewing fails to detect all type of the buildings. Information about the height of the building, boundaries and location of buildings and in-situ information can improve the damage assessment, as it make possible to make a differentiation in the damage type and level.
## List of attributes derived from remote sensing

Table 2.2: List of attributes both at the building scale and the region’s scale

<table>
<thead>
<tr>
<th>Buildings</th>
<th>Homogeneous areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Footprint: (boundaries of target building)</td>
<td>Boundaries of target area</td>
</tr>
<tr>
<td>Roof Shape: flat or gable</td>
<td>Number of buildings included in the area</td>
</tr>
<tr>
<td>Shape of the building: (square, rectangular, round)</td>
<td>Concentration of buildings within the target area: (dense or sparse)</td>
</tr>
<tr>
<td>Size of the building (Small, Big)</td>
<td>Identification of homogeneous areas (Downtown, Residential, Commercial, Recreational areas)</td>
</tr>
<tr>
<td>Average height</td>
<td>Average height of buildings within the target area</td>
</tr>
</tbody>
</table>

- Land use (Buildings, road, river, sport park, bridge)
- Land Cover (Street, Avenue, tree, water, shadow)
- Adjacent of a building: (Building, street, tree)
- Distance of adjacent buildings
- Characterization of well shaped buildings: (Yes or No)
- Total square footage
<table>
<thead>
<tr>
<th>Damage grade</th>
<th>Description</th>
<th>Summary</th>
<th>Example damage to masonry buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 1</td>
<td>Negligible to Slight Damage</td>
<td>No Structural Damage. Slight Non-Structural Damage.</td>
<td>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.</td>
</tr>
<tr>
<td>Grade 3</td>
<td>Substantial to Heavy Damage</td>
<td>Moderate Structural Damage. Heavy Non-Structural Damage.</td>
<td>Large and extensive cracks in most walls. Roof tiles detached. Chimney fracture at the roof line. Failure of individual non-structural elements (partitions, gable walls).</td>
</tr>
<tr>
<td>Grade 4</td>
<td>Very Heavy Damage</td>
<td>Heavy Structural Damage. Very Heavy Non-Structural Damage.</td>
<td>Serious failure of walls. Partial structural failure of roofs and floors.</td>
</tr>
<tr>
<td>Grade 5</td>
<td>Destruction</td>
<td>Very Heavy Structural Damage.</td>
<td>Total or near total collapse</td>
</tr>
</tbody>
</table>

Table 2.3: Damage classification for a residential building from EMS-98: Summary of the damage grades.
References


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