DEVELOPING SEISMIC MITIGATION MEASURES FOR SUSTAINABLE CITIES: A STRUCTURED DATABASE APPROACH

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ABSTRACT

Seismic mitigation measures are becoming increasingly important in order to support the sustainable development of cities around the world. Disaster Risk Reduction is a consolidated field of study and an integral part of civil protection and construction practices. The definition of strategies aiming at reducing the risk requires two fundamental steps: the first consists of the evaluation of the impact in the current state while for the second, the impact is estimated having adopted appropriate mitigation strategies. The comparison between the losses (of buildings, human lives, and economic) calculated in the two steps defines the effectiveness of the mitigation measures considered. The impact is defined through the consideration of three factors: hazard, vulnerability, and exposure. The hazard is the probability that a fixed event occurs in a fixed period of time; the vulnerability is the probability that an element at risk reach a fixed level of damage; the exposure represents the vulnerability distribution on the invested area. Vulnerability and exposure are strictly connected: with respect to the buildings, the vulnerability depends on their typological and structural characteristics, so the exposure represents the distribution on the investigated area of these building's features. This paper presents a procedure to define the exposure of the current state of an investigated area through the buildup of a structured database to facilitate the knowledge of the area. The database is populated using the ISTOS survey form, developed and customized by the ISTOS research center on the basis of previous works of the PLINIVS study center. Aim of the build-up of the database is the knowledge on the vulnerability distribution on the territory at the current state to have a start point for considerations on mitigation assumptions.

Keywords: Risk assessment, disaster risk reduction, mitigation plans, vulnerability analysis and impact assessment

1. INTRODUCTION

In recent years, the world has witnessed the devastating impact of earthquakes on cities and their populations. The need for effective seismic mitigation measures has become increasingly important as the world's population continues to grow, and cities become more densely populated. Sustainable cities are designed to minimize the impact of natural disasters on the population, the economy, and the environment, adopting measures are strategies or techniques designed to reduce the impact of an earthquake on structures and their occupants.

Mitigation measures aim to reduce the impact/risk of a specific investigated area, having defined the impact as the quantification of building losses, human lives, and economic losses. For this reason, the first step to be taken to be able to define the most effective mitigation measures in the investigated area is to evaluate the impact at present. The second phase involves an assessment of the possible mitigation strategies to be put in place and the definition of the impact following their adoption. The effectiveness of a mitigation measure can be defined as the percentage reduction of impact obtained compared to the current state. The impact is estimated on the basis of the consideration of three fundamental factors: hazard, vulnerability, and exposure (Figure 1).

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The hazard is differently defined based on the type of analysis (scenario/risk); in the first case it represents the probability that a single event can occur in the investigated area in a fixed time, instead in the second case it is the probability that all the possible events that can hit the area occurs in the fixed area in the fixed time. The vulnerability represents the probability that an exposed element can achieve or exceed a level of damage for a fixed value of hazard. It depends on the characteristics of the considered element at risk. It is common assumption in the literature that vulnerability strictly depends on its vertical typology[1], although more recent studies show that the other typological characteristics can greatly affect the behavior of the structure[2]. Buildings are grouped in vulnerability classes (generally identified from the A – more vulnerable – to the D – less vulnerable) based on their similar behavior with respect to the investigated event. For every vulnerability class a vulnerability model is associated, in terms of curves or damage probability matrices (DPM), that represent the increase in the probability of reaching or exceeding a level of damage as the value of the hazard increases. The exposure represents the vulnerability distribution of the exposed elements on the investigated area. In literature, some works aimed to investigate the effectiveness of mitigation measures have been produced. The PLINIVS Study Centre built CAESAR II[3], a platform developed for local authorities to estimate losses for risks and scenarios analyses. The tool works on a grid with cells of 250x250m; at each cell a PGA values and the buildings distribution on four vulnerability class is associated. The exposure model on the grid has been done exploiting collected data and census information. Surveys activities have been conducted exploiting the PLINIVS form[3], and the detected buildings have been classified with the S.A.V.E.[2] procedure; the classification of no-detected buildings has been done through the BINC[4] tool exploiting the census zone. Combining these values with a fixed vulnerability model, the impact in terms of buildings (collapsed or unavailable), population (deaths, injuries, and homelessness), and economic losses (reconstruction costs, restoration costs, demolition and rubble removal costs, health care costs, evacuation costs and emergency costs) is estimated.

The CAESAR II tool has also a section for multicriteria analysis, in which is possible assume that the vulnerability of some buildings is reduced (a percentage of buildings with vulnerability class A are mitigated in vulnerability class B or C or D, a percentage of buildings with vulnerability class B are mitigated in vulnerability class C or D, and so on). Based on these mitigation assumptions, the new impact is estimated. The items relating to the results correspond to those calculated without mitigation, except for an additional field relating to 'economic losses' representative of the mitigation costs.

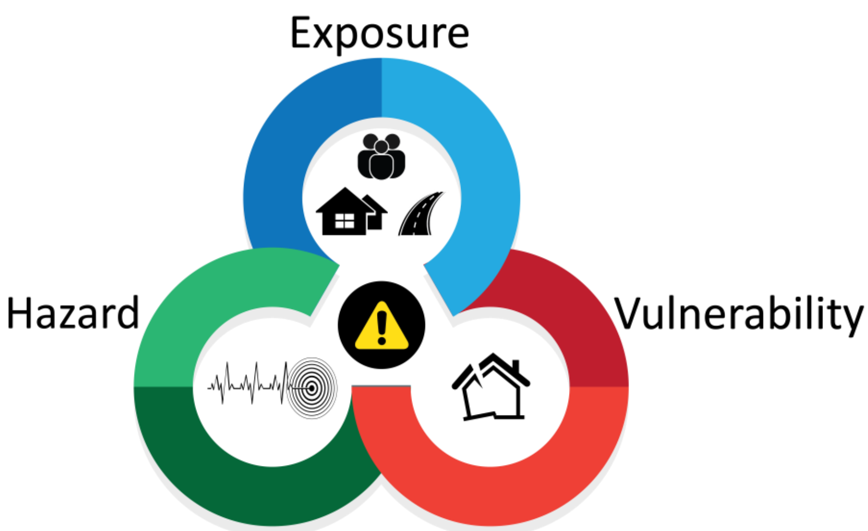


Figure 1Venn diagram, Risk = Exposure x Vulnerability x Hazard

The mitigation strategies influence the vulnerability distribution on the investigated area, so the difference between the impact with/without the mitigation measures only depends on the exposure map. The aim of this paper is to outline an activity that could allow the definition of an exposure map for the island of Cyprus. To this purpose, a structured database approach involves creating a database that contains information leading to the development of seismic mitigation measures. This information includes the structural characteristics of typical Cypriot buildings, the location, type of retrofitting measures, the effectiveness, cost, and feasibility. The database can be used to analyze the effectiveness of various measures in different scenarios and can help the selection of appropriate measures for a particular location. The database can also be used to compare the cost-effectiveness of different measures. For example, the cost of retrofitting an existing structure with seismic dampers may be compared to the cost of building a new structure with inherent seismic resistance. The database can also be used to identify the most feasible measures for a particular location, considering factors such as soil type, seismic activity, and building codes. This approach can be used to develop seismic mitigation measures for both new and existing structures. For new structures, the database can be used to identify the most appropriate measures to incorporate into the design while for existing structures the database can be used to identify retrofitting options that can improve their seismic performance.

In addition to the structured database approach, collaboration among stakeholders is essential in developing effective seismic mitigation measures. Stakeholders include engineers, architects, urban planners, policymakers, and the community. Collaboration can help ensure that the measures are appropriate for the location, meet the needs of the community, and are feasible and sustainable. The development of a database requires field inspection and the collection of data for the buildings of an area by means of a survey form. A survey form for building characteristics is designed to collect information about the features, design, and functionality of a building. This type of survey form can be used by architects, engineers and researchers to better understand the building's "identity" and at a later stage to classify it in an exposure and vulnerability class.

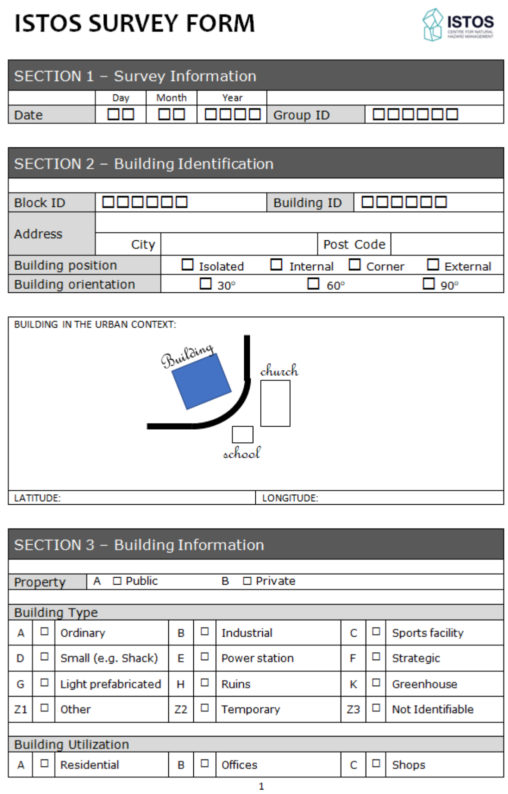
2. SURVEY FORM

The ISTOS project[6] focuses on ensuring the safety of buildings and infrastructure, reducing the risks posed by natural disasters such as earthquakes, floods, and medicanes, and managing the aftermath of such catastrophes. By bridging the gap between various scientific domains and promoting social initiatives for mitigating the impact of natural hazards, the project aims to generate positive impact on the natural, built, and social environments.

The ISTOS is a field survey form (Figure 2) which is developed based on a corresponding form created by PLINIVS Study Centre, an Italian center of competence of the Italian Department of Civil Protection. The form aims to collect data on the physical and socio-economic impact of natural disasters, including earthquakes, floods, etc. and it is designed to be used by researchers and other stakeholders involved in disaster risk reduction and management. The ISTOS survey form is organized in eleven sections, each containing specific information about the building. These sections are essential in providing comprehensive and accurate data about a building's construction, structural characteristics, geological features, and factors affecting the response against various natural hazards.

Section 1 of the ISTOS survey form is the survey information. It contains basic information about the survey, such as the date it has been conducted, the surveyor's name, and the location of the building. This information is important for identifying the survey and ensuring that it is correctly recorded for future reference. Section 2 includes the building identification. It contains information about the building's characteristics given by a GIS platform, such as its block ID, building ID, address, the building's position etc. These data are important in identifying the building and providing context for the survey results. Section 3 contains the building information and incorporates information about the building's type (ordinary, industrial, power station etc.), buildings utilization (residential, office, shop etc.). Section 4 of the ISTOS survey form collects data about the building characteristics. It includes information about the building's construction materials, such as reinforced concrete, steel, stone masonry etc. and information respecting the number of floors, the height of the floors etc. This information is necessary to determining the building's structural integrity and its potential for seismic vulnerability. Section 5 refers to the construction and specifically it involves information about the period of construction. Based on the construction period an engineer can estimate if that building is erected with the use of a seismic code and which code precisely. Section 6 of the ISTOS survey form refers to the structural characteristics of the building. It encloses information about the building's structural components, such as its vertical and horizontal structures, roof shape, and the thickness of the exterior walls. Sections 7 and 8 contain information about cladding and openings respectively. Cladding's section concerns only R/C building and opening's section refers to the percentage of openings in the façade, the primary material of the windows, the conservation state etc. Section 9 describes the interventions, where the surveyor must check the period of intervention and its conservation state. Sections 10 and 11 are essential in assessing buildings exposure and seismic vulnerability. Plan regularity refers to the building's symmetry and regularity in its shape, size, and layout.

Buildings with irregular shapes or layouts are typically more susceptible to damage from seismic activity than buildings with regular and symmetrical plans. Regularity in a building's plan is essential for distributing forces evenly throughout the structure and preventing concentrated areas of stress that can lead to structural failure. The existence of a soft story either on ground level (pilotis) or on a level other than the first, or the presence of short columns affect to a great extent the seismic response of the structure.



ISTOS SURVEY FORM

ISTOS

SECTION 1 – Survey Information					
	Day	Month	Year		
Date	☐☐	☐☐	☐☐☐☐	Group ID	☐☐☐☐☐☐

SECTION 2 – Building Identification				
Block ID	☐☐☐☐☐☐	Building ID	☐☐☐☐☐☐	
Address				
	City		Post Code	
Building position	☐ Isolated	☐ Internal	☐ Corner	☐ External
Building orientation	☐ 30°	☐ 60°	☐ 90°	

BUILDING IN THE URBAN CONTEXT:

LATITUDE: LONGITUDE:

SECTION 3 – Building Information								
Property	A	☐ Public	B	☐ Private				
Building Type								
A	☐	Ordinary	B	☐	Industrial	C	☐	Sports facility
D	☐	Small (e.g. Shack)	E	☐	Power station	F	☐	Strategic
G	☐	Light prefabricated	H	☐	Ruins	K	☐	Greenhouse
Z1	☐	Other	Z2	☐	Temporary	Z3	☐	Not Identifiable
Building Utilization								
A	☐	Residential	B	☐	Offices	C	☐	Shops

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Figure 2 ISTOS Survey Form

Several features of a building can significantly impact its structural integrity and vulnerability to seismic activity. Among these features there are some essential criteria in order to have a close estimation of a building's exposure and vulnerability class against a natural hazard. These features are the following; construction material, age, vertical and horizontal structural elements, plan regularity, roof shape and number of floors.

The field survey will be assisted by a mobile application for both android and IOS devices to facilitate a more rapid recording of property information. This application is at the development stage and will enable the surveyors to easily and quickly input data for each building. Once imported in the database, the database will process and analyze the data to provide the vulnerability class of each building, the exposure and finally a risk map of the surveyed area.

3. DATA RESULTS

A group of researchers, part of ISTOS team, recently visited the city of Larnaca in Cyprus for a field inspection, divided into three areas, Sotiros, Agios Georgios and Drosia and their findings have been recorded using the ISTOS survey form. During the survey the group has recorded 234 residential buildings and compiled the data in the database for further analysis. The researchers, using the ISTOS survey form, highlighted the importance of using modern tools and technology and the necessity of the mobile application to facilitate the work. The application, once made available, will enable the surveyors to collect data, saving time and improving the accuracy of the results quickly and accurately.

As the collected data grows the database can be utilized in a variety of ways. The data can be analyzed to identify trends in the types of materials used in construction in Larnaca, or to identify any areas in which houses may require repairs or upgrades. Additionally, the data can be used to assess the overall quality of housing in the area and to identify any areas that may require further investigation or attention. Once the data has been collected using the survey form, it can be used to generate pie charts and/or histograms that show the percentage of houses made from each type of structural material. This information can be useful in identifying areas which are more susceptible to damage from natural disasters. For example, areas in Cyprus with a high percentage of houses built before 1991 may be more vulnerable to earthquake as there was no local seismic code enforced at that time. The data can also be used to generate a map that indicates the vulnerability class of houses in a particular area. This can be done using a Geographic Information System (GIS). GIS technology allows for the collection, storage, analysis, and visualization of spatial data. By overlaying data on a map, it is possible to identify areas that are at high risk of damage from natural disasters.

The ISTOS approach involves initially assigning a base score, depending on the nature of the vertical structure, which is subsequently adjusted by applying modifier coefficients based on the typological, geometrical, and structural characteristics of the building. The weight of these modifiers is determined in advance by analyzing the statistics of seismic damage resulting from previous earthquakes. The two most important factors in assigning the vulnerability class are the vertical structure, which provides an overview of the structure's behavior, and the age of the construction. The latter, while not a structural factor, considers the various building types that evolve over time. The ISTOS method identifies four vulnerability classes, labeled A, B, C, and D in descending order of vulnerability.

Figure 3 depicts the distribution of surveyed buildings across different vertical macro-typologies, including reinforced concrete and various types of masonry structures. The data illustrates that the Agios Georgios area has a significant percentage of reinforced concrete buildings, accounting for over 90% of the investigated structures. The Sotiros area has a high percentage of “mixed type” buildings, accounting for 71.4% of the surveyed buildings. “Mixed type” buildings are defined as those which consist of more than one material type (e.g. masonry and reinforced concrete). Further, the Drosia area has the highest percentage of reinforced concrete structures, representing 100% of the surveyed buildings.

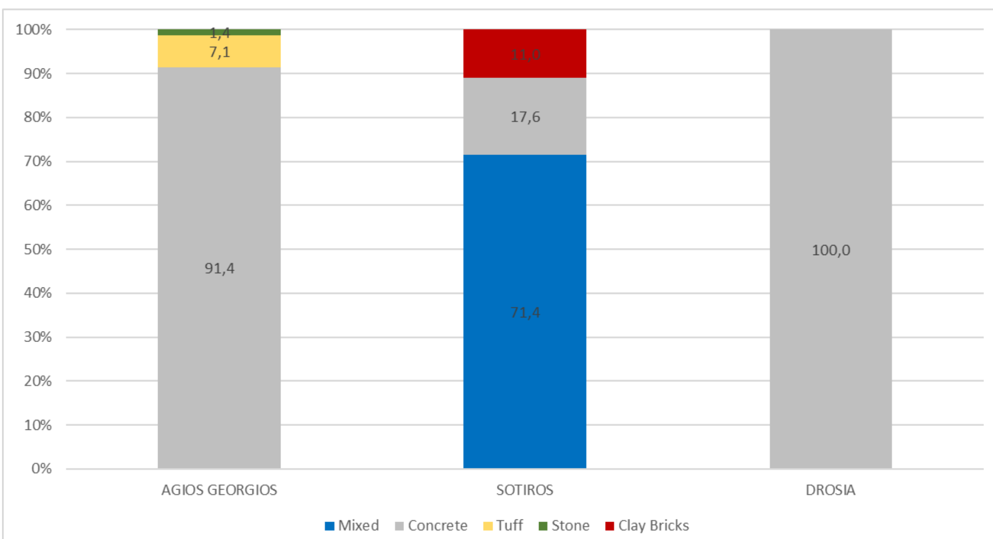

Figure 3 Investigated buildings distribution on the vertical macro-typologies

Figure 4 diagram shows the overall distribution of buildings in the three districts based on the main building material. It is noteworthy to mention that the percentage of houses defined as “mixed type” amount approximately to 28% of the surveyed buildings.

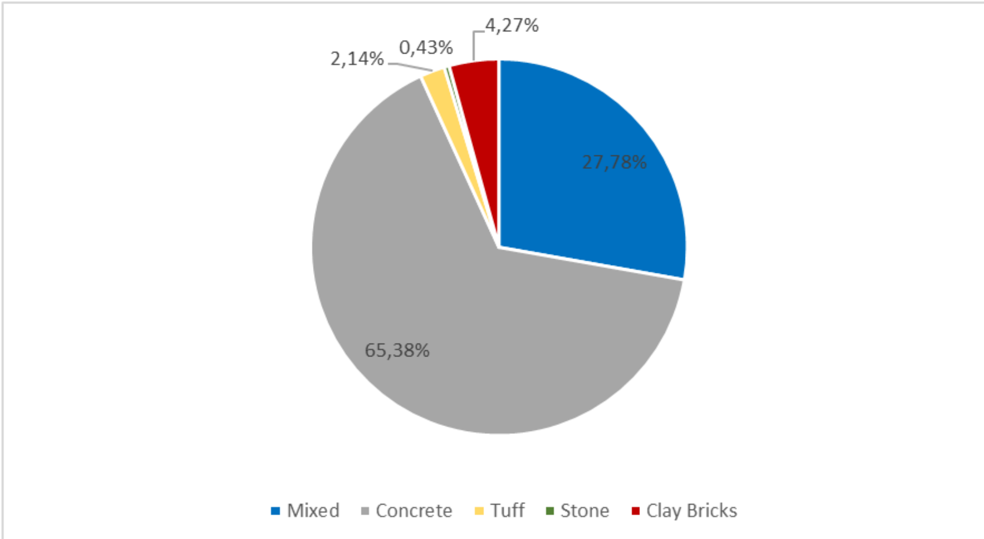

Figure 4 Overall distribution of buildings based on main structural material

Figure 5 depicts the distribution of the surveyed buildings based on their age of construction. Notably, a discernible variation in color has been utilized to indicate the buildings constructed during the period of 1961-1991. It is noteworthy to observe that the initial anti-seismic code in Cyprus was introduced in 1994. Furthermore, the analysis highlights that the areas of Sotiros and Drosia are characterized by a higher number of constructions built prior to 1971.

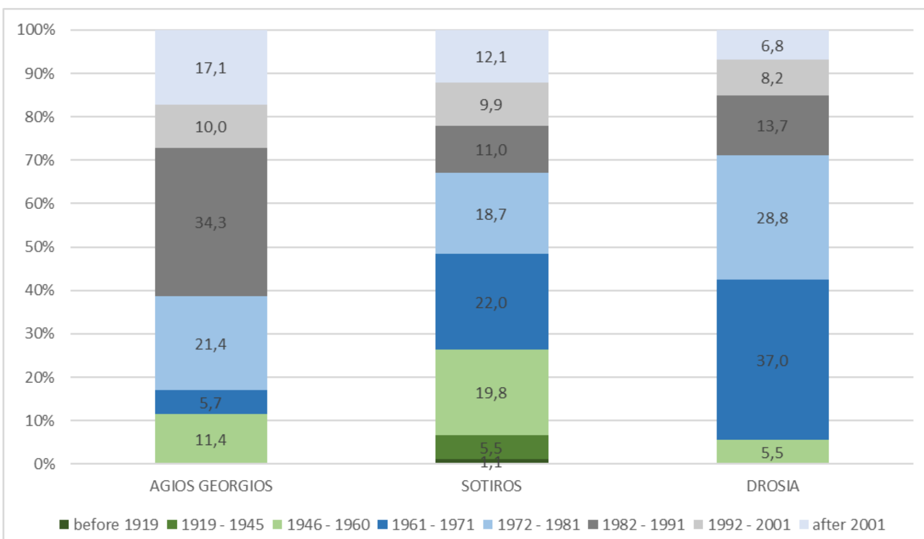

Figure 5 Investigated buildings distribution on the age of construction

In conclusion, the utilization of the ISTOS criteria has enabled the determination of the vulnerability classes of the surveyed buildings, which are presented in Figure 6. The analysis of the survey data reveals that the majority of the building stock has poor-quality construction, as evidenced by the prevalence of buildings classified as either A or B. The area of Drosia exhibits the highest proportion of buildings classified under vulnerability classes A and B. However, overall, the vulnerability distribution is relatively consistent across the three surveyed areas, with no significant variations between them.

Figure 6 Investigated buildings distribution on the vulnerability classes

4. CONCLUSION

The development of effective seismic mitigation measures is crucial for sustainable cities. A structured database approach can be used to develop and compare different measures' cost-effectiveness and feasibility. Collaboration among stakeholders and research groups as ISTOS is also essential in ensuring that the measures are appropriate and meet the needs of the community. With the use of an appropriate survey form, a structured database approach and collaboration among stakeholders, cities in Cyprus can become more resilient to earthquakes and other natural hazards, ensuring the safety and well-being of their populations.

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