THE IMPACTS OF POST-DISASTER URBAN TRANSFORMATION ON MULTI HAZARD VULNERABILITY AND RESILIENCE

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Abstract

This paper focuses on long-term evaluation of post-disaster reconstruction and impacts of natural hazards on urban transformation. Based on a systematic building stock survey, this study analyses the effects of the destructive 1995 earthquake on the urban development of Aigio, Greece. Three building surveys were conducted: I) 1995: After the earthquake, including results of detailed damage surveys; II) 2005: Large scale survey after 10 years; III) 2015: Evaluation of post-disaster reconstruction process. By considering the changes of pre- vs. post-event vulnerability and resilience capacities of the built environment, this long-term evaluation allows the comparison between planned reconstruction measures and actual urban transformations within a 20-year time frame (Delta "Δ"-Consideration). During each survey the Vulnerability Classes according the European Macroseismic Scale 1998 (EMS-98) have been assigned. It can be displayed that EMS-98 works as a useful tool for the evaluation of earthquake vulnerability and urban resilience, both, on a micro (single-building) and a macro (urban) scale. Building Typologies are presented as a meta-level which can link engineering approaches and disaster risk reduction on an urban scale. Actual measures of reconstruction are systematically studied and assigned to the resilience capacities (persistence, adaptation, transformation). It is displayed that the lack of an integrated approach and interdisciplinary cooperation between earthquake engineering and urban planning results in deficiencies of the reconstruction process and creates new risks, emerging from urban transformation, as shown by a multi-hazard analysis. A complementary Urban Resilience perspective which integrates the interrelation of social processes and built environment is presented.

Keywords: Urban Resilience, Post-disaster Reconstruction, Multi Hazard, Vulnerability analysis; EMS 98

1. Introduction

Post-disaster reconstruction efforts were all too often guided by one-sided short-term relief through structural measures, insufficiently coordinated and rarely monitored, hereby displaying the lack of interdisciplinary cooperation and integrated perspective that should consider the socio-spatial interrelations of built environment and social processes. Thus, disasters tend to reoccur, eventually not initiated by the same hazard, but yet due to the interference of multi-hazard events. Therefore, long-term evaluation appears as a crucial tool to analyze changing dynamics in order to identify remaining and emerging vulnerabilities as well as to understand and promote resilience capacities. There is a need for integrated approaches that evaluate reconstruction processes, account for long-term strategic developments and incorporate multi-hazard assessment in order to effectively address disaster risk reduction.

Designing those processes requires interdisciplinary cooperation to develop complementary perspectives that can mitigate the uncertainties of complex risks. Today the majority of human beings live in urban areas, agglomerating their assets and values. They are the driving force of economic growth, most vulnerable and simultaneously the incubator of innovations. However, their extensive, often unplanned urban development and excessive consumption of resources is concurrently causative for the occurrence of the most severe disasters. This ‘Planetary Urbanization’ stresses the necessity of ‘Urban Resilience’- the capacity of a city to cope with changes.

Long-term evaluation of post-disaster reconstruction is an essential tool to understand resilience. The impact of natural hazards on urban settlements was studied by Schwarz [1] by combining earthquake engineering and urban planning approaches within a complementary perspective in order to address multi-risk factors more effectively. The paper presents a methodology for the long-term evaluation of post-disaster reconstruction processes to display the impacts of natural hazards on urban transformation in order to develop integrated approaches for disaster risk reduction based on the interdisciplinary cooperation of earthquake engineering and urban planning with an urban resilience focus. For the model study of Aigio, Greece, an integrated approach has been proposed that can help understanding urban resilience and improving sustainable post-disaster development.

2. Data and Tools for Evaluating Post-Disaster Reconstruction

2.1 Methodology - Resilience and Δ(Delta)-Consideration

Understanding the concept of resilience is essential to evaluate as well as to design a sustainable post-disaster reconstruction process. Resilience can be defined as the “capacity of a system to absorb disturbance [Persistence] and reorganize while undergoing change [Adaptation and Transformation] so as to still retain essentially the same function, structure, identity, and feedbacks” [2].

Resilience is framed by three basic components: (I) systems characteristics, (II) prevailing paradigms and (III) disruption and reorganisation [3]. In other words, resilience is a systems’ capacity to cope with initiated change and sustain the path from actual status towards target status. Understanding resilience request to analyze the occurred change, while it is at the same time a strategic tool to design change:

- *Actual status* is defined by the system’s characteristics and requests to analyze ‘what has changed’ since the disruption
- *Target status* is defined by prevailing paradigms, because it requests a strategy for ‘what should change’ to reorganize.

Therefore, addressing change itself appears as the linkage between analysis and strategy. Rather than describing resilience as a given characteristic of the actual status, it can be observed retrospectively by analyzing the occurred change between the disruption (caused by the disaster impact) and the reorganisation - displayed by the resilience capacities as implemented measures during reconstruction (persistence, adaptation and transformation of a systems’ elements before vs. after).

The tool of "Δ(Delta)-Consideration" [4] was developed to evaluate the post-disaster reconstruction process. It serves to systematically identify and compare the development before and after a destructive event, linking disruption and reorganisation. This urban transformation analysis considers different methodological concepts to evaluate the occurred change:

- Socio-spatial Continuum: displaying the interaction of built environment and social processes;
- Spatial levels: zoom-ins and zoom-outs based on multi-scale consideration allows aggregating information, reaching from general development trends (macro level: urban development), intermediate scales (meta level: building types) to a detailed level (micro level: single buildings) providing a common database for different disciplines working scales,
- Temporal scale: based on different building survey periods a long-term evaluation is provided;
- Resilience capacities: based on differentiating built environments capacities to perform change observable measures of reconstruction are categorized (persistence, adaptation, transformation).
- Multi hazard assessment: based on the mapping of multi-hazard exposures.

Based on these tools the post-disaster reconstruction process is evaluated within a long-term observation period that considers different spatial levels and multi-hazard risks. Information is deduced from an urban analysis and refined by aggregated data from a comprehensive in-situ single-building survey. Urban development strategies that account for the integration of disaster risk reduction into sustainable urban development can be derived while the elaborated engineering approach is retained. Basic methodological feature is the systematic Δ-Consideration that provides data about changing vulnerabilities on a single buildings scale within a 20years' time frame - in the following applied for the case study of Aigio.

2.3 Macro Scale: Urban development

Aigio (Αίγιο) is a medium-size Greek city. Its 3000 years of retraceable history were portentously accompanied by the presence of multiples hazards that carved its development patterns (destructive historic events in: 23, 1748, 1817, 1861, 1888). Fig. 1 reconstructs the urban morphogenesis on a macro scale by composing historic town plans, cadastral plans, satellite imagery and digital data.

The mapping displays that rapid urban growth started with the industrialisation in late 19th century. Since the 1960s the inner city densified based on the replacement of traditional buildings by 'Polykatoikias' (the typical Greek 'multi-story building'; RC frame structures). At the same time, widely unregulated suburbanisation (peripheral urbanisation) increased and lead to growth into multi-hazard prone areas. Renewal to the inner city bases on the replacement of traditional building typologies and construction types (adobe, masonry) by RC frame structures resulted in decreased seismic vulnerability, however at the expense of the replaced built heritage and counteracted by the development into (multi-)hazard prone areas at the urban fringe. Rather than proactively preventing these risks or mitigating them by planning interventions, deficiencies remain and urban transformation results in new risks. At the same time, widely unregulated suburbanisation (peripheral urbanisation) increased and lead to growth into multi-hazard prone areas. Renewal to the inner city bases on the replacement of traditional building typologies and construction types (adobe, masonry) by RC frame structures resulted in decreased seismic vulnerability, however at the expense of the replaced built heritage and counteracted by the development into (multi-)hazard prone areas at the urban fringe. Rather than proactively preventing these risks or mitigating them by planning interventions, deficiencies remain and urban transformation results in new risks [5]

2.4 Meta Scale: Urban design and building typologies

In order to reduce disaster risks engineering and urban planning approaches have to be better interrelated. This requires an applicable level of mutual interest to refine the insights of macro scale of urban development (urban layout, land use etc.) and relate it to the micro scale of the single buildings. This meta level is formed by the taxonomic classification of single buildings into building typologies, applicable for both disciplines.

Fig. 1 – Urban development from ancient to present times (more intensive red is older) [1]

Based on a photo documentation of every single building the building stock can be categorized based on its typological similarities into building typologies (see Fig. 2. top line). Those building typologies are defined in order to present a complementary approach to the engineering taxonomy used for the vulnerability analysis (Building Types based on the European Macroseismic Scale EMS-98 [6]). The classification of a typology is broad enough to connect different perspectives across-scale (micro to macro). This allows refinement without losing the insights on urban development trends.

Fig. 2 – Building Type taxonomy (taken from [1])

2.5 Micro Scale: Single building

Fig. 2 describes the existing Building Types within the city of Aigio, based on the classification of the EMS-98. The taxonomy refines the assigned vulnerability classes of the EMS-98 in order to elaborate the risk assessment. Therefore, the different building types evident in the city are classified according to parameters (construction type, vulnerability classes, use, floor class, seismic codes) that were adapted for the case study of Aigio. It is shown that the preliminary assessed building typologies (see Fig. 2, top line) can be related to the EMS-98, giving evidence for applicability for both, engineering and urban planning perspective. Given this insight for earthquake hazards, the EMS-98 is further developed to be adapted for multi-hazard vulnerability analysis (see 4.).

3. Evaluation the Post-Disaster Reconstruction Process

3.1 Data sets of the Δ-Consideration

Basic methodological feature is the systematic Δ-Consideration that provides data of the urban transformation on a single buildings scale considering a 20 years' time frame after the disaster. Fig. 3 displays the three underlying layers. Fardis et al. [7] presented an elaborated damage study (inner city, 2014 buildings, including damage grades, construction types, storeys, reconstruction measures and funding for 1995-1998) which forms the first layer used for this study. It is followed by the detailed building survey of Earthquake Damage Analysis Center (EDAC) in 2005 that included the entire city (7590 buildings) and photo documentation for the inner city (II layer). It is used for the application of EMS-98 to compare the building stock vulnerability within a 10 years' time frame [8]. This survey is sequenced by the third layer: the re-evaluation of the inner city building stock by the authors in 2013 (including construction type, storeys, use, conditions and vulnerability classes for 2964 buildings).

3.2 Damage caused by the 1995 and actual building conditions

The Δ-Consideration case study starts with the damage analysis after the 1995 Aigio Earthquake (M=6.5, 26km depth, 18km northwest City Centre, horizontal PGA=0.54g). Within the affected region 26 People died in two collapsed high-rise RC structures, 200 were injured, 2.100 became homeless. Damage costs were estimated US$ 660 Mio, while reconstruction funding was approx. US$ 200 Mio. Within the region 1887 buildings were damaged beyond repair.

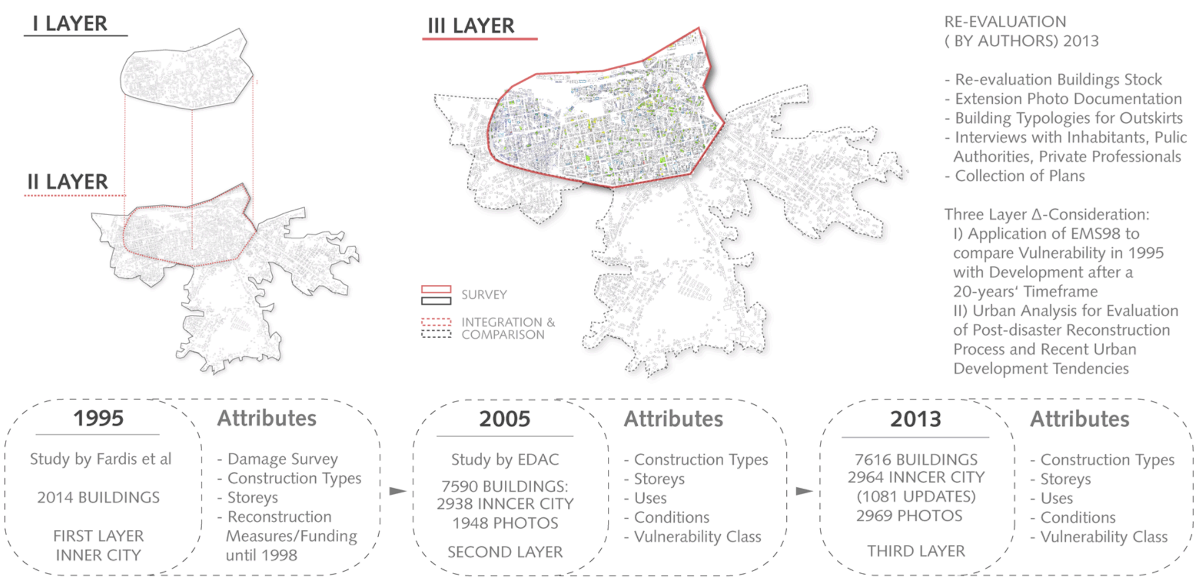


Fig. 3 – Δ-Consideration data sets: building stock surveys 1995 | 2005 | 2013 (taken from [1])

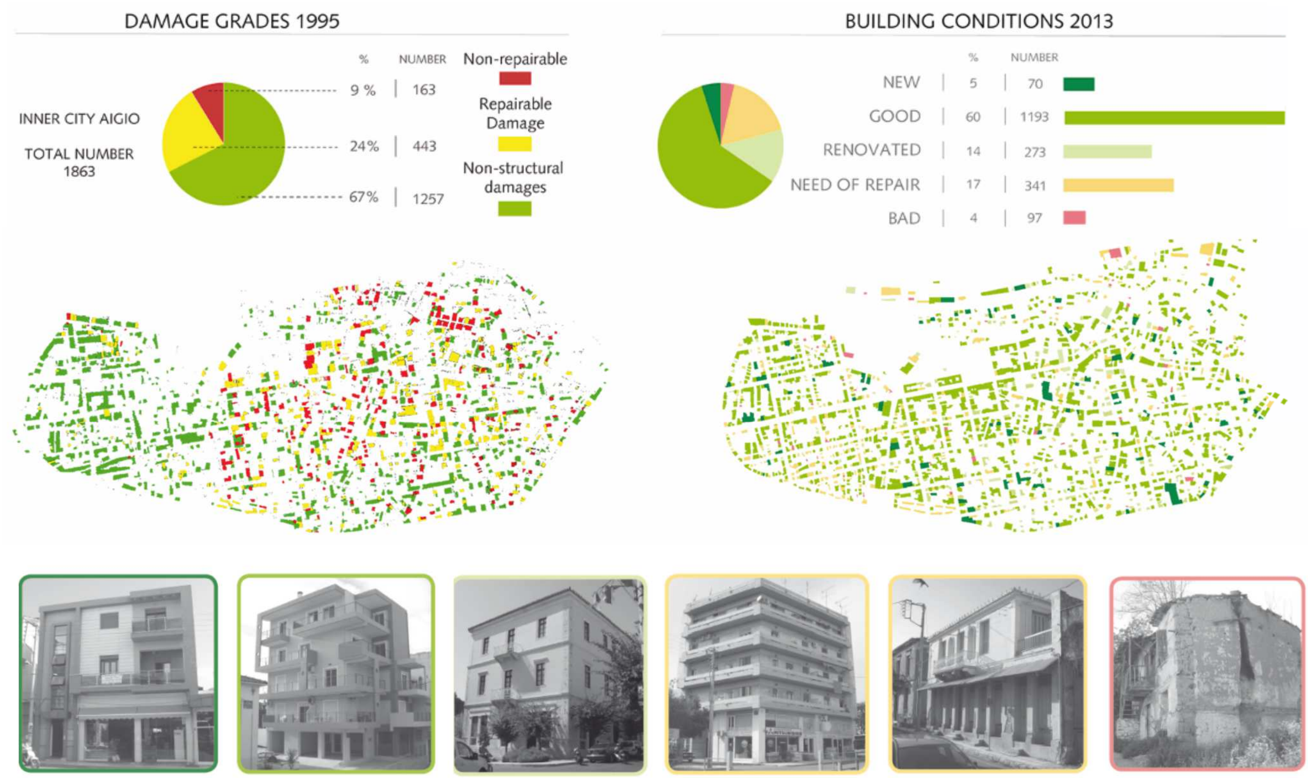


Fig. 4 – Observed damage grades 1995 [7, 8] and building conditions 2013 with examples [1]

Special interest and intensive research considered the Greek seismic codes from 1984. Two consecutive damage surveys were conducted. Fig. 4 displays the 1995 survey; 1996: 8155 buildings, 25% very structural damage–collapse, 28% moderate to serious structural damage, 47% undamaged or slight non-structural damage. The “before-after” comparison allows contrasting the occurred damage with the surveyed data of the actual building stock conditions in 2013 as shown in Fig. 4. During the 1995 earthquake all damage grades occurred to all building types (adobe, masonry, RC). The building stock remained in ‘generally good conditions’ while the ‘need for repair’ or ‘renovation’ remained constant and the level of ‘critical building conditions’ was reduced. Accordingly, the building stocks vulnerability decreased as displayed in [4].

3.3 Types of urban change 1995-2005-2015

The long-term evaluation of the reconstruction in Aigio is analyzed and displayed in the developed Evaluation Scheme for Post-Disaster Reconstruction Processes by Schwarz et al in [9]. To analyze the impacts of post-disaster urban transformation on multi hazard vulnerability and resilience it is necessary to understand that the reconstruction process continues two decades after the event: building activities are still related to the disaster impacts (within 2005-2013: 46% replacement of traditional structures, 38% demolition and replacement and 16% of the voids were rebuilt by Polykatoikias), indicating the decelerated, but evident continuation of the reconstruction process. By comparing the before and after status using the Δ-Consideration evidence for the resilience capacities can be observed in terms of the ‘occurred measures of change’ on a single building scale.

The systematic re-evaluation of the building stock for the period 2005-2013 enables to classify the observed measures of change in the built environment into three different types with respective subcategories. Those describe the resilience capacities of the building stock to cope with the occurred change by the disaster impacts.

Fig. 5 – Resilience Capacities applied to types and number of changes (NoCh) and exemplification [1]

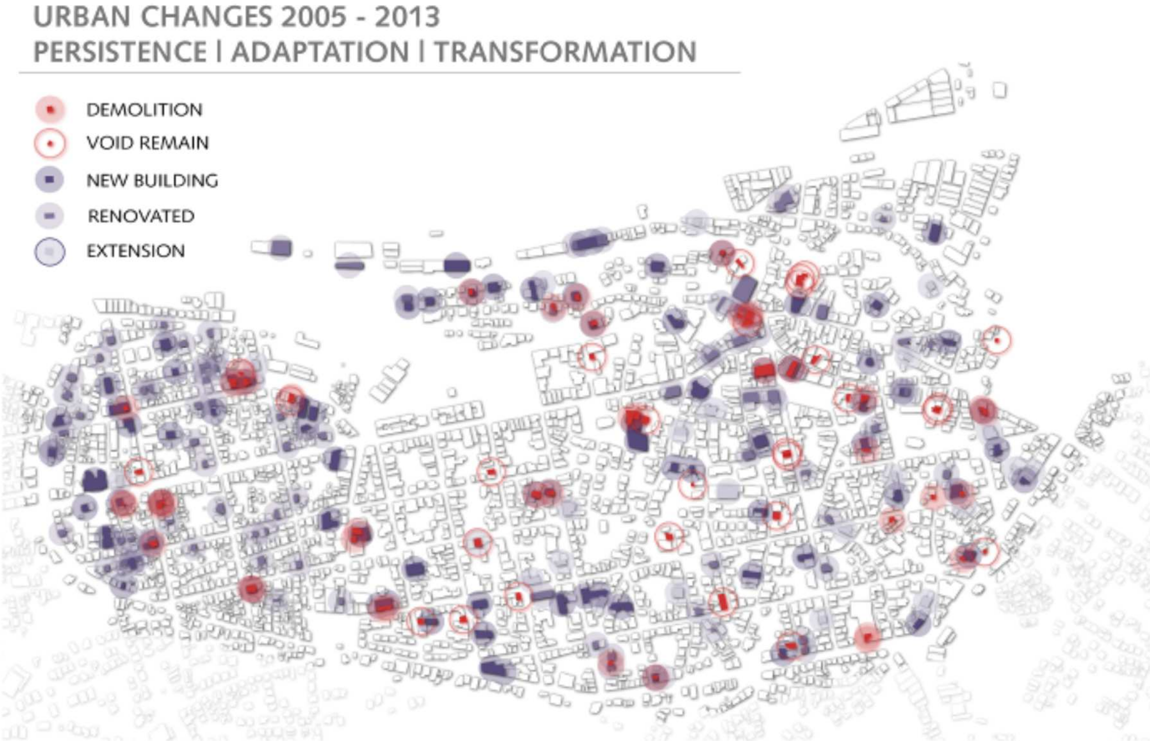


Fig. 6 – Analysis and Mapping of Types of Change - Case study of Aigio [1]

The following types of change have been introduced for a detailed evaluation (see Figures 5 and 6):

Persistence (What is still there and persisted?): Out of the 74 classified Heritage Buildings many could have been renewed, however, deterioration continues and voids remain.

Adaptation (What has been changed while the structure remained?): "Changes in use" and "Completion" (4%): minor quantity and importance of change; "Extensions" (10%): expression of the incremental building process; only RC, mostly from 2-3 or 3-4 storeys; "Renovation/ Restoration" (31%): 3% of the building stock, mostly low-rise residential buildings of all construction types.

Transformation (What was there before, but ceased-to be or emerged as new?): "Demolition" (22%): mostly traditional building types with 1-2 storeys in need of repair and bad conditions, but also speculative demolition of buildings in good conditions, including plot merging; "Replacement" and "New Buildings" on voids (33%): Mostly high-rise RC structures (>3 storeys) with residential use.

It can be concluded that 31% of the building stock changed within a 20 years' time frame. Observable measures of urban change within 2005-2013 occurred to 45% as adaptations and to 55% as transformation.

4. Multi-hazard Mapping and Multi-Hazard Vulnerability Analysis

Disaster risks emerge from the exposure to multiple hazards, while the damageability depends on the vulnerability of the building stock and its resilience capacities. After having provided evidence of the built environments' resilience capacities to cope with change by evaluating the urban transformation process the multi-hazard vulnerability is analyzed.

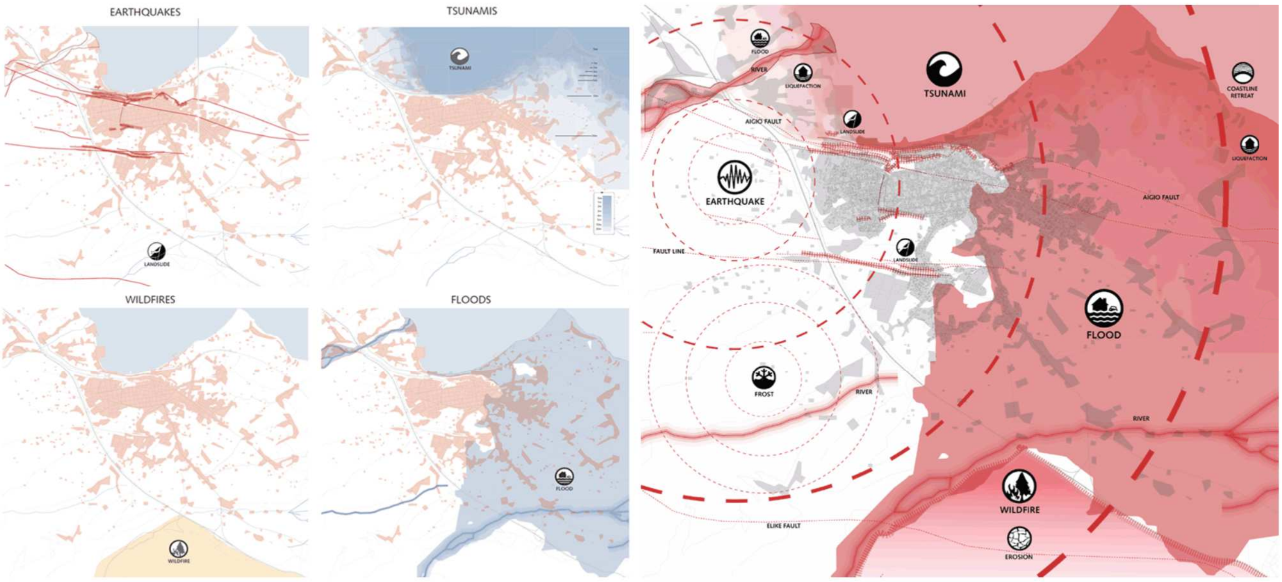
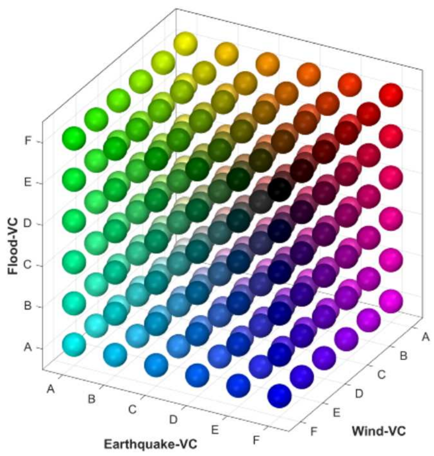


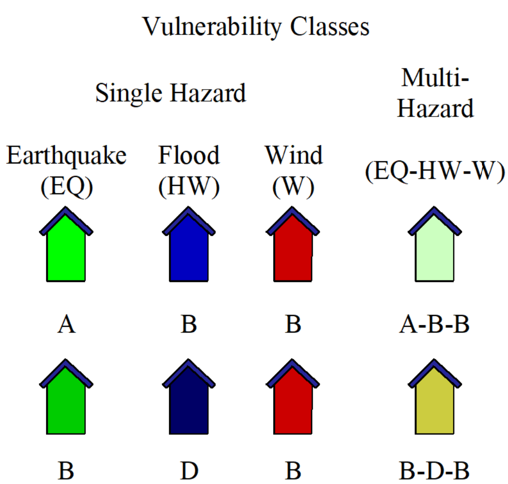
Fig. 7 – Hazard exposure Aigio (earthquake, tsunami, wildfire, floods and multi-hazard mapping) [1]

Based on data from real events, historical observations and current research results Fig. 7 provides a multi-hazard mapping for earthquake, tsunami, wildfire and flood exposure that is overlaid to define multi-risk locations. The mapping can be applied to define the exposure of the urban area as well as critical infrastructures in order to adapt land use management and territorial planning to reduce disaster risks.

The EMS-98 can be applied to define the vulnerability to earthquake damages. Using the tool of Δ-Consideration the changing vulnerability due to urban transformation can be displayed. In order to analyze the multi-hazard vulnerability of the building stock Schwarz & Maiwald [10] adapted and further developed the method of the EMS-98 to be applicable for other single hazards such as wind and flood hazards.

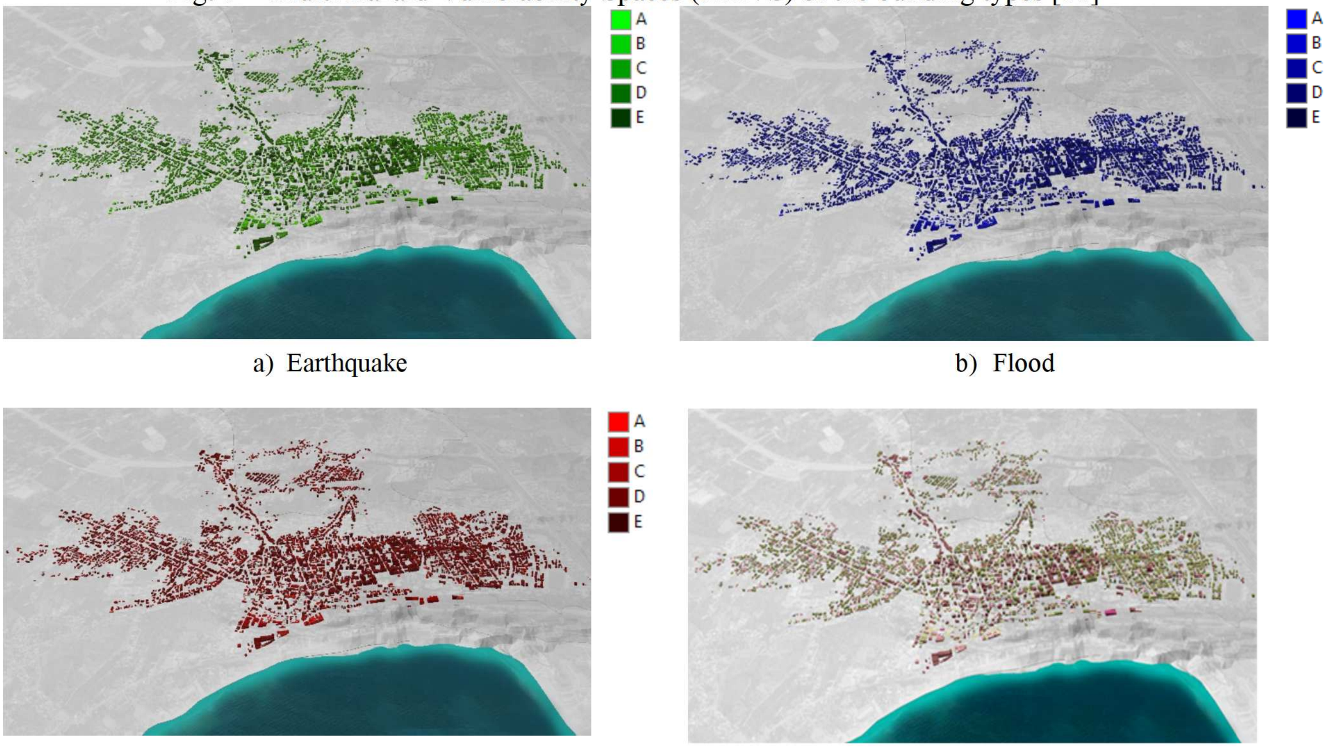


a) Color coding of the MHVS



b) Examples

Fig. 8 – Multi Hazard Vulnerability Spaces (MHVS) of the building types [11]



a) Earthquake

b) Flood

c) Wind

d) Multi Hazard
(Color representation according to Figure 8a)

Fig. 9 – Application of the MHVS: Single and Multi Hazard Vulnerability of the case study Aigio.

Fig. 8a) shows the developed scheme of the Multi Hazard Vulnerability Spaces (MHVS) that arranges the vulnerability classes for the single hazards according to the range of building types from A to F. Combining the single hazard scales forms a Multiple Hazard (three dimensional) Vulnerability Space (MHVS). By applying the colour coding the multi-hazard vulnerability of the building stock can be displayed as exemplified in Fig. 8b).

On the basis of the relevant building data (see Fig. 2), the vulnerability classes for the three considered natural hazards are assigned to the existing buildings of the study area. For the visualization of these vulnerability classes, the "prototype" solution (as presented in [12]) is applied to the case study of Aigio. After defining fundamental colours for the individual natural hazards (earthquake: green, flood: blue, wind: red), other ("mixed") colours are following from the colour theory (see Fig. 8b). Figures 9a) to c) show the single hazard vulnerability analysis for earthquake, flood and wind in a 3D model of the city.

As shown in the Figures 8a) and 9d) it is possible to analyse and display the multi-hazard vulnerability of the building stock. Combined with the Δ-Consideration a systematic tool to analyze the impacts of urban transformation on multi-hazard vulnerability of a city can be provided.

Another way of visualizing the vulnerability of the building stock of an investigation area is the "3D bubble plot". The different shares of the individual vulnerability combinations are represented with the diameter of the globes. For the investigation area, Fig. 10 shows that several (or a few) dominant types stand out.

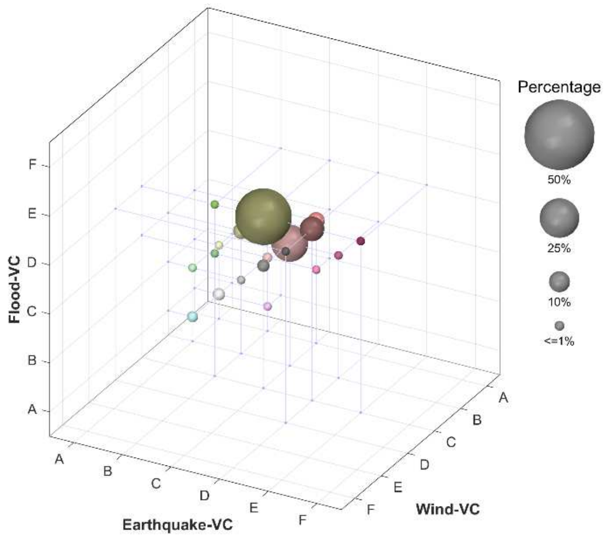


Fig. 10 – Multi Hazard Vulnerability (MHV) of the study: condensed representation

For each building stock, a characteristic "foot print" can be given, which reflects the long-time adaptation to the dominant natural hazards after the history of damaging events. Note: The “foot print” given represents the building stock elaborated in 2013 (see Fig. 3), i.e., the impact of reconstruction and urban transformation is included. Similar elaborations are given in [11] for investigation areas Germany and Switzerland, in particular for towns being repeatedly affected by earthquakes or floods.

In principle, such a representation is also suitable for reconstructing the urban development of particularly exposed areas affected by various natural hazards. Changes in the building stock can be highlighted in the form of a Delta (Δ) Consideration.

6. Conclusions and transferability

This study presents a methodological framework for the systematic analysis of the impacts of post-disaster urban transformation on multi-hazard vulnerability and resilience. Using the case study of Aigio, Greece, as a model area the applicability of the concept is presented and transferability to other contexts is provided.

Cities are the mankind’s most valuable artifacts; natural hazards threaten their sustainable development. As disasters emerge from different hazard exposures multi-hazard vulnerability as well as resilience capacities have to be analyzed in order to understand the risk. As presented in this paper, this demands for interdisciplinary approaches that combine engineering and urban planning perspectives.

Based on the results of three consecutive single-building surveys during a 20 years time frame after the destructive earthquake the impacts of natural hazard on urban transformations were systematically analysed using the tool of Δ-Consideration. Evidence on the resilience of the building stock is given by evaluating the observed measures of change during the post-disaster reconstruction process.

Different types of coping with change were classified according to the resilience capacities (persistence, adaptation, transformation). Expressing the quantitative impact of the earthquake damages, reconstruction and urban transformation illustrates that 31% of the building stock changed within a 20 years’ time frame. Observable measures of urban change within 2005-2013 occurred to 45% as adaptations and to 55% as transformation.

By adapting and further developing the method of the EMS-98 it was possible to analyse and display the multi-hazard vulnerability of the building stock. Combined with the Δ-Consideration the dynamic changes of risks that result from urban transformation processes can be systematically studied. Evaluating the resilience capacities of the building stock is an essential instrument to reduce disaster risks and design sustainable urban development. In addition, these results can be used for more coherent damage and loss modelling. The requirements for the practical application of the EMS-98 as well its reliability and predictability for simulated earthquake damage modelling is discussed [13].

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