

URBAN DESIGN PERSPECTIVES ON THE USE OF BUILDING TAXONOMIES REFERRING TO EMS-98 CLASSIFICATION

A. Schwarz ⁽¹⁾, C. Kaufmann ⁽²⁾, J. Schwarz ⁽³⁾

⁽¹⁾ Project Manager, Department of Urban Planning, State Capital of Potsdam, Germany

⁽²⁾ Senior Researcher, Earthquake Damage Analysis Center (EDAC), Bauhaus-Universität Weimar, Germany

⁽³⁾ Head, Earthquake Damage Analysis Center (EDAC), Bauhaus-Universität Weimar, Germany

Abstract: *The world is rapidly urbanizing and disasters threaten the sustainable development of cities. Designing resilient change requires understanding risks resulting from urban transformation and deducing resilience strategies. This paper presents an urban design perspective on the development of an integrated earthquake engineering and urban planning approach intended to create disaster risk reduction concepts on a city level (urban scale) based on a structural type related (single-building) scale. The main aim of this paper is to provide a method for the evaluation of risks of the building stock by using an in-depth urban transformation analysis - so called Delta-Consideration. Criteria for identifying development paths of the building stock are presented. They recognize the evaluation of risk as a dynamic (time-dependent) process differentiating spatial (macro to micro) levels and multi-hazard vulnerabilities. These scales can be integrated into a tool set for the systematic evaluation of post-disaster reconstruction process and used to identify resilience capacities of the building stock. The applicability of the method is demonstrated for case studies, in particular for the city of Aigio, Greece. Following the destructive 1995 earthquake consecutive building surveys were conducted within ten-year intervals representing a total 20-year time frame as basis for a consistent evaluation of the post-disaster urban transformation process. The development of the city and its urban extension is displayed in different historical phases including the impacts of natural hazards. The hazards are presented according to the vulnerability classes of the European Macroseismic Scale (EMS-98). The building types of the EMS-98 act as a linking meta-level relevant for both engineering and urban planning perspectives. The application of the method is explained, finally leading to procedures to translate the surveyed buildings into the scheme of EMS-98 building types. Following previous studies, the application of the EMS-98 Building Types for multi-hazard vulnerability analysis is displayed. Furthermore, newly developed building typologies are introduced to integrate additional features relevant for the development of urban planning concepts and the evaluation of resilience capacities. In sum, it can be concluded that a single-building scale is not enough to mitigate urban disaster risks and integrated approaches, combining earthquake engineering and urban planning are needed.*

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 analyse 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. Cities 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 to increase ‘Urban Resilience’- the capacity of a city to cope with changes - in order to create sustainable development.

2 Data and Tools for Evaluating Post-Disaster Reconstruction

2.1 Methodology - Resilience and Δ(Delta)-Consideration

Risk can be described as the exposure of a system to a hazard whose impact manifest based on the systems vulnerability and its resilience capacities. Understanding not only vulnerability but 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” (Walker 2004).

Fig. 1 displays the relation of resilience and sustainability. Resilience is framed by three basic components: (I) systems characteristics, (II) prevailing paradigms and (III) disruption and reorganisation (Deadlow 2013). 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 analyse 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 analyse ‘what has changed’ since the disruption
- *Target status* is defined by prevailing paradigms, because it requests a strategy for ‘what should change’ to reorganize (Kegler 2014)

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 analysing the occurred change between the disruption (caused by the disaster impact) and the reorganization. Accordingly, the long-term evaluation of post-disaster reconstruction is an essential tool to understand the urban resilience capacities displayed by the actual measures of change (persistence, adaptation and transformation of a systems’ elements before vs. after). The impact of natural hazards on urban settlements was studied by (Schwarz 2015) by combining earthquake engineering and urban planning approaches within a complementary perspective in order to address multi-risk factors more effectively.

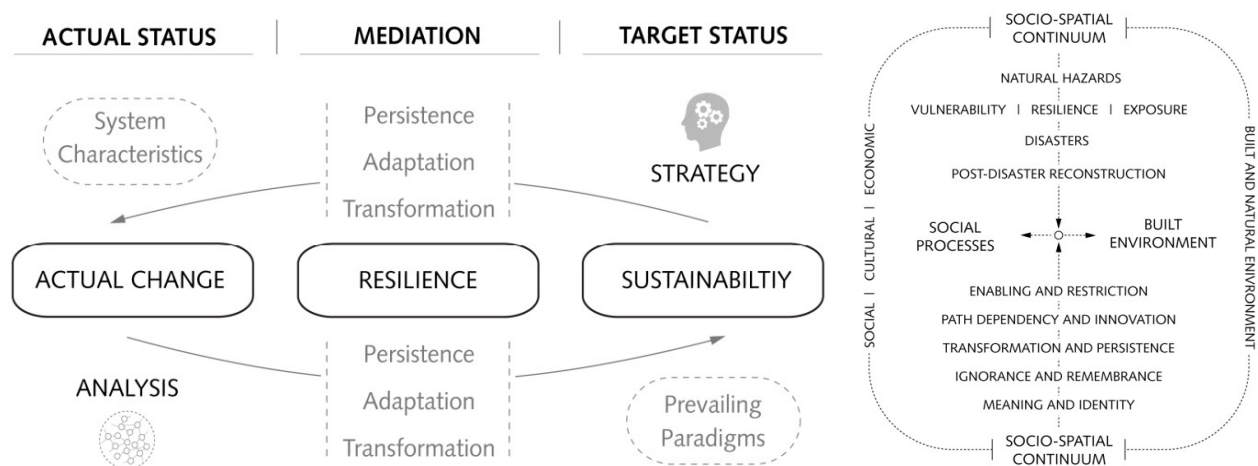


Fig. 1– Relation of Actual Change - Resilience – Sustainability (Schwarz 2015)

As a result the tool of “ Δ (Delta)-Consideration” (Schwarz 2017) was developed to evaluate post-disaster reconstruction processes. It serves to systematically identify and compare the development before and after a destructive event, linking disruption and reorganization. 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 as a spatial expression; stressing that the reorganization of the built environment is embedded in an socio-cultural and -economic context that enables or restricts change
- 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. 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.

2.2 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. 2 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) (Chtouris 1993). At the same time, widely unregulated suburbanisation (peripheral urbanisation) increased and lead to growth into multi-hazard prone areas. Renewal of 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 (Schwarz 2015).



Fig. 2 – Urban development from ancient to present times (more intensive red is older) (Schwarz 2017)

2.3 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 between macro and micro level. Zooming in from the macro scale of urban development (urban layout, land use etc.) towards an urban block (Fig. 3) displays the change of the urban layout, the interaction of buildings (density, use etc.) while covering the micro scale of the single buildings. This coverage can be describes as a meta level.

It is formed by the taxonomic classification of single buildings into building types (as introduced by EMS-98) focussing on vulnerability. Moreover this paper intents to display that the classification of so called 'building typologies' can help to integrate the resilience capacities of the building stock. 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. 4 top line). Those building typologies are defined in order to present a complementary approach to the engineering taxonomy used for the vulnerability analysis of the EMS-98 (Grünthal 1998). The classification of a typology is broad enough to connect different perspectives across-scale (micro to macro). The building typologies relate to the EMS classification and remain applicable for both disciplines. This allows refinement without losing the insights on urban development parameters – combining vulnerability and resilience perspective.

2.4 Micro Scale: Single building

Fig. 4 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 can be related to the EMS-98 (see Fig. 3 and 4 top line), 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.).

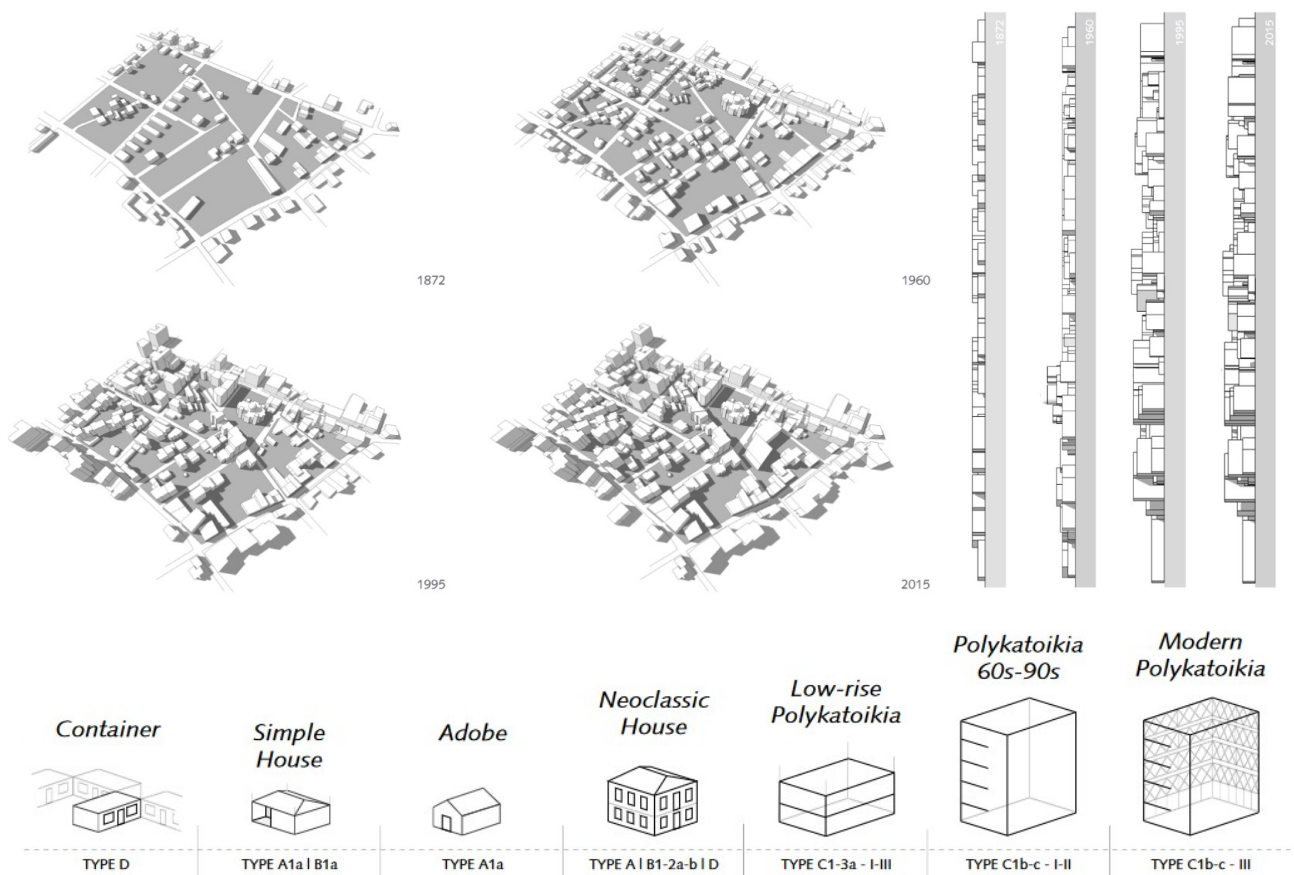


Fig. 3 – Urban transformation on the level of a selected urban block and building typologies

| BUILDING TYPE - TAXONOMY | | A | | B | | C | | | | | | | | | | | |
|-----------------------------|--|--|--|--|--|--|--|--------------------------------------|--|--------------------------------------|----------------------------------|----------------------------------|--|--|--|--|--|
| RELATED BUILDING TYPOLOGIES | | | | | | | | | | | | | | | | | |
| BUILDING TYPE | | A | | B | | C | | | | | | | | | | | |
| CONSTRUCTION TYPE | | SIMPLE MASONRY | | MASONRY | | REINFORCED CONCRETE | | | | | | | | | | | |
| Material | | Adobe Natural Stone Masonry | | Brickwork | | RC Frame/Brickwork I RC Wall | | | | | | | | | | | |
| VULNERABILITY CLASS | | A B - C C | | B - C C | | C - D E | | | | | | | | | | | |
| USE | | Residential Mixed Use Commercial | | Residential Mixed Use Commercial | | Residential Mixed Use Commercial | | Residential Mixed Use | | Residential Mixed Use | | | | | | | |
| FLOOR CLASS | | 1 - 2 | | 1 - 2 3 - 4 | | 1 - 3 | | 4 - 6 | | > 6 | | | | | | | |
| SEISMIC CODE | | - | | - | | 1959 - 1983 1984 - 1994 > 1995 | | 1959 - 1983 1984 - 1994 > 1995 | | 1959 - 1983 1984 - 1994 > 1995 | | | | | | | |
| TYPES | | A1 A2 A3 | | B1a B2a B3a | | B1b B2b | | C1a - I C1a - II C1a - III | | C2a - I C2a - II C2a - III | C2b - I C2b - II C2b - III | C2c - I C2c - II C2c - III | | | | | |
| Relevant | | 20 | | 6 | | 4 5 | | 12 | | 12 | 12 | | | | | | |
| Total | | 34 | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | |

Fig. 4 – Building Types - Taxonomy (Schwarz 2015)

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. Fardis et al. (Fardis 1995) 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 (second layer). It is used for the application of EMS-98 to compare the building stock vulnerability within a 10 years' time frame (Langhammer 2006).

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\$ 200Mio. Within the region 1887 buildings were damaged beyond repair.

Special interest and intensive research considered the Greek seismic codes from 1984. Two consecutive damage surveys were conducted. Fig. 5 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 1995 and 2013 as shown in Fig. 5. During the 1995 earthquake all damage grades occurred to all building types (adobe, masonry, RC). In 2013 the building stock is in ‘generally good conditions’ while the ‘need for repair’ or ‘renovation’ remained and the level of ‘critical building conditions’ was reduced. Accordingly, the building stocks vulnerability decreased as displayed in (Schwarz 2017).

3.3 Types of urban change 1995-2005-2015

The long-term evaluation of the reconstruction in Aigio is analysed and displayed in the developed Evaluation Scheme for Post-Disaster Reconstruction Processes as developed in (Schwarz 2018). To analyse 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. The following types of change have been introduced for a detailed evaluation (see Fig. 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.

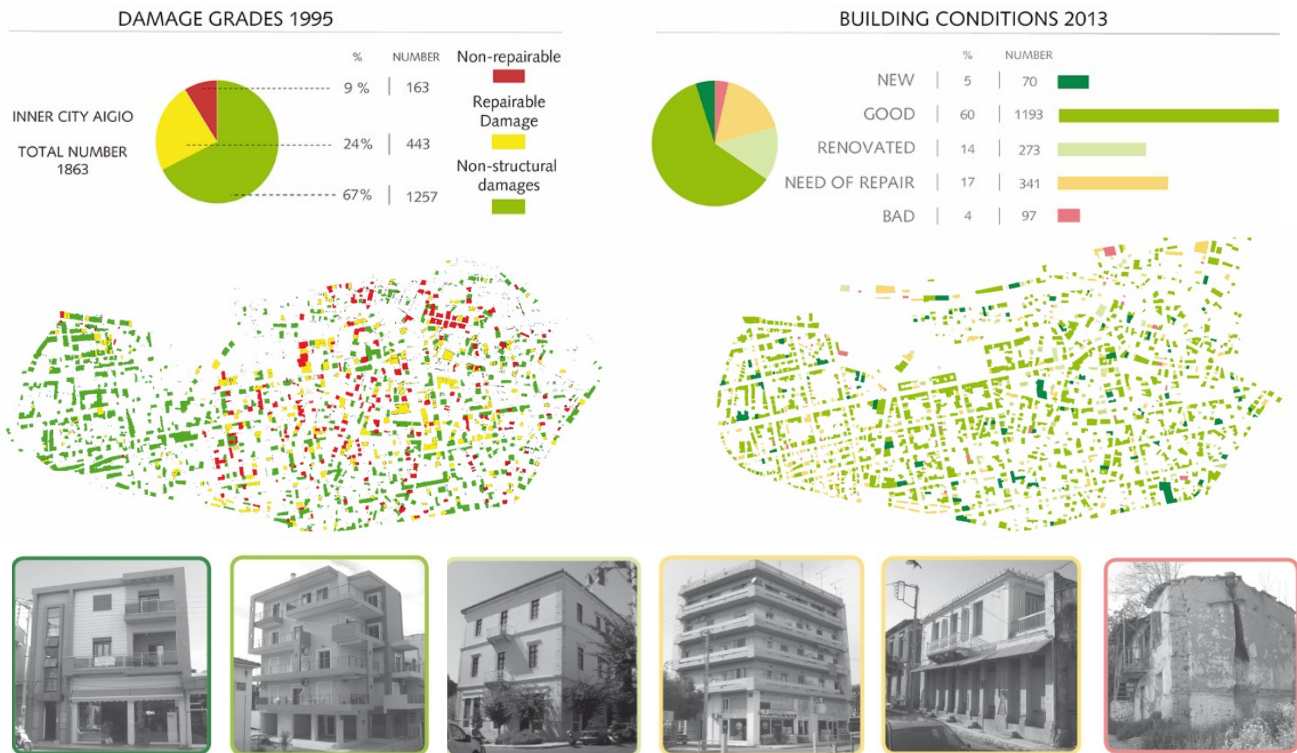


Fig. 5 – Observed damage grades 1995 (Fardis 1995) and 2013 with examples (Schwarz 2015)

| OBSERVED MEASURES OF URBAN CHANGE | | | | | EXAMPLES | |
|--|----------------------------|---|------|-----|---|---|
| Type | Measure | Scheme | NoCh | [%] | 2005 | 2013 |
|  I Persistence | Remained in Ruins |  | - | - |  |  |
| | Void Remained |  | - | - | | |
|  II Adaptation | Renovation |  | 86 | 31 |  |  |
| | Restoration |  | | | | |
| | Change in Use |  | 4 | 1 |  |  |
| | Completion |  | 8 | 3 |  |  |
| | Extension |  | 26 | 10 |  |  |
|  III Transformation | Demolition |  | 59 | 22 |  |  |
| | New Building (On Void) |  | 91 | 33 |  |  |
| | New Building (Replacement) |  | | | | |

Fig. 6 - Resilience Capacities applied to types and number of changes (NoCh) and exemplification for the observed measures change within the time frame of 2005 - 2013 (Schwarz 2018)

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 analysed.

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 analyse the multi-hazard vulnerability of the building stock (Schwarz J *et al.* 2019) adapted and further developed the method of the EMS-98 to be applicable for other single hazards such as wind and flood hazards.

Fig. 8a) shows the developed scheme of the Multi Hazard Vulnerability Spaces (MHVS) that arranges the vulnerability classes (see EMS-98 in Grünthal 1998) 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, 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 Maiwald 2019) 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 analyse 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" (Fig 8a). The different shares of the individual vulnerability combinations are represented with the diameter of the globes. For the investigation area this is shown in (Schwarz 2019).

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, i.e., the impact of reconstruction and urban transformation is included. Similar elaborations are given in (Schwarz J 2019) 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.

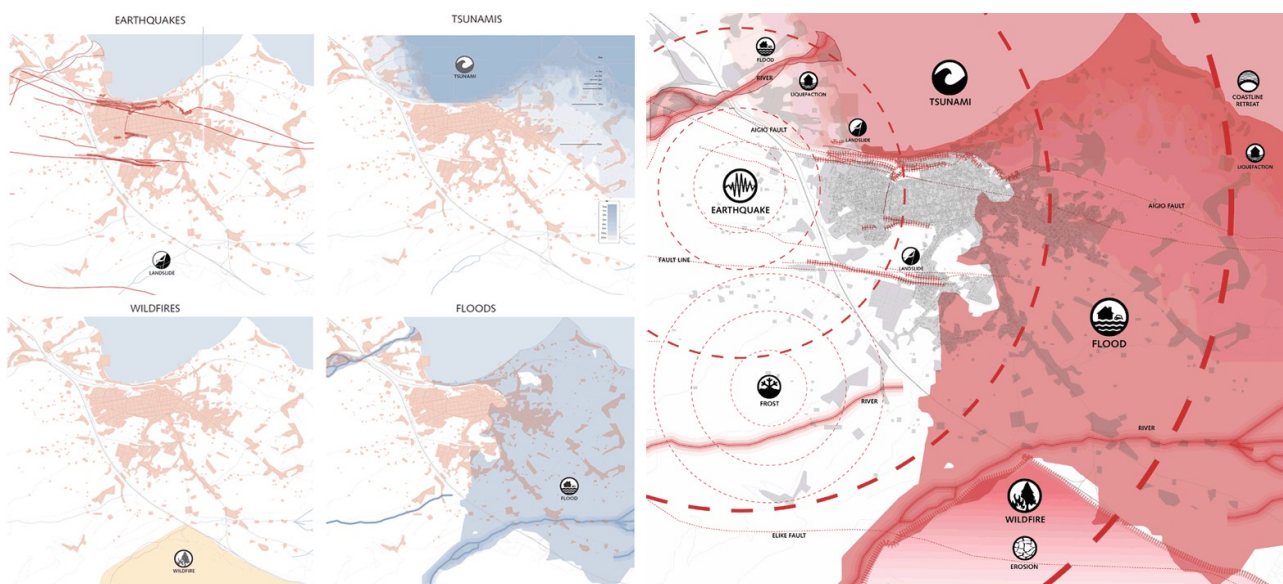


Fig. 7 – Hazard exposure Aigio for single hazards (earthquake, tsunami, wildfire, floods) and combined in multi-hazard mapping (Schwarz 2017)

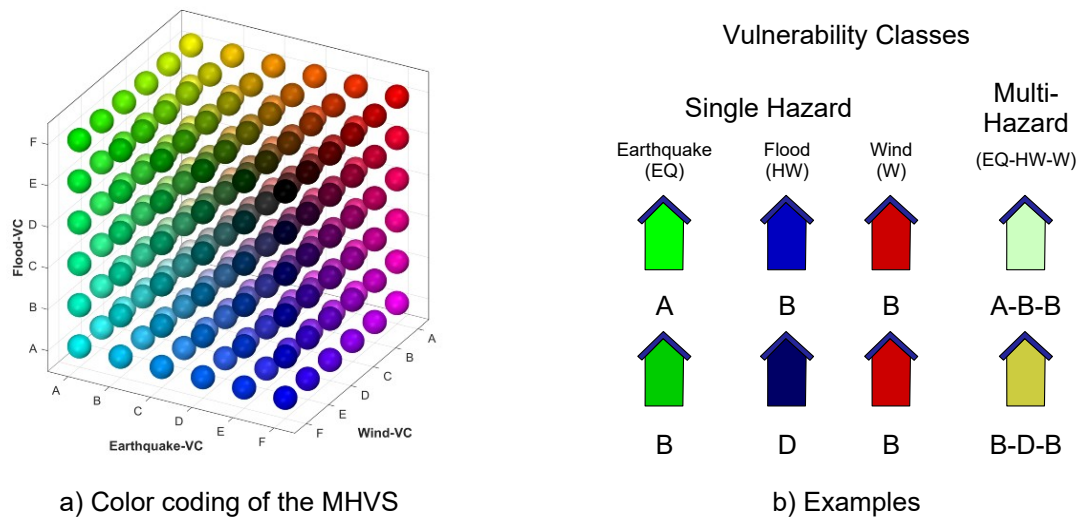


Fig. 8 – Multi Hazard Vulnerability Spaces (MHVS) of the building types (Schwarz 2019)

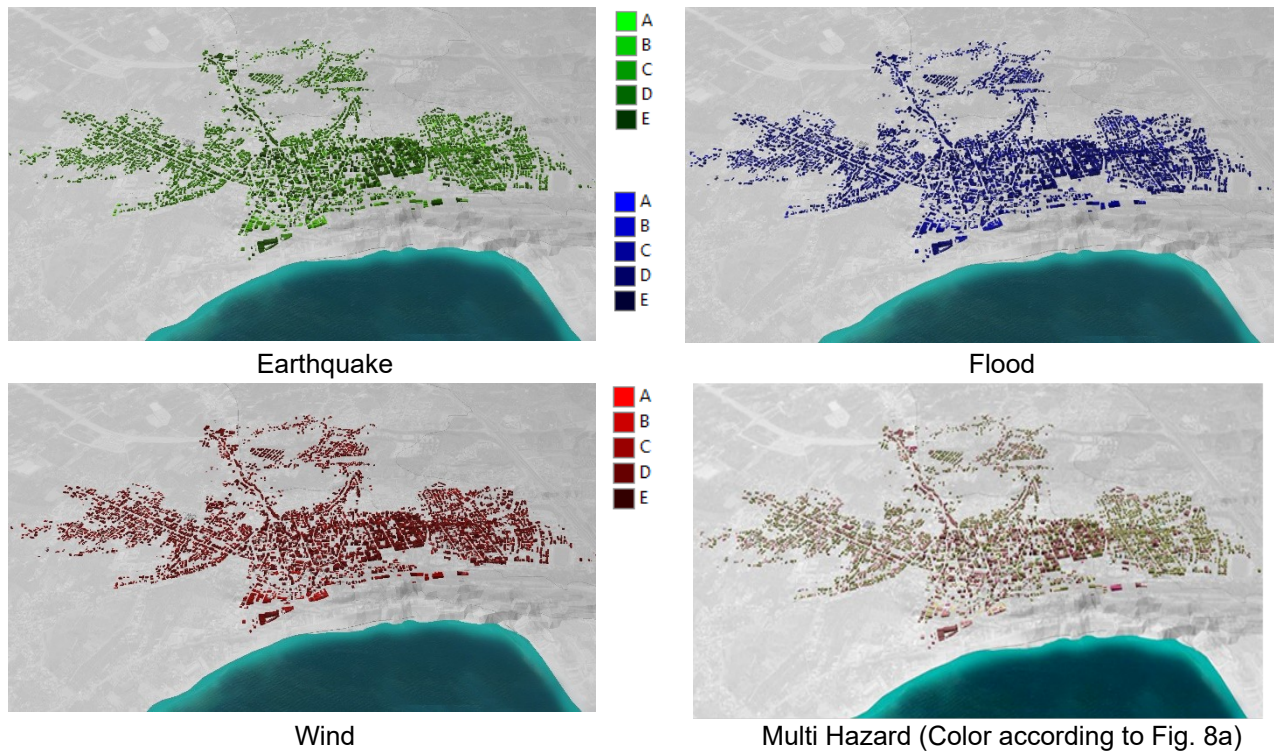


Fig. 9 – Application of the MHVS: Single and Multi Hazard Vulnerability of the case study Aigio.

5 Building Typologies – An Urban Design perspective on building taxonomies

As Fig. 4 displays the building types based on EMS-98 for the case study of Aigio representing the engineering perspective for earthquake vulnerability of the building stock. Combined with the Multi-hazard Vulnerability Analyses (Fig. 8 and 9) a comprehensive image of the building stock vulnerability is presented.

As stressed above sustainable development requires to understand the resilience. The long-term evaluation of the post-disaster reconstruction process of the case study (Schwarz 2015) revealed that a singularly vulnerability-focused approach appear as insufficient as it does not include the resilience capacities of the building stock and discriminates traditional building types in favour of modern construction types based on their structural quality. To include the resilience capacities newly developed building typologies are

introduced that integrate additional features relevant for the development of sustainable urban planning concepts.

The idea of a socio-spatial continuum opposes a sharp division of relevant parameters. To apply an integrated approach with a long-term perspective requires representing social and spatial criteria equally. Fig. 10 shows a (non-exhaustive) matrix of socio-spatial parameters with assessment criteria to score the building typologies according to their vulnerability and resilience capacities equally within a comparable framework. These parameters include the structural vulnerability characteristics (retaining the engineering perspective) while extending the assessment range by additional features that incorporate the resilience capacities of the building typologies.

Rather than constructing a predetermined formula this matrix provides a range of criteria that has to be weighted among and against each other in a specific context within an iterative process. The interrelation and contradiction of the parameters offers the possibility to rate them according to different thinkable perspectives. It becomes a tool for the negotiation (systems characteristics and prevailing paradigms) of future change (persistence, adaptation, transformation) to achieve sustainable development within an integrated (reconstruction or) planning process. This openness itself allows to incorporate the contradictory concept of resilience – first as a retrospective analysis of occurred change secondly as a negotiation of projected change – and combines engineering and urban planning perspectives.

Fig. 11 displays the resulting difference of assessment results for a traditional and a modern building typology within a net diagram.

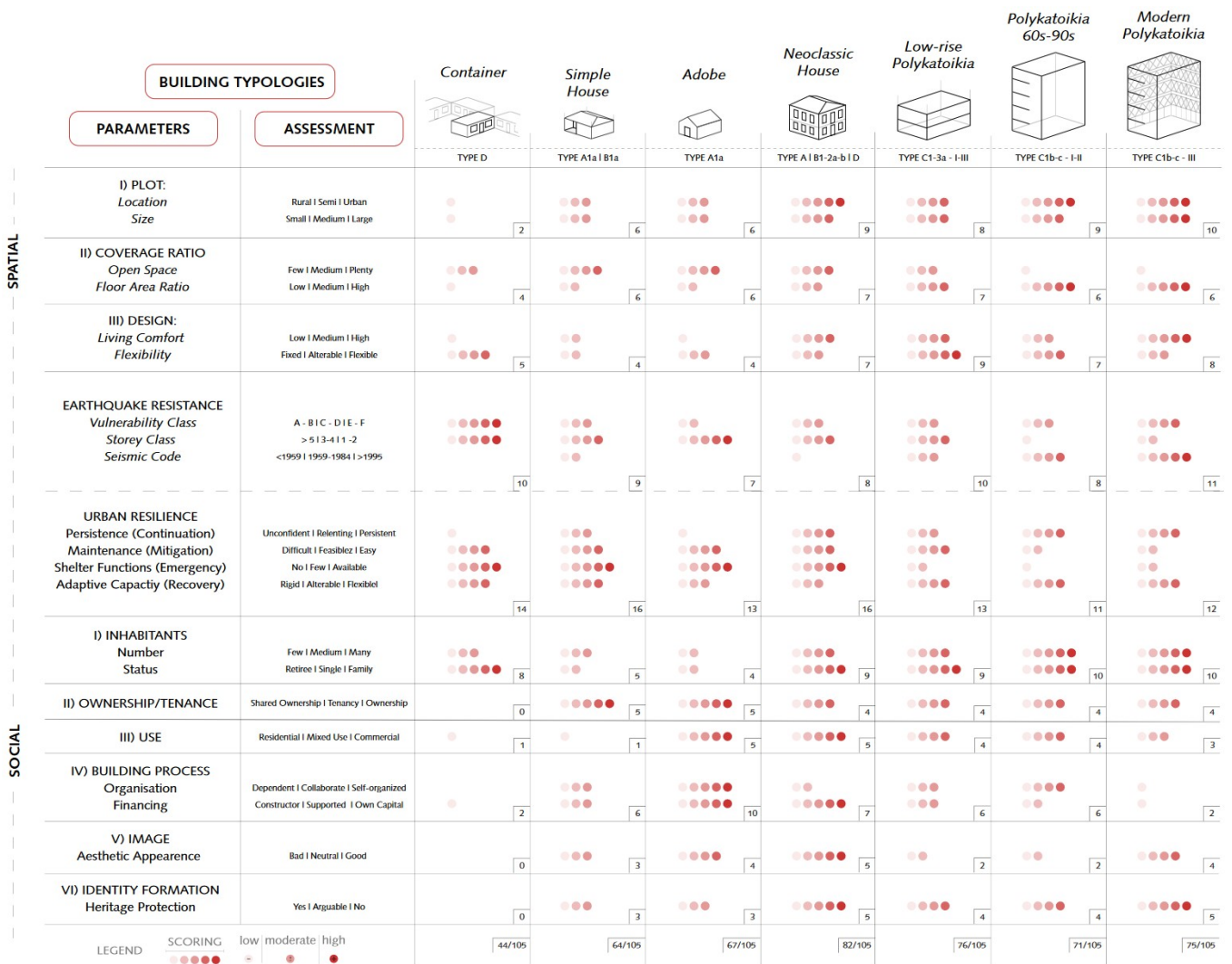


Fig. 10 – Matrix to evaluate building typologies (Schwarz 2015)

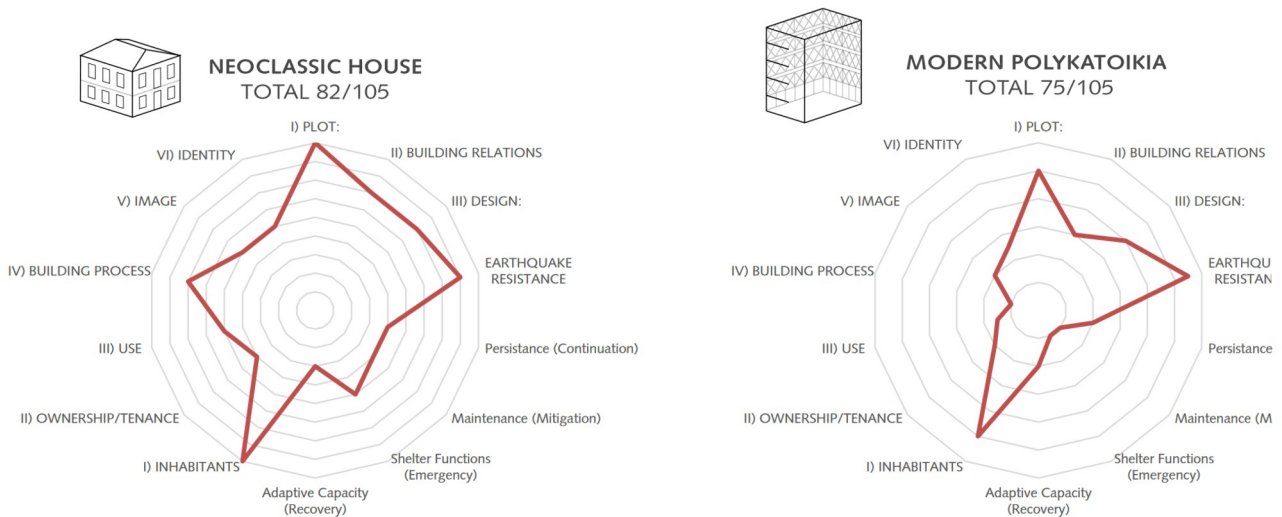


Fig. 11 – Net diagram - Comparison of building typologies criteria based on matrix

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 (Maiwald 2019).

7 References

- Deadlow K, Beckmann V, Schlueter M, Arlinghaus R (2013): Explaining institutional persistence, adaptation, and transformation in East German recreational-fisheries governance after the German reunification in 1990. *Ecological Economics*, 96, pp. 36-50.
- Chtouris S, Heidenreich E, Ipsen D (1993): *Von der Wildnis zum urbanen Raum. Zur Logik der peripheren Verstädterung am Beispiel von Athen*. Campus Verlag, Auflage 1.
- Grünthal G (ed.), Musson RMW, Schwarz J, Stucchi M (1998). European Macroseismic Scale 1998. *Cahiers de Centre Européen de Géodynamique et de Seismologie*, 15, Luxembourg.
- Fardis M, Karantoni F, Kosmopoulos A et al (1999): Study and statistical processing of the damages from the 15-6-95 Aigio earthquake. Data Collection, University of Patras, Final report to OΑΣΠ/EPPO.
- Kegler H (2014): Resilienz. Strategien & Perspektiven für die widerstandsfähige und lernende Stadt. *Bauwelt Fundamente*, 151
- Langhammer T, Schwarz J, Loukopoulus P, Abrahamczyk L, Karantoni F, Lang D (2006): Intensity-based risk assessment for European earthquake regions – The 1995 Aigio Earthquake. *First European Conference on Earthquake Engineering and Seismology*, Geneva, Switzerland.
- Maiwald H, Schwarz J (2019): Simulative Earthquake Damage Modeling Based on EMS-98 – Reliability and Predictability. *17th World Conference on Earthquake Engineering*, Sendai Japan.
- Schwarz A (2015): Change by design, not by disaster. Post-disaster reconstruction and urban transformation. Re-evaluating the case study of Aigio, Greece. Technical University Berlin, Germany.
- Schwarz A, Oikonomou M, Schwarz J (2017): Long-term Evaluation of Post-disaster Reconstruction and Impacts of Natural Hazards on Urban Transformation - The case study of Aigio, Greece. *Proceedings 16th World Conference on Earthquake Engineering*, Santiago, Chile.
- Schwarz A, Oikonomou M, Schwarz J (2018): Long-Term Evaluation of Post-Disaster Reconstruction - The Case Study Of Aigio, Greece. *16th European Conference on Earthquake Engineering*, Thessaloniki, Greece.
- Schwarz A, Maiwald H, Schwarz J (2019): Resilience targeted analysis of urban transformation based on post-disaster reconstruction and Multi-Hazard Vulnerability Analysis (MHVA). *12th Canadian Conference on Earthquake Engineering*, Quebec City, Canada.
- Schwarz J, Maiwald H (2012): Empirical vulnerability assessment and damage description for natural hazards following the principles of modern macroseismic scales. *15th World Conference Earthquake Engineering*, Lisboa, Portugal.
- Schwarz J, Maiwald H, Beinersdorf S, Kaufmann C (2018): Evaluation of the vulnerability of existing building stocks under single and Multi Hazard impact. *16th European Conference on Earthquake Engineering*, Thessaloniki, Greece.
- Walker B, Holling C, Carpenter S, Kinzig A (2004): Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society*, 9 (2), Article 5.