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# Resilience targeted analysis of urban transformation based on post-disaster reconstruction and Multi -Hazard Vulnerability Analysis (MHVA)

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## ABSTRACT

The paper focuses on long-term evaluation of post-disaster reconstruction strategies and the impact of natural hazards on urban transformation. After a destructive event, reconstruction presents an inevitable necessity, intending to design a process that readjusts the urban system by improving its capacities to sustain itself against predictable risks. Experiences from historical and recent reconstruction processes indicate a lack of interdisciplinary cooperation and integrated approaches that take into consideration the socio-spatial interrelations. In order to adjust the urban structure against multiple and repeating hazards being, these approaches need to be based on the evaluation of post-disaster reconstruction and design a long-term development process.

Exemplarily, results of a case study in Southern Europe (Aigio, Greece) are presented. Based on a systematic building stock survey, the effects of the destructive 1995 earthquake on the urban development of Aigio are taken as initial model study. Three building surveys were conducted at different times and with sufficiently large distance between them; the first after the earthquake (1995) including results of detailed damage surveys, the second in 2005 (ten years after the earthquake to consider the reconstruction process) and the recent evaluation. By considering the changes of pre- vs. post-event vulnerability as well as 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 in form of the proposed Delta (Δ)-consideration including the Vulnerability Classes of the building stock according to the European Macroseismic Scale 1998 (EMS-98). Measures of reconstruction are studied in systematic way considering different impact levels reaching form demolition to the replacement by other structural types. A complementary Urban Resilience perspective is presented which integrates the interrelation of social processes and built environment into the engineering approach.

Keywords: Multi-hazard vulnerability analysis, Post-disaster reconstruction, Urban resilience, Societal impacts, Seismic rehabilitation

## 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. 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 and derive 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.

## DATA AND TOOLS FOR EVALUATING POST-DISASTER RECONSTRUCTION

### 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 the 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

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 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 (meso level: urban design) to a detailed level (micro level, single building) 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 categorised (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 scale 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 on a single buildings scale within a 20years' time frame for the case study of Aigio.

### Multi-hazard Assessment

The urban development of the target city Aigio is carved by the impact of different natural hazards. Based on data from real events, historical observations and current research results Figure 1 provides a multi-hazard mapping for earthquake, tsunami, wildfire and flood exposure that is overlaid to define multi-risk areas that should be considered in territorial and urban planning. The exposure of urban development and critical infrastructures can thus be determined.

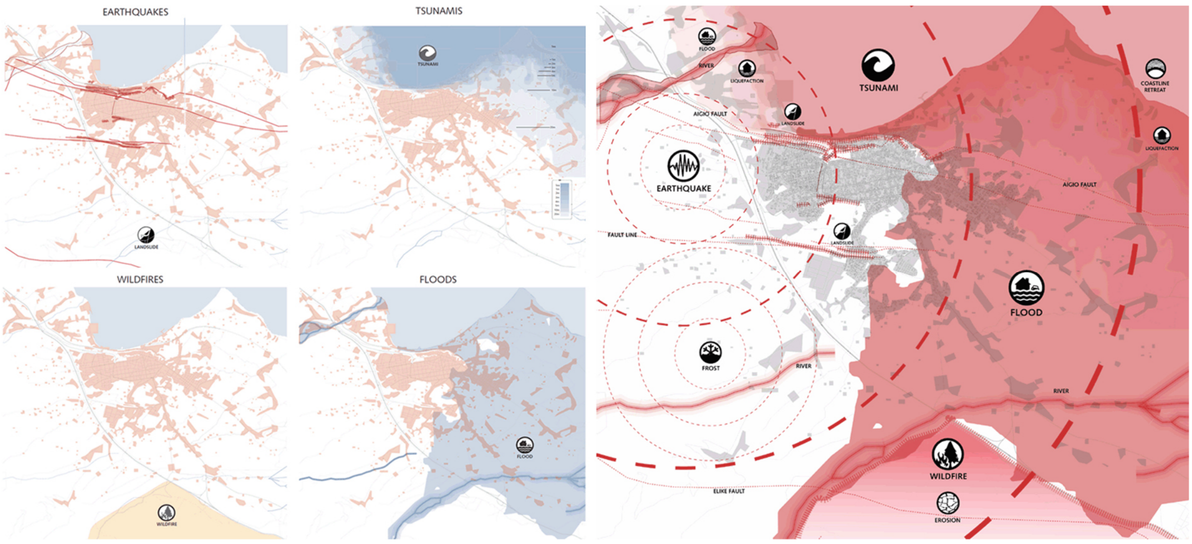


*Figure 1. Hazard exposure of Aigio (earthquake, tsunami, wildfire, floods and multi-hazard mapping)*

**Macro Scale: Urban development**

Aigio (Αίγιο) is a medium-size Greek city, located on the North Peloponnese, in the Region of Achaea, Western Greece. Its population of 26.000 inhabitants has shrunken around 10% continuously within the last 20 years. Within its 3000 years of retraceable urban development the city passed from ancient prestige and flourishing trade towards deindustrialization and stagnation in the middle 20$^{th}$ century. This process was portentously accompanied by the presence of multiples hazards that carved its development patterns. The cities' pure persistence displays the long-term resilience, which is not at least the result of thoughtful choice of location in a multi-hazard prone area, earthquakes and tsunamis being the most impactful hazards (destructive historic events in: 23, 1748, 1817, 1861 and 1888). Figure 2 reconstructs the urban morphogenesis on a macro scale by composing historic town plans, cadastral plans, satellite imagery and digital data. Growing from an ancient nucleus, Aigio always had a strong relation to its fertile hinterland. The mapping displays that this relation became increasingly overlaid by suburbanisation. Evidently 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 based on Le Corbusier's idea of the 'Dom-ino House').

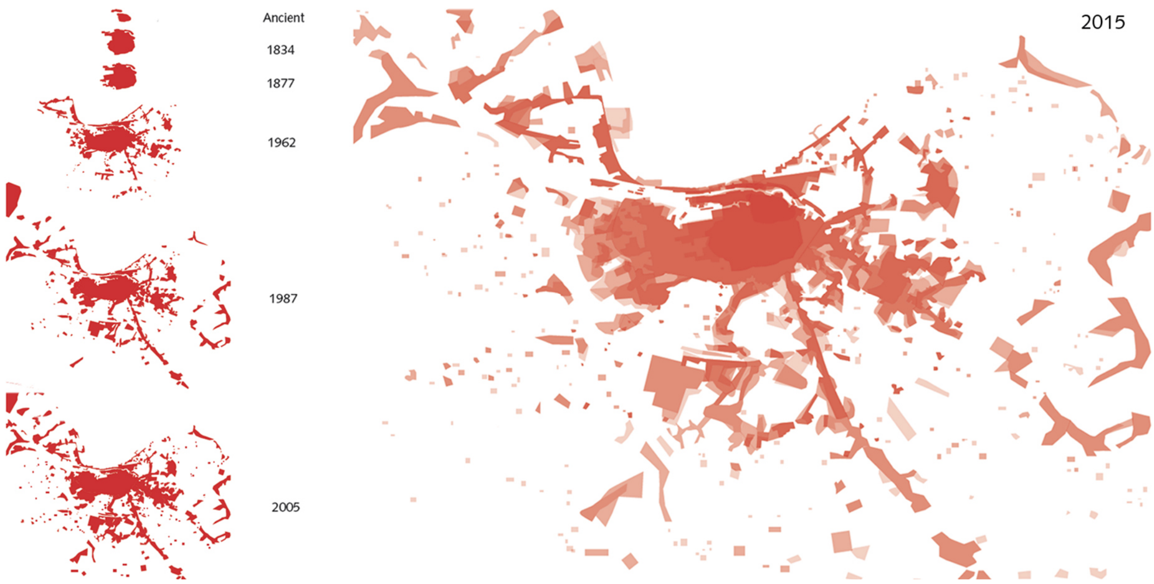


*Figure 2. Urban development from ancient to present times (the darker the older)*

At the same time, widely unregulated suburbanisation (peripheral urbanisation) increased. Recent expansion reveals the growth trend into multi-hazard prone areas. Renewal to the inner city bases on the replacement of traditional building typologies and construction types (adobe, masonry) by Polykatoikias using the system of 'antiparochi' (plot-for-flat exchange between owner and contractor). At the fringe the city grew unregulated and is retroactively formalized and incrementally integrated through amendments to urban plans [5]. This complex urban development system distributes the rise of land value partially towards the owners and results in more equitable distributed and decreasing vulnerability due to the extensive renewal of the existing building stock based on a single building typology (including modern seismic codes etc.), however at the expense of the replaced built heritage. Furthermore, this equitable distribution of structural vulnerability is counteracted by the development into (multi-)hazard prone areas. Rather than proactively preventing these risks or mitigating them by planning interventions, deficiencies remained and urban transformation results in new risks.

## Meso Scale: Urban design and building typologies

The scale of urban structure serves as an intermediate level, which refines the spatial components of the general urban development (urban layout, land use etc.) and regards the interaction of the single buildings (urban block) as well as typological similarities for taxonomic classification (building typologies). This level of generalization and possible detail-consideration encompasses a variety of influencing factors that enables to merge the approaches of engineering and urban planning on an applicable level of mutual interest, while giving expression to the socio-spatial continuum of built environment and social processes. Based on the photo documentation of every single building the building stock can be categorized based on its typological similarities into building typologies (see Figure 3. 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 defined by the 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 overall categories. Building typologies act as a meta level, applicable for urban planning as well as earthquake engineering approaches.

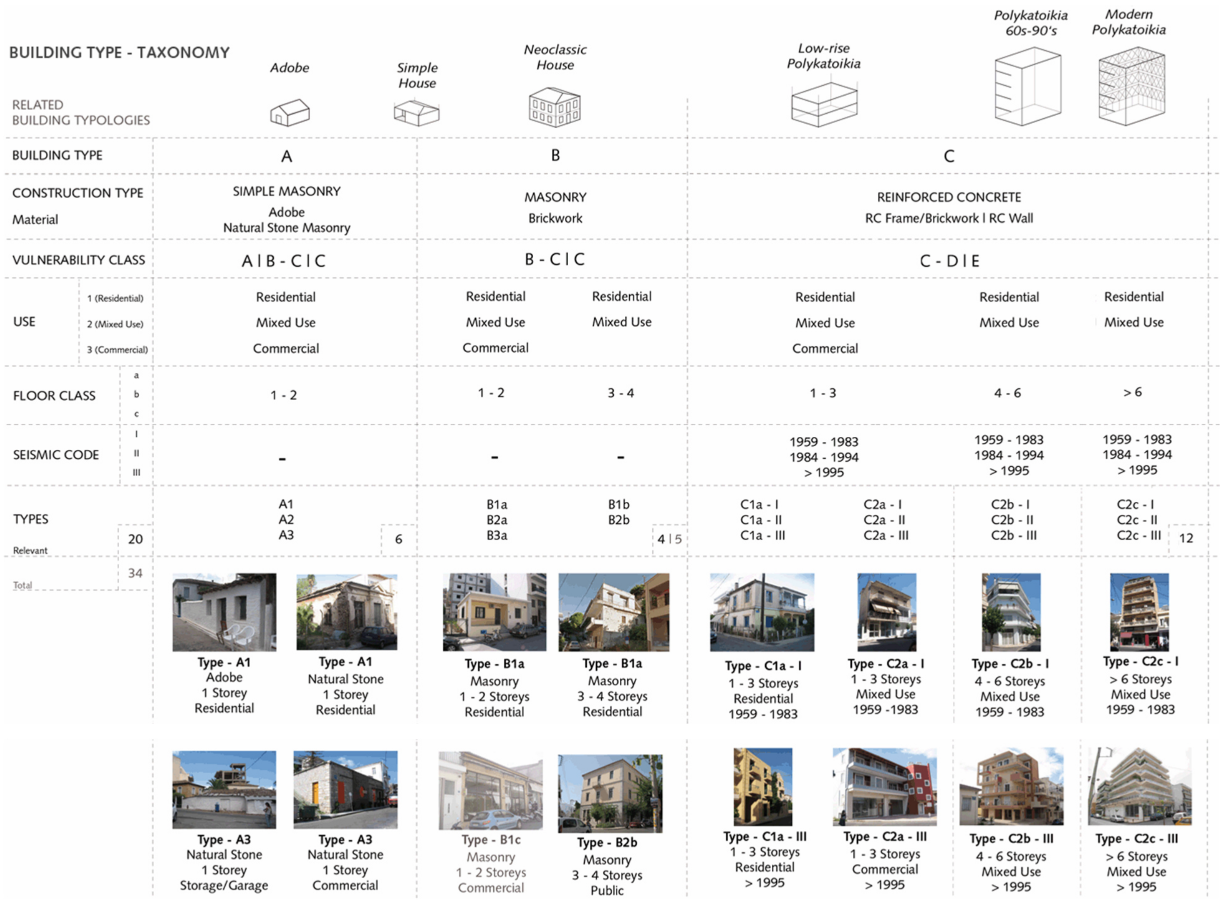


*Figure 3. Building Type taxonomy*

### Micro Scale: Single building

Figure 3. 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 of Aigio, Greece. The preliminary assessed building typologies (see Figure 3, top line) can be related, giving evidence for applicability for both, engineering and urban planning perspective.

## EVALUATION THE POST-DISASTER RECONSTRUCTION PROCESS

### Datasets and Delta-consideration

Basic methodological feature is the systematic Δ-Consideration that provides data on a single buildings scale within a 20 years' time frame. Figure 4 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 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).

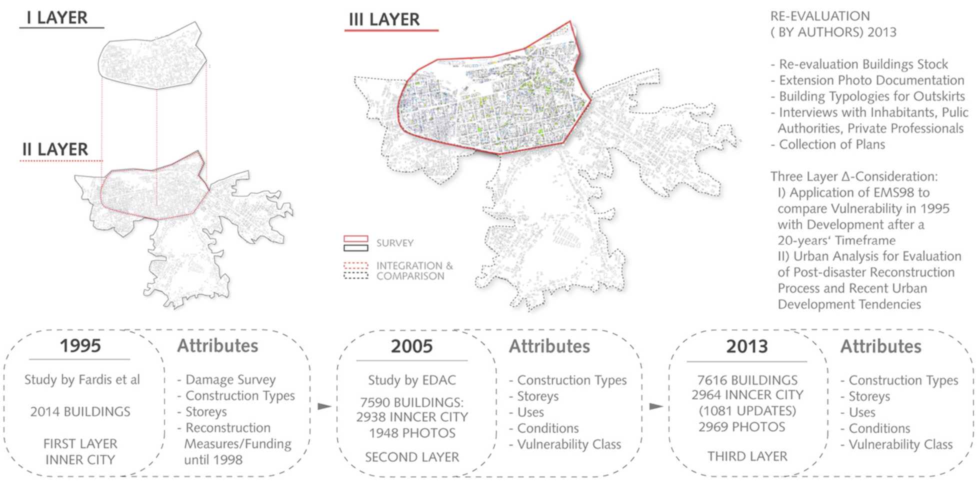


*Figure 4. Δ-Consideration and building stock surveys 1995 | 2005 | 2013*

### Damage caused by the 1995 and actual building conditions

In the night of June 15, 1995 an earthquake of appalling severity shook the City of Aigio (M=6.5, 26km depth, 18km northwest of the City Centre, horizontal Peak Ground Acceleration 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 about US$ 660 Mio, while actual reconstruction funding was approx. US$ 200 Mio. Impact severity was considerably high all over the urban centre of Aigio, in particular around the fault line that runs through the city. within the region 1887 buildings were destroyed or damaged beyond repair. Special interest and intensive research about this earthquake aroused as the Greek seismic codes from 1984 (replacing those of 1959) underwent the first heavy reality test. Two consecutive damage surveys were conducted (1995: 3346 buildings; 24% unusable, 24% temporary unusable, 52% usable; 1996: 8155 buildings, 25% very structural damage – collapse, 28% moderate to serious structural damage, 47% undamaged or slight non-structural damage).

Initiating the before-after comparison appears most logical by contrasting the occurred damage in the inner city of Aigio with the surveyed data of the actual building stock conditions in 2013 as shown in Figure 5. During the 1995 earthquake all damage grades occurred to all building types (adobe, masonry, RC). The building stock remained in generally good conditions (1995: 67% | 2013: 79%), while the need for repair or renovation remain constant (1995: 24% | 2013: 24%) and the level of critical building conditions improved (1995: 9% | 2013: 4%). This is expressed in the changes of vulnerability as well.

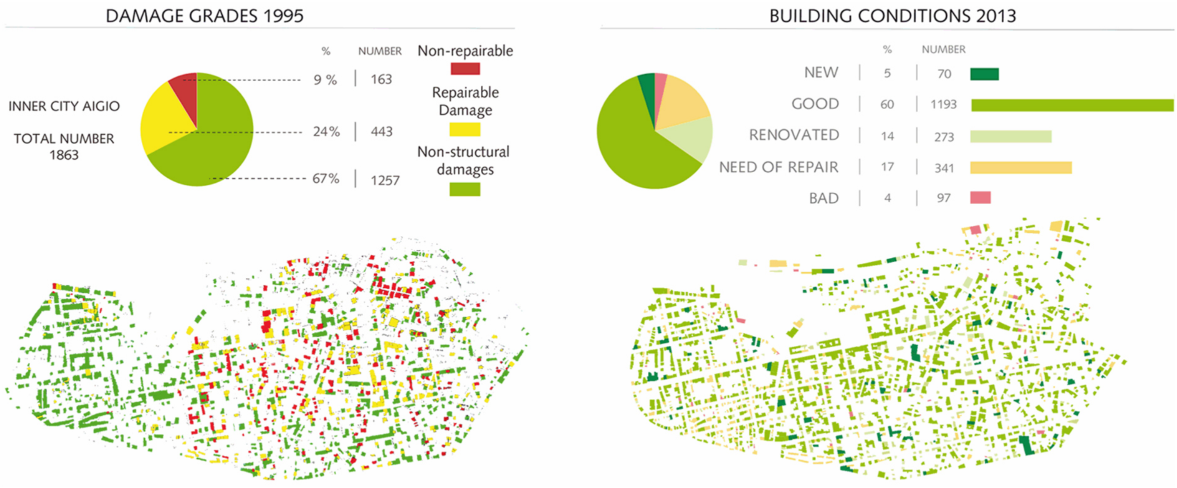


*Figure 5. Observed damage grades 1995 [7, 8] and building conditions 2013*

Based on the available data [9] the reconstruction funding is analysed in order to determine the possible measures of reconstruction (see Figure 6). The funding distinguishes between buildings with 'non-repairable' or 'repairable' damage. Accordingly, the supposed types of funded reconstruction are either 'replacement' or 'restoration'. These 'tagging' and damage surveys predetermined the beneficiaries and excluded applicants for reconstruction funding (seismic loans). In total 5460 beneficiaries were funded: 2957 with non-repairable, 2503 with repairable damages. Today, however, there is uncertainty about the state or repair or replacement for 2614 buildings in the region as 32% of the applicants were not approved, thus excluded from 'seismic loans'. Certain paradoxes of the reconstruction can be highlighted:

- Temporary housing lasted for 20 years and became permanent (lack of long-term commitment): After 20 years half of the supposedly temporary houses remained in permanent use (see Figure 6), displaying that earthquake resistance does not equal resilience and the deficiencies of the reconstruction process created new risks that determine the actual (pre-event) conditions and future impact severity (increased vulnerabilities and new inequalities).
- Buildings with 'repairable damage' were demolished (difference of actual damage and tagged damage).
- Buildings funded for reconstruction were left in ruins (difference of supposed measures and real action) or were rebuilt elsewhere (promoted suburbanisation often in multi-hazard prone areas).

**Types of urban change 1995-2002-2013**

Available data for the first reconstruction phase (1995 until the approval of the statutory town plan in 2002) is taken from an Urban Design Study for the inner city [10]. The type of reconstruction phase can be described as a state-subsidised, but market-driven process of susceptible quality that spares proactive planning interventions. Delays in the approval of the Town Plan (seven years) and the renewal of the General Development Plan allowed individual rebuilding to determine urban transformation. As displayed in Figure 7 reconstruction began first hastily, using the absence of adapted building restrictions, followed by a phase of deceleration. Within this period a massive 'post-disaster destruction' occurred: while only 163 suffered non-repairable damage, 798 buildings (41% of the inner city building stock) were either replaced (42%), demolished without replacement (35%) or remained in ruins (23%).

Two decades after the event, building activities are still related to the earthquake impacts, indicating the decelerated, but evident continuation of the reconstruction process. The measures observed during the first phase can be retraced for the period 2005-2013 Δ-Consideration (see Figure 7): 46% replacement of traditional structures, 38% demolition and 16% of the voids that remained after the demolition of the first phase were now rebuilt by Polykatoikias.

Understanding the actual significance of these observations and the transformation of urban development requires analysing the occurred changes in-depth on a single building scale. In this second phase a continuation of the reconstruction process defined urban development. New tendencies permeated the gaps left by the disaster (e.g. large scale structures), while general development trends proceeded to gain ground (e.g. replacement of traditional buildings). 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 change.

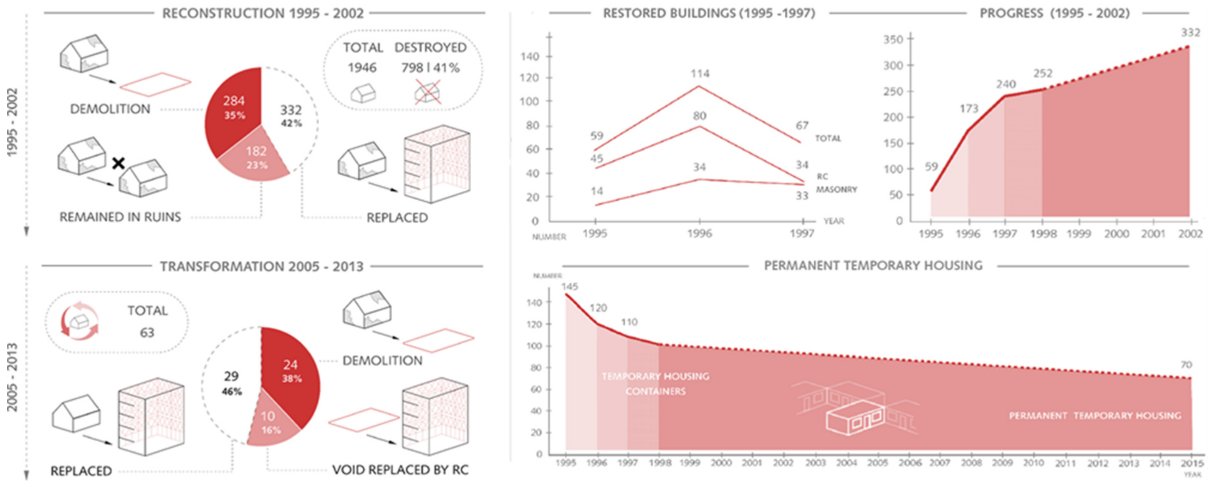


*Figure 6. Reconstruction 1995-2002 and urban transformation 2005-2013*

The following types of change have been introduced for a detailed evaluation (see Figure 7):

*Persistence* (What is still there and persisted?): Out of the 74 classified Heritage Buildings many could have been renewed, with great efforts and very good results, however, deterioration continues, displaying the need for an urban renewal program.

*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 Polykatoikias, mostly from 2-3 or 3-4 storeys, thus partly counteracting the buildings restrictions of the town plan; “Renovation/ Restoration“ (31%): 3% of the building stock, mostly low-rise residential buildings of all construction types, indicating the evidence of maintenance backlog, but also the slow image rehabilitation of traditional building 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, often violating building restrictions based on plot-merging in order to construct high-rise or large scale structures.

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.

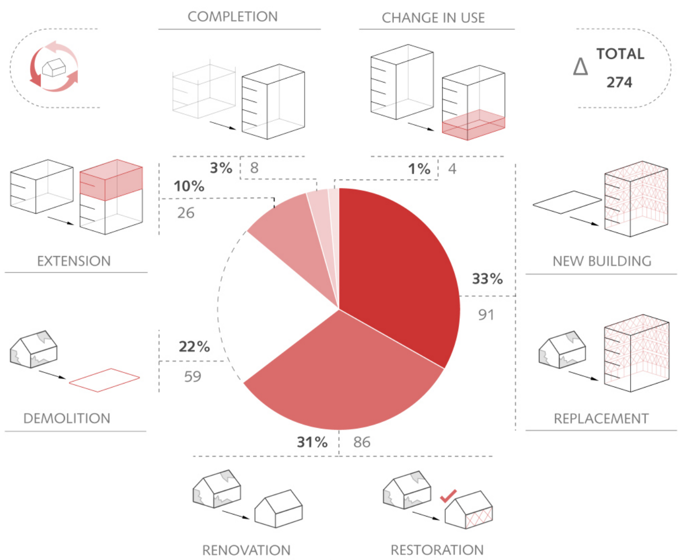


*Figure 7. Types of change (2005-2013): Persistence | Adaptation | Transformation*

## EVALUATION OF URBAN PLANNING APPROACHES

The former equilibrium of building types became unbalanced as traditional masonry structures decreased by 15% (1995: 42,9% | 2013: 28,2%) being replaced by Polykatoikias (1995: 57,1% | 2013: 71,8%). The cityscape transformed, even though the urban layout remained. New construction types were introduced (RC wall replacing RC frame with masonry infill), the amount of high-rise buildings that violate the buildings restrictions of the town plan increased, formerly unknown large scale structures permeated the voids in the urban layout, changing the urban morphology and affecting the small scale business structure. Real transformation as revealed by the re-evaluation indicate the actual increase of building heights. Comparing the statutory Town Plan of 2002 (enacted seven years after the earthquake) that is based on micro-seismic zonation with the actual development displays that around 200 buildings do not comply with the regulation, indicating that engineering efforts remained deficient as urban planning instruments were enforced delayed and being violated on a regular basis. For effective implementation earthquake resistance must be embedded into a complementary urban resilience perspective that follows an integrated approach, which mainstreams disaster risk reduction into sustainable post-disaster development.

## CONCLUSIONS AND TRANSFERABILITY

This study presents a methodological framework for the systematic long-term evaluation of post-disaster reconstruction processes that was designed to be transferable and applicable to other contexts, using the case study of Aigio as a model area. Based on the results of the 20years' Δ-Consideration the impacts of natural hazard on urban transformations can be systematically analysed. It can be concluded that there is a continuation of the post-disaster reconstruction process, which led to a massive modernisation of the traditional building stock including an observable acceleration of general development trends and the rise of new tendencies. Vulnerability to earthquake hazard decreased, even though the engineering approach remained party ineffective due to the inconsistent integration of urban planning. This conceptual vulnerability of the reconstruction process created new risks that redefined the resilience capacities, thus the conditions for future hazard impacts.

Ongoing studies refer to the cities alongside the Chilean Pacific coastline and the damage after the February 27, 2010 Maule earthquake and the subsequently induced tsunami impacts. Surveys are performed by the Earthquake Damage Analysis Center immediately after these events and repeated in 2013 and 2016. Additionally, available areal images are applied to map and evaluate the phases and types of reconstruction [11]. Recently, similar studies have been initiated for the Palu region (Indonesia) considering the September 28, 2018 earthquake and subsequent tsunami impact.

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