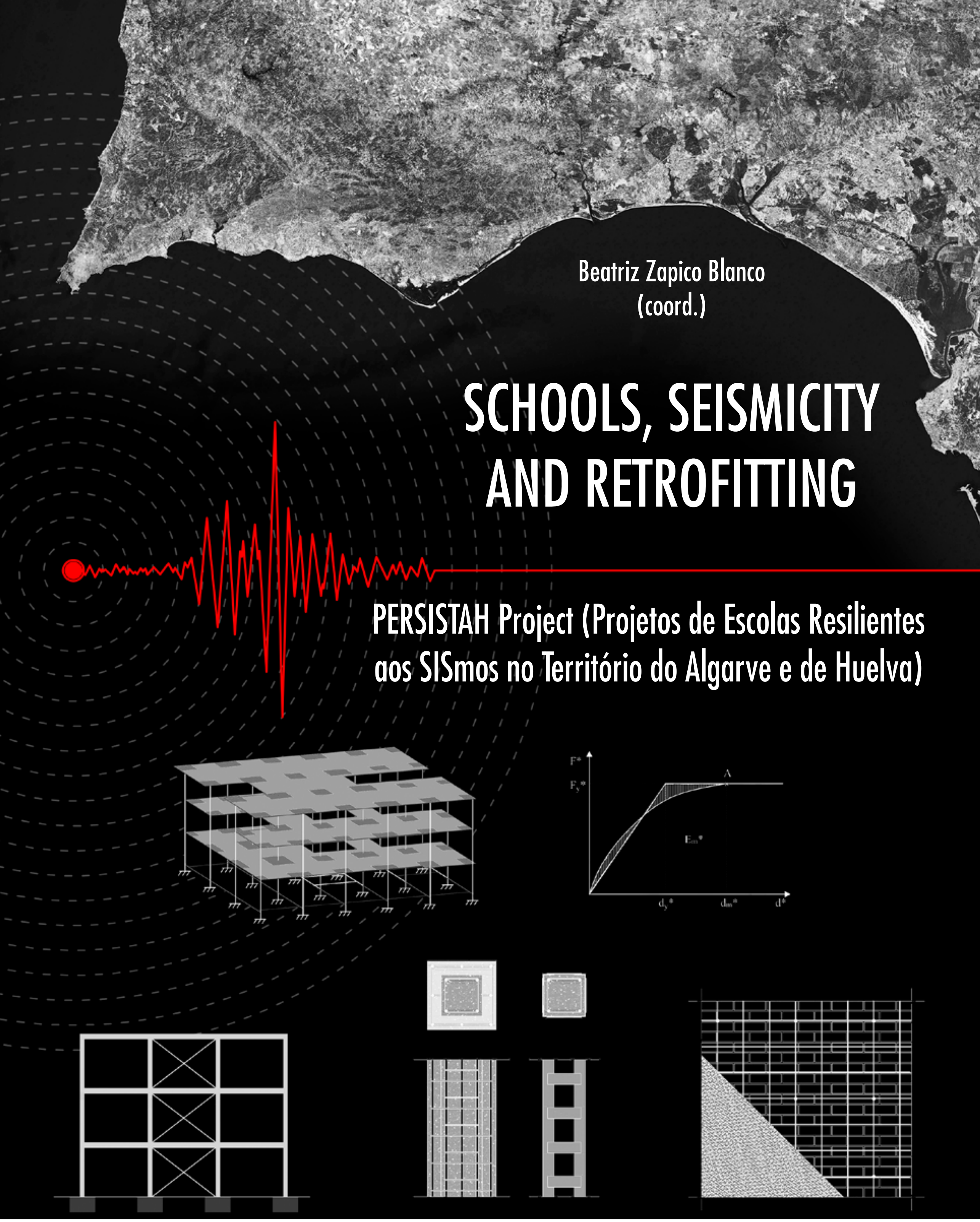

Beatriz Zapico Blanco
(coord.)

SCHOOLS, SEISMICITY AND RETROFITTING

PERSISTAH Project (Projetos de Escolas Resilientes aos SISmos no Território do Algarve e de Huelva)

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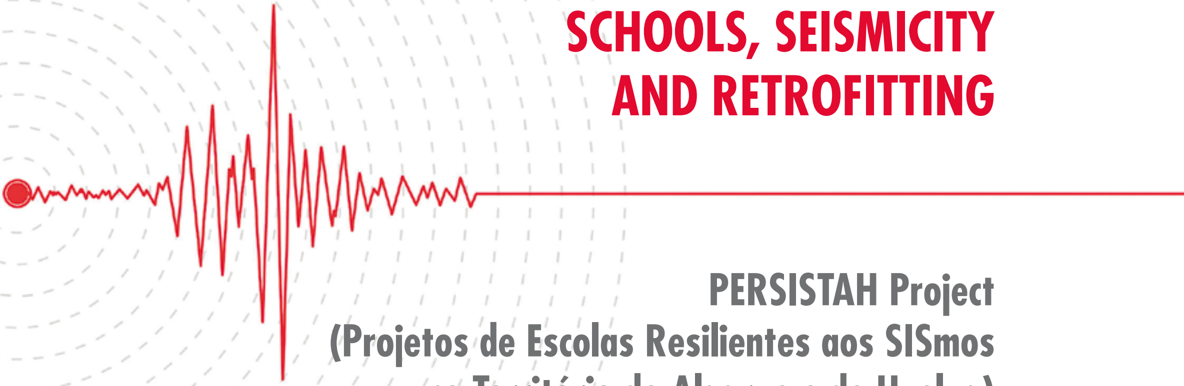

PERSISTAH Project
(Projetos de Escolas Resilientes aos SISmos no Território do Algarve e de Huelva)

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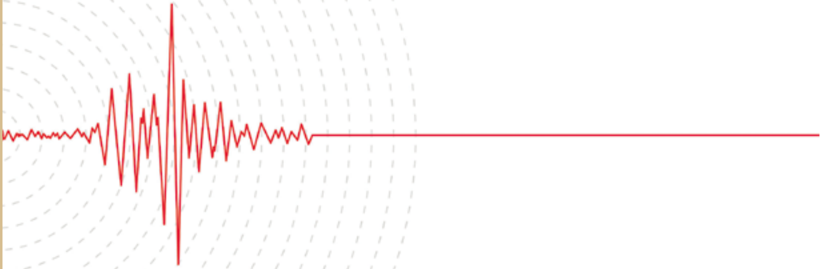

Symbols

A	Thermal expansion Coefficient
A_I	Architectural impact
a_b	Base ground acceleration
a_{gR}	Reference peak acceleration
a_g	Ground acceleration for a type A soil
a_r	Reference PGA ($T_R = 475$).
C	Soil factor
C_I	Cost index
d	MDOF system equivalent displacement
d*	SDOF system equivalent displacement
d_{Di}	Average displacement associated to a damage limit state
$d_{et}*$	SDOF elastic displacement
d^*_m	Displacement at plastic hinge formation
d_t	MDOF target inelastic displacement
d_t*	SDOF target inelastic displacement
$d*_{t,D}$	Displacement associated to a damage limit state
d_u*	SDOF ultimate deformation
d_y*	SDOF deformation at yield point
E	Modulus of elasticity (Young's modulus)
E_b	Brick modulus of elasticity
E_m*	Plastic hinge formation energy
E_I	Efficiency index
F*	SDOF system equivalent force
f_b	Brick Compressive strength
f'_c	Concrete characteristic compressive strength
Fi	Set of MDOF applied forces
f_k	Masonry characteristic compressive strength
f_m	Mortar strength
F_y	Yield strength
F_u	Ultimate strength
F_y*	SDOF Yield strength

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G	Shear modulus
K	Contribution factor
K_f	Constant depending on the brick and mortar combination (EC-6)
k_m^*	Bilinear curve stiffness factor
κ_ξ	Damping modification factor
m^*	SDOF equivalent mass
m_i	MDOF standardised masses of each floor
M_w	Seismic moment magnitude
N	MDOF node of freedom
q	Behaviour factor, considering structural system and ductility
q_c	Point resistance of the static penetrometer
q_u	Unconfined compressive strength
R_I	Reinforcement index
S	Soil amplification factor
$S_e(T)$	Elastic response spectrum
T	Vibration period of a linear SDOF system
T^*	SDOF equivalent system period
T_A, T_B	Characteristic parameters of the response spectrum (NCSE02)
T_B	Lower limit of the period of the constant spectral acceleration branch (EC8-1)
T_C	Upper limit of the period of the constant spectral acceleration branch (EC8-1)
T_D	Value defining the beginning of the constant displacement response range of the spectrum (EC8-1)
T_r	Return period
t_0	Shear resistance
U	Poisson Coefficient
V	MDOF system base shear
v_s	Transverse elastic waves or shear waves propagation speed
v_l	Longitudinal elastic waves propagation speed
W	Density
α_1, α_2 y α_3	Reinforcement index importance factors.¡
$\alpha(T)$	Value of the normalised elastic response spectrum
β_{Di}	Standard deviation of the displacement logarithm d_{Di}
Γ	MDOF-SDOF transformation factor
η	Damping correction factor with reference value
λ	MDOF Lateral load parameter
μ	Ductility coefficient
ξ_i	Equivalent damping
ρ	Dimensionless risk factor
Φ	Cumulative distribution function for the normal distribution
ϕ_i	MDOF Displacement at each floor
$\%S_e$	Spectral acceleration percentage

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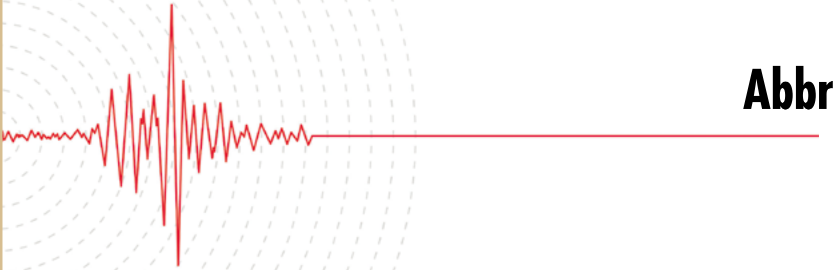

Abbreviations

CFRP	Carbon fibre reinforced polymer
DL	Damage limitation damage state
EC8	Eurocode 8
EC6	Eurocode 6
EC8-1	Eurocode 8, part 1
EC8-3	Eurocode 8, part 3
EMS	European Macroseismic Scale
ERSTA	Algarve Seismic Risk and Tsunami Study *Estudio do Risco Sísmico e de Tsunamis do Algarve*
FRP	Fibre reinforced polymers
IGN	Spanish National Geographic Institute
IGM	Geological and Mining Institute of Spain
LNEG	Portugal's National Laboratory of Energy and Geology
MDOF	Multi-degree of freedom system
NC	Near collapse damage state
NCSE02	Normativa de Construcción Sismorresistente Española de 2002
OP	Operacional damage limit state
PERSISTAH	Projetos de Escolas Resilientes aos SISmos no Território do Algarve e de Huelva
PNRRC	Plataformas Nacionales para la Reducción de Riesgo de Catástrofes
PGA	Peak ground acceleration
PSHA	Probabilistic seismic hazard analysis
RC	Reinforced concrete
RSAEEP	Reglamento de Segurança e Acçoes para Estructuras de Edificios e Pontes
SD	Significant damage limit state
SIRCO	Seismic Risk Simulator *Simulador de Risco sísmiCO*
SDOF	Single-degree of freedom system

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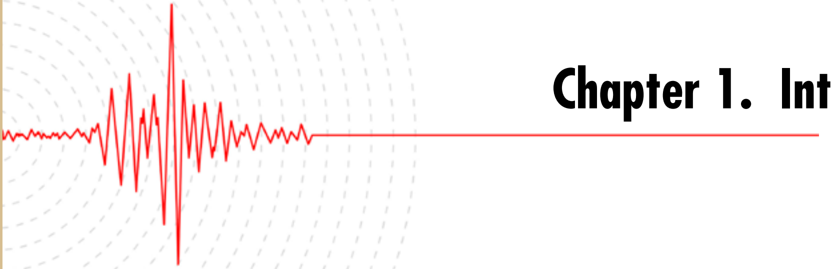

Chapter 1. Introduction

This document presents the work carried out within the European research project PERSISTAH (*Projetos de Escolas Resilientes aos SISmos no Território do Algarve e de Huelva*, in Portuguese), which has been developed jointly by the University of Seville (Spain) and the University of Algarve (Portugal). This research project focuses on the study and assessment of the seismic risk of primary school buildings in the Algarve (Portugal) and Huelva (Spain) regions. To this end, the objectives established by the National Platforms for Disaster Risk Reduction (PNRRC) of the National Civil Protection Commissions of Portugal and Spain have been considered.

Earthquakes are among the natural disasters that cause the greatest number of casualties and economic losses worldwide. Numerous studies establish the importance of studying the seismic risk of buildings in order to estimate and evaluate the possible damage that can be caused by a seismic action, with the aim of minimising human losses and impacts on material and economic assets. The destructive potential of an earthquake depends on its magnitude, but also on the seismic resilience of the affected area.

In Europe, Earthquakes have historically caused significant damage and loss of life. The earthquakes that occurred in this continent at the beginning of the 20th century cost around 29 billion euros and caused 19 000 casualties (Battarra *et al.*, 2018).

The Iberian Peninsula has moderate seismic activity (Morales-Esteban *et al.*, 2014). However, most activity is concentrated in the south, which is characterised by large earthquakes ($Mw \geq 6$), with long return periods (Morales-Esteban *et al.*, 2014), making the population unaware of the danger. This activity is due to the convergence between the Eurasian and African tectonic plates and the proximity of the Azores-Gibraltar fault (Morales-Esteban *et al.*, 2014). The Algarve-Huelva region is located in the south-west of the Iberian Peninsula. This area is close to the Marques de Pombal, Saint Vicente and Horseshoe faults, which have caused some of the most significant earthquakes that have affected the Iberian Peninsula, such as the 1755 Lisbon earthquake-tsunami

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(Mw = 8.7 – 9.0) and the 1969 earthquake (Mw = 8). The first is also the largest documented seismic event to have affected Europe, killing 100 000 people. The maximum seismic intensity of this region, based on past earthquakes, is high in the Algarve (IX-X) and Huelva (VII-VIII) (Teves-Costa *et al.*, 2019). Although there is significant seismic risk, few seismic studies of the area have been carried out, as most seismic studies of the Iberian Peninsula focus on the east and south-east.

The seismic vulnerability of the region's buildings was evaluated using estimation methods such as SIRCO (Seismic Risk Simulator) (Fazendeiro Sá *et al.*, 2016) or ERSTA (Algarve Seismic Risk and Tsunami Study) (Autoridade Nacional de Protecção Civi [ANPC], 2010). They conclude that it is possible to reduce seismic risk by improving prevention and emergency plans. In this sense, rigorous vulnerability analyses of existing buildings and the implementation of appropriate retrofitting solutions can contribute to the reduction of the levels of physical damage, human losses and the economic impact of future seismic events.

The seismic behaviour of buildings plays a key role in the destructive potential of an earthquake. The vulnerability of existing buildings has been the focus of European interest in recent years. This is due to the damage caused by recent earthquakes, such as the L'Aquila earthquake in 2019 (Italy), the Lorca earthquake in 2011 (Spain) and the Amatrice earthquake in 2016 (Italy) (Ruiz-Pinilla *et al.*, 2016; Del Gaudio *et al.*, 2017; Fiorentino *et al.*, 2018). A large part of the buildings of these cities were severely damaged during these earthquakes. Therefore, enhancing the seismic performance of buildings has become a major concern (Mazzoni *et al.*, 2018) , which can be achieved through the implementation of seismic retrofitting techniques.

The school buildings in the PERSISTAH project have been chosen as the object of study because of their relevance in case of an earthquake. On the one hand, their community present a high vulnerability, due to their low adult/child ratio and high occupation, making the evacuation of the building during an emergency complicated. Moreover, in the event of an earthquake, not only physical damage and injuries are expected: children would also be emotionally affected in a significant way. In this regard, several studies have shown that serious psychological problems can arise on children who have suffered the effects of an earthquake and the benefits of preparedness (UNICEF, 2011). On the other hand, school building structures also present high seismic vulnerability. Their typically simple and repetitive layouts were designed and calculated based on old regulations that did not take into account the seismic action. Approximately 50% of the buildings were designed with reinforced concrete and have two or three floors, and they have seismically weak elements such as short columns. This type of buildings were significantly damaged during the 2011 Lorca

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earthquake (Ruiz-Pinilla *et al.*, 2016). Furthermore, the area is characterised by the presence of superficail soft soil layers, which can amplify the effects of earthquakes.

In addition to this, due to their public nature, schools can also be used as shelters after a disaster. All this makes it essential to assess and guarantee their structural stability in the event of an earthquake.

It is important to note that in the event of an earthquake, both regions (Algarve and Huelva) would be equally affected. One of the objectives of the project is to improve the knowledge related to the current situation of each country, particularly on seismic standards and construction practices. In this sense, the seismic regulations, construction techniques, civil protection policies and seismic risk reduction strategies of both countries have been compared. In addition, a database has been developed with information sheets from each primary school (142 in Algarve and 138 in Huelva), taking into account the specifications of each region.

The main types of primary schools have been identified in this project. Subsequently, an inventory of the constructive and structural characteristics of each building has been created. With this information, the vulnerability of each school has been analysed through a non-linear static (pushover) analysis for obtaining the capacity curve. Finally, the ranking of the seismic behaviour of each school has been made through the *School-Score* system (a system of prioritisation of the seismic risk of school buildings). Seismic behaviour has been evaluated according to the hazard, vulnerability and exposure of each building.

1.1. PROJECT OBJECTIVE AND JUSTIFICATION

The PERSISTAH project was conceived based on a number of key points regarding the seismic resilience of the Algarve and Huelva regions:

- A significant part of the known seismic sources around the Algarve and Huelva areas would have a transboundary impact.
- Knowledge of existing hazards and the seismic vulnerability of buildings is essential for effective emergency response.
- It is important to study the application of mitigation measures in schools in the face of a possible seismic event.
- The development of educational material and the communication of seismic risk to students and teachers would reduce the vulnerability of the community.
- Making recommendations for rehabilitation aimed at technicians involved in construction will have a positive effect on the risk reduction.

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- The creation of cooperative links in risk mitigation efforts between these two neighbouring regions will enhance the regions seismic resilience.

Based on these points, the main objective of the European project PERSISTAH is the assessment of the seismic vulnerability of primary schools in the Algarve (Portugal) and Huelva (Spain) regions cooperatively. To this end, the objectives established by the National Platforms for Disaster Risk Reduction (PNRRC) of the National Civil Protection Commissions of Portugal and Spain have been considered.

This objective can be subdivided into the following goals:

- the classification of the school buildings of the area,
- the assessment of their vulnerability,
- the definition of a vulnerability index that allows to compare them,
- the definition of rehabilitation measures for those buildings which may need them,
- the application of those measures to one Portuguese and one Spanish school pilot building,
- the creation of educational guides to create awareness of the seismic risks in the school community, and
- the dissemination of the project results, where the present document is to be found.

1.2. MAIN OUTCOMES OF THE PROJECT

The PERSISTAH research project was conceived for having an impact on the Portuguese and Spanish society. This impact is maximised by the singularities of the seismicity of this geographical area, the international cooperation for risk reduction, and the relevance of the buildings under study.

Accordingly, the PERSISTAH research project has contributed to shaping a society that is more resilient to earthquakes.

The first contribution is the analysis of the seismic vulnerability of school buildings, which are very vulnerable to earthquakes. They play a fundamental role in the lives of children, who are the most vulnerable people in this type of event. After a disaster, the children should feel safe when returning to school, which means a return to normality. Moreover, because of their design and their public nature, they can be adapted as shelters after a disaster.

The **analysis of the schools seismic vulnerability** has been carried out through an integrated assessment methodology. This methodology is based on

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a vulnerability analysis through the building capacity curve, used to obtain the structural performance point of the building. With this information, the damage probability of the school building is calculated.

This methodology has been implemented in a new software (Estêvão, 2019; Estêvão, 2020), where was implemented the adaptation of a set of computer programming routines previously developed in the applications *EC8spec* (Estêvão, 2016) and *SIMULSIS* (Estêvão and Oliveira, 2012). The purpose of this software is to obtain the *School-score*, which is based on the damage probability and other parameters, such as the vulnerability of non-structural elements, number of students, aspects affecting evacuation, etc. These are essential elements to take into account when studying the seismic vulnerability of a school building. Obtaining a high value for this parameter indicates that the school is more vulnerable to earthquakes. In this context, a new school database was created with the collaboration of all team members. A list with the classification of the schools has been drawn up based on their *School-score*, and it will be taken into consideration for future seismic retrofitting interventions in the buildings. Furthermore, a series of training activities for technicians on the aspects of the methodology applied and the particularities of the seismic retrofitting design have been carried out, in order to reduce the structural and non-structural risk of the buildings.

Another fundamental factor in this project is the significance of and need for **international cooperation** between countries when it comes to the reduction of seismic risk, since both regions, which present very similar geographical conditions, would be affected equally in the event of an earthquake.

Finally, another key point of the project is **the creation of seismic risk awareness among the educational community** and their training in this subject. Children are the future of our society and play a vital role in it. They learn at school, and bring their knowledge home to their families, which makes of the schools a powerful motor for change. A seismic event causes a great psychological impact on them, and therefore, education and communication of existing risks is essential. A series of trainings have been carried out through a number of activities and seminars in schools for both teachers and students. These dealt with issues related to identifying risks both inside and outside the school building. In addition, earthquake drills were carried out. This action is key to increasing awareness of seismic risk and learning how to act in the event of an earthquake. A number of pedagogical resources for teachers have also been developed. These materials include practical activities for children to learn about these subjects in a fun way, together with easy self-protection actions to be carried out before and after a seismic event[1].

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[1] *Why does the ground shake?* (https://dx.doi.org/10.12795/9788447230471).
Practical guide for Earthquake resilient schools (https://dx.doi.org/10.12795/9788447230532).

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1.3. DOCUMENT STRUCTURE

In the present document, the methodology and seismic regulations applied in the vulnerability analysis and subsequent seismic retrofitting of school buildings will be presented. This methodology responds to the objectives and main ideas of the project. Later on, the seismic hazard of the Algarve and Huelva area is discussed, as well as the seismic action used in each region for seismic analysis. In addition, the characterisation and typological classification of school buildings carried out for their subsequent seismic analysis is shown. Finally, several seismic retrofitting techniques proposed by the different regulations are outlined, as well as the different techniques studied in the project.

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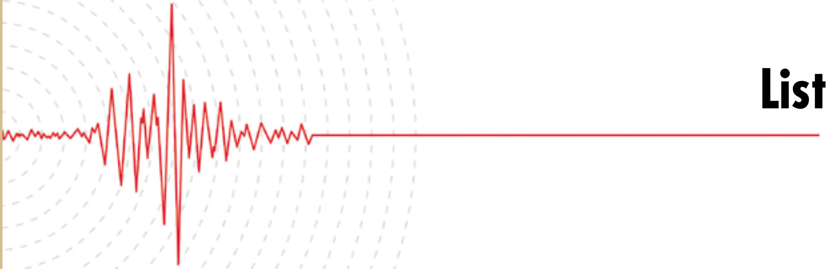

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The PERSISTAH project presents a series of essential aspects, which have supported its contribution in the formation of a more seismically resilient society. These aspects are: the singularities of the seismicity of this geographical area, the interest in the typology of school buildings and the analysis of their seismic vulnerability, the development of a seismic retrofitting methodology, which has been applied in two pilot schools of Huelva and the Algarve, the communication of seismic risk to the school community, and finally, the international cooperation for risk reduction.

In the present book, the methodology and seismic regulations applied in the vulnerability analysis and subsequent retrofitting of school buildings is presented. Then, the seismic hazard of the Algarve and Huelva area is explained, as well as the seismic action used in each region for seismic analysis based on the different seismic regulations. Later, the characterization and typological classification of school buildings carried out for subsequent seismic analysis are shown. Finally, several seismic reinforcement techniques proposed by the different regulations are outlined, in greater depth in the case of the solutions studied in the project.

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