

A Multidisciplinary Approach for Multi-risk Analysis and Monitoring of Influence of SODs and RODs on Historic Centres: The ResCUDE Project

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Abstract. The presented paper describes the ReSCUDE project, developed by the Department of Civil, Environmental, Land, Construction and Chemistry (DICATECh) of the Polytechnic University of Bari under the grant Attraction and International Mobility, of the Italian Ministry of Education, University and Research. The project focuses on the evaluation of the effects of Slow-Onset Disasters (SODs), and Rapid Onset Disasters (RODs) on historic town centres. To this end, an integrated approach based on innovative geomatics, building techniques and advanced behavioural models, is being applied to the old town built area of Ascoli Satriano (FG) and Molfetta (BA) in the Apulia Region (Italy). Over the next three years, the ResCUDE project will allow to perform in-depth analyses on the historic built environment of the identified case studies, fostering the processes of its knowledge, assessment, control, management and design, in connection to the risks deriving from ROD and SOD events. The expected outputs will be useful to define possible scenarios for civil defence purposes and undertake actions aimed at risk mitigation.

Keywords: Geomatics for risk management · Slow onset disaster · Rapid onset disaster · SOD · ROD · Multi-risk analysis · Retrofit building technologies · Agent-based simulation · Cultural heritage

1 Introduction

In recent decades, the increasing anthropization has considerably amplified the negative impact of critical events, both natural (earthquakes, landslide, subsidence) and/or triggered by anthropogenic causes (panic in crowded places, terrorist attacks) on the safety of the Built Environment (BE), consisting of a network of street, buildings, infrastructures, open spaces and its users.

Over the long-term period the BE is also influenced by very slow phenomena, such as the climate change, which have a direct impact on the climate of the cities, pollution and rainfall levels, energy consumption and aging of buildings. Such critical events,

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with reference to the disasters they can lead to and how fast they can occur, are usually referred to as Slow-Onset Disasters (SODs), and Rapid Onset Disasters (RODs), as defined by United Nation [1]. The BE (and its users) is increasingly subject to SODs and RODs, showing poor resilience as evidenced, for example, by the damages resulting from the seismic sequences that affected Central Italy in 2016–17, and the accident occurred in Turin during the 2017 UEFA Champions League Final broadcast, when about 1500 people were injured.

This is even more evident in highly valued historical-cultural contexts, such as historic centres, where the level of risk increases exponentially with the simultaneous growth of their value and vulnerability due to aging. Historic districts represent an exception in management, planning and transforming necessities. The socio-economic relevance in re-use of residential buildings stock, socio-cultural significance of historic formal and environmental values and the explication of interaction between the necessity to accommodate human needs - health, safety, self-sufficiency - and external territory conditions, constitute the basis of the cultural landscape values of historic districts [2].

According to the slow process of their generation, historic districts represent the result of a system of overlapped techniques and materials application along the time [3].

Urban morphology, spatial configuration, type, density and use, as well as the layout and the organization of the public spaces, contribute to make the access difficult to these areas characterized by multiple enclosures, narrow streets with their labyrinthine nature and a limited number of access routes, deriving from the defence strategies of ancient cities [4–6]. Moreover, old towns are affected by intense pedestrian and tourist flows [7], who may not be aware of their surroundings or how to reach a safe place, in case of evacuation [8]. This can lead to the adoption of risk-increasing behaviours by evacuees, thereby decreasing their safety. Historic building types and their constructive materials can amplify this effect, but at the same time their value needs to be preserved. As is not feasible to demolish buildings for creating new escape routes, thought must be given to innovative solutions compatible with the historic urban context [9].

These things considered, the BE is characterized by a high complexity level due to its interactions with natural components and human presence. The need of assessing and increasing the resilience of the BE and monitoring the effects of SOD and ROD over time clearly emerges. Survey and monitoring geomatics techniques can play an important role, in the frame of an integrated methodology that must necessarily include the knowledge of building performance and their opportunity in transformation for their improvement, and the modelling of human spatial and social behaviour response during emergencies.

The project AIM1871082-1, Cultural Heritage Research Line, developed by the Department of Civil, Environmental, Land, Construction and Chemistry (DICATECh), Politecnico di Bari under the call Attraction and International Mobility, of the Italian Ministry of Education, University and Research (MIUR), hereafter named ResCUDE (RESilient Cultural Urban context to Disaster Exposure), is aimed at analysing and facing these critical issues by mean of a holistic approach, that encompass the joint use

of geomatics and resilient urban methodologies, land-use and managing techniques and an agent-based approach.

The project, whose description and its progress are hereafter presented, will develop over three years (from October 2019 to October 2022) and will be jointly developed by the Geomatics, Building Technologies and Urban Planning Groups.

2 The ResCUDE Project

The ResCUDE project aims at addressing the needs for a better understanding of the effects of SOD and ROD on historic town centres. To this end, a multi-risk analysis is being applied to the historical BE, in order to the define its vulnerability and exposure to critical events (and the related damage), evaluate its levels of resilience and outline targeted mitigation actions.

SODs and RODs have been usually analysed extensively in a separate way. At present, it is still necessary to deepen:

- the mechanisms of potential interaction between RODs and SODs and the increase in magnitude of the latter;
- interaction of people with the RODs;
- the intrinsic resilience of the man-made environment towards the RODs;
- the mitigation potential of the man-made environment against the negative effects caused by SODs.

Current poor BE resilience usually depends on the fact that:

– risk mitigation/prevention strategies for RODs exclude the open spaces and human/user reactions, focusing just on the building;
– interactions between buildings and surrounding areas for risk reduction seem to be ignored, although they could lead to unpredictable critical safety conditions for open urban areas (i.e. uncontrolled car parking or inaccessible streets may make inaccessible the nearby open areas);
– risk increasing conditions such as crowding, and users' types are often ignored;
– causes and effects of ROD/SODs combination are usually neglected.

Moreover, for SODs with a variable intensity over time (i.e. air pollution), risk reduction strategies marginally consider the potential of BE as a resilience-increasing element (i.e. typical strategies adopted to limit pollution are: vehicle stops, restriction of cars circulation, reduction of heating hours).

The project wants to fill the previous gaps by fostering the integration between processes of knowledge, assessment, improvement and monitoring of BE in case of risks related to ROD/SOD. In this frame, geomatics data is being collected and/or generated on purpose, with the double aim of:

1. building a comprehensive 3D database of the BE, focusing on the historical centres, the acquired dataset will enable the opportunity of applying innovative approaches for:

- Defining the performances of building aggregates to SOD, by collecting morpho-typological characters and technological features of buildings in historic districts from urban plans, usually expressed by classes of categories (e.g. building typologies, number of floors, constructive techniques, levels of conservations). These features constitute a Geographic Information System, used for the creation of main cataloguing maps in compounding the "Historic District Plan", and define a comprehensive model for assessing the potential level of resilience in response to climate change.
- Adopting human response analyses in disasters by outlining spatial cognition and social behaviour in situations of panic and simulating evacuation and interventions in case of ROD. This methodology is based on the analysis of the behaviours in outdoor scenarios, as well as the influence on human choices of gender, age, health and other features, and focus on properties of the environment as activated, perceived and cognized by humans and on critical situations produced and driven by behavioural relationships between agents and with places, both of which tend to overlap in emergency situations [10].

2. monitoring the structures over time, in order to identify potentially critical phenomena, as subsidence or landslides when present, and control they evolution and influence on the BE.

The project is organized in three work packages, better described in the following paragraphs.

2.1 WP1 - Definition of an Integrated Geomatics Monitoring System for the Definition of the Influence of SOD on ROD in Historical Centres

The activities foreseen in WP1, coordinated by the Geomatics Group, are aimed at the extraction of multi-sensor and multi-scale 3D models, both through photogrammetric techniques and Synthetic Aperture Radar Interferometry (InSAR).

WP1 will be developed as follow:

– Analysis of multi-sensor geo-spatial data for the extraction of high-precision Digital Surface Model (DSM) that will constitute the database on which three-dimensional simulations will run at predetermined time intervals. DSMs will be also deployed for delimiting areas subject to SOD and ROD in historical centres.
– Exploitation of long-term Differential Interferometry Synthetic Aperture Radar (DInSAR) time series and other ancillary information (where available), as the geological setting of the investigated areas, to highlight subsidence and/or landslide phenomena [11].
– Development of algorithms for the processing of data acquired from satellite sensors operating in the thermal band, and hyperspectral data from airborne sensors and/or Unmanned Aerial Vehicle (UAV) systems. This will allow the production of Land Surface Temperature (LST) maps to support analyses on surface urban heat islands.

- Generation of 3D models at urban scale, which can be integrated with LST data, in order to better understand the intervention areas and supporting the mitigation actions of the effects of the investigated phenomena.
- Implementation of a prototype WebGIS portal capable of providing detailed three-dimensional information aimed at identifying the portion(s) of the building needing modifications/restoration and improve its performance.

2.2 WP2 - Analysis of Resilience and Potential Mitigation in Buildings and Systems of Them

WP2 is coordinated by Building Technology Group. The activities focus on the relations between buildings in historic districts and the boundary environment in a long-term perspective in order to:

- Define a comprehensive model aimed at the assessment of potential level of resilience in historic districts exposed to climate change (SOD). The knowledge of the historic building stock, as a combination of morpho-typological characters and technological solutions, represents the starting point of the analysis [12].
- Analyse and model technologies and materials for the mitigation of negative effects of SODs [13], mainly related to the human wellbeing and the reduction of energy consumptions, solving the aesthetic normative constrain. Here, technologies and materials require a different scale of application: from the district scale to assess the outdoor comfort and the microclimate alteration, to the building scale to consider the comfort indoor and the energy needs (both as average and peak values).

2.3 WP3 - Agent Based Modelling and Simulation of Human Spatial Behaviour in Urban Historic Centres During RODs

The effort allocated in WP3 will be carried out by the Urban Planning Group. In historic centres, RODs can lead to critical disaster conditions faster, undermining the host community's safety as well as resulting in time loss, which in an emergency equates to loss of life [14]. The aim of this WP is to enhance the understanding of the effect of physical and social settings in case of RODs. This is crucial in improving the safety of individuals and groups and to plan strategies, procedures and operations for preventing, controlling and managing risks and to optimize operational decision-making in emergency responses.

More in detail, WP3 main objectives are to investigate:

- Pedestrian dynamics and flows to identify localized critical aspects, evaluating the impacts and cascade effects and analysing its re-arrangement, including the development of evacuation time maps, space utilization maps and density maps.
- Major factors of human spatial cognition and behaviour during an emergency, evaluating interactions and interference arising between people and between people/environment.
- Relation with crowd conditions and high-density built spaces, understanding at what point does a crowd emerge.

- Behaviour of key agent types, evaluating how their choices in different risk scenarios affect the whole emergency management.
- Risk level of different spatial configurations evaluating their degree of criticality and assessment of the performance of different functional areas.
- Evacuation procedures to define strategies for evacuation management, including low-level emergency service response and high-level system resilience implementation.

3 Employed Methodologies

The methodologies that are being employed in a synergic manner in the project, are briefly discussed hereafter.

3.1 Geomatics Techniques

Geomatics is widely used in the field of cultural heritage preservation, with the purpose of reconstructing the shape of structures with a high level of accuracy, investigate their conditions and monitor their stability and changes over time. Some interesting applications are discussed in [15] and [16].

At the same time, 3D geomatics data constitute the element on which to base all the activities related to the documentation, the analysis and the enhancement of the built environment, as well as an input in the human behaviour simulation tool helping the decision-maker in risk management activities.

The critical issue previously evidenced requires a number of different geomatics methodologies to be employed in the project that are:

- Survey techniques useful to acquire 3D data at different scales of investigation (ranging from the single building to the district). Satellite and aerial photogrammetry, including UAV are being used to obtain DEMs [17, 18]. A slightly different approach, included in an open source tool for DEMs generation from high resolution optical satellite imagery, will also be considered [19].
- Monitoring techniques able to identify/measure subsidence/displacement phenomena and temperatures on large areas. Multi-temporal SAR datasets, where available, will provide useful information on both the spatial and temporal patterns of displacements, if present, through the generation of time series [20] using the DInSAR technique, while thermal image acquired from satellite [21] will allow the production of Land Surface Temperature (LST) maps. Satellite dataset will be considered also to assess the albedo value at large scale [22].

Geomatics techniques suitable to be employed are listed in Table 1 and Table 2

3.2 Buildings Technologies

The assessment of cultural heritage prone to climate change (SOD) requires the quantification of resilience as the main instrument in evaluating multi-dimensional risk

Table 1. Survey methodologies employed in the project

Survey				
Photogrammetric techniques	Ground resolution	Elevation accuracy	Limitation	Advantages
Using optical satellite imagery	1–10 m	1–10 m	Fix. scheduled data acquisition	Large area coverage
Using aircraft/UAV	0.1–1 m	0.01–1.0 m	Small area coverage	On demand data acquisition

Table 2. Monitoring methodologies employed in the project

Monitoring	
DInSAR	Accuracy = cm/year
LST	Resolution = 1–30 m

assessment to SOD. However, the assessment of resilience, by definition, should involve mitigation and adaptation behaviours in a synergic way [23]. In the field of Cultural Heritage, the traditional process of recovery (knowledge – diagnosis – intervention) should be adapted to the resilient point of view [23].

Because of the cultural relevance, the methodology should include three main goals:

- The identification of inherent behaviours of the cultural heritage in decreasing the effects of climate change locally (adaptive characters).
- The detection of critical elements in the Built Environment that increase the exposure and affection to climate change, as well as the recognition of the most exposed elements to the effect of climate change (risk exposure).
- The study of opportunities offered by complex and critical systems to be transformed to increase the resilient behaviour (mitigation solutions).

As aforementioned in Sect. 2.2, the assessment of resilience should involve analysis both at district and building scale.

At district scale, local microclimate alterations have to consider geometric and physic features of buildings as well as their environmental conditions. It is the case of protocols useful in determining Urban Heat Island Intensity (UHII) according to the Oke classification in Local Climate Zones [25]. Geometric and morphological features of buildings, physic characters and anthropogenic loads represents all the characters involved in evaluating classes of exposures to local Heatwave amplification or overheating. Direct local surveys of micro-climate and Land Surface Temperature (LST) maps (by satellite acquisition) represent the main tools in exploring behavioural attitude of district to be prone to local exacerbation of heatwaves (ROD). Moreover, the quantification of albedo value or the reflectance of surfaces is also required at large scale, as the result of large-scale analysis. Albedo physic parameter contributes in modifying local conditions for energy assessment as a consequence of potential

temperatures reached by exposed surfaces; for local temperatures variation, the albedo parameter represents the capacity of materials in re-emitting in the system longwave [26]. Values could be computed as their direct measures on a sample (by spectrophotometer) or comparing database and previous data collected for traditional materials.

Whereas, software-based on Computational Fluid Dynamics (CFD) (e.g. ENVI-met) support the creation of virtual models to test mitigation actions at district scale.

At building scale, morpho-construction techniques and state of maintenance support the recognition of opportunity of transformation at sub-system scale [27]. However, because of the presence of traditional techniques, direct surveys should be required in order to quantify thermal and optical parameters that can influence the assessment of comfort indoor and the energy needs at building scale. Here, dynamic simulation tools are the main instruments in correlating outdoor microclimate conditions – scaled in previous phase – and indoor energy and comfort results at building scale.

3.3 Multi-agent Simulation

The investigation of human factors is of fundamental importance in evaluating risk through emergency plans and operations. An innovative feature of the research to represent dynamic and complex social systems in case of RODs, is the scientific approach through a Multi-Agent modelling and simulation framework [28].

Multi-Agent Systems are particularly suitable for modelling cognitive processes and human interaction between people and their environment. Agent-based modelling performed in the proper manner [29], can be used to analyse emerging social phenomena at group and crowd level, in our case applied to RODs [30]. This is also the fundamental technique to build computational simulations for these case studies, in order to apply modelling of individuals and social relationships in spatially explicit virtual environments [31].

The computer-based simulation is a method of realistic replication of human activities and use of space. It allows for hypothesis testing, verification and calibration of modelling formalization, the drawing up of recommendations based on the analysis of what if scenarios and the performance analysis of different case studies [32]. The comparison of simulated scenarios will help to define solutions that can improve BE resilience. Additionally, this approach is useful for the study of worst-case scenarios and disruptions that are not directly observable. A final advantage of the proposed methodology is to support knowledge structuring, where the main problem for the decision makers is their missing knowledge and lack of functional models [33].

4 Requirements for the Geomatics Dataset

In this preliminary stage, the main requirements of the 3D dataset have been outlined. With reference to the described activities, the main requirements are:

- High resolution DSMs (around meter or better) to support the analysis of morphological features of complex urban systems at districts scale such as the historic ones; here, models support the recognition of geometric and constitutive elements of open areas and elementary linear units (streets) as well as the features of built environment as an aggregate that can modify locally inherent qualities.
- High resolution Surface Temperature models in order to support the analysis at large scale of local microclimate alterations derived from urban (inherent) constitutive features and anthropogenic heat loads derived from human activities. In detail, the model resolution should be comparable with (or lower than) the smaller element of the districts that - usually for high compact areas - is the canyon featured by 2–3 m width.

Since Multi-Agent systems develop simulations which must represent the dynamic variation of the system under study, the virtual environment built on the DSM should act a changing layer on which the social simulation takes place [34]. Thus, the main requirement for the digital layout of the area is the capacity of representing the real time evolution of risks in order to trigger agents' spatial behaviours [35]. Indeed, in accordance with its transition states, agents adapt their behaviours, e.g. movements. The digital environment not only needs to be dynamic in time, but also in space. These things considered, the digital model of the environment based on the DSM dataset should update at a pace which must fit both with:

- The temporal scale of the simulation, which will range from the immediate choices of individuals, e.g. evacuees, first responders and emergency managers, to long term decision making on design, urban regeneration and strategic planning.
- The spatial scale of the simulation, which will range from the area surrounding individuals and their behaviour in space, to the configuration of the urban neighbourhood area.

5 Case Studies – Ascoli Satriano and Molfetta Municipalities

The historic districts placed in the municipalities of Ascoli Satriano (FG) and Molfetta (BA), in the Apulia Region – Italy, have been selected as case studies, considering:

- Their peculiar location. Referring to the Koppen-Geiger classification, Apulia region has many different climates, due to its orography. The oceanic climate is associated at the promontory of Gargano, in the north-east part, and the sub-appennine zone, located at north-west, both featured by high altitude; whereas along the cost and hills, humid sub-tropical (Cfa) and hot-summer Mediterranean (Csa) climates are predominant. Ascoli Satriano and Molfetta are located in the Daunian sub-appennine and on the eastern coasts respectively. Consequently, they are representative of two major Apulian climates, Cfa and Csa [36]. Thus, the two municipalities differ also in terms of Heating Degree Days (HDD) as defined by Italian law: Ascoli Satriano has 1652 HDD representative of climatic zone D, while Molfetta has 1142 HDD, and is included in climatic zone C.

- The different morphology on built environment. As a clear consequence of local values and previous events, Molfetta and Ascoli Satriano show different morphologies in district arrangement. The two districts mainly include residential buildings; however, tower houses – with vertical development of dwelling on 3–4 floors – are representative for Molfetta's district, while dwellings in Ascoli Satriano are featured by two floors and a horizontal development.
- Construction materials. Molfetta is representative of the traditional use of calcareous squared stone – with regular bonds - as prevalent construction material. Here, the structures are usually associated to compounded walls made by two layers of stone (inner and outer) and an incoherent system of mortar and slices of stones in the middle. Roofs are usually flat and have a structural wooden sub-layer. In the outer part there are both traditional (calcareous stone paving) and modern (paving or bituminous layers) materials. On the other hand, buildings in the historic districts of Ascoli Satriano are featured by pitched roofs while walls are very heterogeneous. In fact, walls made by small bricks and tufa blocks were combined with or substituted the original one made by irregular bonds of calcareous stones.
- Their representativeness of two ancient towns typical of the Italian landscape. From a preliminary evaluation of their plan and topography, both case studies present interesting typological affinities and comparable differences, hereafter described, which may play a determinant role in influencing pedestrian spatial behaviour during emergencies.
  - Molfetta is a coastal town. Its origins can be traced to a small fisherman's village. The historic district is a peninsula surrounded by the Adriatic Sea on three sides. Until the 1800s, the water lapped the southern side which made the old town almost an island. The plan has the shape of an ellipse with the sites of the cathedral and the castle (destroyed in 1416, now Town Hall Square) in its vertices. Along the minor axis is the main street where 14 side streets converge. These streets run parallel and present sudden changes of section, in ancient times this had the function of trapping and disorienting enemies if they managed to enter the city.
  - Ascoli Satriano is located on the edge of the Apennines. In 1456 an earthquake totally destroyed the ancient site and forced relocation of the surviving inhabitants to the site of the current town. Since then the planimetric layout of the old town centre has remained unchanged despite it has been rebuilt many times following seismic events. This is characterized by a labyrinth of narrow alleys that climb up the hillside. This orography determines the spatial configuration and distribution of the streets of the ancient city, which is dominated by the Ducal Palace. This is a massive building placed at the highest point to protect against war attacks from the plain. On the opposite side the cathedral, as a landmark, stands out among lower buildings. The other hillside is steeper, inaccessible and with no buildings, this allows for wide views over the valley.
- The different exposure to natural disasters, both for BE and man. Figure 1 and Fig. 2 highlighted the risk exposure to earthquake, landslide for Ascoli Satriano e Molfetta respectively, as well as human and built vulnerability for classes of ages and period of construction.

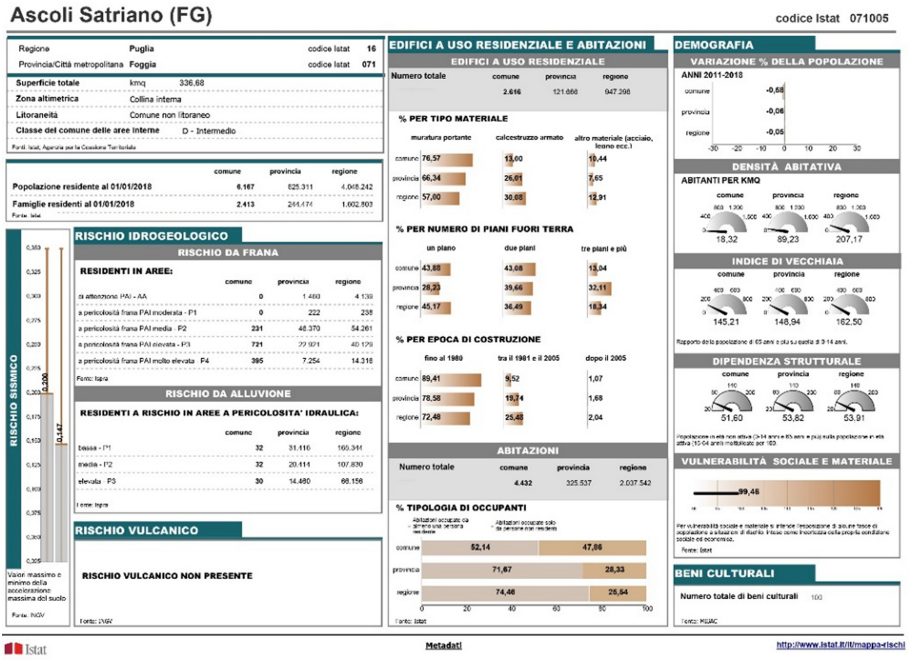

Fig. 1. Ascoli Satriano ISTAT Risk indicators [37]

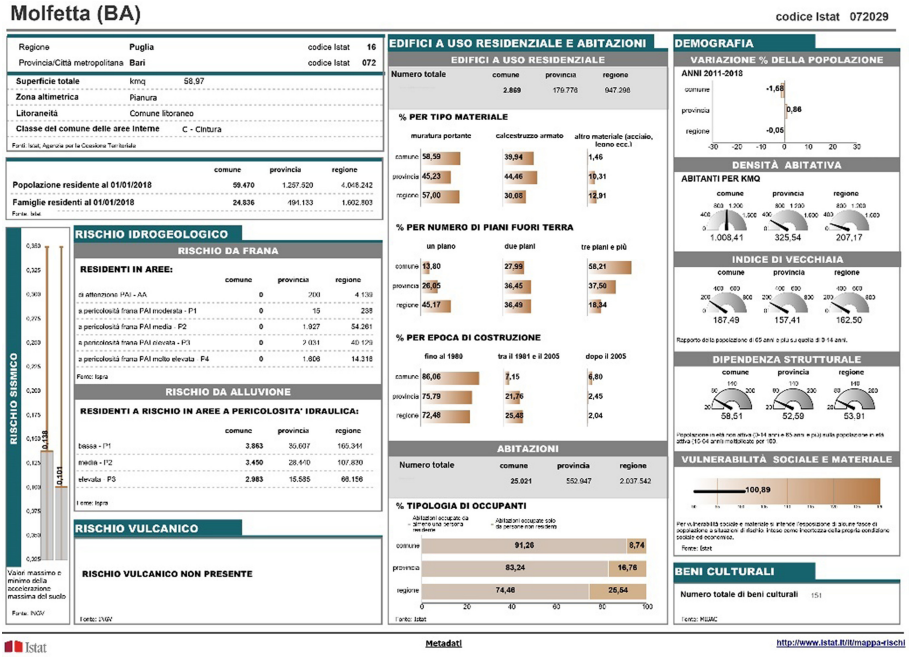

Fig. 2. Molfetta ISTAT Risk indicators [37]



Fig. 3. Subsidence phenomena evidenced By DInSAR data [38]

– Ongoing subsidence phenomena affecting Ascoli Satriano that can provide further elements to the multi risk analysis. Displacements in the satellite Line Of Sight direction, obtained from DInSAR data, are evidenced by permanent scatterers (dots in Fig. 3) that show a velocity of displacements of some centimeters per year.

Available geomatics data are listed in Table 3.

Table 3. Available geomatics data [39]

Digital terrain model	Cell size = 8 × 8 m
Ortophoto	Res. = 0,5 × 0,5
BE shapefiles	

6 Conclusive Remarks

The assessment of the consequences of SOD and ROD on the BE and its users represent a complex task, due to the difficulties in the prompt detection of critical events (both in the long and short-term period), and the proper evaluation of the human behaviour in response to such events. The particular constructive characteristics (narrow/crowded streets, presence of ancient/valuable buildings and heterogeneous constructive techniques/materials) of historical centres makes them more prone to be damaged by ROD and SOD effects.

Recent catastrophic episodes, along with the growing awareness of the increasing negative action of the weathering due to climate change, underline the need to improve the resilience of the historical BE towards these events. This problem necessarily requires an integrated approach that must take into account the topography and the constructive elements of the investigated areas and consider the human factor and its interaction with the BE during potentially critical occurrences.

As discussed in this work, geomatics methodologies applied at the high-resolution survey and monitoring of the cultural heritage provide a very useful tool for measuring and controlling the evolution of historical centres. However, a thorough assessment of the problem requires also accurate information on the efficiency of the buildings for mitigating the negative effects of SOD, as well as reliable dimensionally constrained simulation models of the human behaviour in case of ROD.

Over the next three years, the ResCUDE project will allow to carry out in-depth analyses on the identified case studies, integrating spatial, human and behavioural data, improving the processes of knowledge, evaluation, control, management and design of the BE in relation to the risks deriving from ROD and SOD events. The expected outputs will be used to define possible scenarios for civil defence purposes and undertake actions aimed at risk mitigation. Findings can be included in emergency planning for decision makers and emergency managers.

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