WP 5 - Strategies for improving/designing resilience of BETs

T5.1 Development of resilience-increasing solutions (i.e. architectural/technological design strategies), evaluated through simulations, and based on the selected metric/KPIs, according to a 4R approach

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Abstract

As discussed in the previous deliverables, SUOD and SLOD events are responsible for a significant share of documented accidental fatalities. Regardless of their scale on time, or their unfolding time, both risks are growing based on the growing population density; nevertheless, they can be reduced or mitigated by undertaking strategic interventions. In fact, the European Commission demands from, and offers funds to each Member State to contrast the actual trend by implementing available mitigation measures. Starting from WP1 and WP2 results, the purpose of this document is to collect, structure and describe the available risk reduction and mitigation strategies for SLOD and SUOD events, and their combination, for moving towards a resilient BE. To this end, it also integrates literature review gaps by identifying three main leading groups of strategies: morphological factors, physical-material and construction factors, and dedicated systems aimed at supporting proper users' behaviors and managers' strategies (including evacuation and emergency planning). The deliverable also analyses different case studies of mitigation strategies from the literature highlighting the specific or combined mitigation potential, their extension and the actual level of implementation. This work is intended to be used as a risk mitigation strategies pool (portfolio/ inventory, guidelines) for designers and public administrations. However, the classification of the mitigation measures is complex due to the influence of several parameters, including the behavioral ones. It must be noted that the effectiveness of measures applied in a specific urban context could be not always suitable for other contexts and vice versa. To overcome this limit, simulation-based tools (see WP5-T5.2) will support the effective assessment of each strategy and their combination.

Keywords

Slow-Onset Disasters; Sudden-Onset Disasters; Built environment; Historical Built Environment; Pollution, Urban Heat Island; Earthquake; mitigation measures

Approvals

Role	Name	Partner	Date
Coordinator	Enrico Quagliarini	UNIVPM	-
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0.1	13.10.2021	Deliverable structure and main content	Martha Caramia	POLIMI
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0.3	02.11.2021	Deliverable general review and insertion of SUODs parts	Federica Rosso	UNIPG
1.0	22.03.2023	Updating Table 5 and related comments in view of T-H assessment criteria	Gabriele Bernardini	UNIVPM

Summary

SL.A.5 New BE (form, layout, orientation)

SL.B.1 Urban surface and roughness

SL.B.2 Permeable pavers

SL.B.3 Permeable grass pavers

SL.B.4 City trees

SL.B.11 Cool façade

SL.B.12 Reflective roof / Cool roof

SL.B.13 Green walls

SL.B.14 Green roofs

SL.B.15 Photocatalytic materials

SL.B.16 Algae pbr

SL.C.2 Energy efficiency

SL.C.3 Waste management to avoid pollutant production

SL.C.1 Public transportation

SL.C.2 Shared mobility

SL.C.3 Controlled/limited traffic zones

SL.C.4 Electric and hybrid mobility

SL.C.5 Soft mobility

FRP and FRCM system

Reticolatus system

Add anti-seismic devices (e.g., tie rods, steel tie beams and ring beams) wall-to-wall and wall-to-roof connections

1. Introduction

The global population is growing fast and tends to settle in the most urbanized area (United Nations 2018). For this reason, the 55% of the world's population lives in urban areas. In Italy this percentage is even higher: the 70% of the national population lives in cities and most of it in the northern area, in the Po Valley (Bigi and Ghermandi 2014). As already identified in Deliverable D.2.1 an increase in population feeds two severe and complex environmental problems, affecting humans and ecosystems. These problems are represented by the Urban Heat Island (UHI), which aggravates heat waves and high air pollution concentrations. The two phenomena are strictly related and cause several negative effects on energy production and supply stress, on the health of people, particularly of elderly, poor, disabled and very young citizens. Dense urban areas increase the risk of the two above mentioned SLODs for several reasons: reduced evaporation, transpiration and shading due to limited green areas, increased surfaces temperatures with high thermal capacity, increased air stagnation decreasing the wind speed etc.. Facing urban heat waves and air pollution, spatial planning and urban governance play a particular role in adaptation and mitigation of adverse effects (Bicknell et al. 2012). At the same time, urban areas in Italy are also subject to elevated seismic risk (Godey et al. 2013) and, due to the presence of cultural heritage landmarks as well as high population density, it could be targeted by terrorists attacks (Cuesta et al. 2019). In this panorama, historical built environment (HBE) is particularly vulnerable to SLODs and SUODs, and suitable mitigation strategies should be identified and implemented to increase its resilience. The term "mitigation" is defined as the action or a sum of actions to reduce how harmful, unpleasant, or bad an event can be.
Due to the complexity of the cities, integrated approaches to adaptation and mitigation considering people and built environment are urgently needed (Ruth and Coelho 2007). For this reason, the European Commission is asking each Member State to contrast the actual trend by implementing the available mitigation measures. Also, the EU finances several initiatives within the H2020 research programme to contrast the two SLODs. The purpose of this document is to collect and offer an inventory of solutions and strategies to mitigate both SLODs and SUODs, for moving towards a resilient BE.

2. Inventory of solutions and mitigation measures for an already existing BE and related case studies

The following section presents the most common mitigation measures to contrast SLOD and SUOD events. Mitigation measures can be categorized in three main areas: the first two, "morphological factors" and "physical and construction factors", are strictly related to the features of the built environment while the third, "dedicated systems and behavior strategies" is more related to the users' behavior. It is worth clarifying that the proposed strategies include a suite of approaches that must be implemented in a preventive and long-term perspective, in order to reduce the impacts of disasters on the subsequent stages of recovery, rehabilitation and reconstruction.

Figure 1 – SUODs and SLODs mitigation strategies categories as previously defined in WP2 – D2.2.

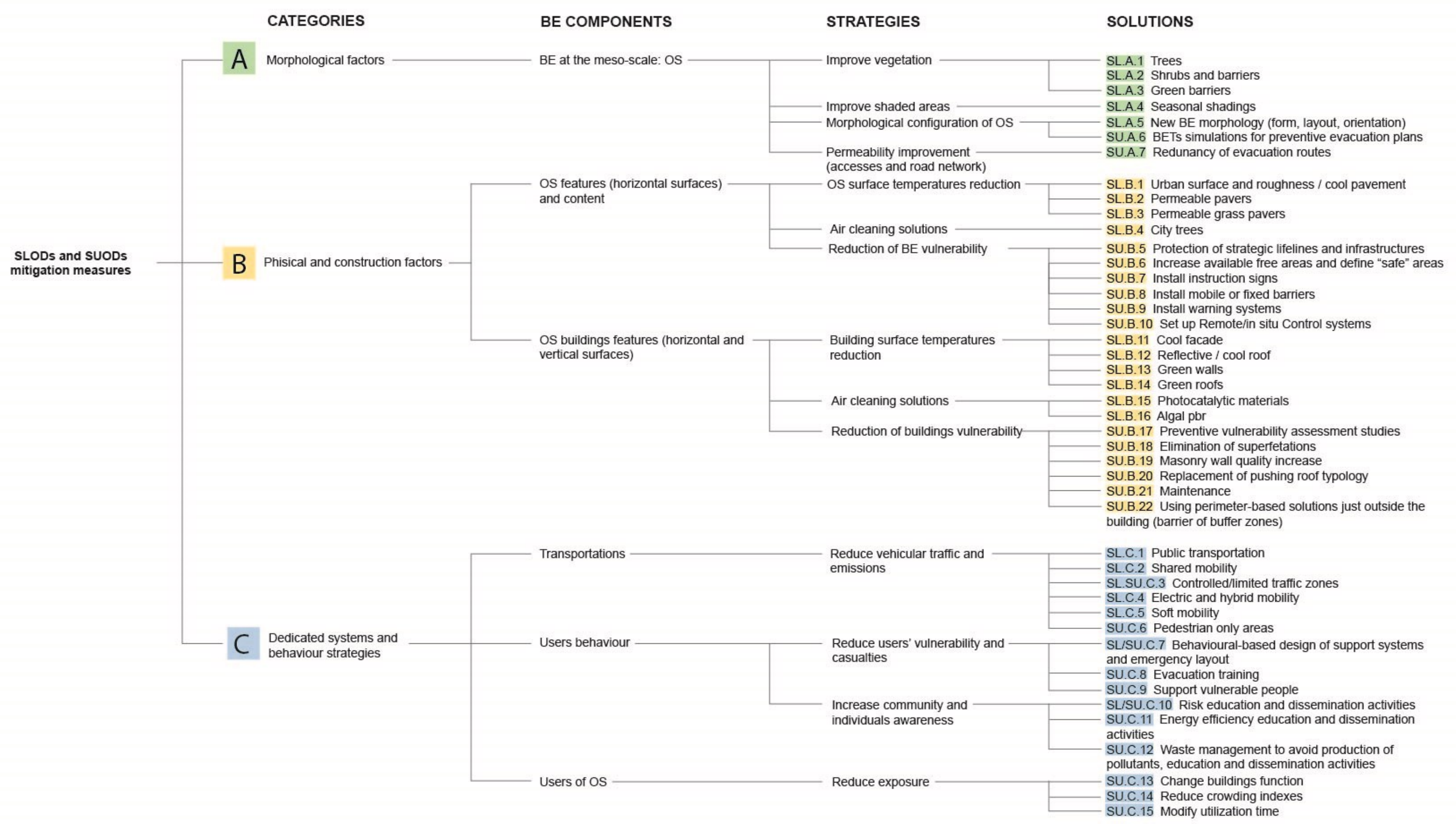


Figure 2 - Mitigation measures collection deconstruction and code allocation based on the established categories

2.1 Mitigation measures to reduce SLODs

This section illustrates the most diffuse solutions to contrast the SLODs phenomena in an already existing BE. These solutions are the ones collected in Figure 2 with a code starting with SL (SLOD) and focus on Urban Heat Island (UHI) and air pollution reduction.

The solutions follow the abovementioned categories and are resumed in Table 1. Also, for each solution, a practical example is shown. The description of each example is reported in the annex.

Table 1 - SLODs mitigation measures inventory, detailing and supporting literature.

Code	Strategy	Solution	References	Case studies	Case studies references
SL.A.1	Improve vegetation	Trees	(Janhäll 2015)(Pastore et al. 2020) (Abhijith et al. 2017) (Abhijith and Gokhale 2015)	Hamburg Milan	(Hamburg.de) (Pastore et al. 2020)
SL.A.2		Shrubs and hedges	(Gromke et al. 2016) (Gallagher et al. 2015) (Gallagher et al. 2015) (Van Ryswyk et al. 2019)		
SL.A.3		Green barriers	(Al-Dabbous and Kumar 2014) (Yin et al. 2007) (Chen et al. 2015)		
SL.A.4	Improve shaded areas	Seasonal shadings	(Hwang et al. 2011)	Expo 2015 Metrosol Parasol Seville Umbrella sky project	(Majowiecki 2015) (Casella 2018) (Sampson 2021)
SL.A.5	Morphological configurations of OS	New BE morphology (form, layout and orientation)	(Andreou 2014) (Biao et al. 2019) (Ratti et al. 2005) (Giovagnorio and Chiri 2012) (Hassan et al. 2020) (Kastner-Klein and Plate, 1999), (Wen and Malki-Epshtein 2018) (Yang et al. 2020)	ENVI-met	www.envi-met.com
SL.B.1	OS surface temperatures reduction	Urban surface and roughness / cool pavement	(Synnefa 2007)	Los Angeles white painting project	(Abdallah 2018)
SL.B.2		Permeable pavers	(Bell et al. 2008)	Derbyshire street	(Susdrain 2014)
SL.B.3		Permeable grass pavers	(Bell et al. 2008)	Lunix pavers	www.ferraribk.it
SL.B.4	Air cleaning solutions	City trees	(Green City Solutions 2021)	Green city solutions	(Green City Solutions 2021)
SL.B. 11	Building surface temperatures reduction	Cool façade	(EPA 2008)	Santorini	(Akbari et al. 2006)
SL.B.12		Reflective roof / cool roof	(Falasca and Curci 2018)	White roof project	(Kptecki 2018)
SL.B.13		Green walls	(Vox et al. 2017) (Manso and Castro-gomes 2015) (Viecco et al. 2018) (Ottelé et al. 2010) (Kohler 2006; Köhler 2008)	Vegetecture Park lane	(Caro et al. 2016) (Sue-feng)
SL.B.14		Green roofs	(Shafique et al. 2018) (Sun et al. 2016)	Madrid city hall Chicago city hall terrace	(Caro et al. 2016) (MWH 2004)

Code	Strategy	Solution	References	Case studies	Case studies references
			(Karachaliou et al. 2016) (Pérez et al. 2015) (EPA 2019) (Imran et al. 2018) (Berardi et al. 2014) (Yang et al. 2008) (Speak et al. 2012)		
SL.B.15	Air cleaning solutions	Photocatalytic materials	(Mo et al. 2009) (Pelaez et al. 2012) (Kolarik and Toftum 2012) (Enea and Guerrini 2010)	Converse walls Volkswagen walls UK	(Elassar 2020) (Casalgrande Padana 2020)
SL.B.16		Algal pbr	(Nasution et al. 2016)	Biq house, Hamburg	(Loomans 2013)
SL.C.1	Reduce vehicular traffic and emissions	Public transportation	(Shahmohamadi et al. 2011) (European Environment Agency 2008) (European Union Parliament 2008, 2009) (Fernyhough 2021)	EnelX	(Fernyhough 2021)
SL.C.2		Shared mobility	(Martinez and Viegas 2017)	Milan: GuidaMI, Car2go, Enjoy, E-vai, SHARE'nGo.	(Di Bartolo et al. 2020)
SL.SU.C.3		Controlled/limited traffic zones	(Grigoratos and Giorgio 2014)	Carpooling Bla bla car Uber	(Setiffi and Lazzer 2018) (Di Bartolo et al. 2020)
SL.C.4		Electric and hybrid mobility	(Grigoratos and Giorgio 2014)	Electric scooters: EM transit, Bird rides Italy, Voi technology Italia, Wind mobility, Bit mobility, Helbiz Italia and Lime technology	(Comune di Milano 2020).
SL.C.5		Soft mobility	(La Rocca 2010) (CIVITAS (Cleaner and better transport in cities) 2016)	Call a bike system – Stuttgart	(Di Bartolo et al. 2020)
SL.C.11	Increase community and individuals' awareness	Energy efficiency education and dissemination activities	(Alaidroos and Krarti 2016) (Salvalai et al. 2013) (Engelmann et al. 2014) (Tévar et al. 2019) (Doubleday et al. 2019) (Kaya et al. 2019) (Zhu et al. 2020) (Zhu et al. 2020) (Blondeau et al. 1997) (Geros et al. 1999) (Hee et al. 2015)	nZEB LEED certifications	(U.S. Green building Council 2019)
		Health education about heat wave hazard	(Ma et al. 2016)	Health care education for elders - Guangzhou, China	(Ma et al. 2016)
		Air pollution awareness education	(Dorevitch et al. 2008; Guo et al. 2020)	PM risk self-awareness in vulnerable groups	(Guo et al. 2020)

Code	Strategy	Solution	References	Case studies	Case studies references
SL.C.12	Waste management	Waste management to avoid production of pollutants – education and dissemination activities	(CIVITAS (Cleaner and better transport in cities) 2016) (Pei 2019)	Sweden example	(OECD)

2.1.1 Morphological factors (A)

Improve Vegetation - SL.A.1 | SL.A.2 | SL.A.3

Vegetation helps to cool the environment, reducing UHI. Vegetative cooling can be applied to create more shaded spaces reducing air temperature or to create shaded walkable paths where the user can benefit of a lower perceived temperature. Also, vegetation performs an important mitigation action against atmospheric pollutants (ozone, nitrogen oxides, sulphur oxides, heavy metals, benzene, atmospheric particulate) working as natural filters (Janhäll 2015). When integrating greenery in the urban environment, it is important to select the proper vegetation according to the SLODs that needs to be mitigated. Increasing the spacing between trees and reducing the cross-sectional area occupied by tree canopies (through increased pruning and selecting smaller trees) can usually reduce street-level personal exposure through increased ventilation (Buccolieri et al. 2009).

Usually, traffic pollution tends to accumulate at street level, causing high exposure for pedestrians. In this context, solid and porous structures in urban street canyons (low boundary walls, shrubs, hedges), which affect flow and dispersion are increasingly discussed (Gromke et al. 2016) (Gallagher et al. 2015). Low vegetation can be applied with proficiency to filter out the particulate matter due to his proximity to the source. Studies observed considerable pollutant removal through designing vegetation barriers closer to the pollutant source and plume's maximum concentration (Al-Dabbous and Kumar 2014).

Improve shaded areas - SL.A.4

If vegetation cannot be integrated in the built environment, another solution can be the seasonal shading. By using temporary shading sails, or structures supporting climbing plants, seasonal shading can help mitigate summer heat waves and make public space accessible during the hottest hours of the day. The temporariness of shading systems can also ensure the maximised solar gain in winter season.

New BE morphology (form, layout, orientation) – SL.A.5

The correct design and construction of new buildings can contribute to low down the urban heat island phenomenon. Simple precautions must be taken into consideration during the design phase such as: height of buildings, distances between them, orientation and position of building and pedestrian path or common space in the outdoor of the BE (Andreou 2014). Narrow streets can create the canyon effect for which temperature increase of 2-4°C (Biao et al. 2019). Another aspect to take in consideration is the ventilation inside street canyons: a poor ventilation leads to an accumulation of pollutants. Architects, planners must consider different urban strategies to limit the pollution risks from vehicular emissions using air pollutant dispersion in order to promote outdoor air quality (Hassan et al. 2020). When the street is narrow (H/W>0.7), the resulting flow regime is skimming flow, which is characterized by recirculating air flow within the street and is adverse for ventilation (Oke 1988).

When designing blocks, recreational spaces such as open squares, parks, and green spaces should be upwind to the prevailing wind direction in summer to ensure good ventilation conditions. At the intersections of the main and secondary roads of the city, buildings should be somewhat receded, and open plazas or green spaces should be created to facilitate the diversion and distribution of wind flows of different directions, thus avoid the formation of vortex zones that impair the dispersion of air pollutants (Yang et al. 2020). Several software can help designers in the determination of best shape for a new building.

2.1.2 Physical & construction factors (B)

This category is related to surfaces and materials that can characterize the BE. There are different mitigation measures depending on the possibility of covering surfaces with greenery or finishing paint.

Reduce surface temperatures – SL.B.1 | SL.B.2 | SL.B.3 | SL.B.11 | SL.B.13 | SL.B.14

Buildings can contribute to the UHI effect: coating surfaces can absorb of reflect heat. Thus, properties of surface materials, in particular, high solar reflectance, high thermal emissivity, and low heat capacity can also beneficially influence UHI mitigation, as they determine how the sun's energy is reflected, emitted, and absorbed (EPA 2008). Also, if surfaces are covered with photocatalytic materials, facades can contrast the concentration of particulate matter.

The use of cool roofs allows to reduce the temperature of the urban environment thanks to a high albedo coefficient of the materials. Also, the usage of evapotranspirant surfaces help roofs to absorb less heat and stay up to lower values of surface temperatures. Cool roofs improve thermal comfort and reduce electricity demand. High albedo materials can reduce the UHI intensity up to 2-3°C (Falasca and Curci 2018).

As already explained for vertical surfaces and roofs, the same characteristics for what concern colour and materials apply for pavement: high albedo coating and light colours can directly influence surface temperature and indirectly the UHI.

Vegetative facades are useful for mitigating the urban microclimate. A green wall can reduce temperature peaks of the façade of a building in summer and increase the thermal insulation during winter. This type of covering allows to create a microclimate in the BE helping to reduce the UHI effect. The presence of green walls can also be beneficial for air pollution. During the day, plants extract CO2 and other toxins from the air through the photosynthesis, resulting in significant air pollutants reduction. The usage of green facades is spreading thanks to the great potential they have.

Green roofs can moderate the effect of UHI. The effectiveness of this measure depends on climate, foliage, coverage. Experimental study shows how the green roof temperature, during hot summer day, can be up to 10 °C lower compared to external air temperature, thus reducing also the building energy consumption compared to traditional roofs (EPA 2019). Green roofs are also capable of absorbing air pollution. Obviously, due to the position, a green roof is less effective than a green wall, or trees and vegetation barriers. Anyway, green roofs have a double influence on air pollution: they can increase energy performance of the building causing less emissions and at the same time the green roof can absorb and remove pollutants from the air.

Air cleaning solutions – SL.B.4 | SL.B.15 | SL.B.16

The use of photocatalytic materials as air cleaning technologies whose application until now were restricted to special cases like clean rooms, hospitals, or industrial applications, can now be profitable for outdoor spaces contrasting the concentration of the particulate matter. In recent years, many studies have focused on the use of photocatalytic air purifiers for removal of indoor contaminants (Mo et al. 2009), (Pelaez et al. 2012). In the last decade the photocatalytic cement-based paint that helps to improve air quality, indoor and outdoor. The materials include titanium dioxide which, when it is exposed to sunlight, acts as photocatalyst and breaks down organic particles by forming free radicals that then oxidise the surrounding air, leading to a reduction in air pollution (Kolarik and Toftum 2012). The materials are mostly used in outdoor applications on so called self-cleaning facades and for degradation of nitrogen oxides in street canyons and also car parks (Enea and Guerrini 2010).

Another option to purify the air from pollutants are the air filters, in different shapes that become elements of the urban design. This bio tech filters can clean the air in the surroundings. Mosses have a huge surface, comparable to the human lung. On this surface, fine dust particles from the air are electrostatically attracted and stick to it. Also, the moss metabolizes the fine dust particles, i.e. “eats” the fine dust (Green City Solutions 2021).

2.1.3 Dedicated systems and behavior strategies (C)

In this section, there are going to be explained all the mitigation measures that are not specific to the specific square or street canyon, but they are on a higher level and when applied, they benefit every single BE.

Reduce vehicular traffic emissions – SL.C.1 | SL.C.2 | SL.SU.C.3 | SL.C.4 | SL.C.5

According to the European Environment Agency (European Environment Agency 2008), transport in Europe consumes one third of all final energy. Therefore, traffic is responsible for most of the greenhouse gas emissions as well as being one of the major causes of air pollution in cities. The pollution given by urban transport is essentially given by the following factors: pollution of private vehicles that contributes to create vehicular traffic and pollution of public transport.

The role of public transportation and how much it works depends on the public administration and single user. Public administration should provide the service to the entire city and the single user should prefer using public transportation instead of private transportation. Not to mention that many citizens using private cars, in addition, to consume more energy, can create traffic congestions that have a negative impact on the urban heat island and air quality. It is necessary to create an efficient local public transport network, otherwise, citizen will be obliged to keep on using private vehicles for travel in urban contexts. A further reduction in harmful gas emissions can come from the quality of public transportation vehicles: the use of hybrid, electric or “fuel cell” engines would reduce urban pollution.

Shared vehicles in the urban center, replacing private cars prove that the actual total number of vehicles in cities is much higher than necessary. The implementation of several typologies of shared vehicles can drastically reduce the number of total vehicles(Martinez and Viegas 2017). Also, congestion would disappear, CO_2 emission would decrease and there would be less need for all on-street parking, freeing several areas where greenery can be implemented.

Local authorities can put in place some measures to reduce viability and lower traffic.

Conventional cars are alimented by petrol, diesel, or gas. A valid alternative is given by electric cars witch power comes from electric energy. The study conducted by the Paul Scherrer Institute (Grigoratos and Giorgio 2014) provides an overview of the environmental impact of today and tomorrow cars with different propulsion technologies. The main advantage is the production of substantially smaller quantities of greenhouse gases (about 30t of Co2 less every 200.000 km).

Using slow mobility such as bicycles, electric scooters and walking can increase urban livability keeping the individual right to move. Consequentially, slow mobility can improve the urban environment referring to air pollution and traffic congestion. To encourage the use of soft mobility, many cities should promote the development of specific infrastructures and services dedicated to its use.

Increase community and individuals' awareness - SL.C.11 | SL.C.12

Reducing emissions related to building consumption and to the production of building materials can have direct consequences on climate conditions and it can indirectly affect the urban heat island effect and the ambient air quality. Reducing energy needs means to reduce the energy production and its related CO_2 and particulate matter pollutions mainly from biomass burning. Also, the position of outlet device can directly increase temperature in outdoor spaces where people usually stand and walk. In addition to passive strategies, it is necessary to provide tools and technologies to produce energy from renewable sources. In the urban context the two main renewable sources are wind and sun. Technological innovations from renewable energy are beneficial to alleviate nitrogen oxides (NO_x) and respirable suspended particle (PM10) concentrations.

The main cause of heat emission is air conditioning. The high demand for electricity, necessary to run air conditioner in the hottest days, results in an increase in harmful gases released into the atmosphere. The human bodies have almost the same perception of the temperatures if using the FAN ventilator or the air conditioning (Jay et al. 2019). The use of the FAN instead of the Air Conditioning should be encouraged. Natural ventilation should be encouraged to keep cool houses. Nighttime ventilation succeeds in decreasing the daily indoor air temperature of 1.5/2°C. This simple measure that a single individual can adopt also works at full scale on an entire building (Geros et al. 1999) reducing next day peak indoor temperature by up to 3°C.

Another aspect related to the increasing awareness is the waste management. Recycling and waste management are processes that start with the individual citizen and end with the proper municipal and administrative waste management. The Citizen has the role and the duty to separate the waste produced by him in the home and work environment, following the instructions given to him by the municipality. There are valid alternatives to open incineration of solid waste. It is possible to reduce the amount of undifferentiated waste destined for burners through correct regulations imposed by the municipality and by a more correct recycling of waste conducted by individual citizens. Reducing waste to be incinerated directly affects the pollution levels and greenhouse gases in the air.

2.2 Mitigation measures to reduce SUODs

This section provides a general framework (Figure 2) of the most diffuse Disaster Risk Reduction (DRR) and Disaster Risk Management (DRM) strategies for SUODs according to the results of previous deliverables (D1.2.4, D1.3.2). Indeed, these strategies have been identified according to a holistic approach to risks mitigation by considering all the BE components involved in the meso-scale analyses: OS as an urban space (i.e., accesses and surrounding network); OS content and its characteristics (i.e., fixed obstacles, pavements, etc.); buildings facing the OS (i.e., facades and roofs); users of the OS. Thus, the specific interventions and solutions have been identified for each BE components by collecting both structural and non-structural measures of DRR. The categories of strategies for SUODs encompass both seismic and terrorism-related issues. The distinction between these risks is clarified in the following sections.

Table 2 - SLODs mitigation measures inventory, detailing and supporting literature.

Code	Strategy	Solution	References	Case studies	Case studies references
SU.A.6	Morphological configurations of OS	Evacuation plans based on BET-related simulations	(Zlateski et al. 2020) (Bernardini et al. 2021)		
SU.A.7	Permeability improvement (accesses and road network)	Redundancy of evacuation routes	(Rus et al. 2018; Cara et al. 2018; Atrachali et al. 2019; Sharifi 2019b, a; Giuliani et al. 2020) (Srinurak et al. 2016)	Nocera Umbra, Città di Castello, Gubbio (Italy)	(Oliveri (a cura di) and Olivieri 2004; Salvo et al. 2012)
SU.B.5	Reduction of BE vulnerability	Protection of strategic lifelines and infrastructures	(Oliveri (a cura di) and Olivieri 2004; Nicholson 2007; Italian technical commission for seismic micro-zoning 2014)	Kyoto	(Ahn et al. 2011)
SU.B.6		Increase available free areas and define «safe» areas	(Santarelli et al. 2018; Artese and Achilli 2019; Anelli et al. 2020; Bernabei et al. 2021)		
SU.B.7		Install instruction signs for evacuation and safe areas	(Bernardini et al. 2019) (Quagliarini et al. 2021a)		
SU.B.8		Install mobile or fixed barriers, dissuaders, or furniture	(Quagliarini et al. 2021a)	Washington Monument (ha-ha barrier and water obstacle), Cardiff City Center (integrated furniture), Phoenix Police Department (trees)	(Federal Emergency Management Agency 2007; Coaffee 2018)
SU.B.9		Set up/install warning systems	(Quagliarini et al. 2021a)	France, Germany	(FOKUS; Nationale 2016)
SU.B.10		Set up Remote/in situ Control systems	(Quagliarini et al. 2021a)	Federation Square, Melbourne;	(Coaffee 2018)
SU.B.17	Reduction of buildings vulnerability	Preventive vulnerability assessment studies	(Ferreira et al. 2019; Quagliarini et al. 2021b; Bernabei et al. 2021)	Coimbra (Portugal); Sant'Antimo (Italy)	(Zlateski et al. 2020; Chieffo et al. 2021)
SU.B.18		Elimination of superfetation	(Frumento et al. 2006)		
SU.B.19		Masonry wall quality increase	(Borri et al. 2014; Mordanova et al. 2016; Kouris and Triantafillou 2018; Maddaloni et al. 2018; De Santis et al. 2021)	Steel connectors; FRP and FRCM; Reticulates system	(Borri et al. 2014, 2019; Valluzzi et al. 2014; Corradi et al. 2016, 2018; Zanello 2017; De Santis et al. 2021)
SU.B.20		Replacement of pushing roof typology	(Frumento et al. 2006)		
SU.B.21		Maintenance	(D'Ayala 2013; Basset-Salom and Guardiola-Víllora 2013)	Lorca (Spain)	(Basset-Salom and Guardiola-Víllora 2013)

Code	Strategy	Solution	References	Case studies	Case studies references
SU.B.22		Using perimeter-based solutions just outside the building (barriers or buffer zones)	(Quagliarini et al. 2021a)	Wall Street (NYC); T-DAYS Via Rizzoli (Bologna)	(Rogers Architects; Pedrini 2017)
SL/SU.C.3	Reduce vehicular traffic	Controlled/limited traffic zones	(Quagliarini et al. 2021a)		
SL.C.4		Pedestrian only areas	(Quagliarini et al. 2021a)		
SL/SU.C.7	Reduce users' vulnerability and casualties	Behavioural-based design of support systems and emergency layout	(Bernardini et al. 2019; Fatiguso et al. 2021)	Foro Annonario (Senigallia, Italy – designed and tested but not implemented)	(Bernardini et al. 2018)
SU.C.8		Evacuation training	(Bernardini et al. 2019; Fatiguso et al. 2021)		
SU.C.9		Support vulnerable people	(Tancogne-Dejean and Laclémence 2016; Chen et al. 2018)		
SL/SU.C.10	Increase community and individuals' awareness	Risk education and dissemination activities	(UNISDR 2015)		
SU.C.13	Reduce exposure	Change buildings function			
SU.C.14		Reduce crowding indexes			
SU.C.15		Modify utilization time			

2.2.1 Morphological factors (A)

The analysis of morphological factors must be approached at the meso-scale, considering both the OS itself and the networks that links it to the surrounding urban areas. Indeed, the strategies focus on issues related both to the morphological configurations of the OS and its permeability, such as the quality of the accesses (e.g., number, width, and positions of the accesses). The modification towards increased resilience of such strategies is limited due to the invasiveness of the possible solutions: indeed, they require direct modifications of the OS configuration, which leads to the disruption of the existing HBE. Other solutions, such as the simulations for preventive planning could be instead applied to the HBE. The below solutions are effective both for seismic and terrorist risks.

Morphological configurations of OS simulations and correlation with preventive emergency planning - SU.A.6

On the other hand, it is possible to intervene indirectly on the OS morphological configuration by means agent-based simulations of the users' movement within the space, in order to improve the effectiveness of emergency plans and predict critical conditions that may arise during emergency management phases (Sharifi 2019a; Giuliani et al. 2020). Indeed, the results of the simulations provide realistic risks scenarios useful for planning evacuation procedure and emergency efforts. In the framework of the BE S^{2}ECURe research, the simulations are carried out on the BETs defined in the WP3 and WP4 (D4.1).

Permeability improvement (accesses and road network) - SU.A. 7

The increase of number and dimension of accesses could have a positive effect on evacuation, as (i) by adding more accesses, the redundancy of possible egress or access paths would reduce the risk of impeded evacuation paths; and (ii) by enlarging the existing accesses, the risk of having the path obstructed by debris from surrounding buildings would be lower, and the transit of rescue vehicles would be facilitated. These solutions are generally applicable on new built environment, more than HBE.

2.2.2 Physical and construction factors (B)

Reduction of BE vulnerability by means of OS features - SU.B.5-10

Recent studies present a holistic approach to resilience in urban area. Indeed, the BE is considered as a complex system whose relationships between individual components must be analysed. Therefore, the above-recalled methods are based on parameters from different fields of investigation and about different urban components (e.g., urban layout, buildings, infrastructures, open spaces, etc.) (Rus et al. 2018; Atrachali et al. 2019).

With respect to seismic vulnerability, a large part of the literature focuses on the protection and reinforcement of the road networks (SU.B.5). Many studies propose analyses concerning assessments of the efficiency of the entire road network within the urban area as a whole (Oliveri (curated by) 2004; Italian technical commission for seismic micro-zoning 2014; Cara et al. 2018; Sharifi 2019b; Giuliani et al. 2020). Such analyses involve different characteristics: the lengthening of the travel times, the closure of some road sections following disasters (Nicholson 2007), the population density to measure the capacity of the escape routes (Ye et al. 2011). These investigations can be supported by algorithm and agent-based simulations for optimizing the emergency planning to define the evacuation paths (Bernardini et al. 2021).

The operability of OS, particularly squares, can be investigated considering the area that may be free from obstacles (i.e. from debris on the ground in case of earthquakes) during the evacuation. The definition of the "safe" area (SU.B.6) within the space of the OS can be determined mainly by vulnerability assessment of buildings facing the OS to provide the probability of their failures (Santarelli et al. 2018; Artese and Achilli 2019; Anelli et al. 2020; Bernabei et al. 2021). Thus, the width of the OS that will remain free from debris is determined based on the vulnerability of the frontiers of the OS and on the accessibility of the evacuation routes of the OS. Such information supports the evacuation planning as well as the identification of priorities of intervention.

Another aid to the evacuation process is the installation of sensors/network devices and signs with instructions for evacuees to indicate escape routes and safe areas (SU.B.7), the operability of escape routes or possible dangers (Bernardini et al. 2019).

Barriers, gates, fences, dissuaders, heavy furniture (SU.B.8) can be implemented in the OS to reduce the vulnerability to terrorists' attacks, both related to explosions and collisions (Quagliarini et al. 2021a). Among the possible barriers and dissuaders, there are fixed or movable ones, as well as elements that are fully integrated with the traditional urban elements (e.g., furniture or trees) or either distinct ones, changing global perception of the BE (e.g., Tigertrap or ha-ha barrier). Additionally, warning systems (SU.B.9) can be included into the above-mentioned strategies applied in the BE, supporting the warning phase with emergency signs or digital alarm services (e.g., APPs). The aim is to support people in their moving during emergency in the BE, as well as to inform and suggest recommendations during the emergency, remotely. These are fully compatible with all the attack types. Finally, the introduction or the setting up of remote or in situ control systems (SU.B.10) could reduce the global vulnerability of the BE prone to the attack. This can consider the presence of personnel to control people and objects (surveillance and metal detector) or the introduction of system that allow to manage people, behaviour and actions remotely (traditional or biometric CCTV).

Reduction of buildings vulnerability - SU.B.17-22

The main strategies for seismic risk reduction focus on the reduction of the seismic vulnerability. Indeed, most studies in these fields provide assessment methods to identify structural weakness of building in a preventive stage. On the other hand, practical solutions to reduce the vulnerability consist of retrofitting and strengthening interventions, particularly on built fronts of the OS.

A preliminary assessment of the vulnerability (SU.B.17) of OS fronts would aid in the identification of priority interventions, in order to plan interventions for reducing the most urgent vulnerable features of the buildings in the HBE.

Removing superfetation (SU.B.18), when possible according to the architectural and cultural features of the building, would allow decreasing the height of the building itself, thus decreasing its vulnerability to earthquakes. This is even more effective when superfetation were added not in accordance to the existing building structural behavior.

The increase of masonry wall quality and structural connections (SU.B.19) can be obtained by means of different solutions. Among them, some allow to improve the connection between the walls' facings and thus the masonry quality, in that it avoids detachment of facings and compression-led instability. Moreover, these solutions allow a monolithic behavior for actions perpendicular to the wall plan. These interventions also allow to improve the behavior of the wall with respect to slenderness. These solutions comprehend (as by Figure 3): applying mortar injections; applying metal connectors; applying prefabricated diatons; applying wall reinforcement by composite nets/grid or stainless-steel strips. The latter strategy is more invasive and sometimes not suitable for preserving the cultural heritage. In this case, the reinforcement has to be built for both of the wall facings and transversal connections should be provided, too and it is thus not feasible in the case of decorated interior facing. Other solutions allow instead to increase of the mechanical properties of the masonry, which is useful in the case of non-high-quality masonry, with decayed joints or small masonry components. These are for example: applying mortar injections; joint repointing. Also reinstalling portions of masonry for masonry continuity by means of repair/replacement, and reinsertion technique would improve the mechanical properties of the wall. Repair/replacement and reinsertion techniques could be conducted for: lesions in the wall; decayed wall components; filling up niches (e.g., canalizations or decorative niches). With respect to masonry wall slenderness, increasing the thickness of the wall could contribute to decrease the slenderness, thus reducing vulnerability. This intervention is only possible when there is no decorative apparatus on the inner facing of the wall, as it cannot generally be modified. The improvement of structural connections (i.e., wall-to-wall, and wall-to-roof/floor connections) can be achieved by means of anti-seismic devices (e.g., tie rods, steel tie beams and ring beams) could support the box-like behavior of the building, thus decreasing its vulnerability to earthquake and preventing Out-Of-Plane failures (Sisti et al. 2016). Finally, as openings constitute vulnerable portions of the façade, aligning openings, even if it is not a solution that is easy to implement, could increase the resistance of load-bearing walls, thus improving masonry quality. Similarly, adding hoops or lintels on the openings could contribute to reduce vulnerability.

Pushing roofs (SU.B.20) increase the vulnerability of the masonry to Out-Of-Plan damages. Therefore, changing the roof materials and scaffolding towards non-pushing roofs can be beneficial to decrease vulnerability (Figure 4). Non-pushing roofs examples are trusses roofs or roofs with scaffolding parallel to the façade. The roof strategy should be compatible with the materials and the behavior of the existing building.

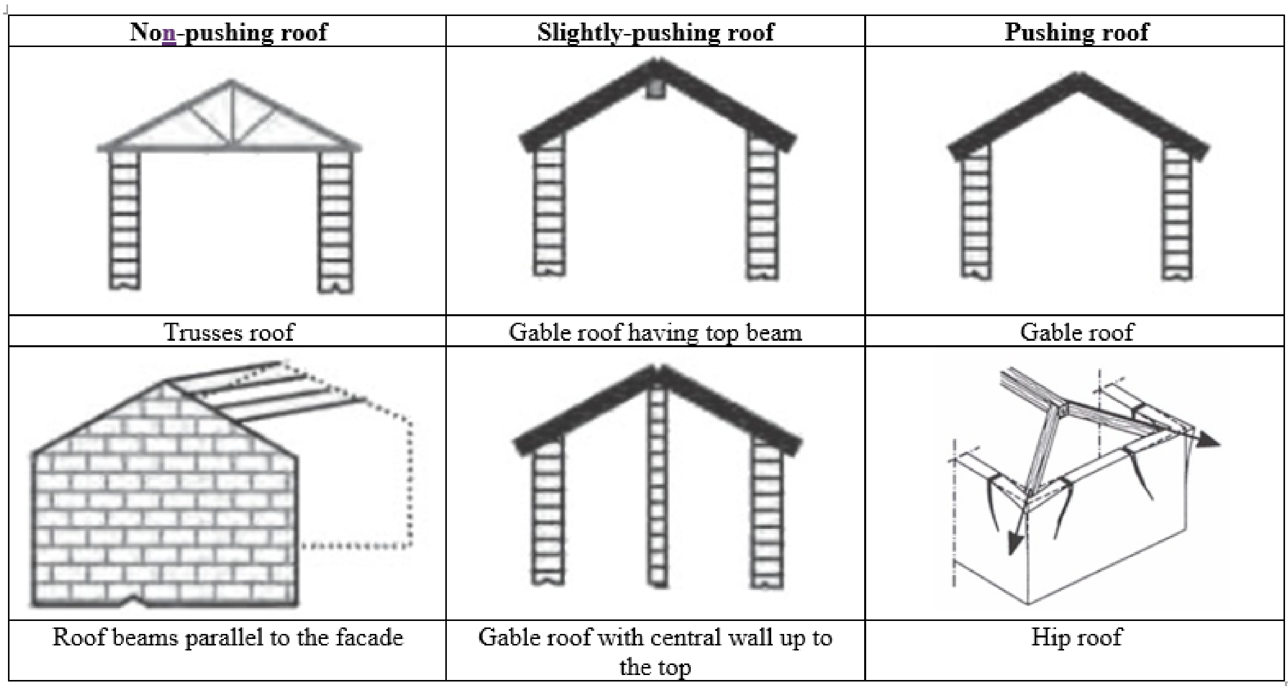


Figure 3. Examples of pushing and non-pushing roof typologies.

Maintenance actions (SU.B.21), such as the punctual substitution of degraded or incorrect structural elements (e.g., wood beams, lintels), could aid in reducing the vulnerability of buildings, and as such should be promoted. The punctual substitution of degraded structural elements, such as wood beams and lintels, would allow to reduce the vulnerability to Out-Of-Plan damages. Moreover, while the compatibility of interventions with the existing masonry building is of crucial importance for its behavior with respect to earthquake, sometimes previous interventions conducted in the past were incorrect and not structurally compatible with the existing structure. These interventions cause higher vulnerability to the seismic response of the masonry building. Thus, their removal and substitution with compatible strategies would allow to decrease the vulnerability of such buildings.

Using perimeter-based solutions (SU.B.22) just outside the building, such as buffer zones or barriers, could aid in the reduction of buildings' vulnerability (and that of the entire BE) to terrorist attacks, being them either explosions or collisions (Quagliarini et al. 2021a). Moreover, such barriers could be useful for avoiding exposure to debris fall during earthquakes. If the buffer zones integrate greenery, they could work also for HW and AP.

2.1.3 Dedicated systems and behavior strategies (C)

In addition to the vulnerability, also exposure, as a component of risk, can be managed by means of indirect measures aimed at ensuring the proper evacuation in the event of a disaster and reducing casualties. These strategies act on the number of users or on their behaviours.

Reduce vehicular traffic – SL/SU.C.3 | SU.C.6

Controlled or limited traffic zones (SU.C.3), such as pedestrian only areas (SU.C.6) reduce the probability of terrorist's attacks both for explosions and collisions. Moreover, such restrictions on vehicular traffic could facilitate and make safer the evacuation of pedestrians due to earthquakes.

Users' vulnerability and casualties – SL/SU.C.7 | SU.C.8-9

Behavioural analysis and simulations allow to trace strategies to assist the evacuees' decisions by suggesting and reminding recommended behaviors via assistance tools (e.g.: apps for personal devices; integrated systems in the built environment, including wayfinding signage; alerts, etc.) (SU.C.7) and educational training activities (SU.C.8). In particular, training actions should be aimed at: (1) increasing individual capacities to autonomous response in emergency conditions (SU.C.8), by means traditional (evacuation exercises and drills) and emerging smart tools (e.g.: VR/AR-centric approach) (Bernardini et al. 2019; Fatiguso et al. 2021); (2) support rescuers in the management of the evacuation process, by mainly focusing on vulnerable and not autonomous users (Tancogne-Dejean and Laclémence 2016; Chen et al. 2018).

Increase community and individuals' awareness – SL/SU.C.10

In addition to such solutions, the dissemination and education campaigns about risks lead to increased community awareness thus improving the users response during emergency and increase their safety (UNISDR 2015).

Reduce exposure - SU.C.13-15

Three types of indirect interventions on exposure are: (i) change the functions of buildings (SU.C.13) to improve the distribution of users' presences according to the operability of the outdoor spaces (e.g.: delocalisation of strategic functions); (ii) reduction of crowding indexes (SU.C.14) related to the uses/functions of buildings and open spaces by decreasing the capacity of spaces or installing controlled entrances devices; (iii) modifying the utilization time of buildings and open spaces (SU.C.15) to control and avoid overcrowding.

3. Common mitigation strategies for SLODs and SUODs

So far, mitigation measures have been considered individually, related to the single SLOD or SUOD they can mitigate. Nevertheless, in §2.1 it was found that some of the identified mitigation measures can mitigate more than one SLOD at the time. For this reason, the purpose of this section is to analyse the impact that mitigation measures can have both on SLODs and SUODs. To do so, in Table 3 all the conceived strategies are collected, and their effectiveness is evaluated. In greater detail, for each strategy, the effect on UHI (air temperature level reduction, solar radiation reflection, heat dissipation), AP (particulate matter dissipation, particulate matter reduction), on the reduction of OSs and buildings vulnerability to seismic and terrorism risks, as well as the effect of all the above-mentioned on users, is investigated. Some of the proposed strategies would be effective for multiple risk only in determined conditions (e.g., a cool plaster on the external envelope is effective on the UHI, but could also be effective for the seismic risk if it is also reinforced, and against P, if it contains self-cleaning pigments). In that case, such strategy is indicated with an "*" on the column where it could be effective, further considerations shall be considered for obtaining multiple advantages.

As analysed before, the impact of the mitigation varies from case to case due to the very complex nature of SLODs and SUODs phenomena. For his reason, the comparison between all strategies has been done considering a qualitative scale reflecting the general mitigation potential (very high, high, medium, low, negligible). However, for each specific case a more precise effect can be calculated considering the specific context.

In the table, an additional parameter, named "Level of implementation", identifies how easily the specific mitigation measure can be implemented in the BE, again as a qualitative indication. To this parameter has been assigned a qualitative scale assigning "+", "++" and "+++" if the measure is respectively *rarely implemented (difficult to implement)*, *often implemented (average difficulty of implementation)*, or *very often implemented (easy to implement)*. Meanwhile, the last column in the table indicates the "effect on users" of the BE of the mentioned strategies, as a Boolean (yes (✓) or not).

Table 3 - Mitigation strategies (based on risk category), implementation (from rarely implemented (+) to very often implemented (+++)) and impact level (from negligible (red) to very high (green)) comparison for SUODs and SLODs.

Code	Strategy	Implementation level	SLODs							SUODs						Effect on USERS
			Effect on UHI				Effect on P			Effect on S			Effect on T			
			Air temperature level reduction	Solar radiation reflection	Heat dissipation	Potential impact	Particulate matter dissipation	Particulate matter reduction	Potential impact	Reduction OS vulnerability	Reduction building vulnerability	Potential impact	Reduction OS vulnerability and hazard	Reduction building vulnerability	Potential impact	
SL.A.1	Trees	+++	✓		✓		✓	✓					✓			✓
SL.A.2	Shrubs and hedges	+++	✓*				✓	✓								
SL.A.3	Green barriers	+	✓*				✓	✓					✓			✓
SL.A.4	Seasonal shadings	++	✓	✓												✓
SL.A.5	New BE morphology (form, layout, orientation)	+	✓		✓		✓			✓				✓		
SU.A.6	BETs simulations for preventive evacuation plans	+++								✓			✓			✓
SU.A.7	Redundancy of evacuation routes	+ + +								✓			✓			✓
SL.B.1	Urban surface and roughness / cool pavement	+	✓	✓	✓											

SL.B.2	Permeable pavers	++	✓													
SL.B.3	Permeable grass pavers	++	✓	✓				✓								
SL.B.4	City trees	+					✓	✓								✓
SU.B.5	Protection of strategic lifelines and infrastructures	++								✓			✓			
SU.B.6	Increase available free areas and define «safe» areas	++								✓			✓			
SU.B.7	Install instruction signs	+++														✓
SU.B.8	Install mobile or fixed barriers, dissuasors or furnitures	+++	✓*			*							✓		v	
SU.B.9	Set up/install warning systems	+++														✓
SU.B.10	Set up Remote/in situ Control systems	+++											✓		a v	
SL.B.11	Cool facade	+	✓	✓	✓						✓*	*				
SL.B.12	Reflective roof / cool roof	++	✓	✓	✓						✓*	*				

SL.B.13	Green walls	+	✓					✓			✓*	*				
SL.B.14	Green roofs	++	✓	✓				✓			✓*	*				
SL.B.15	Photocatalytic materials	+		✓				✓			✓*	*				
SL.B.16	algal pbr	+						✓								
SU.B.17	Preventive vulnerability assessment studies	+++								✓	✓					
SU.B.18	Elimination of superfetations	+	✓*			*					✓					
SU.B.19	Masonry wall quality increase	++									✓					
SU.B.20	Replacement of pushing roof typology	++	✓*	✓*		*					✓					
SU.B.21	Maintenance	+++									✓					
SU.B.22	Using perimeter-based solutions just outside the building (barriers or buffer zones)	++	✓*		✓*	*				✓				✓		✓
SL.C.1	Public transportation	++	✓					✓								
SL.C.2	Shared mobility	++	✓					✓								

SL.C./SU.C.3	Controlled/limited traffic zones	+	✓					✓					✓			✓
SL.C.4	Electric and hybrid mobility	+	✓					✓								
SL.C.5	Soft mobility	+++	✓					✓								✓
SU.C.6	Pedestrian only areas	++	✓					✓					✓			✓
SL/SU.C.7	Behavioural-based design of support systems and emergency layout	+++														✓
SU.C.8	Evacuation training	+++														✓
SU.C.9	Support vulnerable peolple	++														✓
SL/SU.C.10	Risk education and dissemination activities	+++														✓
SL.C.11	Energy efficiency education and dissemination activities	++	✓	✓				✓								✓

SL.C.12	Waste management- to avoid production of pollutants - education and dissemination activities	+++						✓								✓
SU.C.13	Change buildings function	++														✓
SU.C.14	Reduce crowding indexes	++														✓
SU.C.15	Modify utilization time	++														✓

* Potentially applicable, if integrated with different strategies.

[a] Armed terrorist attack only.

[v] Vehicle related terrorist attack only.

Table 3 investigates the potential impact of each strategy on the specific SLOD/SUOD. At the same time each strategy is analysed to understand if it can have a positive effect also on other phenomena. The table shows that SL.A.1, SL.A.3, SL.A.5, SL.B.13, SL.B.14, SL.B.15, SL.B.22, SL.C/SU.C.3 and SU.C.6 are the strategies capable of influencing several phenomena at the same time even though they were conceived only for one of them. This doesn't mean that other strategies are less effective, but it can be useful to consider these when there are more phenomena to be reduced at the same time.

4. Analysis of mitigation solutions related to different hazards combinations and BETs

Having already said that the mitigation strategies implementation is strictly related to the context, it is appropriate to start considering a realistic case in which to study and apply them. For this reason, the solutions will be studied within the BETs. First, it has been necessary to define the most frequent types of hazards. Starting from the Table1 and Table2 of D3.3.1, in which each square has been assigned to the corresponding BET, the most frequent risks combination has been calculated as shown in Table 4. Whenever a square has been calculated as prone to multiple risks at the same time, the risks were counted both individually and in combination. Obviously, in this way the most frequent cases are the one with only one risk at the time. Despite this, a combination of a SLOD and a SUOD will be taken in consideration, while the combination of two SUODs at the same time will be excluded, since it is very unlikely that earthquake and terrorism will occur simultaneously. In addition to the paramount hazard combinations in Table 4 (green cells), the T-H combination has been considered as relevant for all the BETs with the special building (BET 1A, 2A, 4A, 4B). Although the statistical frequency in D3.3.1 results, this combination cannot be considered as impossible in view of the special building interaction with the BET public open space and its rule as an ideal soft-target for terrorist acts (Beňová et al. 2019; The European Commission 2022; Quagliarini et al. 2023).Table 4. Frequency of hazard combinations for each BET. Green cells mark the main single and multirisks for each of the BET according to the statistical analysis of the sample in D3.3.1, while grey lines express the not relevant risks combinations in view of the project purposes and possible occurrence conditions (very low theorical probability).

BET	1A	1B	2A	2B	3	4A	4B	4C	5
S	**14**	**6**	**12**	**7**	**9**	**3**	2	**3**	**6**
H	7	2	9	3	6	1	1	2	4
P	3	3	9	6	6	2	**3**	1	**6**
T	6	4	6	3	4	2	1	1	3
S-H	**6**	2	**6**	3	**4**	1	1	**2**	4
S-P	3	**3**	**6**	**6**	**4**	**2**	**2**	1	**5**
S-T	6	4	4	3	3	2	1	1	3
T-P	1	2	5	3	3	1	1	1	3
T-H	3	2	5	2	**4**	1	1	1	2
P-H	1	2	5	2	3	1	1	1	3
S-P-H	1	2	3	2	2	1	1	1	**3**
S-T-P	1	2	3	3	2	1	1	1	3
S-T-H	3	2	3	2	3	1	1	1	2
T-P-H	1	2	**5**	2	**3**	1	1	1	2
S-T-P-H	1	2	3	2	2	1	1	1	2

Based on the data collected in Table 4, the most the most suitable mitigation solutions will be applied in each BET (Table 5). Nevertheless, in view of the above considerations, the reader should consider that the T-H strategies (which are defined in Table 5 just for BET 3) can be applied to BET 1A, 2A, 4A and 4B, too.

*Table 5. Suitable mitigation strategies for each BET. *: these solutions can be ideally applied to BET 1A, 2A, 4A, and 4B, although they are excluded from T-H applications from a frequency-based perspective.*

BET	Risk	Solutions

1A	S-H	• *Against S*: SL.A.5, SU.A.6-7, SU.B.5-7, SL.B.11-15, SU.B.17-22, SL/SU.C.7, SU.C.8, SU.C.9, SL/SU.C.10 • *Against H*: SL.A.1-5, SL.B.1-3, SU.B.8, SL.B.11-15, SU.B.18, SU.B.20, SU.B.22, SL.C.1-2, SL.C./SU.C.3, SL.C.4-5, SU.C.6, SL.C.11, SU.C.13-15 • *Combined*: SL.A.5, SL.B.11-SL.B.15, SU.B.18, SU.B.20, SU.B.22, SU.C.13-15
1B	S-P	• *Against S:* SL.A.5, SU.A.6-7, SU.B.5-7, SL.B.11-15, SU.B.17-22, SL/SU.C.7, SU.C.8, SU.C.9, SL/SU.C.10 • *Against P:* SL.A.1-3, SL.A.5, SL.B.3, SL.B.4, SL.B.13-16, SL.C.1, SL.C.2, SL.C./SU.C.3, SL.C.4, SL.C.5, SU.C.6, SL.C.11, SL.C.12, SU.C.13, SU.C.14, SU.C.15 • *Combined:* SL.A.5, SL.B.13-SU.B.15, SU.C.13-SU.C.15
2A	S-H and S-P	• *Against S*: SL.A.5, SU.A.6-7, SU.B.5-7, SL.B.11-15, SU.B.17-22, SL/SU.C.7, SU.C.8, SU.C.9, SL/SU.C.10 • *Against H*: SL.A.1-5, SL.B.1-3, SU.B.8, SL.B.11-15, SU.B.18, SU.B.20, SU.B.22, SL.C.1-2, SL.C./SU.C.3, SL.C.4-5, SU.C.6, SL.C.11, SU.C.13-15 • *Against P:* SL.A.1-3, SL.A.5, SL.B.3, SL.B.4, SL.B.13-16, SL.C.1, SL.C.2, SL.C./SU.C.3, SL.C.4, SL.C.5, SU.C.6, SL.C.11, SL.C.12, SU.C.13, SU.C.14, SU.C.15 • *Combined (S-H):* SL.A.5, SL.B.11-SL.B.15, SU.B.18, SU.B.20, SU.B.22, SU.C.13-15 • *Combined (S-P):* SL.A.5, SL.B.13-SU.B.15, SU.C.13-SU.C.15
2B	S-P	• *Against S:* SL.A.5, SU.A.6-7, SU.B.5-7, SL.B.11-15, SU.B.17-22, SL/SU.C.7, SU.C.8, SU.C.9, SL/SU.C.10 • *Against P:* SL.A.1-3, SL.A.5, SL.B.3, SL.B.4, SL.B.13-16, SL.C.1, SL.C.2, SL.C./SU.C.3, SL.C.4, SL.C.5, SU.C.6, SL.C.11, SL.C.12, SU.C.13, SU.C.14, SU.C.15 • *Combined:* SL.A.5, SL.B.13-SU.B.15, SU.C.13-SU.C.15
3	S-H and S-P and T-H*	• *Against S*: SL.A.5, SU.A.6-7, SU.B.5-7, SL.B.11-15, SU.B.17-22, SL/SU.C.7, SU.C.8, SU.C.9, SL/SU.C.10 • *Against H*: SL.A.1-5, SL.B.1-3, SU.B.8, SL.B.11-15, SU.B.18, SU.B.20, SU.B.22, SL.C.1-2, SL.C./SU.C.3, SL.C.4-5, SU.C.6, SL.C.11, SU.C.13-15 • *Against P:* SL.A.1-3, SL.A.5, SL.B.3, SL.B.4, SL.B.13-16, SL.C.1, SL.C.2, SL.C./SU.C.3, SL.C.4, SL.C.5, SU.C.6, SL.C.11, SL.C.12, SU.C.13, SU.C.14, SU.C.15 • *Against T*: SL.A.1, SL.A.3, SL.A.5, SU.A.6, SU.A.7, SU.B.5, SU.B.6, SU.B.7, SU.B.8, SU.B.9, SU.B.10, SU.B.22, SL.C./SU.C.3, SU.C.6, SL/SU.C.7, SU.C.8, SU.C.9, SL/SU.C.10, SU.C.13-SU.C.15

		• *Combined (S-H):* SL.A.5, SL.B.11-SL.B.15, SU.B.18, SU.B.20, SU.B.22, SU.C.13-15 • *Combined (S-P):* SL.A.5, SL.B.13-SU.B.15, SU.C.13-SU.C.15 • *Combined (T-H):* SL.A.1, SL.A.3, SU.B.8, SU.B.22, SL.C./SU.C.3, SU.C.6, SU.C.13-15
4A	S-P	• *Against S:* SL.A.5, SU.A.6-7, SU.B.5-7, SL.B.11-15, SU.B.17-22, SL/SU.C.7, SU.C.8, SU.C.9, SL/SU.C.10 • *Against P:* SL.A.1-3, SL.A.5, SL.B.3, SL.B.4, SL.B.13-16, SL.C.1, SL.C.2, SL.C./SU.C.3, SL.C.4, SL.C.5, SU.C.6, SL.C.11, SL.C.12, SU.C.13, SU.C.14, SU.C.15 • *Combined:* SL.A.5, SL.B.13-SU.B.15, SU.C.13-SU.C.15
4B	S-P	• *Against S:* SL.A.5, SU.A.6-7, SU.B.5-7, SL.B.11-15, SU.B.17-22, SL/SU.C.7, SU.C.8, SU.C.9, SL/SU.C.10 • *Against P:* SL.A.1-3, SL.A.5, SL.B.3, SL.B.4, SL.B.13-16, SL.C.1, SL.C.2, SL.C./SU.C.3, SL.C.4, SL.C.5, SU.C.6, SL.C.11, SL.C.12, SU.C.13, SU.C.14, SU.C.15 • *Combined:* SL.A.5, SL.B.13-SU.B.15, SU.C.13-SU.C.15
4C	S-H	• *Against S*: SL.A.5, SU.A.6-7, SU.B.5-7, SL.B.11-15, SU.B.17-22, SL/SU.C.7, SU.C.8, SU.C.9, SL/SU.C.10 • *Against H*: SL.A.1-5, SL.B.1-3, SU.B.8, SL.B.11-15, SU.B.18, SU.B.20, SU.B.22, SL.C.1-2, SL.C./SU.C.3, SL.C.4-5, SU.C.6, SL.C.11, SU.C.13-15 • *Combined*: SL.A.5, SL.B.11-SL.B.15, SU.B.18, SU.B.20, SU.B.22, SU.C.13-15
5	S-P	• *Against S:* SL.A.5, SU.A.6-7, SU.B.5-7, SL.B.11-15, SU.B.17-22, SL/SU.C.7, SU.C.8, SU.C.9, SL/SU.C.10 • *Against P:* SL.A.1-3, SL.A.5, SL.B.3, SL.B.4, SL.B.13-16, SL.C.1, SL.C.2, SL.C./SU.C.3, SL.C.4, SL.C.5, SU.C.6, SL.C.11, SL.C.12, SU.C.13, SU.C.14, SU.C.15 • *Combined:* SL.A.5, SL.B.13-SU.B.15, SU.C.13-SU.C.15

5. Conclusions and remarks

The aim of this deliverable is to provide an overview of the most common mitigation measures for contrasting both SLODs and SUODs in the BE. The classification of the mitigation measures is complex since each specific effect is influenced by several parameters. For this reason, it can happen that a specific measure applied in a specific context is not suitable for other situations and vice versa. Also, this document tries to identify if there are measures that can produce benefit for more than one event at a time.

Nevertheless, irrespective of effectiveness, the mitigation power of each of the mentioned strategy is acknowledged. For this reason, it has been possible to evaluate whether each of them could influence only the phenomenon they were conceived for, or if they could influence also other phenomena. From a cross-analysis it was demonstrated that the implementation of some strategies can facilitate the reduction of more risks at the same time, thus proving effective in multi-risk reduction. On the other side, it should be highlighted that in terms of effectiveness the implementation of multiple strategies, each one capable of mitigating one single SUOD or SLOD, can be more performing than the implementation of one addressing the mitigation all of them.

For this reason, it is important to be able to estimate the mitigating potential of each solution in the specific context through simulations. This could be crucial when selecting the strategies and/or their combination to apply. Such work is foreseen in the following deliverables to compare the effectiveness of the strategies in terms of overall single risk mitigation, overall multiple risk mitigation, and behavioral resilience.

However, not all strategies can be implemented because of peculiar, site-specific limitations, or the difficulty of implementation in terms of costs, feasibility, regulations, etc. In this respect, the Italian historical centers are really binding. For instance, applying a different wall coloring or pavement material (albedo modification) to reduce surface temperature, cannot be always applied due to the regulations imposed by the municipality with respect to colors or materials.

For this reason, it can be useful to distinguish which strategies are easier to integrate in existing consolidated built environment and which are more suitable for new projects (i.e. context dependent). Yet, a preliminary screening has been presented for each of the established BETs according to the most frequent type of risks that such BETs are exposed to. This allocation is useful for future work to deal with a narrower inventory of available solutions to study their feasibility and to compare their context-specific efficacy. This shortest inventory could be defined thanks to simulation-based approach (relying on the general SLOD-to-SUOD and multirisk perspective pursued by the project). T5.2. activities will then oriented towards this goal.

6. References

Abdallah C (2018) Los Angeles Is Painting the Streets White (Again), and Your City Might Be Next | ArchDaily. In: ArchDaily

Abhijith KV, Kumar P, Gallagher J, et al (2017) Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments – A review. Atmos Environ 162:71–86. https://doi.org/10.1016/j.atmosenv.2017.05.014

Abhijith K V., Gokhale S (2015) Passive control potentials of trees and on-street parked cars in reduction of air pollution exposure in urban street canyons. Environ Pollut. https://doi.org/10.1016/j.envpol.2015.04.013

Ahn Y, Tsukaguchi H, Ogawa K, Tanaka K (2011) Study on disaster risk assessment of cultural heritage and road network improvement in historical city. J Disaster Res 6:119–131. https://doi.org/10.20965/jdr.2011.p0119

Akbari H, Berdahl P, Levinson R, et al (2006) Cool Color Roofing Materials Draft Final Report Prepared for. Energy 73

Al-Dabbous AN, Kumar P (2014) The influence of roadside vegetation barriers on airborne nanoparticles and pedestrians exposure under varying wind conditions. Atmos Environ. https://doi.org/10.1016/j.atmosenv.2014.03.040

Alaidroos A, Krarti M (2016) Evaluation of passive cooling systems for residential buildings in the Kingdom of Saudi Arabia. J Sol Energy Eng Trans ASME. https://doi.org/10.1115/1.4033112

Andreou E (2014) The effect of urban layout, street geometry and orientation on shading conditions in urban canyons in the Mediterranean. Renew Energy 63:587–596. https://doi.org/10.1016/j.renene.2013.09.051

Anelli A, Mori F, Vona M (2020) Fragility Curves of the Urban Road Network Based on the Debris Distributions of Interfering Buildings. Appl Sci 10:

Artese S, Achilli V (2019) A GIS TOOL FOR THE MANAGEMENT OF SEISMIC EMERGENCIES IN HISTORICAL CENTERS: HOW TO CHOOSE THE OPTIMAL ROUTES FOR CIVIL PROTECTION INTERVENTIONS. ISPRS - Int Arch Photogramm Remote Sens Spat Inf Sci XLII-2/W11:99–106. https://doi.org/10.5194/isprs-archives-XLII-2-W11-99-2019

Atrachali M, Ghafory-Ashtiany M, Amini-Hosseini K, Arian-Moghaddam S (2019) Toward quantification of seismic resilience in Iran: Developing an integrated indicator system. Int J Disaster Risk Reduct 39:101231. https://doi.org/10.1016/j.ijdrr.2019.101231

Basset-Salom L, Guardiola-Víllora A (2013) Influence of the maintenance in seismic response of Lorca historic centre masonry residential buildings after the 11 May 2011 earthquake. In: Structural Studies, Repairs and Maintenance of Heritage Architecture XIII. WIT Transactions on the Built Environment, pp 343–354

Bell R, Cole D, DeAngelo B, et al (2008) Reducing Urban Heat Islands : Compendium of Strategies Trees and Vegetation

Bellocchi S, Klöckner K, Manno M, et al (2019) On the role of electric vehicles towards low-carbon energy systems: Italy and Germany in comparison. Appl Energy 255:113848. https://doi.org/10.1016/J.APENERGY.2019.113848

Beňová P, Hošková - Mayerová Š, Navrátil J (2019) TERRORIST ATTACKS ON SELECTED SOFT TARGETS. J Secur Sustain Issues 8:453–471. https://doi.org/10.9770/jssi.2019.8.3(13)

Berardi U, GhaffarianHoseini AH, GhaffarianHoseini A (2014) State-of-the-art analysis of the environmental benefits of green roofs. Appl. Energy

Bernabei L, Mochi G, Bernardini G, Quagliarini E (2021) Seismic risk of Open Spaces in Historic Built Environments: A matrix-based approach for emergency management and disaster response. Int J Disaster Risk Reduct 65:102552. https://doi.org/10.1016/j.ijdrr.2021.102552

Bernardini G, David C, Santarelli S, et al (2018) Multi-hazard emergency management in historical centers: methods and tools for increasing mass-gathering safety in case of earthquake. TEMA, Technol Eng Mater Archit (e-ISSN 2421-4574) 4:120–133. https://doi.org/10.17410/tema.v4i2.190

Bernardini G, Lovreglio R, Quagliarini E (2019) Proposing behavior-oriented strategies for earthquake emergency evacuation: A behavioral data analysis from New Zealand, Italy and Japan. Saf Sci 116:295–309. https://doi.org/10.1016/j.ssci.2019.03.023

Bernardini G, Romano G, Soldini L, Quagliarini E (2021) How urban layout and pedestrian evacuation behaviours can influence flood risk assessment in riverine historic built environments. Sustain Cities Soc 70:102876. https://doi.org/10.1016/j.scs.2021.102876

Biao L, Cunyan J, Lu W, et al (2019) A parametric study of the effect of building layout on wind flow over an urban area. Build Environ. https://doi.org/10.1016/j.buildenv.2019.106160

Bigi A, Ghermandi G (2014) Long-term trend and variability of atmospheric PM10 concentration in the Po Valley. Atmos Chem Phys 14:4895–4907. https://doi.org/10.5194/acp-14-4895-2014

Blondeau P, Spérandio M, Allard F (1997) Night ventilation for building cooling in summer. Sol Energy 61:327–335. https://doi.org/10.1016/S0038-092X(97)00076-5

Borri A, Castori G, Corradi M, Sisti R (2014) Masonry wall panels with GFRP and steel-cord strengthening subjected to cyclic shear: An experimental study. Constr Build Mater 56:63–73. https://doi.org/10.1016/j.conbuildmat.2014.01.056

Borri A, Corradi M, Castori G, Molinari A (2019) Stainless steel strip – A proposed shear reinforcement for masonry wall panels. Constr Build Mater 211:594–604. https://doi.org/10.1016/j.conbuildmat.2019.03.197

Buccolieri R, Gromke C, Di Sabatino S, Ruck B (2009) Aerodynamic effects of trees on pollutant concentration in street canyons. Sci Total Environ. https://doi.org/10.1016/j.scitotenv.2009.06.016

Cara S, Aprile A, Pelà L, Roca P (2018) Seismic Risk Assessment and Mitigation at Emergency Limit Condition of Historical Buildings along Strategic Urban Roadways. Application to the “Antiga Esquerra de L’Eixample” Neighborhood of Barcelona. Int J Archit Herit 12:1055–1075. https://doi.org/10.1080/15583058.2018.1503376

Caro JC, Armour T, Fernandez M (2016) Madrid + Natural: Nature-based Climate Change Adaptation

Casalgrande Padana (2020) Self Cleaning - Casalgrande Padana

Casella B (2018) Il Metropol Parasol simbolo del rapporto tra tradizione e innovazione | Civiltà di Cantiere. In: Civiltà di cantiere - Città e Territ.

Chen X-S, Liu C-C, Wu I-C (2018) A BIM-based visualization and warning system for fire rescue. Adv Eng Informatics 37:42–53. https://doi.org/10.1016/j.aei.2018.04.015

Chen X, Pei T, Zhou Z, et al (2015) Efficiency differences of roadside greenbelts with three configurations in removing coarse particles (PM10): A street scale investigation in Wuhan, China. Urban For Urban Green. https://doi.org/10.1016/j.ufug.2015.02.013

Chieffo N, Formisano A, Miguel Ferreira T (2021) Damage scenario-based approach and retrofitting strategies for seismic risk mitigation: an application to the historical Centre of Sant'Antimo (Italy). Eur J Environ Civ Eng 25:1929–1948. https://doi.org/10.1080/19648189.2019.1596164

CIVITAS (Cleaner and better transport in cities) (2016) Cycling in the City Smart choices for cities. 1–22

Coaffee J (2018) Beyond Concrete Barriers Innovation in Urban Furniture and Security in Public Space

Comune di Milano (2020) Mobilità. Pubblicato il bando per contributi all'acquisto di veicoli a basso impatto ambientale - Mobilità. Pubblicato il bando per contributi all'acquisto di veicoli a basso impatto ambientale

Corradi M, Borri A, Castori G, Sisti R (2016) The Reticulatus method for shear strengthening of fair-faced masonry. Bull Earthq Eng 14:3547–3571. https://doi.org/10.1007/s10518-016-0006-5

Corradi M, Di Schino A, Borri A, Rufini R (2018) A review of the use of stainless steel for masonry repair and reinforcement. Constr Build Mater 181:335–346. https://doi.org/10.1016/j.conbuildmat.2018.06.034

Cuesta A, Abreu O, Balboa A, Alvear D (2019) A new approach to protect soft-targets from terrorist attacks. Saf Sci 120:877–885. https://doi.org/10.1016/j.ssci.2019.08.019

D'Ayala D (2013) Assessing the seismic vulnerability of masonry buildings

De Santis S, AlShawa O, de Felice G, et al (2021) Low-impact techniques for seismic strengthening fair faced masonry walls. Constr Build Mater 307:124962. https://doi.org/10.1016/j.conbuildmat.2021.124962

Di Bartolo C, Bosetti S, De Stasio C, Malgieri P (2020) Smart choices for cities Cities towards Mobility 2.0: connect, share and go! Cities towards Mobility 2.0: connect, share and go! Smart choices for cities

Dorevitch S, Karandikar A, Washington GF, et al (2008) Efficacy of an Outdoor Air Pollution Education Program in a Community at Risk for Asthma Morbidity. J Asthma 45:839–844. https://doi.org/10.1080/02770900802339759

Doubleday K, Hafiz F, Parker A, et al (2019) Integrated distribution system and urban district planning with high renewable penetrations. Wiley Interdiscip. Rev. Energy Environ.

Elassar A (2020) Converse is sponsoring giant murals that break down air pollutants in 13 cities around the world - CNN Style. In: CNN Style

Enea D, Guerrini GL (2010) Photocatalytic properties of cement-based plasters and paints containing mineral pigments. Transp Res Rec. https://doi.org/10.3141/2141-10

Engelmann P, Kalz D, Salvalai G (2014) Cooling concepts for non-residential buildings: A comparison of cooling concepts in different climate zones. Energy Build. https://doi.org/10.1016/j.enbuild.2014.07.011

EPA (2008) Urban heat island basics. In: Reducing Urban Heat Islands: Compendium of Strategies | Heat

Island Effect | US EPA

EPA (2019) Using Green Roofs to Reduce Heat Islands. In: Heat Islands

European Environment Agency (2008) Transport

European Union Parliament (2009) European Parliament Directive 2009/30/EC. Off J Eur Union L140/88-L140/113

European Union Parliament (2008) Renewable energy directive. Eur Wind Energy Conf Exhib 2008 1:32–38

Falasca S, Curci G (2018) Impact of Highly Reflective Materials on Meteorology, PM10 and Ozone in Urban Areas: A Modeling Study with WRF-CHIMERE at High Resolution over Milan (Italy). Urban Sci 2:18. https://doi.org/10.3390/urbansci2010018

Fatiguso F, Bruno S, Cantatore E, et al (2021) Built Environments Prone to Sudden and Slow Onset Disasters: From Taxonomy Towards Approaches for Pervasive Training of Users. In: Gervasi O. et al. (ed) Computational Science and Its Applications – ICCSA 2021. ICCSA 2021. Lecture Notes in Computer Science, vol 12956. Springer, Cham, pp 125–139

Federal Emergency Management Agency (2007) FEMA 430: Site and Urban Design for Security: Guidance Against Potential Terrorist Attacks

Fernyhough J (2021) Enel X launches bid to power Australia's electric bus revolution. In: The Driven

Ferreira TM, Mendes N, Silva R (2019) Multiscale Seismic Vulnerability Assessment and Retrofit of Existing Masonry Buildings. Buildings 9:91. https://doi.org/10.3390/buildings9040091

FOKUS F KATWARN

Frumento S, Giovinazzi S, Lagomarsino S, Podestà S (2006) Seismic retrofitting of unreinforced masonry buildings in Italy. In: NZSEE. University of Canterbury. Civil and Natural Resources Engineering, pp 341–350

Gallagher J, Baldauf R, Fuller CH, et al (2015) Passive methods for improving air quality in the built environment: A review of porous and solid barriers. Atmos. Environ.

Geros V, Santamouris M, Tsangrasoulis A, Guarracino G (1999) Experimental evaluation of night ventilation phenomena. Energy Build 29:141–154. https://doi.org/10.1016/s0378-7788(98)00056-5

Giovagnorio I, Chiri GM (2012) The Environmental Dimension of Urban Design: A Point of View. Intech i:13. https://doi.org/10.1016/j.colsurfa.2011.12.014

Giuliani F, De Falco A, Cutini V (2020) The role of urban configuration during disasters. A scenario-based methodology for the post-earthquake emergency management of Italian historic centres. Saf Sci 127:104700. https://doi.org/10.1016/j.ssci.2020.104700

Godey S, Bossu R, Guilbert J (2013) Improving the mediterranean seismicity picture thanks to international collaborations. Phys Chem Earth 63:3–11. https://doi.org/10.1016/j.pce.2013.04.012

Green City Solutions (2021) CITYTREE - Green City Solutions

Grigoratos T, Giorgio M (2014) Non-exhaust traffic related emissions. Brake and tyre wear PM

Gromke C, Jamarkattel N, Ruck B (2016) Influence of roadside hedgerows on air quality in urban street canyons. Atmos Environ. https://doi.org/10.1016/j.atmosenv.2016.05.014

Guo S-E, Chi M-C, Hwang S-L, et al (2020) Effects of Particulate Matter Education on Self-Care Knowledge Regarding Air Pollution, Symptom Changes, and Indoor Air Quality among Patients with Chronic Obstructive Pulmonary Disease. Int J Environ Res Public Health 17:4103. https://doi.org/10.3390/ijerph17114103

Hamburg.de Grünes Netz

Hanley S (2021) Volkswagen Uses Pollution-Absorbing Paint To Advertise ID.3 In UK

Hassan AM, ELMokadem AA, Megahed NA, Abo Eleinen OM (2020) Urban morphology as a passive strategy in promoting outdoor air quality. J Build Eng. https://doi.org/10.1016/j.jobe.2020.101204

Hee WJ, Alghoul MA, Bakhtyar B, et al (2015) The role of window glazing on daylighting and energy saving in buildings. Renew Sustain Energy Rev 42:323–343. https://doi.org/10.1016/j.rser.2014.09.020

Hwang RL, Lin TP, Matzarakis A (2011) Seasonal effects of urban street shading on long-term outdoor thermal comfort. Build Environ 46:863–870. https://doi.org/10.1016/j.buildenv.2010.10.017

Imran HM, Kala J, Ng AWM, Muthukumaran S (2018) Effectiveness of green and cool roofs in mitigating urban heat island effects during a heatwave event in the city of Melbourne in southeast Australia. J Clean Prod 197:393–405. https://doi.org/10.1016/j.jclepro.2018.06.179

Italian technical commission for seismic micro-zoning (2014) Handbook of analysis of emergency conditions in urban scenarios (Manuale per l'analisi della condizione limite dell'emergenza dell'insediamento urbano (CLE); in Italian), 1st edn. Rome, Italy

Janhäll S (2015) Review on urban vegetation and particle air pollution - Deposition and dispersion. Atmos. Environ.

Jay O, Hoelzl R, Weets J, et al (2019) Fanning as an alternative to air conditioning – A sustainable solution for reducing indoor occupational heat stress. Energy Build 193:92–98. https://doi.org/10.1016/j.enbuild.2019.03.037

Karachaliou P, Santamouris M, Pangalou H (2016) Experimental and numerical analysis of the energy performance of a large scale intensive green roof system installed on an office building in Athens. Energy Build. https://doi.org/10.1016/j.enbuild.2015.04.055

Kaya O, Klepacka AM, Florkowski WJ (2019) Achieving renewable energy, climate, and air quality policy goals: Rural residential investment in solar panel. J Environ Manage. https://doi.org/10.1016/j.jenvman.2019.109309

Kohler M (2006) Living wall systems - a view back and some visions . 4th Annu Green Rooftops Sustain Communities Conf Award Trade Show

Köhler M (2008) Green facades-a view back and some visions. Urban Ecosyst. https://doi.org/10.1007/s11252-008-0063-x

Kolarik J, Toftum J (2012) The impact of a photocatalytic paint on indoor air pollutants: Sensory assessments. Build Environ 57:396–402. https://doi.org/10.1016/j.buildenv.2012.06.010

Kouris LAS, Triantafillou TC (2018) State-of-the-art on strengthening of masonry structures with textile reinforced mortar (TRM). Constr Build Mater 188:1221–1233.

https://doi.org/10.1016/j.conbuildmat.2018.08.039

Kptecki P (2018) New York City Painted Over 9.2 Million Square Feet of Rooftop White. In: Insider

La Rocca RA (2010) Soft Mobility and Urban Transformation. Some European Case Studies. J L Use, Mobil Environ 3:85–90

LE governement (2021) Public transport - Fast and free, the best way to explore the country

Li H, Harvey JT, Holland TJ, Kayhanian M The use of reflective and permeable pavements as a potential practice for heat island mitigation and stormwater management. https://doi.org/10.1088/1748-9326/8/4/049501

Loomans T (2013) The World's First Algae-Powered Building Opens in Hamburg. In: inHabitat

Ma WJ, Lin QX, Lin HL, et al (2016) Effectiveness of health education about heat wave hazard prevention in the elderly: a mixed effect model analysis. Zhonghua Liu Xing Bing Xue Za Zhi 37:1228—1232. https://doi.org/10.3760/cma.j.issn.0254-6450.2016.09.009

Maddaloni G, Di Ludovico M, Balsamo A, et al (2018) Dynamic assessment of innovative retrofit techniques for masonry buildings. Compos Part B Eng 147:147–161. https://doi.org/10.1016/j.compositesb.2018.04.038

Majowiecki M (2015) Roof of the pedestrian walkway for the Milan Expo 2015 exhibition complex. In: Majowiecki website

Manso M, Castro-gomes J (2015) Green wall systems : A review of their characteristics. Renew Sustain Energy Rev 41:863–871. https://doi.org/10.1016/j.rser.2014.07.203

Martinez LM, Viegas JM (2017) Assessing the impacts of deploying a shared self-driving urban mobility system: An agent-based model applied to the city of Lisbon, Portugal. Int J Transp Sci Technol 6:13–27. https://doi.org/10.1016/j.ijtst.2017.05.005

Mo J, Zhang Y, Xu Q, et al (2009) Photocatalytic purification of volatile organic compounds in indoor air: A literature review. Atmos. Environ.

Mordanova A, De Santis S, De Felice G (2016) State-of-the-art review of out-of-plane strengthening of masonry walls with mortar-based composites. Struct Anal Hist Constr Anamn diagnosis, Ther Control - Proc 10th Int Conf Struct Anal Hist Constr SAHC 2016 337–343. https://doi.org/10.1201/9781315616995-44

MWH (2004) GREEN ROOF TEST PLOT 2003 END OF YEAR PROJECT SUMMARY REPORT

Nasution B, Jansen K, Afari-Kwarteng J, Ten Pierik S (2016) Algae as Filter for Air Quality in Buildings

Nationale SG de la D et de la S (2016) FAIRE FACE ENSEMBLE. VIGILANCE, PRÉVENTION ET PROTECTION FACE À LA MENACE TERRORISTE

Nicholson AJ (2007) Road network unreliability: Impact assessment and mitigation. Int J Crit Infrastructures 3:346–375. https://doi.org/10.1504/IJCIS.2007.014115

OECD SWEDEN conclusions and recommendations

Oliveri (a cura di) M, Olivieri M (2004) Regione Umbria. Vulnerabilità urbana e prevenzione urbanistica degli effetti del sisma: il caso di Nocera Umbra. Urban - INU 44:

Ottelé M, van Bohemen HD, Fraaij ALA (2010) Quantifying the deposition of particulate matter on climber vegetation on living walls. Ecol Eng. https://doi.org/10.1016/j.ecoleng.2009.02.007

Pastore MC, Boeri S, Gambino D, et al (2020) ForestaMi. In: For. Rep. 2020

Pastore MC, Boeri S, Gambino D, et al Gruppo di ricerca: Politecnico di Milano FCL-Future City Lab DAStU Responsabile scientifico

Pedrini L (2017) Bologna, le fioriere anti-terrorismo dei T-Days. Le foto

Pei Z (2019) Roles of neighborhood ties, community attachment and local identity in residents' household waste recycling intention. J Clean Prod 241:118217. https://doi.org/10.1016/j.jclepro.2019.118217

Pelaez M, Nolan NT, Pillai SC, et al (2012) A review on the visible light active titanium dioxide photocatalysts for environmental applications. Appl. Catal. B Environ.

Pérez G, Vila A, Solé C, et al (2015) The thermal behaviour of extensive green roofs under low plant coverage conditions. Energy Effic. https://doi.org/10.1007/s12053-015-9329-3

Quagliarini E, Bernardini G, D'Orazio M (2023) How Could Increasing Temperature Scenarios Alter the Risk of Terrorist Acts in Different Historical Squares? A Simulation-Based Approach in Typological Italian Squares. Heritage 6:5151–5188. https://doi.org/10.3390/heritage6070274

Quagliarini E, Fatiguso F, Lucesoli M, et al (2021a) Risk Reduction Strategies against Terrorist Acts in Urban Built Environments: Towards Sustainable and Human-Centred Challenges. Sustainability 13:901. https://doi.org/10.3390/su13020901

Quagliarini E, Lucesoli M, Bernardini G (2021b) How to create seismic risk scenarios in historic built environment using rapid data collection and managing. J Cult Herit 48:93–105. https://doi.org/10.1016/j.culher.2020.12.007

Ratti C, Baker N, Steemers K (2005) Energy consumption and urban texture. Energy Build 37:762–776. https://doi.org/10.1016/j.enbuild.2004.10.010

Rogers Architects NYSE: Financial District Streetscapes. Bollards and barriers

Rus K, Kilar V, Koren D (2018) Resilience assessment of complex urban systems to natural disasters: A new literature review. Int J Disaster Risk Reduct 31:311–330. https://doi.org/10.1016/j.ijdrr.2018.05.015

Salvalai G, Pfafferott J, Sesana MM (2013) Assessing energy and thermal comfort of different low-energy cooling concepts for non-residential buildings. Energy Convers Manag. https://doi.org/10.1016/j.enconman.2013.07.064

Salvo G Di, Giuffré M, Pellegrino P, B. P (2012) Prevenzione e ricostruzione per la riduzione del rischio sismico. Planum XV Confere:

Sampson H (2021) Umbrella Sky Project: How a Mary Poppins-inspired installation became a tourist magnet - The Washington Post. In: Washington Post

Santarelli S, Bernardini G, Quagliarini E (2018) Earthquake building debris estimation in historic city centres: From real world data to experimental-based criteria. Int J Disaster Risk Reduct 31:281–291. https://doi.org/10.1016/j.ijdrr.2018.05.017

Setiffi F, Lazzer GP (2018) Riding free-riders? A study of the phenomenon of BlaBlaCar in Italy. Contemp

Collab Consum 77–96. https://doi.org/10.1007/978-3-658-21346-6_5

Shafique M, Kim R, Rafiq M (2018) Green roof benefits, opportunities and challenges – A review. Renew Sustain Energy Rev 90:757–773. https://doi.org/10.1016/j.rser.2018.04.006

Shahmohamadi P, Che-Ani AI, Etessam I, et al (2011) Healthy environment: The need to mitigate urban heat island effects on human health. Procedia Eng 20:61–70. https://doi.org/10.1016/j.proeng.2011.11.139

Sharifi A (2019a) Urban form resilience: A meso-scale analysis. Cities 93:238–252. https://doi.org/10.1016/j.cities.2019.05.010

Sharifi A (2019b) Resilient urban forms: A review of literature on streets and street networks. Build Environ 147:171–187. https://doi.org/10.1016/j.buildenv.2018.09.040

Sisti R, Corradi M, Borri A (2016) An experimental study on the influence of composite materials used to reinforce masonry ring beams. Constr Build Mater 122:231–241. https://doi.org/10.1016/j.conbuildmat.2016.06.120

Speak AF, Rothwell JJ, Lindley SJ, Smith CL (2012) Urban particulate pollution reduction by four species of green roof vegetation in a UK city | Elsevier Enhanced Reader. In: Atmos. Environ.

Srinurak N, Mishima N, Fuchikami T, Duangthima W (2016) Analysis of Urban Morphology and Accessibility Character to Provide Evacuation Route in Historic Area. Procedia - Soc Behav Sci 216:460–469. https://doi.org/10.1016/j.sbspro.2015.12.061

Sue-feng T Living Walls: Horticultural Wonders in the Concrete Jungle - 台灣光華雜誌

Sun T, Grimmond CSB, Ni GH (2016) How do green roofs mitigate urban thermal stress under heat waves? J Geophys Res. https://doi.org/10.1002/2016JD024873

Susdrain (2014) Case study, Derbyshire Street Pocket Park, London Borough of Tower Hamlets

Synnefa A (2007) Cool-colored coatings fight the urban heat-island effect. SPIE Newsroom. https://doi.org/10.1117/2.1200706.0777

Tancogne-Dejean M, Laclémence P (2016) Fire risk perception and building evacuation by vulnerable persons: Points of view of laypersons, fire victims and experts. Fire Saf J 80:9–19. https://doi.org/10.1016/j.firesaf.2015.11.009

Tévar G, Gómez-Expósito A, Arcos-Vargas A, Rodríguez-Montañés M (2019) Influence of rooftop PV generation on net demand, losses and network congestions: A case study. Int J Electr Power Energy Syst. https://doi.org/10.1016/j.ijepes.2018.09.013

The European Commission (2022) Security by Design: Protection of public spaces from terrorist attacks

U.S. Green building Council (2019) LEED - Reference guide for building design and construction

UNISDR (2015) Sendai framework for disaster risk reduction 2015-2030

Valluzzi MR, Modena C, de Felice G (2014) Current practice and open issues in strengthening historical buildings with composites. Mater Struct Constr 47:1971–1985. https://doi.org/10.1617/s11527-014-0359-7

Van Ryswyk K, Prince N, Ahmed M, et al (2019) Does urban vegetation reduce temperature and air pollution concentrations? Findings from an environmental monitoring study of the Central

Experimental Farm in Ottawa, Canada. Atmos Environ 218:116886. https://doi.org/10.1016/j.atmosenv.2019.116886

Viecco M, Vera S, Jorquera H, et al (2018) Potential of particle matter dry deposition on green roofs and living walls vegetation for mitigating urban atmospheric pollution in semiarid climates. Sustain. https://doi.org/10.3390/su10072431

Vox G, Blanco I, Schettini E (2017) Green façades to control wall surface temperature in buildings. Build Environ. https://doi.org/10.1016/j.buildenv.2017.12.002

Wen H, Malki-Epshtein L (2018) A parametric study of the effect of roof height and morphology on air pollution dispersion in street canyons. J Wind Eng Ind Aerodyn. https://doi.org/10.1016/j.jweia.2018.02.006

Yang J, Shi B, Shi Y, et al (2020) Air pollution dispersal in high density urban areas: Research on the triadic relation of wind, air pollution, and urban form. Sustain Cities Soc. https://doi.org/10.1016/j.scs.2019.101941

Yang J, Yu Q, Gong P (2008) Quantifying air pollution removal by green roofs in Chicago. Atmos Environ. https://doi.org/10.1016/j.atmosenv.2008.07.003

Ye M, Wang J, Huang J, et al (2011) Methodology and its application for community-scale evacuation planning against earthquake disaster. Nat Hazards 61:881–892. https://doi.org/10.1007/s11069-011-9803-y

Yin S, Cai JP, Chen LP, et al (2007) Effects of vegetation status in urban green spaces on particles removal in a canyon street atmosphere. Shengtai Xuebao/ Acta Ecol Sin. https://doi.org/10.1016/s1872-2032(08)60007-4

Zanello E (2017) miglioramento sismico con trefoli in acciaio inox. La torre Nord el Castello di Compiano. Recuper. e Conserv. Mag.

Zhu Y, Wang Z, Yang J, Zhu L (2020) Does renewable energy technological innovation control China's air pollution? A spatial analysis. J Clean Prod. https://doi.org/10.1016/j.jclepro.2019.119515

Zlateski A, Lucesoli M, Bernardini G, Ferreira TM (2020) Integrating human behaviour and building vulnerability for the assessment and mitigation of seismic risk in historic centres: Proposal of a holistic human-centred simulation-based approach. Int J Disaster Risk Reduct 43:101392. https://doi.org/10.1016/j.ijdrr.2019.101392

ANNEX – Description of practical examples of application of mitigation strategies

SL.A.1 – SL.A.2 – SL.A.3 Improve vegetation

Greening of existing infrastructure provides natural habitats for wildlife and spaces for human enjoyment in increasingly dense cities. Transport links should be converted into linear parks, creating new nature areas. This mitigation strategy has been applied by the city of Hamburg. In fact, Hamburg has announced a plan to implement a city-wide network of green spaces by 2030, linking the city's outer ring with its dynamic centre through a series of walking and cycling-friendly regeneration habitats. This choice is not guided only by the will to beautify the urban space but also to better address impacts of climate change. The green network could at once reduce urban heat island effects, improve air quality and provide manifold public health benefits associated with urban greenery (Hamburg.de).

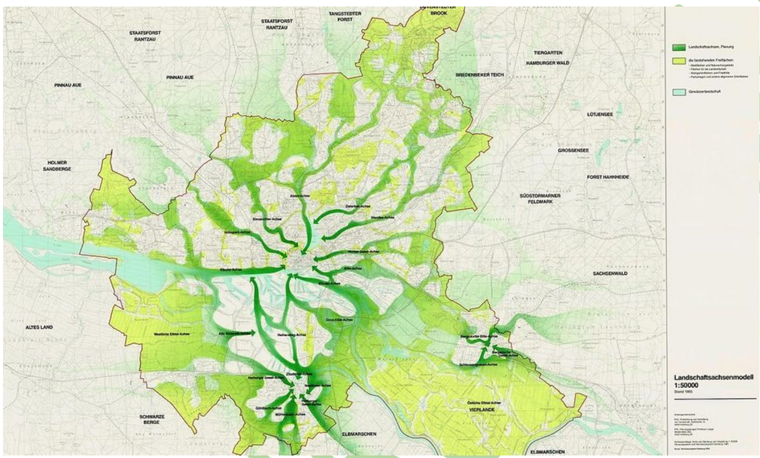


Figure 4 -

Another example is the new territorial administration plan for the city of Milan. Also in this case, the municipality suggests the development of new green areas, parks, green infrastructures especially inside dismissed areas. Also, the ideals of the city administration plan inspired projects such as "ForestaMI". This project aims at planting three million of trees by 2030, to purify air, provide a better landscape and fight the effects of climate change (Pastore et al. 2020).

The examples of Hamburg and Milan are not the only ones. Halifax, Vittoria-Gasteiz, Medellin, Niteroi, Cleveland, Atlanta, Denver, Singapore are all cities developing similar strategic plans and project to improve greenery in the urban space (Pastore et al.).

SL.A.4 Seasonal shading systems

Seasonal shading systems can improve the quality of living in the microclimate during the hot season. A practical example is the shading system of Expo 2015, realized in Milan. The masterplan of the entire area was based on two major roads, the cardo and the decumanus, with a minimum extension of one kilometer and 400 meters. Since the exhibition was performed during summer, a shading system has been designed to cover the two major axis. The system has been studied through simulations in order to define a double structure that allows both shading and the correct ventilation underneath the membranes (Majowiecki 2015).

Figure 5 – Expo2015 decumanus with the shading system, Milan

Another example, slightly more scenographic is the Metrosol Parasol in the city of Sevilla. At the time it was built, it was defined the largest wooden structural work in the world. the creation of this huge structure allowed the redevelopment of the ancient Plaza de la Encarnaciòn, which was abandoned and used only as a parking lot. Nowadays this plaza is a new contemporary urban center in where users can enjoy the public space and also experience the Metrosol Parasol thanks to the stairs stairs leading to the roof terrace (Casella 2018).

Figure 6 - Metrosol Parasol in the city of Seville

Shading systems can be simpler and temporary as the ones created by the "Umbrella sky project". In this case, the shading is provided in streets thanks to several colorful umbrellas, fixed on suspended cables. The solution not only is extremely useful for mitigating the heat stress, but it is a powerful instrument for the regeneration of trivial and not very noteworthy places. Also, the simplicity and beauty of the system have favored its spread all over the world (Sampson 2021).

Figure 7 - Umbrella sky project in the city of Agueda, Portugal

SL.A.5 New BE (form, layout, orientation)

To develop more resilient buildings, it is important to establish some simple principles since the design phase. In fact, at this stage, it is very common to choose building characteristics that can be responsible of increasing the urban heat island effect. Another aspect that must take into consideration is the fact that buildings can influence the shape of urban canyons, thus air ventilation in the streets.

Software is a powerful tool for developing architectures that are more integrated in the built environment. For example, instruments like Ladybug Tools allow to develop environmental analysis to shape a perfect building during design process considering wind flows, solar radiation and material properties. Also, there are software like ENVI-met capable of foretelling the pollution in the built environment.

SL.B.1 Urban surface and roughness

The same assumptions made for cool and reflective roofs can be done for pavements. Solar reflective "cool" pavements stay cooler in the sun than traditional pavements. Pavement reflectance can be enhanced by using reflective aggregate, with the usage of materials with high albedo coefficient.

In Los Angeles, the Bureau of Street Services tested a new creative approach to fight rising temperatures covering one neighbourhood street in each of the LA's 15 council districts with CoolSeal, a more reflective asphalt-based coating. This to reach a reduction of 3°C in perceived temperatures (Abdallah 2018).

Figure 8 - Los Angeles white painting project

SL.B.2 Permeable pavers

Permeable paving can improve water absorption and slow rainwater run-off and can be easily installed in interstitial spaces between buildings. More permeable surfaces will help cities to better cope with extreme weather events and increased sudden precipitation whilst reducing the heat island effect. In fact, in climate where the availability of water is not a problem, the use of permeable and retentive pavement can also create benefit in the modification of the existing microclimate.

Depending on hydraulic conductivity and albedo coefficient, each material can reach a specific temperature. A study in California (Li et al.), compared samples of different surfaces (concrete, asphalt and pavers) to test the differences and prove that permeable pavers, especially under wet conditions could give lower surface temperatures creating a cooling effect. Also, results showed that using high albedo and permeable pavement can potentially help mitigate near-surface heat island and improve the air quality as well as possibly improving human thermal comfort. Compared to the impermeable pavement, permeable pavement has a low thermal impact (i.e. heat exchange) on near-surface air.

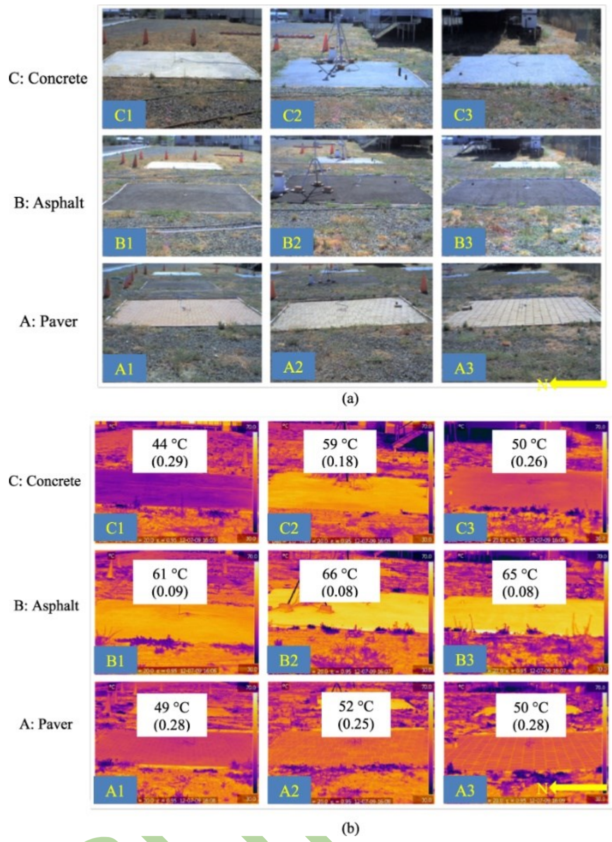
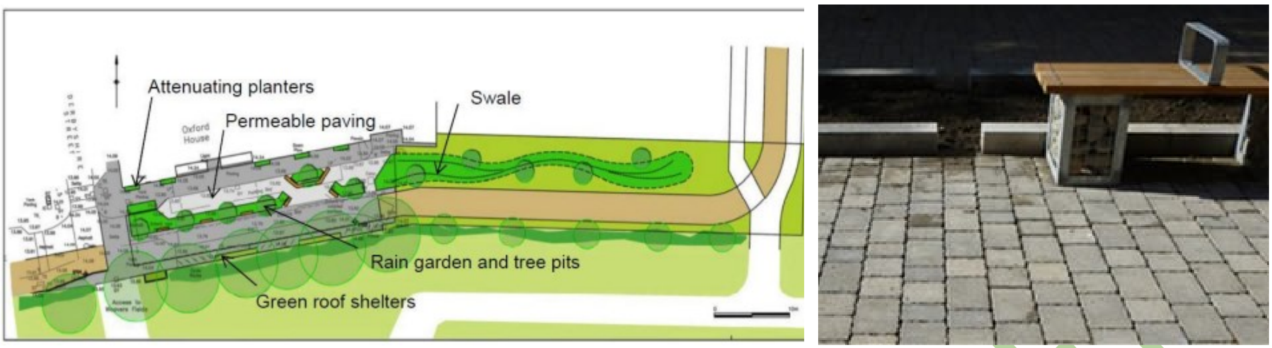


Figure 9 - Optical and thermal images of esperimental test sections. (a) Optical images. (b) Infrared thermal images under dry conditions. (lighter is hotter, average surface temperatures are listed with albedo in parentheses)

A concrete example is the one of Derbyshire Street Pocket Park in London. This area was a dead-end section of the public highway, used primarily for parking. The project resulted from the proposed installation of a new cycle route as well as working with Oxford House to create new outside space for community events. Within the project several sustainable aspects have been developed, including the application of SuDS (Sustainable Drainage Systems) to promote them and use the scheme as a case study for developers (Susdrain 2014). In particular, the project layout foresees 45 m^2 of permeable block paving to facilitate drainage and decrease summer surface temperatures.



(a) (b)

Figure 10 – (a) Derbyshire Street proposed layout (b) Derbyshire permeable pavement

SL.B.3 Permeable grass pavers

Grass in an experimental plot was found to reduce maximum surface temperature by up to 24 °C when compared to concrete. The implementation of grass not only make city greener but helps the drainage had contributes to the reduction of Urban heat island.

The permeable pavers available on the market are a lot, but here it is illustrated the permeable paver produces by an Italian company named “Ferrari BK”. Compared to other competitors, this product optimised the grass area with a covering rate of 57% compared to the 37% of the traditional permeable pavers. The more grass is present on the ground the more the surface is permeable, and the greenery helps in the absorption of pollutants

Figure 11 – Lunix Permeable grass paver

SL.B.4 City trees

The city tree is a freestanding “living display panel” consisting of 1.682 individual plant pots arranged in a vertical concrete grid. The project aims to exchange sponsorship of City tree units for corporate advertising. Each city tree includes rainwater capture technology linked to moisture sensors which automatically hydrate the plant beds as needed. The basis for each plant pod is a species of moss known for its ability to capture airborne particulates. After a 10 week period of monitoring, the city tree provided the following results: 1.3 million cubic metres of air purified and 65 grams of ultra-fine dirt particles filtered out, which corresponds to the pollutant of 14.400 kilometers car ride. In general the system can reduce fine dust pollution in its immediate vicinity by up to 53%, it filters 3500 m^3 of air every hour and it can cool the temperature in its immediate vicinity by up to 2.5 °C on warm days (Green City Solutions 2021).

Figure 12 - City Tree developed by Green City Solutions.

SL.B.11 Cool façade

The finish of outside vertical surfaces of buildings can have an impact on temperatures but also on the air quality. Depending on the surface properties and coatings a wall can contribute to the mitigation of SLODs.

Light colour paintings are known for having a high albedo coefficient, low heat capacity and high thermal emissivity. For their reflective properties, white paintings have been historically exploited to cool buildings in hot, sunny climates. A "cool" wall is an exterior wall surface that stays cool in the sun by strongly reflecting sunlight and by efficiently emitting thermal infrared radiation.

An example of cool wall is provided by cities of the Mediterranean area, where traditional historical centers are all painted in white in order to reflect the heat during summer. The image below represents the case of Santorini in Greece.

Figure 13 - Buildings with white-washed walls in Santorini, Greece

SL.B.12 Reflective roof / Cool roof

Nowadays, not all the existing roofs are reflective or cool simply because they have been built during a period in which these parameters weren't considered so important. Thanks to research, solutions have been developed and are suitable both for new and existing roofs. Painting roods white is a low-cost improvement that reduces energy consumption of building in the hottest period. Sun reflecting paints and materials such as light-toned gravels can reduce solar gains. An example of this solution is the White roof project. It is a non-profit organisation promoting benefits of coating dark roofs with solar reflective paint. This modification decreases roof surface heat absorption (white roofs can reflect up to 90% of sunlight, compared to 20% for dark roofs) and can reduce cooling-related electricity usage by up to 40%. Local communities are encouraged to actively participate in making these simple changes. The project has painted over 100 roofs since 2010. Roof-repainting projects have included a 220,000-foot warehouse, a network of homeless shelters, and 20 cooperatively owned rooftops, called the Model Block, in a historic neighbourhood on the Lower East Side (Kptecki 2018).

Figure 14 - The white roof project in New York.

SL.B.13 Green walls

Vegitecture, developed by Capella Garcia Arquitectura, is a new concept in green wall design: it is a large-scale independent vertical infrastructure, separated from the original building. The first 21m high Vegitecture wall has been implemented in Barcelona. The system presents stairs and its own irrigation and fertiliser system while offering park-line urban spaces. Since this type of green walls runs independently from the existing building, Vegitecture can enhance exposed, unused walls in dense urban areas. Installing green facades and living walls has many benefits on the environment, buildings and human health.

Figure 15 - Vegitecture by Capella Garcia Arquitectura installed in Barcelona.

These benefits can involve both the internal comfort in buildings and the quality of outdoor air absorbing pollutants (Viecco et al. 2018), (Ottelé et al. 2010). Large areas of greenery help to suppress dust particles (high surface related to the specific volume), improving air quality around buildings and busy highways and this could also lead to a reduction in respiratory illness. According to the (Kohler 2006; Köhler 2008) if an inner city neighbourhood were greened on all possible facades 4% of annual dust-fall could be trapped on the leaves increasing the air quality.

Another example is the Park Lane by CMP. It is one of the most famous examples from Taichung city in Taiwan. This huge piece of green wall is composed of more than 150 thousand pots of various plants, Scandent Scheffera, Common Lantana, spider ivy, Calico plant, and so on. This green wall has been created with the intentions of purify the air, lower down both indoor and outdoor temperatures and beautifying the surroundings. A green wall of this size could absorb 200 kg of CO_2, while producing 150 kg of O_2 everyday (Sue-feng).

Figure 16 - Park lane by CMP in Taichung, Taiwan

SL.B.14 Green roofs

Green roof can be designed in different ways. A new building can be designed with a green roof, but it is also possible to integrate green roofs over already existing buildings. An example of green roof integration is the Cibeles Centre green roof installed over Madrid's city hall. 130 squared meters, with more than 4.000 plants from a range of species have been placed on the flat roof of the city hall.

Figure 17 - Green roof installed over Madrid city hall.

As has been stated before, the implementation of green infrastructure elements provides regulating ecosystems services to the urban environment. These include stormwater management, heat island control, aesthetic value and improvement of air and water quality. In particular, research in the field has demonstrated the potential of green roofs as a strategy for adapting urban ecosystems to the impact of climate change. Temperature reductions up to 4.5°C over summer were reported in the area of Madrid where the green roof has been implemented.

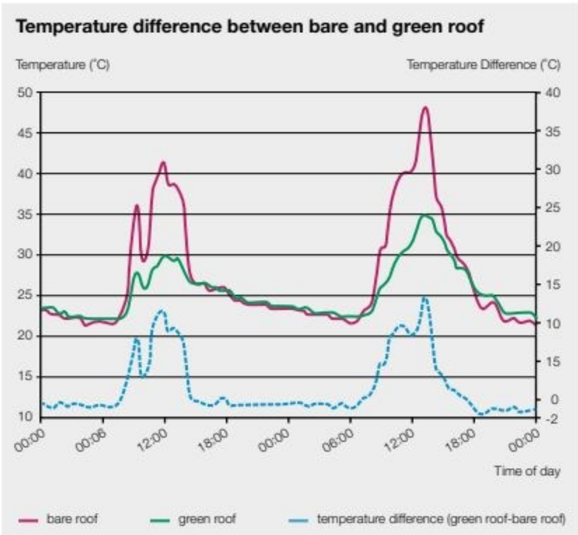


Figure 18 - Retroffitting housing with lightweight green roof technology

Another similar example is the green roof of Chicago City Hall. The green roof is the result of an EPA study, an initiative to fight the heat island effect and to improve the urban air quality. The roof extends over 3604 square meters with a monitoring system for plant survival as well as other environmental features such as temperature monitoring (MWH 2004).

Figure 19 - Green roof installed over Chicago City Hall terrace.

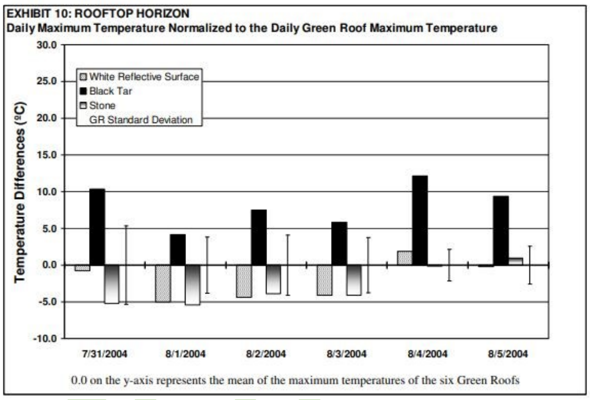


Figure 20 - Daily maximum temperature normalized to the daily green roof maximum temperature in Chicago.

SL.B.15 Photocatalytic materials

Nowadays, paintings and finishes evolved and are capable not only of reflecting light but are also capable of fighting pollution. Several renowned brands such as Converse and Volkswagen have been using photocatalytic, smog-eating paint to create murals across the world (Elassar 2020). This type of technology uses light energy to break down noxious air pollutants and convert them into harmless substances. Any surface coated with this type of paint becomes an active air-purifying surface that helps protect city users from harmful gases.

Figure 21 -Mural realized by Converse with photocatalytic paint

100 square meters of photocatalytic paint can filter as much air pollution out of the air as a comparable area with plants. These types of paints can also reduce sulphur oxide, ammonia, and carbon monoxide. This is possible because the colour mixture contains titanium dioxide crystals which break down chemical substances such as NOx, when exposed to light and humidity (Hanley 2021).

Figure 22 - Mural realized by Volkswagen with photocatalytic paint across UK.

To tackle down UHI and air pollution, there are also other technologies than paints. One of them is the Bios Self-Cleaning. It is a treatment used for ventilated facades and cladding. Thanks to the Hydrotect technology, when the Bios Self-Cleaning treatment comes into contact to sunlight, it triggers a reaction able to eliminate not only bacteria, but especially the pollutants in the air. It breaks down dirt that has settled on the surface of the tiles, so that it can be removed by rainwater, thanks to the superhydrophilicity of the ceramic material. It has been estimated that a 1000 square meters of Bios Self-Cleaning® facing can purify the air like a wood the size of a football pitch or remove the nitrogen oxides (NO_x) emitted by 70 cars during one day (Casalgrande Padana 2020).

SL.B.16 Algae pbr

The Microalgae are able to capture carbon dioxide and their biomass has a high energy yield and, above all, does not come into competition with agricultural land and sources of drinking water. Applying therefore the closed cultivation systems of microalgae become a special solar thermal for the presence of water which absorbs the solar heat. In addition to the well- known solar thermal benefits, the growth of Microalgae produces biomass and captures carbon dioxide, hence it helps to improve the energy performance of the building. Nowadays, the BIQ house in Hamburg built by ARUP and a mixed group of architects and biologists is the first and only existing and inhabited algae-powered building in the world.

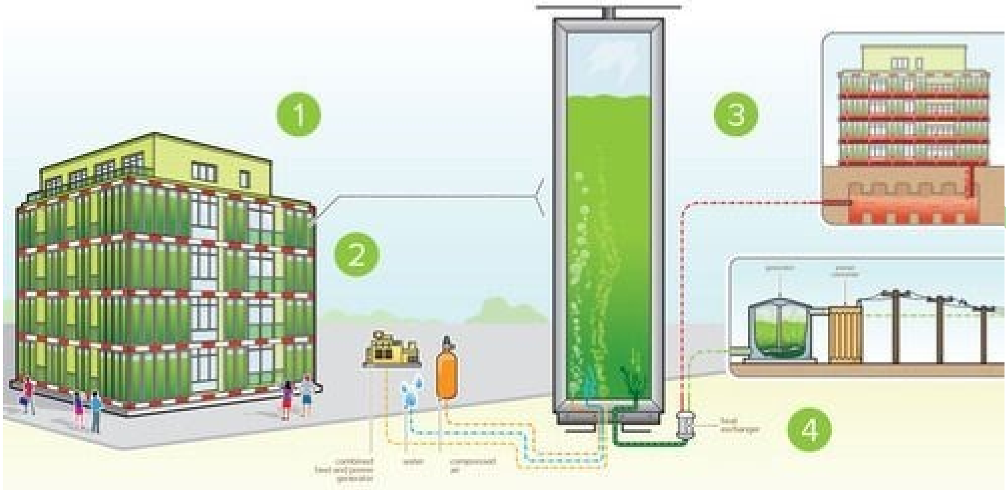


Figure 23 - Functional scheme of BIQ house in Hamburg

SL.C.2 Energy efficiency

Investing over a renewed and more efficient building stock is a key to improve cities and reduce the rising temperatures phenomenon and air pollution. With this in mind, both government authorities and private associations have developed protocols to promote buildings that produce the minimum amount of emissions, exploiting passive strategies and more efficient systems.

The European commission defined the common standard of nZEB, which stands for "Nearly Zero Energy Building". The nZEB is a building with very high performance in which the very low energy requirement is covered almost completely by energy from renewable sources, produced in situ.

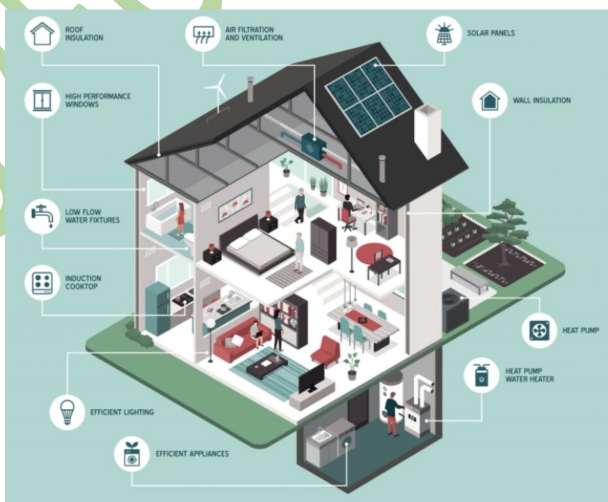


Figure 24 - nZEB strategies scheme

The nZEB standard regards only new buildings, but similar strategies can be applied in building renovations to improve systems and reduce consumption. Therefore, industries have developed devices to make existing buildings smarter and cut down consumption such as smart light bulbs, smart water meter, smart electricity meter, smart curtains, light sensor, motion sensors, smart plugs and switches. Also, the replacement of the old boilers with condensing boiler, the implementation of heat pumps, solar thermal system or photovoltaic systems are all valid strategies to improve building energy consumption.

Another option for improving energy efficiency is related to materials. The selection of low-impact building materials can help to reduce construction carbon footprint. The selection of proper materials can also contribute to achieve higher standards for the whole building. An example of this is the LEED certification, where a specific section is dedicated to Materials and resources. This category focuses on minimizing the embodied energy and other impacts associated with the extraction, processing transport, maintenance, and disposal of building materials (U.S. Green building Council 2019).

Figure 25 - An environmental product declaration (EPD) for building materials, according to the LEED standards.

SL.C.3 Waste management to avoid pollutant production

Since 1980s, Sweden has followed key principles for the management of products and waste: the precautionary principle, the substitution principle and the waste hierarchy and producer responsibility, Sweden has been active in eliminating hazardous substances from products and waste. The waste management policy has focused on the municipal waste rather than the industrial waste. Recycling rates for some waste streams, such as paper/cardboard and aluminium cans, are very high in Sweden. Municipalities have implemented separate collection systems for household waste, including separation of hazardous waste, to promote recycling and ensure proper disposal. Energy from waste, in the form of landfill gas and heat from waste incineration, is highly utilised and constitutes a substantial part of the energy supply.

Sweden has improved waste disposal practice since the 1980s; for example, air toxic emissions from incinerators have been reduced. Further effort is necessary, however, to improve smaller landfill sites and landfill practice. Legal frameworks for hazardous waste management and waste export and import have been improved. Sweden banned the export of hazardous waste to non-OECD countries in 1988. To progress further, Sweden should promote waste prevention, and strengthen proper management of industrial waste and of construction and demolition waste.

In general, from the Sweden example, it is recommended that consideration be given to the following proposals:

- develop a systematic procedure for priority setting in risk reduction;
- evaluate the procedures for reporting to the product register to maintain its usefulness for overview and enforcement;
- improve landfill management with, inter alia, leachate treatment and prevention of hazardous waste contamination, especially at smaller sites;
- develop a strategy including a legislative framework and the provision of basic statistics, to improve industrial and construction/demolition waste management;
- initiate producer responsibility for other prioritised waste streams;
- for the management of products, identify priority areas and formulate medium- to long-term strategies with clear targets, based on current work on priority setting and survey of material flows;
- in the long term, continue efforts to co-ordinate policies related to products and waste in developing and implementing a cost-effective framework in line with the ecocycle principle; integrate chemicals policies further into the ecocycle principle as a means of detoxifying ecocycles (OECD).

SL.C.1 Public transportation

In the transportation sector there are different examples of applied strategies that are helping in diminishing SLODs. Firstly, it can be useful to categorize the type of intervention whether it is related to public transportation system, shared mobility, electric and hybrid mobility or soft mobility.

Australia is an example of improvement of public transportation system. In fact, together with Enel X, the authorities have been replacing traditional buses with a dense network of electric buses to support electrification of public transport across the country. This cooperation between public transport authorities and private industries allows the replacing of traditional polluting diesel buses with cleaner and more sustainable vehicles (Fernyhough 2021).

Figure 26 - Enel X electric buses replacing traditional polluting diesel buses.

Luxembourg is the first country in the world to offer free public transport nationwide. This choice was the solution to traffic jams and to incentivize public transports (LE governement 2021). In this way, Luxembourg managed to diminish the total number of vehicles on roads.

SL.C.2 Shared mobility

In general, since it is impossible to eliminate completely vehicles from cities, authorities give incentives to those who buy electric cars with the aim of reducing CO_2 emissions. Another option to reduce the total number of vehicles can be the shared mobility. For sharing mobility, it is intended car sharing, bike sharing, ride sharing, ride sourcing and park share.

The car sharing has boomed in several cities. Milan is an example of this phenomenon. Since 2016, five different car sharing operators provide their services to the city. The car sharing system not only works in the city area, but it is extended to the surrounding metropolitan boundaries and the wider regional area. The different services, from round trip to free-floating car sharing, provide multiple and flexible shared-mobility services. Currently, the active services In Milan are: GuidaMI, Car2go, Enjoy, E-vai and SHARE'nGo (Di Bartolo et al. 2020).

Figure 27 - Major car sharing spread in the city of Milan.

SL.C.3 Controlled/limited traffic zones

An example of such measures can be found in Milan where public authorities established “Limited traffic areas” to the most polluting vehicles. In this way, both the air pollution can be controlled together with the number of vehicles that can actually run the roads lowering the recirculation of the deposited dangerous particles.

Also, sustainable mobility can be a solution to reduce the number of vehicles in cities. An example is represented by carpooling. This type of mobility consists of private shared vehicles, with the aim of cutting down the number of vehicles and costs related to transportation. In Italy, the most famous carpooling is “BlaBlaCar”. It is a French start up, born in 2006, that consists of a web platform that connects drivers with potential passengers. BlaBlaCar arrived in Italy in 2012 and since then, it spread all over the country. The average user of the service is a traveller of 32 years old. People travel for different reasons: work, vacations or to reach relatives. People who use this service care about the environment: in two years BlaBlaCar users saved 500.000 tons of fuel and 1 million tons of CO_2 haven't been released in the air (Setiffi and Lazzer 2018).

Ride sourcing is another example of sustainable short trips in urban areas. It is a service that allows passengers to connect with and pay drivers who use their personal vehicles for trips. Based on GIS and GPS technologies on internet-enabled devices, it allows to organize ride sharing in real time. Uber and Lyft are forerunners who have revolutionized the way people look for a solution for their short trips in urban areas (Di Bartolo et al. 2020).

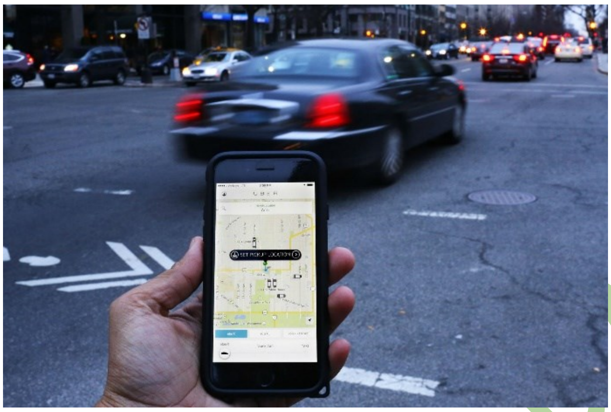


Figure 28 - Uber app for ride sourcing.

SL.C.4 Electric and hybrid mobility

To solve air quality problems, public authorities are also encouraging hybrid and electric vehicles (Bellocchi et al. 2019). Among those there is the electric micro mobility. In all cities, electric scooters are becoming so popular thanks to the low price and the easy of use. For example, it has been estimated that only for the city of Milan around 7600 scooters are rented per day. To satisfy the increasing demand, now there are seven private companies providing scooters: EM transit, Bird rides Italy, Voi technology Italia, Wind mobility, Bit mobility, Helbiz Italia and Lime technology. In addition, thanks to government's bonus also the number of private scooters is increasing (Comune di Milano 2020).

Figure 29 - Electric scooters in the city of Milan.

SL.C.5 Soft mobility

The city of Stuttgart has developed a set of various measures for promoting sustainable mobility. Among these the "Call a bike system" has been in operation since 2009 and nowadays comprises 450 bicycles and 100 pedelecs with 44 stations. The implementation of so many bicycles in the city created the need of other connected services such as bike parking, showers and wardrobes for employees who commute by bike (Di Bartolo et al. 2020).

Figure 30 - Bike sharing station in Stuttgart

SU.B. 5 Protection of strategic lifelines and infrastructures

The plan for road network improvement in the urban area in Kamigyo Ward, Kyoto proposes the ampliation of the roads to 7 m and a reinforcing of the buildings along the roads connected to this extension of the road (Ahn et al. 2011).

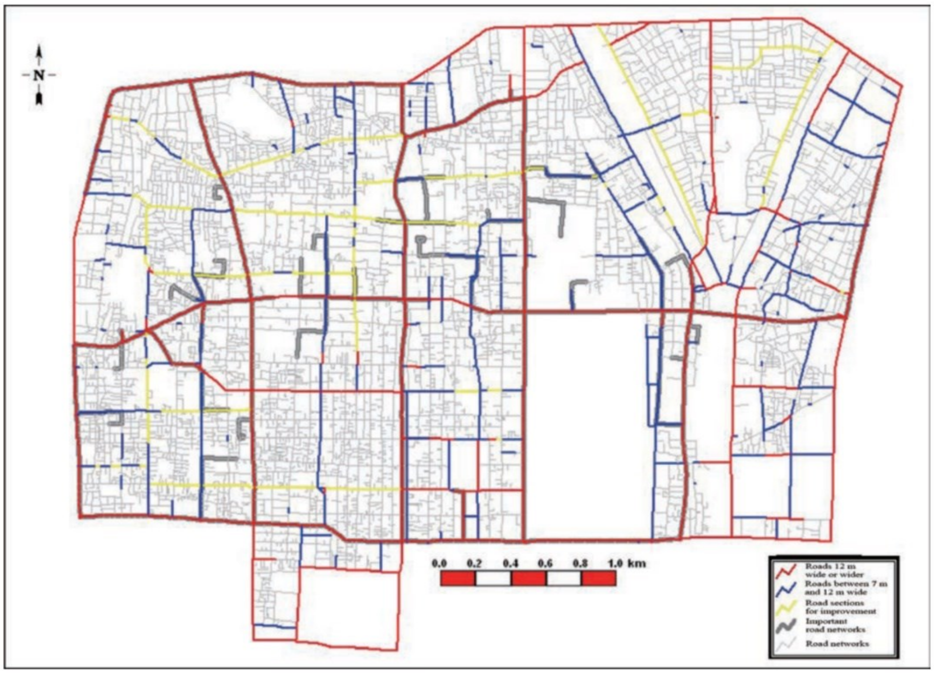


Figure 31: Plan for road network improvement (Ahn et al. 2011).

SU.B.19 Solutions for masonry wall quality increase Steel connectors

An innovative system of wall connectors is based on the use of helical stainless steel bars (Maddaloni et al. 2018). The bars are by dry application using a special spindle after drilling a pilot hole. This method can be used as easy and quick repairing solution to stitch the cracks because the use of dry application allows the immediate effectiveness of the intervention.

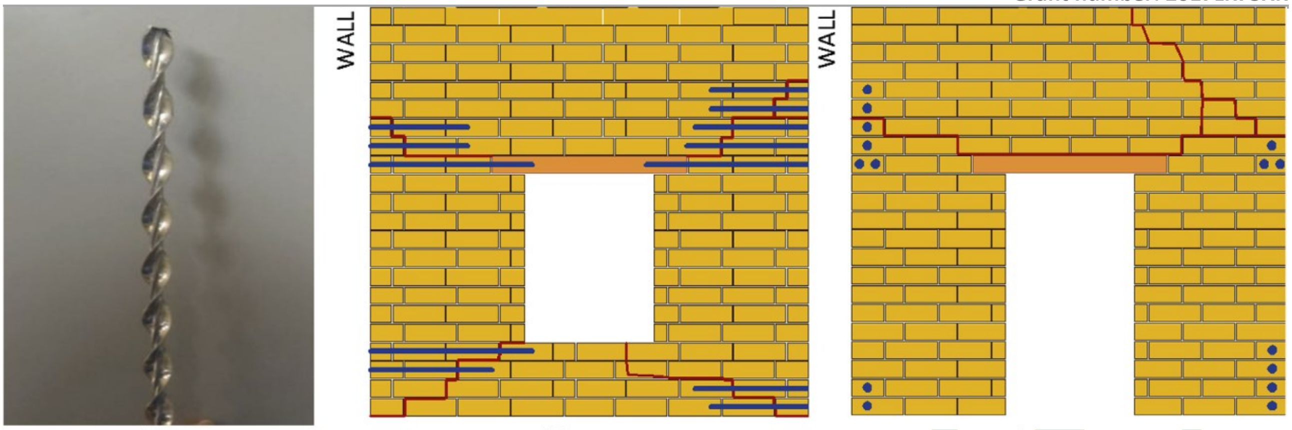


Figure 32 - Helical stainless steel bar and horizontal and transversal application of helical stainless steel bars in the masonry wall. Pictures from (Maddaloni et al. 2018).

FRP and FRCM system

The adoption of composite materials has increasingly been considered for strengthening of both modern and historic masonry constructions and their structural components (walls, arches and vaults, piers and columns. This method constrains the activation of possible failure mechanisms by increasing their seismic capacity and by providing tensile strength with negligible mass increase.

These reinforcement system can be installed by using different type of materials, and according to different layout arrangement on the wall panel (e.g. complete covering of the walls on the two side or only in one side, vertical and horizontal strips) and type of connectors (Mordanova et al. 2016)(Kouris and Triantafillou 2018). This application is particularly effective for masonry walls of multiple leaves (e.g., muro a sacco) because reduce the transversal deformations by increasing the bearing capacity. In fact, the procedure involves also the installation of fiber connector consisting of a bundle of fibers. Then, an inorganic matrix is used for impregnation and anchoring of joints.

The main materials and system are following explained:

- Fibre Reinforced Polymers (FRP) comprising carbon or glass textiles bonded with epoxy resins.
- Fabric Reinforced Cementitious Matrix (FRCM) is a composite material comprising fibres (e.g., carbon, glass, steel, basalt, synthetic and natural fabrics) embedded into inorganic matrices. This system allows faster and cheaper installation, and ensure better fire resistance, vapour permeability, removability, and compatibility with historic lime mortars.

Moreover, these systems are also widely applied for retrofitting of the cultural heritage and its peculiar architectural components, such as arches and vaults, piers and columns (Valluzzi et al. 2014) (Figure 33).

(a) (b)

Figure 33 - Strengthening of thin in folio brick vaults of Casino Ciolina after L'Aquila earthquake, by application of steel reinforced grout at extrados: overall view (a), application of strips (b). Pictures from (Valluzzi et al. 2014)

Reticolatus system

The "Reticolatus" system consists in the realization of a reinforced pointing of the joints on stone- masonry and brick-masonry walls, by means of stainless steel strips and connectors positioned within vertical and horizontal joints (Borri et al. 2014, 2019; Corradi et al. 2016, 2018; De Santis et al. 2021). This system can be installed on a single leaf of the masonry walls or on the both sides of the wall by combining the "Reticolatus" system with joints repointing on one face and applying Glass Fiber-Reinforced Matrix (GFRM) jacketing on the other.

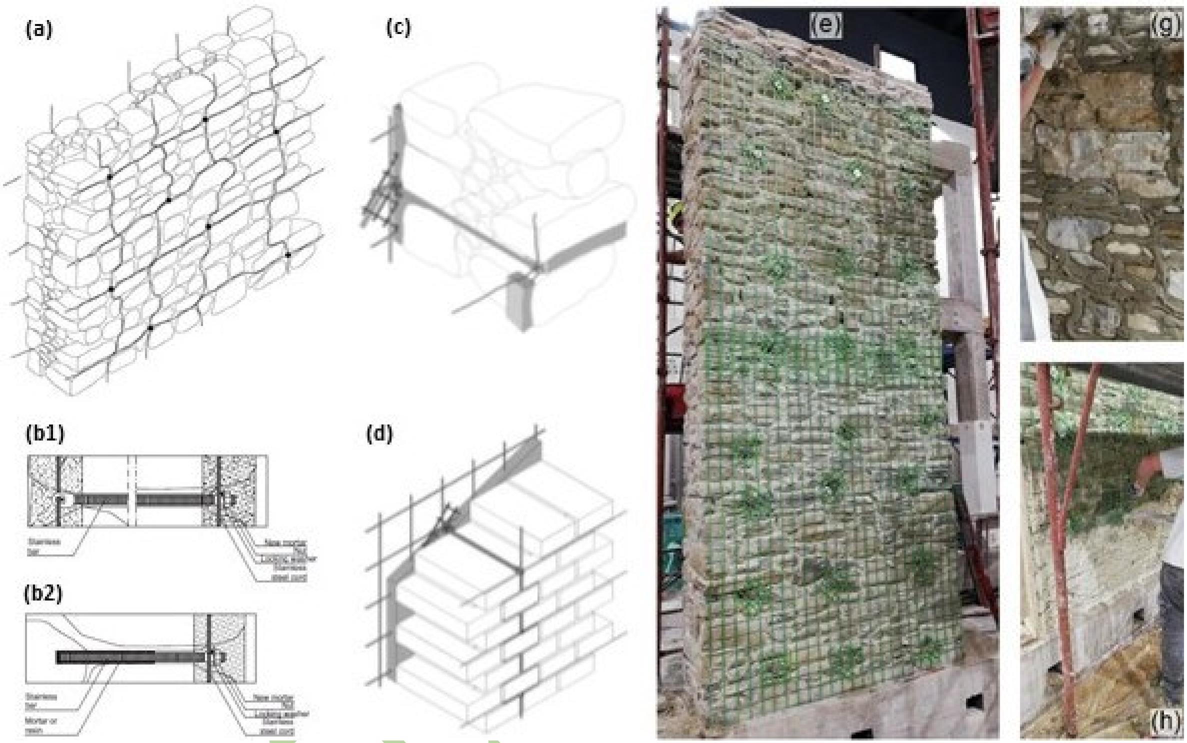


Figure 34 – Stone wall strengthened with "reticolatus" system (a). Detail of through connectors (b1). Detail of not-through connector (b2). Hybrid application of "reticolatus" with GFRP jacketing for stone-masonry panel (c) and brick-panels (d). GFRP mesh laid over the internal side (e). Repointing of the mortar joints of the external side (g). GFRP jacketing of the internal side (h). Pictures from (Borri et al. 2014; De Santis et al. 2021)

The system improves the tensile strength and ductility, thus maintaining the original aesthetic appearance. This retrofitting is particularly effective for historic masonry buildings where the presence of multiple scarcely connected leaves, the low quality of the mortars and the need to preserve the architectural aspect of the structure, require highly effective but low aesthetic impact structural reinforcement solutions. For these reasons, the reinforcement procedure is more suitable for retrofitting on the historic-monumental buildings (Zanello 2017) (Figure 35).

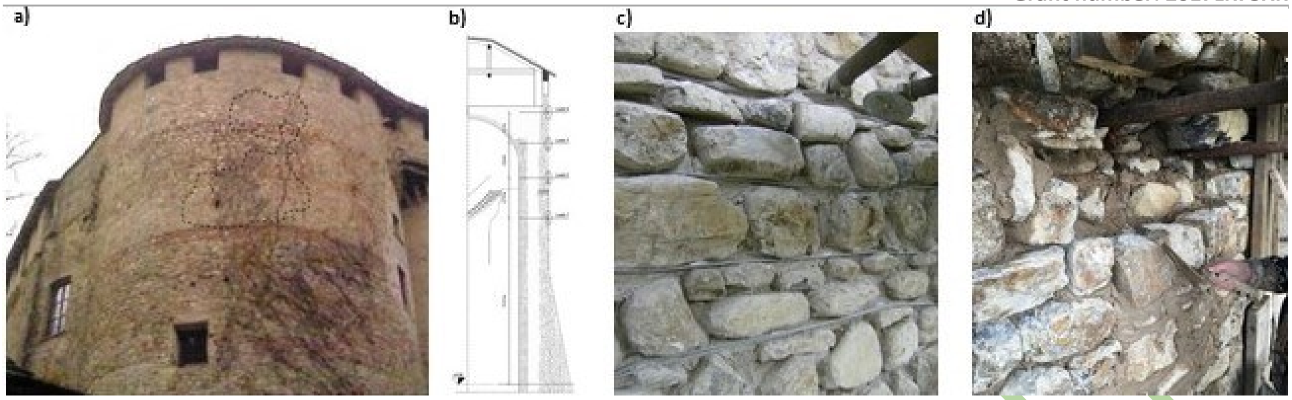


Figure 35 - Intervention of seismic improvement with stainless steel strands on the North tower of the Castle of Compiano - Parma (a). The stainless steel strands have been inserted at different rates of the tower (b,c), then embedded inside the grouting of mortar and bound to the perimeter walls (d). Pictures from (Zanello 2017)

Add anti-seismic devices (e.g., tie rods, steel tie beams and ring beams) wall-to-wall and wall-to-roof connections

The ring beams represent and effective solution to improve the connections of the wall with walls and with the floors and the roof, in order to achieve unitary behaviour of the masonry structure against the earthquake. Nowadays, the following solutions are the most effective for retrofitting (Sisti et al. 2016) (Figure 36):

- Brickwork steel-reinforced ring beam
- Steel-profile ring beam is realized by laying steel plates on the outer sides of the wall and connecting them through bars or rods to the masonry below.
- Reinforced masonry ring beams by the adoption of composite materials coupled with inorganic cement-based matrices. It consists in the reconstruction of the upper part of stone- or brick-masonry with composite materials-based grid (e.g., GFRP) completely embedded into the horizontal mortar bed joints. This reinforcement method is particularly suitable for historic building because allows to keep the fair-faced masonry appearance.

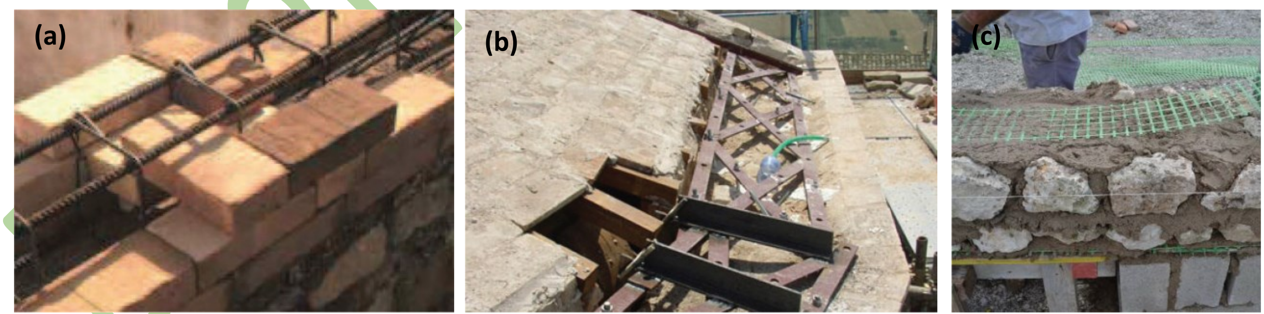


Figure 36 – Examples of ring beams by (Sisti et al. 2016): brickwork steel-reinforced ring beam (a); steel-profile ring beam (b); stone ring-beam strengthened with GFRP grids (c).

Barriers and fences SU.B.22

Examples of solutions integrated in the BE, which can reduce the OS vulnerability to terrorisms while being integrated in the OS are some specific applications of NOGO barriers/bollards (e.g., NYC, by Rogers Architects) or jerseys hosting greenery (e.g., Bologna, pedestrian area Ugo Bassi-Rizzoli-Indipendenza).

Figure 37. On the left, bollards in NYC, Wall Street, by Rogers Architects (image taken from (Rogers Architects)*); on the right, jerseys with greenery in Bologna (image taken from* (Pedrini 2017)*).*