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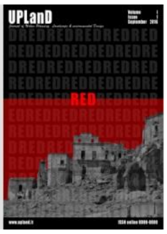

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CLIMATE CHANGE, URBAN VULNERABILITY AND ADAPTATION STRATEGIES TO PLUVIAL FLOODING

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HIGHLIGHTS

- Cities are increasingly prone to urban flooding due to heavier rainfall, denser populations, augmenting imperviousness, and infrastructure aging.
- Characteristics of buildings, open spaces and population increase the urban vulnerability to pluvial flooding.
- Building adaptive capacity can help to reduce urban vulnerability and risk.
- There are three feasible adaptation strategies for cities: coping, incremental and transformative.

ABSTRACT

In the study of impacts that multiple extreme events (natural and human) can produce on ecosystems, phenomena related to weather and climate changes represent a relevant, but not new, threats for human settlements, which have always faced with changing environmental and weather conditions. However, human activity of territorial alteration that took place over the centuries represents a disturbing action to the natural system, which requires new design approaches.

The construction of buildings and spaces with impervious surfaces and the introduction of specific activities in urban areas have altered the natural hydrological cycle. The combination of these anthropic features with the increase in the frequency and intensity of extreme precipitation events determines substantial impacts on built environment and population. In relation to this, it is necessary to work starting from the knowledge of the vulnerability characteristics of the affected systems, in order to implement suitable strategies and measures able to enhance a system's ability to adapt to change.

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1. INTRODUCTION

Extreme events have affected the history of human settlements since antiquity, repeating in different ways and forms (earthquakes, floods, hurricanes, etc.) (IRDR, 2014; C40, 2015) and causing huge damages to the built environment at urban and architectural scale. However, the human action of development of cities, the urban population growth and the high concentration of people and activities in urban areas occurred in the last two centuries make urgent the definition of an appropriate design response to current and future changes.

Such disruptive action for the natural system has resulted in excessive soil sealing, altering the hydrological system. In parallel to the increase of surface runoff volumes, there is an increase in the frequency and intensity of extreme precipitation events (heavy rainfall, rainstorm, heavy snow, hail).

Cities constitute a considerable pressure factors on the local (and global) climatic and environmental system and, at the same time, the most vulnerable human settlements to the impacts of extreme weather and climate events. The combination of these phenomena with specific urban characteristics (geographic, morphological, typological, technical and construction, cultural, socio-economic, etc.) determines significant effects on built heritage and population. The produced impacts, depending from the dangerousness of the event, are a direct result of intrinsic factors of the affected system, both physical and social, real responsible of climate and environmental risk which cities are subject. In fact, as shown unfortunately by different environmental disasters and calamities (tsunami, hurricanes, etc.), for the same event (intensity, magnitude, frequency) vulnerability have a greater impact on type and intensity of the effects, depending on context-specific factors of sensitivity, exposure and adaptive capacity.

According to these considerations, the relationship between climate change and urban environment is very interesting, actual and no longer negligible. The strong impact of event on population and on architectural and urban heritage requires the adoption of design strategies able to reduce vulnerability of the built, aimed to develop resilience in affected systems, increasing their adaptive capacity.

2. CITY CLIMATE HAZARD AND VULNERABILITY OF URBAN SYSTEM

2.1 *Hazard and impacts on urban areas: natural or human contribution?*

The study of phenomena linked to climate change and related technical measures and solutions to reduce the impacts cannot be conducted without taking into account the interaction with human systems.

Refer to natural hazards such as events causing disasters produced solely by the magnitude of the event is an error; different socioeconomic, cultural and political factors produce such disasters, although not properly taken into account by communities and governments (Bankoff, 2010). As already mentioned, these human factors, for the same hazard conditions, determine the level of risk and damage of the affected elements. Alteration of natural balances, population growth, uncontrolled land use and resource exploitation are among the main causes of the formation of social disasters, conventionally defined natural (Acot, 2007; Kelman, 2010; Marotta & Zirilli, 2015).

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called 'earthquakes' and 'hurricanes' are the natural forces; what are seen afterwards are the results of the impact of those forces on human settlements (where) damage destruction and death are conditioned by the decisions and actions of society over time.

James Lewis, 1999

Natural hazards are a part of life. But hazards only become disasters when people's lives and livelihoods are swept away. The vulnerability of communities is growing due to human activities that lead to increased poverty, greater urban density, environmental degradation and climate change.

Kofi Annan, 2003

These statements highlight the relationship between "natural" disasters and characteristics of the affected communities: man with his actions has compromised the natural balance, making it difficult to identify the causes of natural disasters and calling into question their effective "naturalness" (Marotta & Zirilli, 2015). As stated by different authors, natural disasters do not exist, because a dangerous event is characterized by human choices and actions that occur before, during or after the event, which impact on society itself (Marotta & Zirilli, 2015). In relation to this, the two most common definitions are "*unnatural disasters*" (Pulls, 1977; Abramovitz, 2001) and "*unnatural hazards*" (Hewitt, 1983; Kelman, 2010; 2011).

The dangerousness related to climate and weather events is linked more to the peculiarities of the affected elements and systems rather than the event itself, which therefore becomes hazard if there are conditions that would turn it into threat (IPCC, 2012). Although often associated with the concept of disaster, extreme weather event it is not always the primary cause, and critical situations can also occur without reaching extreme values. Geographical, socio-economic, institutional and morphological (planning and regulatory instruments) factors and the level of information and awareness of various actors involved greatly affect the response capacity of built environment and population, determining their degree of exposure and sensitivity (Peltonen et al., 2005; Wilhelmi & Hayden, 2010).

Consequently, in the analysis of the impacts produces by pluvial flooding on urban system, is not sufficient to know intensity, frequency and duration of the event. It is necessary to investigate the internal features of the affected system, which define its structural organization and its ability to cope, manage and recover after extreme event, or its vulnerability.

2.2 Characteristics and consequences of pluvial flooding in urban areas

Pluvial flooding is a typically urban phenomenon, caused by either intense or prolonged rainfall events, which generate high runoff volumes that exceed the capacity of drainage systems (Ochoa-Rodriguez et al., 2013; SEPA, 2015). It is usually associated with extreme rainfall events (> 20-25 mm / h), but can also occurs with less intense precipitation (~ 10 mm / h) or melted snow where the ground is frozen, saturated or has low permeability (Falconer , 2009; Maksimovic & Saul, 2015).

Currently, the main debate is about the name, the meaning and the characteristics of this phenomenon. In particular, there are different opinions regarding its formation, generated only by direct surface runoff and ponding caused by rainwater (DEFRA, 2010; Parker et al., 2011; SEPA, 2015) or also by the flow caused by sewers and urban minor watercourses, whose capacity has been exceeded as a result of extreme event (Schmitt et al., 2004; Pitt, 2008). The second approach is being adopted, taking the name of surface water flooding to indicate flooding phenomena resulting from direct (pluvial flooding) and indirect (flash flooding, sewer flooding, groundwater flooding) runoff (Pitt, 2008; Falconer, 2009 Local Government Association, 2014; FRC, 2016).

These phenomena are a result of the combination of both precipitation events and properties of environmental system; specific physical, social and morphological characteristics of urban environment may cause danger and damage related to human action rather than the natural one (Table 1) (Falconer, 2009; Houston et al., 2011; Queensland Government, 2011).

Table 1: Characteristics of built environment and impacts on urban system

Meteorological Extreme Events + Urban phenomenon	CAUSES Characteristics of built environment	IMPACTS ON BUILT ENVIRONMENT AND POPULATION	
		Direct (Immediate)	Indirect (Delayed or longer lasting)
Heavy rainfall + Pluvial flooding	**Infrastructural characteristics** Road or rail embankments can be barriers to surface flow and cause deep ponding Restriction or closing of existing channels Road or rail underpasses **Topographic characteristics** Road and open spaces with high slope **Superficial characteristics** Low permeability **Urban drainage systems** Insufficient capacity of underground drainage systems	**Physical impacts** Damage to infrastructures and buildings (and their contents) Damage to cultural and heritage sites Loss and damage to goods and livelihoods **Economic impacts** Cost of clean-up, of living in temporary accommodation, of restoration and rebuilding **Impacts on health and life** Loss of life e health problems (physical and mental illnesses) **Environmental impacts** Ecological damage Water quality degradation	**Physical impacts** Disruption to transport, economic and social activities Vehicular mobility interruption **Economic impacts** Commerce and business interruption **Impacts on health and life** Increased vulnerability of survivors (stress and anxiety) **Environmental impacts** Ecosystem resource loss Avalanches Landslides

Sources: Falconer (2009); Houston et al. (2011); Queensland Government (2011)

The physical features listed may cause surface ponding, sewers flooding and high speed of water flows (Nott, 2006; Falconer, 2009; Houston et al, 2011) with direct and indirect impacts on built environment and population. Consequently, the vulnerability assessment of urban system considers the characteristics of both social and built system.

2.3 Vulnerability to climate change: definition, approaches and drivers

In urban pluvial flooding impacts assessment, vulnerability is the most interesting factor although there is no consensus among disciplines and researchers about its meaning, application and measurement (Adger, 2006).

"*We are still dealing with a paradox: we aim to measure vulnerability, yet we cannot define it precisely*" (Birkmann, 2006): this statement highlights the confusion within the different scientific communities regarding the approaches to use for understanding vulnerability, which has led to several attempts of classification. Some authors distinguish vulnerability in two or more interacting dimensions, without a clear agreement on the meaning of its terms. It is possible to distinguish between an internal and external (Chambers, 1989; Bohle, 2001), biophysic (or natural) and social (or socio-economic) (Cutter, 1996; Klein & Nicholls, 1999; Brooks, 2003) or physical-environmental, socio-economic and external assistance (Moss et al., 2001) dimensions. Other studies identify the vulnerability as the interaction of physical, economic, social and environmental factors (UN&ISDR, 2004).

Beyond the sectoral and practical differences, it is possible to connect these various approaches to a minimum classification, which distinguishes between two fundamental and independent dimensions of vulnerability: the scale of analysis (sphere) and the knowledge domain (Füssel, 2005; 2007) (Table 2).

Table 2: Classification of vulnerability factors

	Knowledge domain	
Sphere	**Socioeconomic**	**Biophysical**
Internal	Household income, social networks, access to information	Topography, environmental conditions, land cover
External	National policies, international aid, economic globalization	Severe storms, earthquakes, sea-level change

Source: Füssel (2007)

In C.C. studies there are two prevailing tendencies in which vulnerability can be viewed: the amount of (potential) damage caused by a particular hazard to a system (biophysical vulnerability) and a state that exists within a system before it encounters an hazard (socio-economic vulnerability) (Brooks, 2003; Ciurean et al., 2013). The first case emphasizes the impacts assessment, and vulnerability exists only because hazard exists (end-point or outcome vulnerability). In the second case, vulnerability exists independently of external stress, refers to the intrinsic characteristics of system and determines the nature and magnitude of impacts generated (starting point or contextual vulnerability). According to this subdivision, it is possible to recognize many approaches, graphically represented in Figure 1 (Cutter, 1996; Füssel, 2005; 2007; Eakin and Luers, 2006; Ciurean et al., 2013; Tahmasebi, 2013).

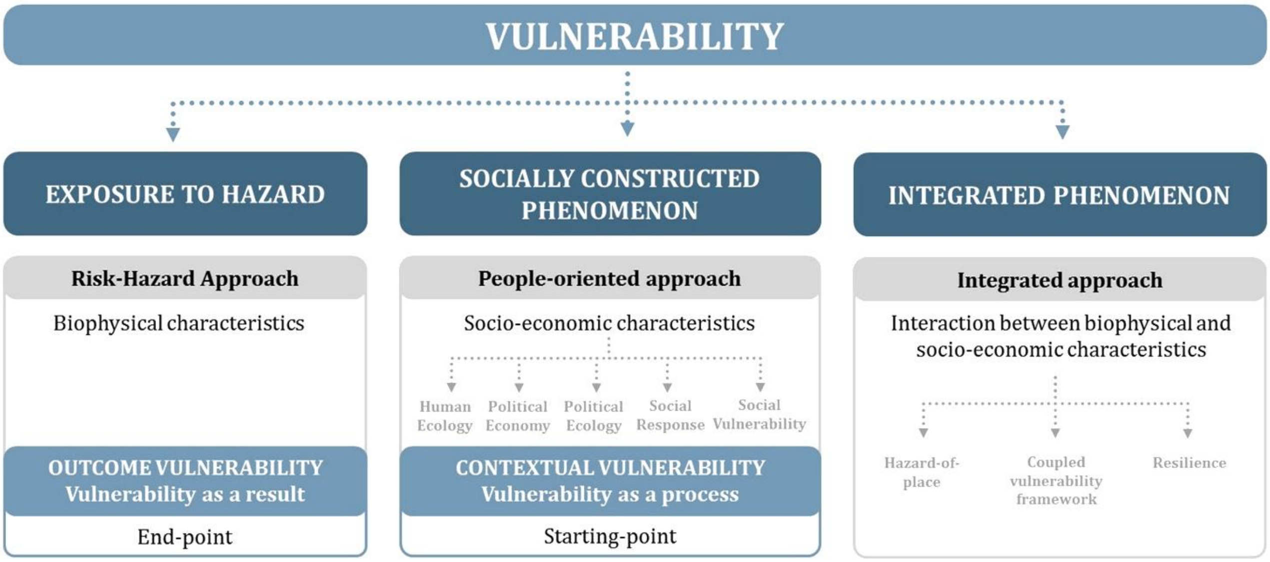

Figure 1: Typology of vulnerability assessment approaches

In relation to this diversified scenario, IPCC suggests an interesting approach; in the fifth report, defines vulnerability as the propensity or predisposition of a system to be adversely affected, mainly resulting from its internal characteristics (IPCC, 2012). In vulnerability assessment, IPCC considers both biophysical and social factors as determinants in the identification of exposure, sensitivity and response capacity (Füssel & Jol, 2012). These parameters, in relationship to hazard, represent climate risk drivers (Figure 2) according to the following formula (UN&ISDR, 2004; UNEP, 2004; Daudet, 2011; Lindley et al., 2011):

$$\boldsymbol{R} = H * V = H * \left(\frac{E * S}{RC}\right)$$

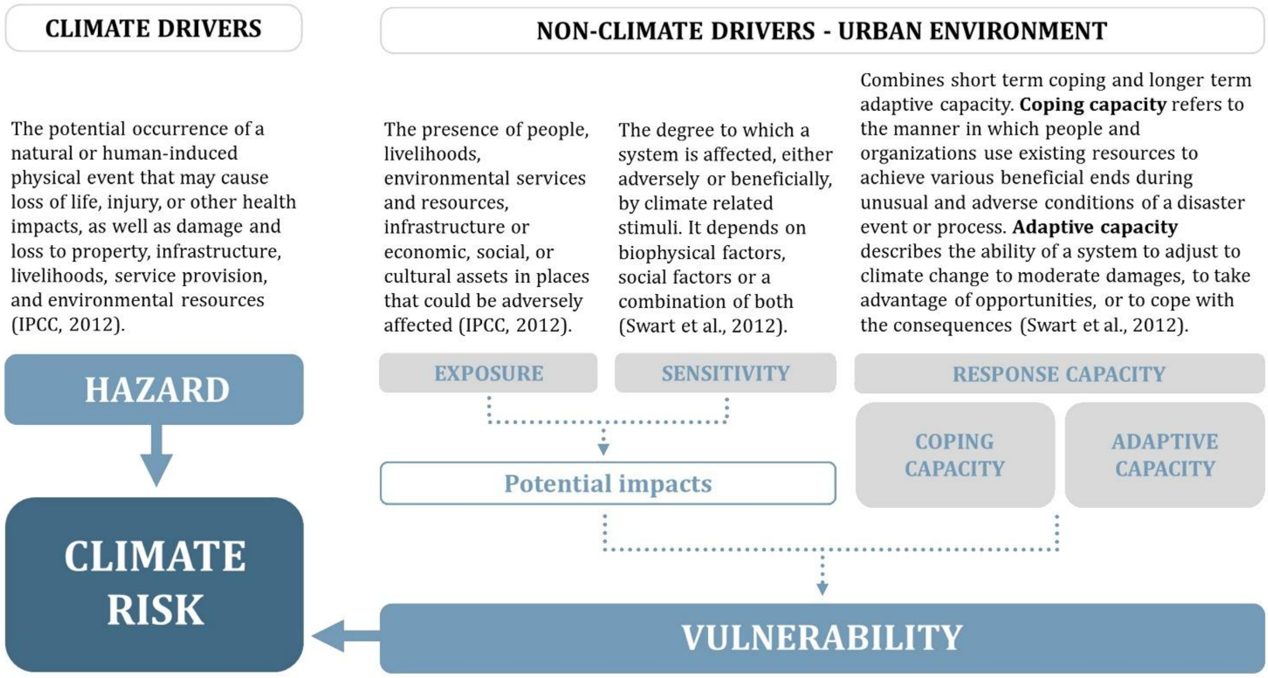

Figure 2: Climate Risk Framework

In Table 3 are highlighted some vulnerability factors, classifiable in relation to mentioned drivers; such characteristics, in a more detailed study, must be explained through the identification of appropriate indicators of exposure, sensitivity and response capacity able to describe the conditions of the urban system.

Table 3: Pluvial flooding vulnerability factors

Socio-economic characteristics	**Demographic characteristics**	Population on flood area, age, ethnicity, etc.
	Socio-economic characteristics	Public health, public safety, welfare, education, trust in institutions, access to sanitation, access to information, income, building occupancy, etc.
Bio-physical characteristics	**Site characteristics**	Building on flood area, location, topography, land cover, land use, etc.
	Building/structure characteristics	Type of construction, foundation, condition of the building, lower levels, building materials and finishes, historical significance, etc.

Starting from the knowledge of the physical and social characteristics, it is possible to work with the tools of Environmental Design increasing the adaptive capacity of the built environment, in order to improve the performance of buildings and open spaces and to promote a resilient development of the whole urban system.

Adaptive capacity refers to the property of a system to adjust its characteristics or behavior in order to increase the ability to cope with the consequences of existing or future events. Represents the ability, in the long term, to design and implement effective adaptation strategies, reacting to the continuous evolution of hazard and stress, in order to reduce the probability of occurrence and/or magnitude of damage caused by climatic events. This adaptation process requires the ability to learn from experiences in order to cope present events and to apply these lessons to future (Brooks and Adger, 2004), ensuring a dynamic balance. This condition can only be reached through a multiscalar approach, able to face the problems related to C.C., ensuring efficient use of resources, environmental protection, optimal management of environmental flows and cycles and individual well-being and health. The Environmental Design is able to hold together these aspects and to work simultaneously on multiple dimensions and levels, emphasizing the differences and the complexity of human settlements.

3. STRATEGIES AND ADAPTATION MEASURES TO PLUVIAL FLOODING IN URBAN AREAS

The implementation of a theoretical model for vulnerability assessment has substantial consequences on the identification of strategies. Vulnerability assessments based on an end-point interpretation are strongly focused on technological adaptation to reduce impacts, and can lead to counter-productive policies, characterized by an excessive reliance on solutions based only on the use of technology as an element able to increase the resistance of the affected systems (e.g. through the realization of protective barriers). Instead, vulnerability understood as a starting point (contextual vulnerability) tend to focus on sustainable development strategies that increase the response capacity of communities and people affected mainly with social measures (e.g. reduction of poverty, strengthening of collective action) (Füssel, 2009; Fellmann, 2012).

An integrated approach, assessing the complexity of urban system, allows identifying appropriate technological-environmental adaptive strategies and measures, whose concrete application on the built environment depends on the characteristics of social component (access to resources, management skills, information, awareness, etc.).

The European Environmental Agency, in the study of adaptation strategies to C.C. for cities, identifies three possible approaches, graphically represented in Figure 3: coping, incremental and transformative (EEA, 2016). Coping adaptation faces immediately the impacts of an extreme event, trying to restore the previous state on a local scale. With an exclusively reactive action, the risk of mal-adaptation is very high, which is a result of a vulnerability assessment based only on biophysical factors (EEA, 2016). The incremental adaptation, although includes prevention against future negative impacts, still considers the change as a risk from which to protect, unlike transformative adaptation, with which is possible to work on a broader temporal and spatial scale. This approach, considering change as an opportunity, includes further goals of improving quality of life under varying external conditions. It includes reactive and proactive measures, reversible, aimed at changing biophysical and socioeconomic factors. With this systemic approach is possible to operate according to a strategic vision, in the long term and in a multiscalar way (EEA, 2016).

Notwithstanding the need to combine these various approaches, transformative approach is the most effective, although with some disadvantages. Providing a resolution of challenges and problems in a different way from the past, this approach may involve some risks if measures have not been sufficiently tested and monitored. As a result, this approach is based on a continuous and long-term learning process that requires monitoring and evaluation of results. However, this can be a lengthy process; therefore, the adoption of incremental measures may be useful to gain time to prepare transformational measures in parallel (Table 4) (EEA, 2016).

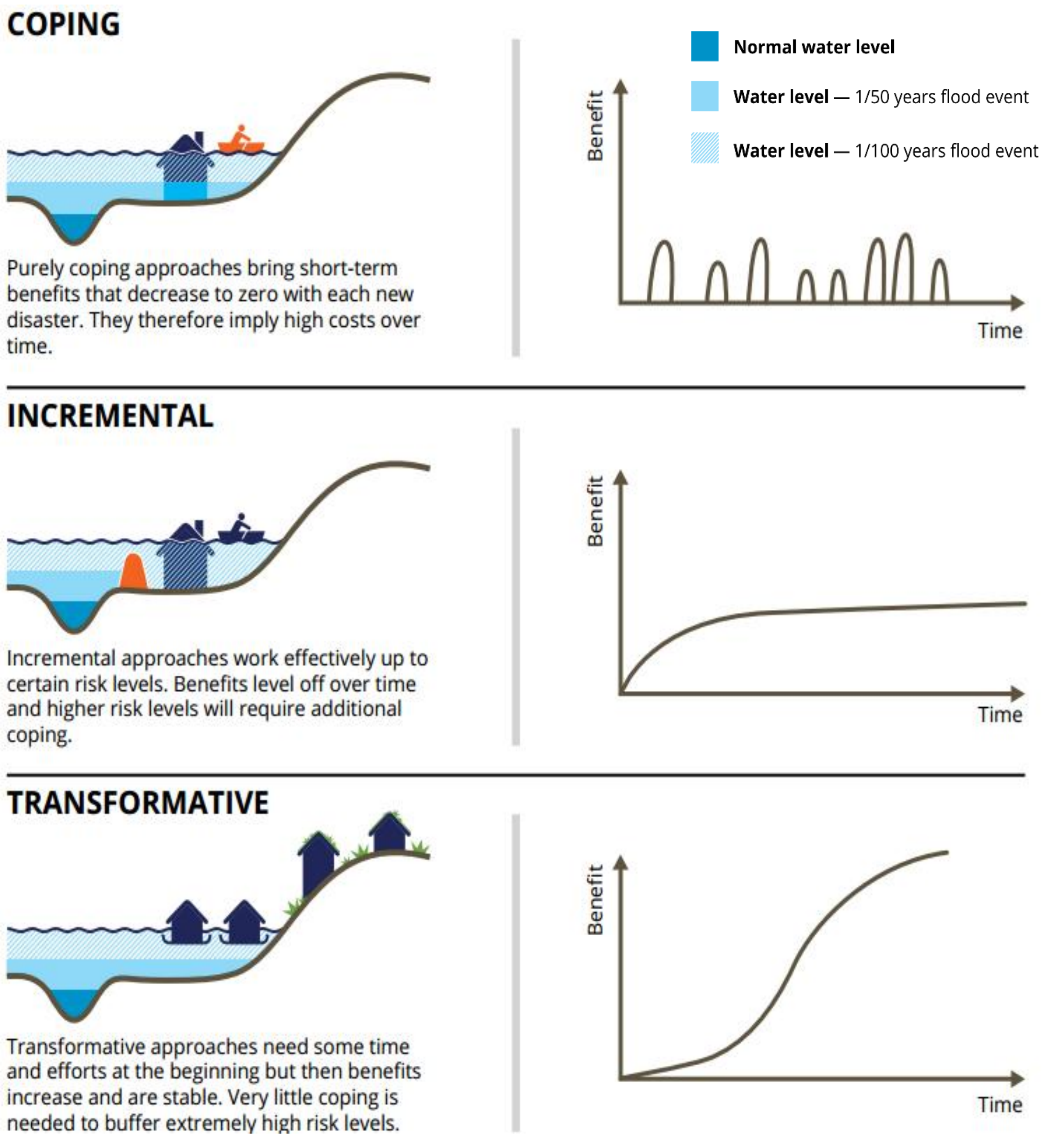

Figure 3: Adaptations strategies to pluvial flooding. *Source: EEA (2016)*

Table 4: Incremental and transformational adaptation measures to flooding

INCREMENTAL MEASURES	TRANSFORMATIONAL MEASURES
Build more dikes and floodgates	Create space for water; retention areas
Reinforce existing dikes	Reduce soil sealing to allow natural drainage
Pump water out	Place infrastructure on higher grounds
Floodgates at buildings	Retreat from low-lying, potentially flood-prone areas
	Floating buildings and infrastructure
	Develop infrastructure that can be temporarily flooded without any damage (non-sensitive use of ground floor and basements)

Source: EEA (2016)

With relation to the assessed vulnerability, is more advisable to combine these adaptive strategies with structural measures applicable on different spatial scales (city/catchment, neighbourhood, building), classified in Table 5 depending on the main contribution offered.

Table 5: Structural adaptation measures to flooding

Categories	Measures	Spatial scales		
		City/ Catchment	Neighbourhood /Public spaces	Building/ Private property
	Resilience measures			
Source control/ Attenuation	Green roofs, blue roofs, green walls			X
	Green areas, pervious surfaces (porous and permeable surfaces and paving – interlocking and open cell pavers)	X	X	X
Filtration	Filter strips, filter trenches, bio-retention areas, constructed wetlands		X	X
Infiltration	Infiltration basins	X	X	
	Soakaways, Infiltration trenches, Rain gardens		X	X
Transport and convey	Swales, channels, rills	X	X	
	Inlets, outlets and control structures (landscaped pipes, perforated pipes, weirs, orifices, vortex control devices and spillways)		X	X
Retention & detention	Detention basins, Retention ponds, Geo-cellular drainage	X	X	
Reservoirs/ Storage	Water squares, artificial detention basins	X	X	
	Underground reservoirs, cisterns, rain barrels			X
Elevation	Building elevation			X
Relocation	Building relocation			X
Floatation	Floating pathway, platform and islands	X	X	
	Floating buildings			X
Raising	Cantilevered pathways, elevated promenades		X	
	Resistance measures			
Barrier	Dams, Breakwaters	X		
	Floodwalls, demountable barriers, embankments	X	X	X
Flood-proofing	Wet-proofing, dry-proofing			X
	Waterproofing external walls and materials			X
	Emergency floodproofing measures (sandbag dykes)		X	X

Source: Shaw et al. (2007); Silva & Costa (2016); SuDS (n.d.); Climateapp (n.d.)

An approach based solely on protection (resistance measures) of built is not very effective, as the continuous changes that cities are subject can make these measures, effective in the present, inadequate in the future. Therefore, is recommended the combination with adaptive measures (resilience measures), in order to decentralize surface runoff, through specific but spread actions (Figure 4).

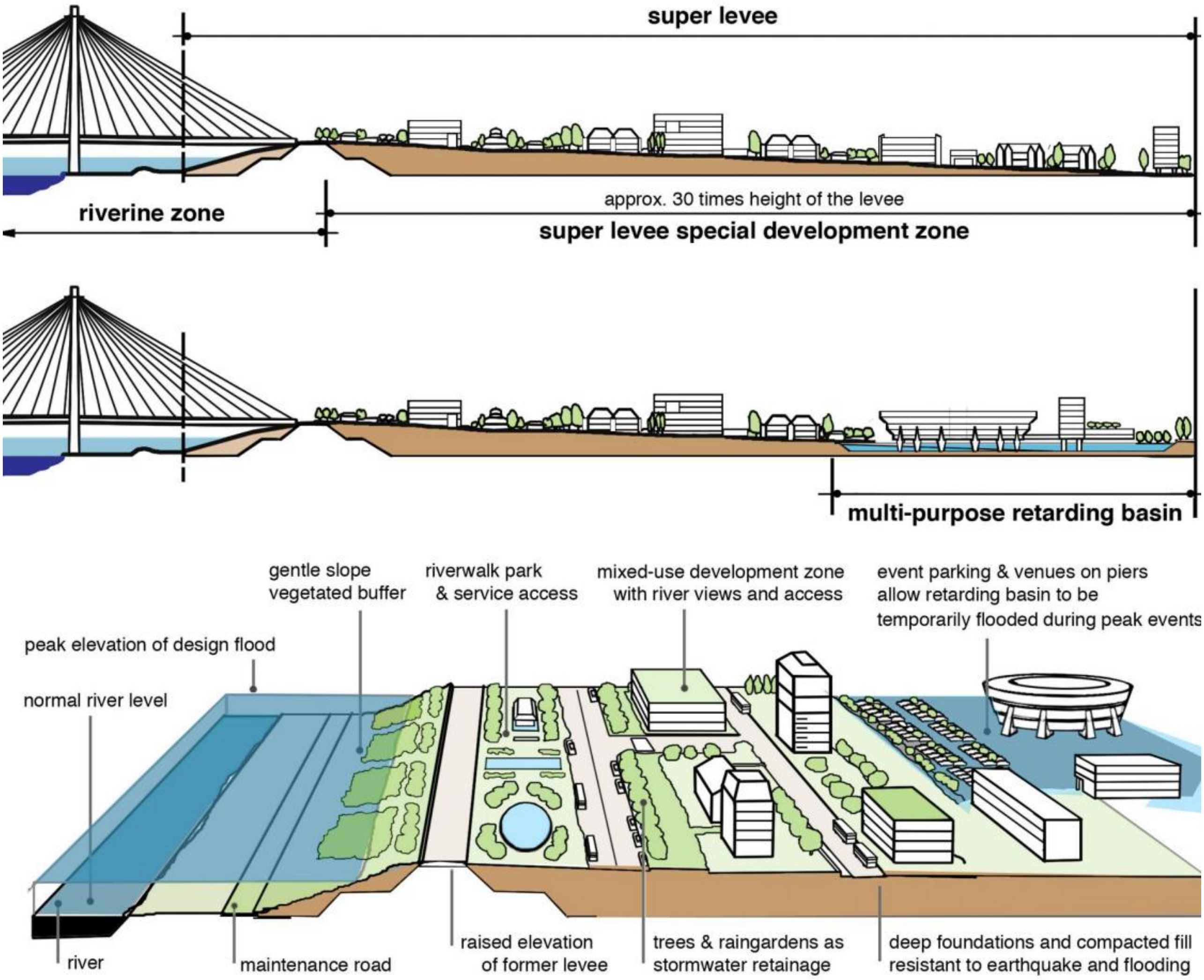

Figure 4: Design for flooding. *Source: Watson & Adams (2011)*

4. Conclusion

The effects of C.C. represent a noticeable and no longer negligible reality, which needs real actions aiming to repair damage caused by past events and to protect human settlements from impacts of future changes.

In urban areas, where these phenomena have more clear consequences, is necessary to operate taking into account not only climatic alterations, but also the evolutionary processes of city, built and population. Population and soil consumption growth, aging and obsolescence of the housing stock and inadequacy of infrastructures networks represent some of the main causes of damage and the greatest urban vulnerability factors.

In relation to pluvial flooding phenomena, the extreme imperviousness of soils, the inefficiency of drainage system and the failed reuse of rain and wastewater involving relevant uncomfortable environmental conditions, requiring timely action in order to avoid happening and overlapping of risk situations.

The typical Environmental Design approach allows identifying flexible design strategies and actions, aimed to reduce vulnerability of built system, which ensures the possibility to operate again if the boundary conditions should change. In this perspective, acting on increase of adaptive capacity allows to provide for short-term measures, able to cope immediately with the problem, and long-term transformative measures, which, although substantial efforts, can make higher benefits in time and space.

Theoretical fundamentals and practical tools to operate according to this vision are widely available to designers, planners, decision makers and inhabitants; it remains only to increase the awareness regarding the importance and the needs to activate suitable processes for the real execution of these interventions.

1. INTRODUZIONE

Eventi estremi accompagnano la storia degli insediamenti fin dall'antichità e si ripetono secondo modalità e forme diverse (terremoti, alluvioni, uragani, etc.) (IRDR, 2014; C40, 2015) generando ingenti danni sul patrimonio costruito sia alla scala urbana sia a quella architettonica. Tuttavia, l'azione antropica di costruzione delle città, l'urbanizzazione della popolazione e l'elevata concentrazione di persone e attività in ambito urbano avvenute negli ultimi due secoli rendono urgente la definizione di una risposta progettuale adeguata ai cambiamenti in atto e futuri.

Tale azione di disturbo per il sistema naturale ha comportato un'eccessiva impermeabilizzazione dei suoli, alterando il sistema idrologico. Parallelamente all'incremento dei volumi di deflusso superficiale delle acque (*surface runoff*), si registra un aumento della frequenza e intensità degli eventi di precipitazione estrema (*heavy rainfall, rain storm, heavy snow, hail*).

Oltre a caratterizzarsi come fattori di pressione sul sistema climatico-ambientale locale (e globale), le città si configurano come gli insediamenti umani maggiormente vulnerabili agli impatti generati dagli eventi climatici estremi. La combinazione di tali eventi con specifiche caratteristiche dell'ambiente urbano (geografiche, morfologiche, tipologiche, tecnico-costruttive, culturali, socio-economiche, etc.) determina effetti sul patrimonio costruito e sulla popolazione di notevole entità. Gli impatti generati, oltre che dipendenti dalla pericolosità dell'evento, sono diretta conseguenza di fattori intrinseci al sistema colpito, sia fisici che sociali, veri responsabili del rischio climatico e ambientale cui le città sono soggette. Infatti, come dimostrato purtroppo da disastri ambientali ed eventi calamitosi anche di altra natura (tsunami, uragani, etc.), a parità di evento (intensità, magnitudo, frequenza) è il parametro vulnerabilità ad incidere maggiormente sulla tipologia e intensità degli effetti, a sua volta dipendente da fattori di sensitività, esposizione e capacità adattiva, variabili in relazione al contesto.

Alla luce di tali riflessioni, di grande interesse e attualità appare il rapporto tra cambiamenti climatici e ambiente urbano, ormai non più trascurabile. Il forte impatto dell'evento sulla popolazione e sul patrimonio architettonico e urbano rende necessaria l'adozione di strategie progettuali in grado di ridurre la vulnerabilità del costruito, mirate a sviluppare resilienza nei sistemi colpiti, aumentandone la capacità adattiva.

2. *CITY CLIMATE HAZARD* E VULNERABILITÀ DEL SISTEMA URBANO

2.1 Hazard e impatti in ambito urbano: contributo naturale o antropico?

Lo studio dei fenomeni connessi al cambiamento climatico, e delle relative misure e soluzioni tecniche per la riduzione degli impatti, non può essere condotto senza tener conto dell'interazione con i sistemi antropici.

Riferirsi agli hazard naturali come ad eventi capaci di provocare disastri e catastrofi causati esclusivamente dalla magnitudo dell'evento è un errore; diversi fattori socio-economici, culturali e politici concorrono a generare tali disastri, anche se spesso non sono adeguatamente presi in considerazione dalle comunità e dai governi (Bankoff, 2010). Come già accennato, tali fattori di origine antropica, a parità di condizioni di hazard, determinano il livello di rischio e di danno degli elementi colpiti: l'alterazione degli equilibri naturali, l'incremento demografico, l'incontrollato consumo di suolo e di sfruttamento delle risorse sono tra le principali cause di formazione di disastri convenzionalmente definiti naturali, ma che in realtà hanno una radice antropica, caratterizzandosi come disastri di tipo sociale (Acot, 2007; Kelman, 2010; Marotta & Zirilli, 2015).

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> *Natural hazards are a part of life. But hazards only become disasters when people's lives and livelihoods are swept away. The vulnerability of communities is growing due to human activities that lead to increased poverty, greater urban density, environmental degradation and climate change.*
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> Kofi Annan, 2003

Tali affermazioni mettono in evidenza il rapporto tra disastri "naturali" e caratteristiche delle comunità colpite: l'uomo con le proprie azioni ha compromesso gli equilibri naturali e ha reso difficile l'individuazione delle cause di disastro naturale, mettendone in discussione l'effettiva "naturalezza" (Marotta & Zirilli, 2015). Come affermato da diversi autori, i disastri naturali non esistono, poiché un evento pericoloso si caratterizza come tale a causa delle scelte e delle azioni umane che avvengono prima, durante o dopo l'evento e che si ripercuotono sulla società stessa (Marotta & Zirilli, 2015). In relazione a ciò, le due definizioni più diffuse sono quelle di "*unnatural disasters*" (Tiranti, 1977; Abramovitz, 2001) e "*unnatural hazards*" (Hewitt, 1983; Kelman, 2010; 2011).

La pericolosità relativa ad eventi climatici e meteorologici è legata più alle peculiarità degli elementi e sistemi colpiti che non all'evento in sé, che pertanto assume la caratteristica di hazard se esistono condizioni tali da trasformarlo in minaccia (IPCC, 2012). Pur essendo spesso associato al concetto di disastro, l'evento climatico estremo non sempre ne è la causa primaria, e situazioni critiche possono verificarsi anche senza il raggiungimento di valori estremi. Caratteristiche geografiche, socio-economiche, morfologiche e istituzionali (strumenti di pianificazione e regolamentazione) e il livello di informazione e consapevolezza dei vari attori coinvolti influenzano notevolmente la capacità di risposta dell'ambiente costruito e della popolazione, determinandone il grado di esposizione e di sensitività (Peltonen et al., 2005; Wilhelmi & Hayden, 2010).

Di conseguenza, nell'analisi degli impatti che il *pluvial flooding* genera sul sistema urbano, non è sufficiente conoscere intensità, frequenza e durata dell'evento, ma vanno indagate le caratteristiche interne al sistema colpito che definiscono la sua organizzazione strutturale e quindi la sua capacità di fronteggiare, gestire, recuperare in seguito all' evento estremo, ovvero la sua vulnerabilità.

2.2 Caratteristiche e conseguenze dei fenomeni di pluvial flooding in ambito urbano

Il *pluvial flooding* è un fenomeno tipicamente urbano, causato da intensi e/o prolungati eventi meteorici che generano elevati volumi di deflusso superficiale (*runoff*) eccedenti la portata dei sistemi di drenaggio (Ochoa-Rodríguez et al., 2013; SEPA, 2015). È solitamente associato ad eventi piovosi estremi (>20-25 mm/h), ma può verificarsi anche con precipitazioni meno intense (~10 mm/h) o neve sciolta laddove il terreno è congelato, completamente impregnato o ha una bassa permeabilità (Falconer, 2009; Maksimovic & Saul, 2015).

Attualmente è ancora in atto il dibattito riguardo la denominazione, il significato e le caratteristiche del fenomeno. In particolare, esistono opinioni differenti relative alla sua formazione, generata solo dal deflusso diretto e da ristagni superficiali derivanti dalle acque meteoriche (DEFRA, 2010; Parker et al., 2011; SEPA, 2015) o anche dal deflusso provocato da fognature e corsi d'acqua minori la cui capacità è stata superata in seguito all'evento estremo (Schmitt et al., 2004; Pitt, 2008). Il secondo approccio è quello più adottato, assumendo la denominazione di *surface water flooding* per indicare fenomeni di allagamento risultanti da deflussi diretti (*pluvial flooding*) e indiretti (*flash flooding, sewer flooding, groundwater flooding*) (Pitt, 2008; Falconer, 2009, Local Government Association, 2014; FRC, 2016).

Tali fenomeni sono il risultato della combinazione di eventi di precipitazione e proprietà del sistema ambientale; specifiche caratteristiche fisiche, sociali e morfologiche dell'ambiente urbano possono determinare situazioni di pericolo e di danno connesse all'azione antropica piuttosto che a quella naturale (tabella 1) (Falconer, 2009; Houston et al., 2011; Queensland Government, 2011).

Table 1: Caratteristiche dell'ambiente costruito ed impatti generati a livello urbano

Meteorological Extreme Events + Urban phenomenon	**CAUSES Characteristics of built environment**	**IMPACTS ON BUILT ENVIRONMENT AND POPULATION**	
		Direct (Immediate)	**Indirect (Delayed or longer lasting)**
Heavy rainfall + Pluvial flooding	**Infrastructural characteristics** Road or rail embankments can be barriers to surface flow and cause deep ponding Restriction or closing of existing channels Road or rail underpasses **Topographic characteristics** Road and open spaces with high slope **Superficial characteristics** Low permeability **Urban drainage systems** Insufficient capacity of underground drainage systems	**Physical impacts** Damage to infrastructures and buildings (and their contents) Damage to cultural and heritage sites Loss and damage to goods and livelihoods **Economic impacts** Cost of clean-up, of living in temporary accommodation, of restoration and rebuilding **Impacts on health and life** Loss of life e health problems (physical and mental illnesses) **Environmental impacts** Ecological damage Water quality degradation	**Physical impacts** Disruption to transport, economic and social activities Vehicular mobility interruption **Economic impacts** Commerce and business interruption **Impacts on health and life** Increased vulnerability of survivors (stress and anxiety) **Environmental impacts** Ecosystem resource loss Avalanches Landslides

Fonti: Falconer (2009); Houston et al. (2011); Queensland Government (2011)

Le caratteristiche fisiche elencate possono provocare ristagni superficiali, esondazione delle fognature e velocità elevate dei flussi di scorrimento (Nott, 2006; Falconer, 2009; Houston et al., 2011) con impatti diretti e indiretti non solo sul sistema costruito, ma anche sulla popolazione. Di conseguenza, nel determinare la vulnerabilità del sistema urbano, vanno considerate anche le caratteristiche del sistema sociale oltre che del sistema costruito.

2.3 Il concetto di vulnerabilità al cambiamento climatico: definizione, approcci e componenti

Nell'analisi degli impatti che il *pluvial flooding* può avere sul sistema urbano, la vulnerabilità rappresenta il fattore di interesse principale, anche se non vi è consenso unanime riguardo il suo significato, applicazione e misurazione, assumendo connotati diversi a seconda del campo di indagine e delle discipline coinvolte (Adger, 2006).

"We are still dealing with a paradox: we aim to measure vulnerability, yet we cannot define it precisely" (Birkmann, 2006): tale affermazione evidenzia la confusione esistente all'interno delle varie comunità scientifiche riguardo gli approcci da utilizzare per la comprensione della vulnerabilità, che ha portato a svariati tentativi di classificazione nel corso del tempo. Diversi autori distinguono la

vulnerabilità in due o più dimensioni interagenti, senza un preciso accordo sul significato dei relativi termini. Si può distinguere tra una dimensione interna ed esterna (Chambers, 1989; Bohle, 2001), biofisica (o naturale) e sociale (o socioeconomica) (Cutter, 1996; Klein & Nicholls, 1999; Brooks, 2003) o fisico-ambientale, socio-economica e di assistenza esterna (Moss et al., 2001). Altri studi individuano la vulnerabilità come l'interazione di fattori fisici, economici, sociali e ambientali (UN&ISDR, 2004).

Al di là delle differenze di settore e applicazione, è possibile ricondurre i vari approcci ad una classificazione minima, che distingue tra due fondamentali dimensioni della vulnerabilità indipendenti tra loro, ovvero la scala di analisi (*sphere*) e il dominio di conoscenza (*knowledge domain*) (Füssel, 2005; 2007), all'interno delle quali ricadono i diversi fattori che la costituiscono (Tabella 2).

Table 2: Classificazione dei fattori di vulnerabilità

	Knowledge domain	
Sphere	**Socioeconomic**	**Biophysical**
Internal	Household income, social networks, access to information	Topography, environmental conditions, land cover
External	National policies, international aid, economic globalization	Severe storms, earthquakes, sea-level change

Fonte: Füssel (2007)

Nell'ambito degli studi relativi al C.C., esistono due orientamenti prevalenti: uno vede la vulnerabilità come il livello di danno (potenziale) provocato da un hazard su un determinato sistema (vulnerabilità biofisica), l'altro la considera come uno stato esistente all'interno del sistema prima di incontrare l'hazard (vulnerabilità socio-economica) (Brooks, 2003; Ciurean et al., 2013).

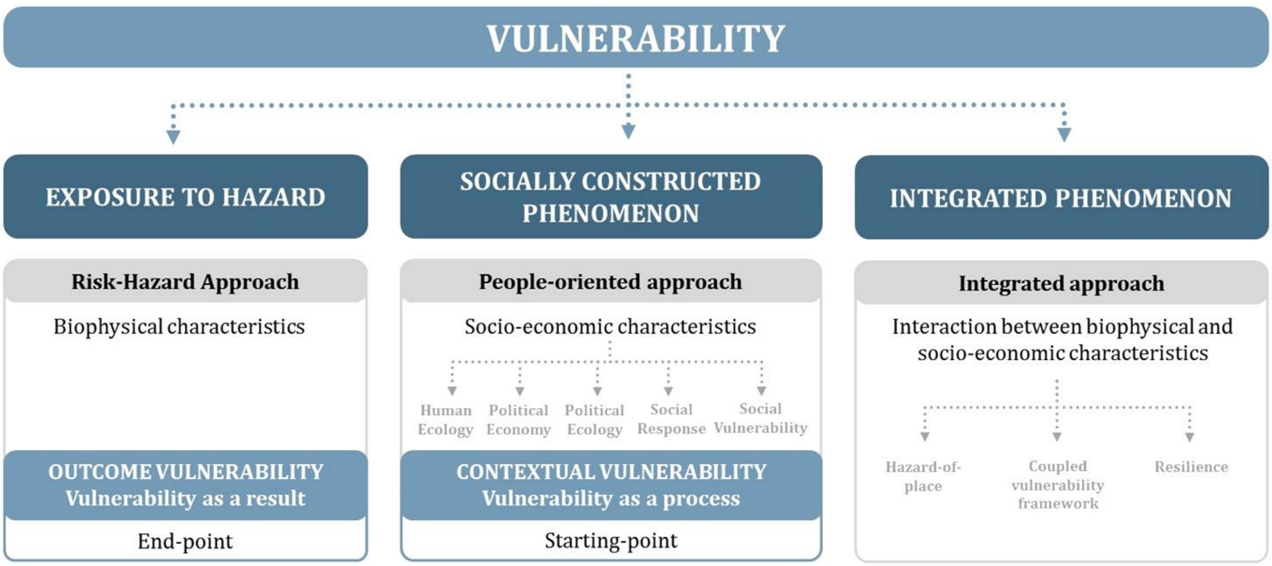

Figura 1: Classificazione degli approcci di valutazione della vulnerabilità

Nel primo caso, si valutano gli impatti prodotti dall'evento e non lo stato preesistente, per cui la vulnerabilità esiste solo perché esiste l'evento (*end-point* o *outcome vulnerability*); nel secondo caso la vulnerabilità esiste indipendentemente dalle sollecitazioni esterne, è definita da caratteristiche intrinseche del sistema e determina la natura e l'entità degli impatti generati (*starting point* o *contextual vulnerability*). In base a tale suddivisione è possibile rintracciare numerosi approcci, alcuni dei quali schematizzati in figura 1 (Cutter, 1996; Füssel, 2005; 2007; Eakin & Luers, 2006; Ciurean et al., 2013; Tahmasebi, 2013).

In relazione ad uno scenario così variegato, uno degli approcci adottabili è quello proposto dall'IPCC, che nel V rapporto definisce la vulnerabilità come la propensione o la predisposizione di un sistema ad essere affetto in maniera negativa, derivante principalmente da caratteristiche interne all'elemento colpito (IPCC, 2012). L'IPCC nella valutazione della vulnerabilità considera sia i fattori biofisici che sociali quali determinanti nell'individuazione di esposizione, sensitività e capacità di risposta (Füssel & Jol, 2012). Tali parametri, se messi in relazione con l'hazard, si configurano come driver del rischio climatico (figura 2) secondo la seguente formula (UN&ISDR, 2004; UNEP, 2004; Daudet, 2011; Lindley et al., 2011):

$$\boldsymbol{R} = H * V = H * \left(\frac{E * S}{RC}\right)$$

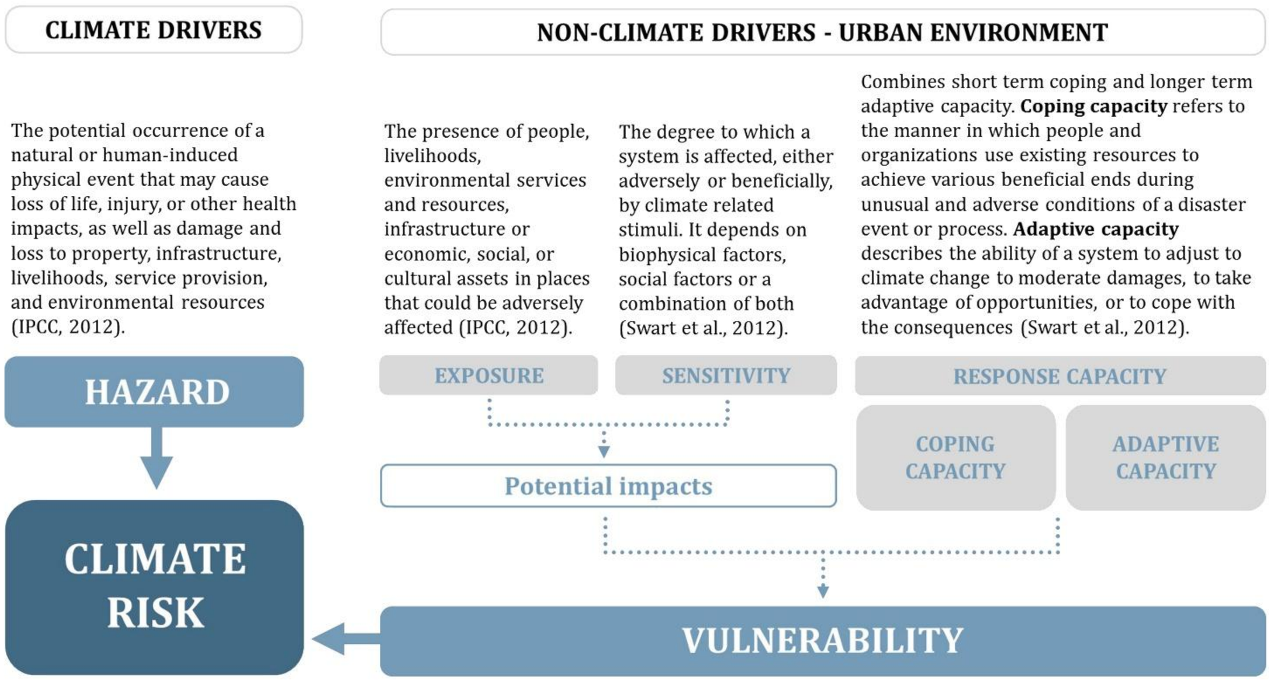

Figura 2: Climate Risk Framework

In tabella 3 si individuano alcuni fattori di vulnerabilità da classificare in relazione ai driver citati; tali caratteristiche, in uno studio più approfondito, vanno esplicitate attraverso l'individuazione di opportuni indicatori di *exposure, sensitivity* e *response capacity* capaci di descrivere le condizioni del sistema urbano.

A partire dalla conoscenza delle caratteristiche fisiche e sociali, è possibile intervenire con gli strumenti propri della Progettazione Ambientale incrementando la capacità adattiva del costruito, al fine di migliorare le prestazioni di edifici e spazi aperti e favorire uno sviluppo resiliente dell'intero sistema urbano.

Table 3: Caratteristiche di vulnerabilità al *pluvial flooding*

Socio-economic characteristics	**Demographic characteristics**	Population on flood area, age, ethnicity, etc.
	Socio-economic characteristics	Public health, public safety, welfare, education, trust in institutions, access to sanitation, access to information, income, building occupancy, etc.
Bio-physical characteristics	**Site characteristics**	Building on flood area, location, topography, land cover, land use, etc.
	Building/structure characteristics	Type of construction, foundation, condition of the building, lower levels, building materials and finishes, historical significance, etc.

La capacità adattiva è definita come la proprietà di un sistema di regolare le proprie caratteristiche o comportamenti in maniera tale da aumentare la capacità di far fronte ad eventi esistenti o futuri. Rappresenta quindi l'abilità nel lungo termine di progettare e implementare strategie di adattamento efficaci, reagendo alla continua evoluzione di *hazard* e stress, al fine di ridurre la probabilità di occorrenza e/o la magnitudo dei danni risultanti dagli eventi climatici. Tale processo di adattamento richiede la capacità di imparare dalle esperienze pregresse per far fronte agli eventi attuali e di applicare tali lezioni per fronteggiare quelli futuri (Brooks e Adger, 2004), al fine di garantire un equilibrio dinamico. Tale condizione è raggiungibile solo attraverso un approccio che sappia affrontare i problemi connessi al C.C. in maniera interscalare, garantendo al contempo un uso efficiente delle risorse, la salvaguardia ambientale, la gestione ottimale dei flussi e cicli ambientali e il benessere e la salute dell'individuo. La Progettazione Ambientale si configura come disciplina capace di tenere insieme tali aspetti, chiamata ad operare contemporaneamente su molteplici dimensioni e livelli, esaltando le differenze e la complessità del sistema insediativo.

3. STRATEGIE E MISURE DI ADATTAMENTO AL PLUVIAL FLOODING IN AMBITO URBANO

L'adozione di un modello teorico per la valutazione della vulnerabilità ha ricadute notevoli sull'individuazione delle strategie di intervento. Studi che valutano la vulnerabilità come *end-point* si concentrano sull'adeguamento tecnologico per ridurre gli impatti, e possono dar luogo a politiche controproducenti, caratterizzate da un'eccessiva dipendenza da soluzioni fondate esclusivamente sull'uso della tecnologia quale elemento in grado di aumentare la resistenza dei sistemi colpiti (ad es. attraverso la realizzazione di barriere protettive). La vulnerabilità intesa come *starting point* (*contextual vulnerability*) dà luogo invece a strategie di sviluppo tali da aumentare la capacità di risposta delle comunità e popolazioni colpite, con misure di tipo più sociale che tecnico (ad es. riduzione povertà, rafforzamento dell'azione collettiva) (Füssel, 2009; Fellmann, 2012).

Con un approccio integrato, nel valutare la complessità del sistema urbano, è possibile individuare opportune strategie e misure tecnologico-ambientali adattive la cui applicazione concreta sul costruito dipende anche dalle caratteristiche della componente sociale (accesso alle risorse, capacità di gestione, informazione, consapevolezza, etc.).

L'*European Environmental Agency*, nello studio delle strategie di adattamento al C.C. per le città europee, individua tre possibili approcci, schematizzati in figura 3: *coping*, *incremental* e *transformative* (EEA, 2016). Con la *coping adaptation* si affrontano nell'immediato gli impatti derivanti da un evento estremo, cercando di ristabilire lo stato preesistente ad una scala prevalentemente locale. Una risposta di tipo esclusivamente reattivo comporta un rischio di *mal-adaptation* elevato, configurandosi come l'esito di una valutazione della vulnerabilità fondata solo su fattori biofisici (EEA, 2016). L'*incremental adaptation*, pur prevedendo, in aggiunta agli obiettivi di breve termine della *coping*, la prevenzione dagli impatti negativi futuri, considera ancora il cambiamento come un rischio dal quale proteggersi, a differenza della *transformative adaptation*, con la quale è possibile intervenire su scale temporali e spaziali più ampie.

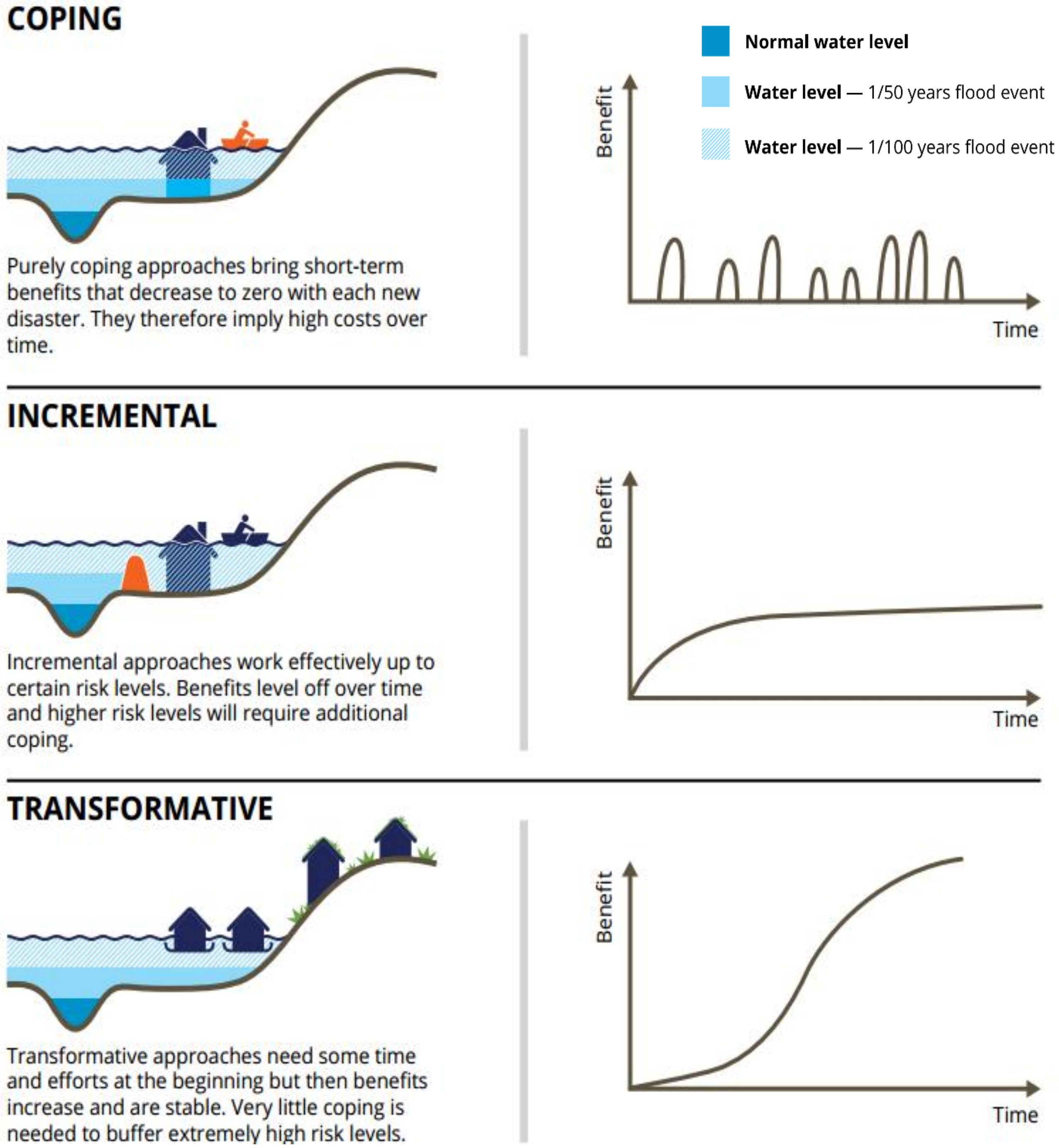

Figura 3: Strategie di adattamento ai fenomeni di flooding. *Source: EEA (2016)*

Quest'ultimo approccio, considerando il cambiamento come opportunità, prevede ulteriori obiettivi di miglioramento della qualità della vita in condizioni esterne variabili. Comprende misure reattive e proattive, reversibili, finalizzate a modificare fattori biofisici e socioeconomici. Con tale approccio sistemico è possibile operare secondo una visione strategica, a lungo termine e in maniera interscalare (EEA, 2016).

Ferma restando la necessità di combinare i vari approcci, l'approccio trasformativo si rivela più efficace, seppure con qualche svantaggio. Prevedendo la risoluzione di sfide e problemi in maniera diversa rispetto al passato, può comportare alcuni rischi se le misure non sono sufficientemente testate e monitorate. Di conseguenza, tale approccio è fondato su un processo di apprendimento continuo, che avviene nel lungo periodo e che necessita di monitoraggio e valutazione dei risultati. L'attuazione può essere lunga, per cui l'adozione di misure di tipo incrementale può essere utile per guadagnare tempo per la realizzazione parallela di misure trasformative (tabella 4) (EEA, 2016).

Table 4: Misure di *incremental* e *transformational adaptation* ai fenomeni di *flooding*.

INCREMENTAL MEASURES	TRANSFORMATIONAL MEASURES
Build more dikes and floodgates Reinforce existing dikes Pump water out Floodgates at buildings	Create space for water; retention areas Reduce soil sealing to allow natural drainage Place infrastructure on higher grounds Retreat from low-lying, potentially flood-prone areas Floating buildings and infrastructure Develop infrastructure that can be temporarily flooded without any damage (non-sensitive use of ground floor and basements)

Fonte: EEA (2016)

Tali strategie adattive, in relazione al livello di vulnerabilità rilevata, possono essere attuate in maniera combinata e interscalare, con misure strutturali applicabili su scale diverse (città/bacino, quartiere, edificio) e classificate in tabella 5 in relazione al principale contributo fornito.

Table 5: Misure strutturali di adattamento ai fenomeni di *flooding* e relativa scala di intervento

Categories	Measures	Spatial scales		
		City/ Catchment	Neighbourhood /Public spaces	Building/ Private property
	Resilience measures			
Source control/ Attenuation	Green roofs, blue roofs, green walls			X
	Green areas, pervious surfaces (porous and permeable surfaces and paving – interlocking and open cell pavers)	X	X	X
Filtration	Filter strips, filter trenches, bio-retention areas, constructed wetlands		X	X
Infiltration	Infiltration basins	X	X	
	Soakaways, Infiltration trenches, Rain gardens		X	X
Transport and convey	Swales, channels, rills	X	X	
	Inlets, outlets and control structures (landscaped pipes, perforated pipes, weirs, orifices, vortex control devices and spillways)		X	X
Retention & detention	Detention basins, Retention ponds, Geo-cellular drainage	X	X	
Reservoirs/ Storage	Water squares, artificial detention basins	X	X	
	Underground reservoirs, cisterns, rain barrels			X
Elevation	Building elevation			X

Relocation	Building relocation			X
Floatation	Floating pathway, platform and islands	X	X	
	Floating buildings			X
Raising	Cantilevered pathways, elevated promenades		X	
	Resistance measures			
Barrier	Dams, Breakwaters	X		
	Floodwalls, demountable barriers, embankments	X	X	X
Flood-proofing	Wet-proofing, dry-proofing			X
	Waterproofing external walls and materials			X
	Emergency floodproofing measures (sandbag dykes)		X	X

Fonti: Shaw et al. (2007); Silva & Costa (2016); SuDS (n.d.); Climateapp (n.d.)

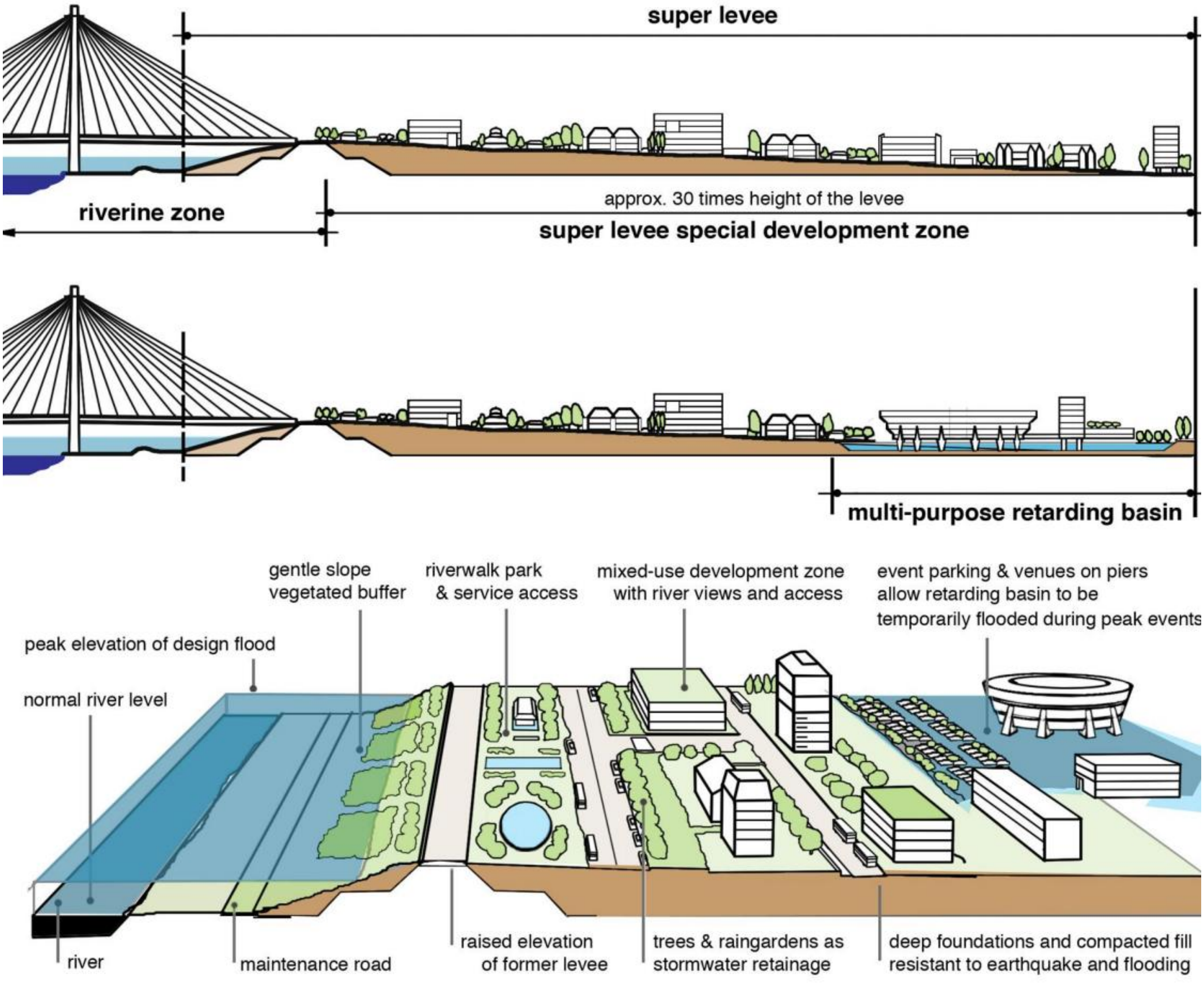

Figura 4: Design for flooding. *Source: Watson & Adams (2011)*

Un approccio fondato esclusivamente sulla protezione (*resistance measures*) del costruito risulta poco efficace, in quanto i continui cambiamenti cui le città sono soggette possono rendere tali misure, efficaci nel presente, inadeguate nel futuro. E' consigliabile pertanto la combinazione con misure adattive (*resilience measures*), al fine di decentralizzare quanto più possibile il deflusso superficiale, mediante azioni puntuali ma diffuse (figura 4).

4. CONCLUSIONI

Gli effetti generati dal C.C. rappresentano una realtà evidente e non più trascurabile, che necessita di azioni concrete non solo per riparare ai danni causati dai fenomeni già avvenuti ma soprattutto per salvaguardare gli insediamenti umani da probabili avvenimenti futuri.

In ambito urbano, dove tali fenomeni hanno le ricadute più visibili, è necessario operare tenendo in considerazione non solo le alterazioni climatiche, ma in particolar modo i processi di evoluzione della città, del costruito e della popolazione, che sono già avvenuti e che potrebbero avvenire. L'incremento demografico e di consumo del suolo, la vetustà e obsolescenza del patrimonio edilizio, l'inadeguatezza delle reti infrastrutturali e impiantistiche si configurano come alcune delle principali cause di danno, rappresentando i fattori di maggiore vulnerabilità urbana che, senza un'opportuna programmazione delle azioni, sono destinate a peggiorare.

In relazione ai fenomeni di *pluvial flooding*, l'eccessiva impermeabilità dei suoli, l'inefficienza della rete fognaria, il mancato riutilizzo delle acque meteoriche e reflue opportunamente trattate, comportano condizioni di discomfort ambientale importanti, che richiedono un'azione tempestiva al fine di evitare il perpetrarsi e il sovrapporsi di situazioni di rischio.

L'approccio tipico della Progettazione Ambientale consente di individuare strategie e azioni progettuali flessibili finalizzate alla riduzione la vulnerabilità del sistema costruito, che garantiscono la possibilità di intervenire nuovamente se le condizioni al contorno dovessero cambiare. In tale ottica, agendo sull'incremento della capacità adattiva è possibile prevedere misure a breve termine, capaci di fronteggiare il problema nell'immediato, e trasformative a lungo termine che, seppur con elevati sforzi, possono apportare maggiori benefici nel tempo e nello spazio.

I fondamenti teorici e gli strumenti pratici per operare secondo tale visione sono ampiamente disponibili a progettisti, pianificatori, decisori e abitanti; resta solo da maturare la consapevolezza riguardo l'importanza e l'urgenza di attivare processi adeguati per la realizzazione concreta di tali interventi.

REFERENCES

Abramovitz, J. (2001). *Unnatural Disasters. Worldwatch Paper 158*. Washington, DC, USA: Worldwatch Institute,

Acot, P. (2007). *Catastrofi climatiche e disastri sociali. Perché le eccezioni stanno diventando la norma*, trad. it. Maria L'Erario, Roma: Donzelli editore (ed. orig. *Catastrophes climatiques, désastres sociaux*).

Adger, W.N. (2006). Vulnerability. *Global Environmental Change, 16*(3): 268-281.

Annan, K. (2003, October 8). Message for the International Day for Disaster Reduction. Retrieved from http://www.unisdr.org/eng/public_aware/world_camp/2003/pa-camp03-sg-eng.htm.

Bankoff, G. (2010, August 23). There are No Such Things as Natural Disasters. Retrieved from http://hir.harvard.edu/no-such-thing-as-natural-disasters/.

Birkmann, J. (2006). *Measuring Vulnerability to Natural Hazards: towards disaster resilient societies*. New York: United Nations University.

Bohle, H.-G. (2001). Vulnerability and Criticality: Perspectives from Social Geography. *Newsletter of the International Human Dimensions Programme on Global Environmental Change*, *2*: 1-7.

Brooks, N. & Adger, W.N. (2004). Assessing and enhancing adaptive capacity, Technical Paper 7. In B. Lim, B. & E. Spanger-Siegfried (eds.), *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*, New York, NY: United Nations Development Programme and Cambridge University Press (pp. 165-182).

Brooks, N. (2003). *Vulnerability, risk and adaptation: a conceptual framework. Working Paper 38*. Norwich, UK: Tyndall Centre for Climate Change Research.

C40 (2015, March 16). City Climate Hazard Taxonomy, C40's classification of city-specific climate hazards. Retrieved from http://www.c40.org/blog_posts/c40-launches-city-climate-change-hazard-taxonomy-for-public-comment.

Chambers, R. (1989). Vulnerability, coping and policy. *IDS Bulletin*, *20*: 1–7.

Ciurean, R.L., Schröter, D. & Glade, T. (2013). Conceptual Frameworks of Vulnerability Assessment for Natural Disasters Reduction. In J. Tiefenbacher (ed.), *Approaches to Disaster Management - Examining the Implications of Hazards, Emergencies and Disasters,* Rijeka, HR: InTech. (pp. 3-32).

Climateapp (n.d.). Adaptation solutions, Retrieved from http://www.climateapp.nl/.

Cutter, S. L. (1996). Vulnerability to environmental hazards. *Progress in Human Geography*, *20*: 529-539.

Daudet, A., Calo, M., Crahay, P., Ham, F., Ilboudo, A., Israel, A.-D., Jacob, J., Mattinen, H., Peroni, J., Pietzsch, S., Radin, N. & Durand Zurdo J. (2011). *Food security & livelihoods surveillance a practical guide for field workers.* ACF International, Technical Department Of Food Security And Livelihoods.

Defra. (2010, March). Surface Water Management Plan Technical Guidance. Department for Environment, Food and Rural Affairs, London, UK. Retrieved from http://www.defra.gov.uk/publications/files/pb13546-swmp-guidance-100319.pdf.

Eakin, H., & A. L. Luers (2006). Assessing the Vulnerability of Social-Environmental Systems. *Annual Review of Environment and Resources*, *31*: 365-394.

EEA (2016). *Urban adaptation to climate change in Europe 2016. Transforming cities in a changing climate.* Luxembourg: Publications Office of the European Union.

Falconer, R. (2009, October 28). EWA Expert Meeting on Pluvial Flooding in Europe. Final Report, European Water Association, Bruxelles. Retrieved from http://www.dwa.de/portale/ewa/ewa.nsf/C125723B0047EC38/B5A125AF564B24E2C1257750002C1FD9/$FILE/EWA%20expert%20meeting%20on%20pluvial%20flood_Final%20Report.pdf.

Fellmann, T. (2012). The assessment of climate change-related vulnerability in the agricultural sector: reviewing conceptual frameworks. *Proceedings of a Joint FAO/OECD Workshop, Building resilience for adaptation to climate change in the agriculture sector*, Rome, IT, April 23–24, 2012.

FRC (2016). Understanding Pluvial Flooding. FloodResilienCity. Retrieved from http://www.floodresiliencity.eu/frc-output/153/3-understanding-pluvial-flooding.

Füssel, H.-M. & Jol, A. (2012). *Climate change, impacts and vulnerability in Europe 2012. An indicator-based report.* Luxembourg: Publications Office of the European Union.

Füssel, H.-M. (2005). *Vulnerability in Climate Change Research: A Comprehensive Conceptual Framework*. Breslauer Symposium Paper 6 and FAVAIA Working Paper 2, Berkeley, CA, USA: University of California International and Area Studies.

Füssel, H.-M. (2007). Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change*, *17*(2): 155-167.

Hewitt, K. (ed.) (1983). *Interpretations of Calamity from the Viewpoint of Human Ecology*. London, UK: Allen & Unwin.

Houston, D., Werritty, A., Bassett, D., Geddes, A, Hoolachan, A. & McMillan, M. (2011). *Pluvial (rain-related)* *flooding in urban areas: the invisible hazard*. York: Joseph Rowntree Foundation.

IPCC (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge, UK, and New York, NY, USA: Cambridge University Press.

IRDR (2014). *Peril Classification and Hazard Glossary*. IRDR DATA Publication N° 1. Beijing: Integrated Research on Disaster Risk.

Kelman, I. (2010, July 9). Natural Disasters Do Not Exist (Natural Hazards Do Not Exist Either). Retrieved from: http://www.ilankelman.org/miscellany/NaturalDisasters.rtf.

Kelman, I. (2011). Understanding Vulnerability to Understand Disasters. In B.L. Murphy & D. Etkin (eds.), *Canadian Disaster Management Textbook*, Canada: Canadian Risk and Hazards Network (cap. 7).

Klein, R. J. T. & Nicholls, R. J. (1999). Assessment of coastal vulnerability to climate change. *Ambio, A Journal of the Human Environment*, *28*(2): 182–187.

Lewis, J. (1999). *Development in Disaster-prone Places: Studies of Vulnerability*. London: Intermediate Technology Publications.

Lindley, S., O'Neill, J., Kandeh, J., Lawson, N., Christian, R. & O'Neil, M. (2011). *Climate change, justice and vulnerability*. York: Joseph Rowntree Foundation.

Local Government Association (2014, August 26). Surface water (pluvial) flooding. Retrieved from http://www.local.gov.uk/web/guest/flood-and-coastal-erosion-risk-management/-/journal_content/56/10171/3569716/ARTICLE-TEMPLATE Accessed 08.10.2012.

Maksimovic, C. & Saul, A. (2015). *Urban Pluvial and Coincidental Flooding*, Londra: IWA Publishing.

Marotta, N. & Zirilli, O. (2015). *Disastri e catastrofi. Rischio, esposizione, vulnerabilità e resilienza*. Rimini: Maggioli.

Moss, R. H., Brenkert, E.L. & Malone, E.L. (2001). *Vulnerability to Climate Change: A Quantitative Approach*. Washington, DC: Pacific Northwest National Laboratory.

Nott, J. (2006). *Extreme events: a physical reconstruction and risk assessment*, Cambridge: Cambridge University Press.

Ochoa-Rodríguez, S., Onof, C., Maksimović, Č., Wang, L.-P., Willems, P., Van Assel, J., Gires, A., Ichiba, A., Bruni, G. & ten Veldhuis, M.-C. (2013). *Urban pluvial flood modelling: current theory and practice*. Retrieved from http://www.raingain.eu/sites/default/files/wp3_review_document.pdf.

Parker, D. J., Priest, S. J. & McCarthy, S. S. (2011). Surface water flood warnings requirements and potential in England and Wales. *Applied Geography*, *31*(3), 891-900.

Peltonen, L., Haanpää, S. & Lehtonen, S. (2005). *The challenge of climate change adaptation in urban planning.* FINADAPT Working Paper 13, Helsinki: Finnish Environment Institute Mimeographs 343.

Pitt, M. (2008). *The Pitt Review: Learning lessons from the 2007 floods*. London, UK: Cabinet Office.

Queensland Government (2011). Understanding floods: questions & answers. Retrieved from http://www.chiefscientist.qld.gov.au/images/documents/chiefscientist/pubs/floods/understanding-floods_full_colour.pdf.

Schmitt, T., Thomas, M. & Ettrich, N. (2004). Analysis and modeling of flooding in urban drainage systems. *Journal of Hydrology*, *299*(*3–4*), 300-311.

Scottish Environment Protection Agency (2015, August 6). Strategic Flood Risk Assessment - SEPA technical guidance to support development planning. Scottish Environment Protection Agency, Stirling, UK, Retrieved from https://www.sepa.org.uk/media/143351/lups-gu23-strategic-flood-risk-assessment-sepa-technical-guidance-to-support-development-planning.pdf.

Shaw, R., Colley, M. & Connell, R. (2007). *Climate change adaptation by design: a guide for sustainable communities*. London: TCPA.

Silva, M.M. & Costa, J.P. (2016). Flood Adaptation Measures Applicable in the Design of Urban Public Spaces: Proposal for a Conceptual Framework. *Water 2016, 8*(7): 1-26.

SuDS (n.d.). SuDS Components. Retrieved from http://www.susdrain.org/delivering-suds/using-suds/suds-components/suds-components.html.

Swart, R., Fons, J., Geertsema, W., van Hove, B., Gregor, M., Havranek, M., Jacobs, C., Kazmierczak, A., Krellenberg, K., Kuhlicke, C., Peltonen, L. (2012). *Urban Vulnerability Indicators*. *A joint report of ETC-CCA and ETC-SIA*, *Technical Report 01/2012.* European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation (ETC/CCA) and European Topic Centre on Spatial Information and Analysis (ETC/SIA).

Tahmasebi, A. (2013). P*astoral Vulnerability to Socio-Political and Climate Stresses: The Shahsevan of North Iran* Berlin, DE: ZEF Development Studies LIT.

Tiranti, D. (1977). The Un-natural Disasters. *The New Internationalist*, *53*: 5-6.

UN & ISDR (2004). *Living with risk: a global review of disaster reduction initiatives*. New York: United Nations & International Strategy for Disaster Reduction.

UNEP (2004). *Reducing disaster risk a challenge for development*. New York: United Nations Development Programme, Bureau for Crisis Prevention and Recovery.

Watson, D., & Adams, M. (2011). *Design for flooding: Architecture, landscape, and urban design for resilience to flooding and climate change*. Hoboken, NJ: John Wiley & Sons.

Wilhelmi, O. V. & Hayden, M. H. (2010). Connecting people and place: a new framework for reducing urban vulnerability to extreme heat. *Environmental Research Letters*, *5*.