CREST

Climate resilient coastal urban infrastructures through digital twinning

CREST

D1.2 Impact and Monitoring assessment framework

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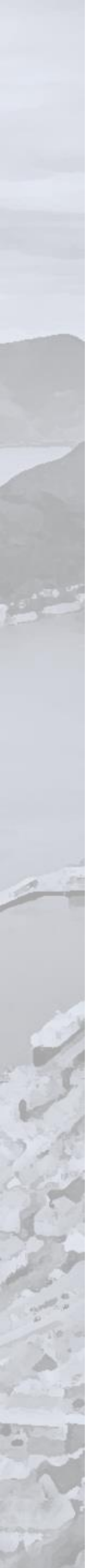

D1.2. Impact and Monitoring assessment framework

Sustainability and resilience monitoring framework of urban area - a global state of the art on the challenges of the resilience of cities in the face of climate change and the evaluation of urban resilience for global use (WP1)

A framework document on the challenges of adaptation and resilience of the coastal cities of Bordeaux (France), Kołobrzeg (Poland), and Møre og Romsdal (Norway) in the face of the challenges of climate change.

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1 Introduction

With the adoption of the Kyoto Protocol in 1997, the vision of the "climate" good changed and the world began to realize the usefulness of internalizing externalities due to climate effects. Consequently, climate change has become a dominant social concern, increasingly challenging governments, businesses, associations, unions and citizens. Due to its complexity, climate change constitutes a market failure requiring harmonization of actions and regulation which often faces the problem of free riding given the particular nature of the climate which can be defined as a global public good.

Over the past few decades and in the face of growing pressure from stakeholders, cities and urban areas have been increasingly forced to set up climate performance indicators, to report information on their climate performance in order to make their territories resilient through the development of adaptation strategies. For example, two thirds of municipalities in metropolitan France are affected by one or more natural risks in this context of global change. The human losses, the economic and financial costs associated with climate change caused by natural disasters are high for the territories and show their level of vulnerability. Beyond exposure to natural risks, territories may face other risks related to industrial sites. For example, territories in France are exposed to the risk of natural disasters with the presence of industrial sites and nuclear reactors which are distinctively distributed over several sites and geographical areas (Dutozia, J., & Voiron-Canicio, C., 2019).

Often manifested by increasing global temperature, drought, dwindling water resources, shrinking ice caps, coastal flooding and erosion, ocean acidification, rising sea level and the increase in extreme weather events, climate change exists and is real. This whole list of effects currently constitutes irrefutable evidence of global warming (Yobom, 2020; Kumar, 2021).

Consequently, all these harmful effects affect all the components of the geographical areas and the different economic sectors distinctively. Although these global issues are seen as distinct in many areas of research and policy, they are inevitably linked, and any mitigation policy in one area could affect circumstances in another (Von Schneidemesser et al., 2015), requiring a holistic approach to solutions (Kumar, 2021).

Globally, contemporary overconsumption of energy is one of the main causes of Greenhouse Gas (GHG) emissions and, consequently, of global warming and climate change (Kumar, 2021).

At the level of cities and territories, the multidimensional impacts of climate change can affect health, water availability, energy and livelihoods, threatening the social and economic development of citizens and local populations.

The frequency of disasters, particularly from floods and storms, has increased fivefold over the past 40 years. Territories and metropolises located in coastal areas are the most exposed because the risk of disaster is very high due to the rise in sea level which is partly due to the effects of climate change (Julca, 2012).

With the advent of climate change, all sectors are facing these effects which have become increasing in recent decades. In addition to the agricultural sector, whose adaptation issues have been the subject of several studies in comparison with issues related to the challenges of cities and territories in the face of climate change. The question of agricultural resilience has enabled farmers to impose a new paradigm of agricultural practices. On the side of the urban economy, the concept of territorial resilience is linked to the paradigm of sustainable development. Resilience is a way of thinking about the maintenance or adaptation of a territory whose components and functioning can be analyzed according to the principles of sustainability (Da Cunha, 2017). From now on, the construction of a resilient city requires that urban planners and landscape architects ensure that long-term effects are considered in the decisions related to land use planning made today. Similarly, it requires local actors not to confine themselves to risk management from a technical-functional perspective but to know the social and territorial vulnerability of their community (Dutozia, J., & Voiron-Canicio, C., 2018).

Currently, cities and urban territories have become the most sensitive areas in the world due to their high climatic vulnerability due to urban population growth and the growth of economic activities.

This situation requires colossal sources of financing from local and international sources and a reassignment of development priorities (Julca, 2012) and urban entities need to put in place an evaluation framework and mobilize indicators in order to provide monitoring the climate performance of their territory.

This literature review provides some answers aimed at fueling the existing debate on the challenges of adaptation and the resilience of cities to climate change by placing urban territories in the middle of the debates. It is organized in three parts.

The first part of this document presents a review of the literature on climate change and its effects at the scale of cities and territories. The second part raises questions about the challenges of adaptation and mitigation of cities in the context of urban resilience. The last part contributes to this debate on vulnerability and urban risk by evaluating the state of the art of tools for assessing vulnerability and urban risk. While contributing to the debate by proposing a new and improved assessment framework, it presents a review of the conceptual frameworks, methodologies and comparative advantages of ten tools.

2 Effects of climate change on cities and urban territories

Climate change is a global phenomenon that widely impacts urban life and poses the most significant threat to life on planet earth (Kumar, 2021), although the effects seem to be slow to manifest in some countries and geographical areas (Yobom, 2020). In addition, changes are observed in air temperature, precipitation patterns, the water cycle and sea level. For example, rising global temperatures lead to rising sea levels, increase in the number of extreme weather events such as floods, droughts and storms, and increase in the spread of tropical diseases. However, these effects manifest themselves differently and depend on the geography of urban areas. At a rise of 1.5°C, twice as many megacities (including Lagos, Nigeria and Shanghai, China) could experience heat stress, exposing more than 350 million people to life-threatening heat by 2050 according to average predictions for the population growth (Dodman et al., 2019). Globally, global warming and urban development are warming metropolitan areas and influencing the chemistry of urban air pollution (Kumar, 2021).

All of these effects are also harmful to economic sectors and activities. The increasing frequency and severity of climate change-related disasters have caused economic damage and loss of life (Tong, 2021). Like several economic sectors, mainly agriculture and livestock, cities and territories are deemed to be in a two-way relationship with climate change. The main reason is that cities are major contributors to CO2 emissions (Chaoui and Robert, 2009) and estimates suggest that they are responsible for 75% of global CO2 emissions, with transport and buildings being among the main contributors (Madlener and Sunak, 2011; Aubry et al., 2017; Elmqvist et al., 2019). All this implies that the size and number of inhabitants of a city are the main parameters that have an influence on the level of emissions of cities and territories. With urban populations increasing to more than two-thirds of the world's population, that is, nearly 7 billion people are expected to inhabit urban areas by 2050 (Leeson, 2018; Tong, 2021). In recent years, the rapid rate of urbanization has led to a massive increase in urban populations, infrastructure and urban settings (Zeng et al., 2022; Sarker et al., 2020).

Besides being a continuous process of economic development of a city, rapid urbanization provides a huge job opportunity for people (Choy et al., 2017; Glaeser, 2020; Zeng et al., 2022). For example, rapid urbanization, urban regeneration, immigration and economic cycles are just some of the various factors that urban areas face (LopezDeAsiain, 2020; Zeng et al., 2022). In addition to the risks associated with anthropogenic activities, natural hazards add more complexity to the urban system. This nuance is particularly critical in cities in emerging economies experiencing rapid urbanization characterized by poor planning, weak institutional systems and insufficient essential urban public services (Sarker et al., 2020; Zeng et al., 2022).

Climate change, which includes an increase in global temperature and a magnitude of extreme weather events, is affecting human populations and stressing the built environment (Kumar et al., 2020) as urban infrastructure is not built with the potential climate change and variability. Concretely, this phenomenon makes cities warmer, while urbanization intensifies this process via the generation of urban heat islands and the radiative forcing of aerosols (Chapman et al., 2017; Zhong et al., 2017; Kumar et al., 2017; al., 2021).

With rising sea levels, threats and challenges take on another form in coastal cities and island states. In Europe, 70% of the largest cities have areas located less than 10 meters above sea level (Kamal-Chaoui and Robert, 2009; Geisler and Currens, 2017). Indeed, the tendency of cities to be located in coastal areas increases their vulnerability to water-related calamities, increasing the risk to assets, livelihoods and urban infrastructure (Kamal-Chaoui and Robert, 2009; Kulp and Strauss, 2019).

Indeed, the most recent climate models predict that climate change will produce a diverse global impact, with effects being more extreme in urban areas (Müller et al., 2011; Kumar et al., 2020) with costly impacts on basic services, infrastructure, housing, livelihoods and health of city citizens (Maharaj, 2015; Satterthwaite et al., 2020). In this section, we will discuss the climatic effects of climate change in terms of interactions with the various parameters that make up urban areas and cities.

2.1 Climate change, urban air pollution and urban territories

Although they are related (Kaur et al., 2021), climate change through the pollution of cities negatively affects the dynamics of territories and poses a major threat to rapidly growing cities (Kaur and Pandey, 2021). Air pollution in urban areas and cities is a major concern worldwide, regardless of a country's level of development (Han et al., 2018).

This close relationship is explained by the fact that climate change results from natural and anthropogenic emissions of air pollutants, in particular GHGs) which have large-scale effects on the climate (IPCC, 2013; Janssens-Maenhout et al., 2019).

Nowadays, the urban environment is characterized by poor air quality and harsher climatic conditions that affect life in cities (Locosselli et al., 2017). WHO (2017) estimates that around 6.5 million deaths are associated with air pollution each year. For example, warmer metropolitan climates increase the impacts of air contamination and therefore, the mortality rate associated with pneumonia (Kumar, 2021).

Inextricably linked, air pollution and climate change have the same sources of emissions (Aunan et al., 2006; Kumar, 2021), with important consequences for human health (Heal et al., 2012).

Indeed, ground-level ozone and black carbon contribute to both air quality degradation and global warming (Shindell et al., 2012; Jiménez and Sáez-Martínez, 2015). Harmful to vegetation and being a major contributor to global warming (Hertig, 2020), ground-level ozone can be dangerous to human health (Manisalidis et al., 2020). In contrast, black carbon also has significant negative effects on health and air quality and causes atmospheric warming (Shindell et al., 2012; Kumar 2021).

By studying the role of air pollution and climate on the growth of urban trees, Locosselli et al. (2019) state that air pollution (Al, Zn, Ba, PM_{10}) has a stronger influence than climate on growth (Heal et al., 2012; Guttikunda, 2014).

Furthermore, the consequences of the interactions between climate change, the urban heat island effect and air pollution are expected to increase the risk of poor human health in cities around the world by the middle of the 21st century (Kumar, 2021) especially since the impacts of climate change on health are greater in areas with lower air quality (Du et al., 2019; Kumar, 2021).

There are several environmental pollutants such as O_3 (Ozone), NO_x (Nitrogen Oxides), VOCs (Volatile Organic Compounds), PM (Suspended Particulates), SO_2 (Sulphur Dioxide), CO (Carbon Monoxide), Heavy Metals and NH_3 (Ammonia) and climate pollutants (smoke from wood stoves, ground-level ozone, black carbon, methane) (Shindel et al., 2017; Kumar, 2021). Intuitively, the urban atmosphere faces more than a single contaminant but rather a complex mix of different contaminants at different times of the day and year (Han et al., 2018; Tan et al., 2021).

For example, the acute effects of pneumonia on mortality increase with warmer weather and are further exacerbated during peak air pollution hours, indicating that a warmer urban climate due to global warming and urban planning can increase the risks of air contamination and pneumonia (Sun et al., 2019; Kumar, 2021).

Thus, climate change could influence the lifetime, dispersal, and associated health effects of many different pollutants, including fine particles ($PM_{2.5}$) i.e. all particles in the air having an aerodynamic diameter less than or equal to 2.5 µm. (e.g., Xu and Lamarque, 2018)

2.2 Health and environmental risks in urban territories in the context of climate change

In general, human health depends on environmental factors and for decades on the evolution of the context of climate change (Rocque et al., 2021). In addition, the situation related to climate change and ongoing urbanization create future health challenges (Ward et al., 2016) which could increase the vulnerability of urban areas.

According to the WHO (2021), climate change influences the social and environmental determinants of health: clean air, drinking water, sufficient food, safe housing. In other words, the pathways through which climate change and variability influence human health are linked to different social, natural, biological and economic factors (Kumar, 2021). Truly, global warming will have considerable direct (responsible for contagious water-borne diseases) and indirect (water-borne diseases) repercussions on the well-being of populations (Shuman, 2010; Kumar, 2021). Between 2030 and 2050, climate change will lead to almost 250,000 additional deaths per year, due to malnutrition, malaria, diarrhea and heat stress (WHO, 2021).

Economically, WHO (2021) posits that the cost of its direct damage to health (excluding costs in health-determining sectors such as agriculture and water and sanitation) is between 2 and $4 billion (US$) per year by 2030. The degree of impact and damage caused depends on the level of economic development and preparedness of cities (Taconet et al., 2020). As a result, urban citizens in low and middle-income countries are the most vulnerable due to their significant exposure to changing weather patterns and air pollutants, and their limited ability to control and especially adapt to these complex climate risks (IPCC, 2014; WHO, 2014; Ma et al., 2020; Kumar, 2021).

Beyond its effects on human health, climate change is deteriorating the surfaces of building materials while amplifying the concentrations of secondary pollutants, such as ozone O_3 (Kumar and Imam, 2013; Xu and Lamarque, 2018; Kumar, 2021; Patz, 2014; Han et al., 2021).

By 2050, many cities in the United States (Patz, 2014; Patel et al., 2022) and around the world (Kumar, 2021) could experience more frequent extreme heat days and face intense and recurrent heat waves, from day and night. Extreme heat events are strongly linked to O_3 exceedance days (Patz, 2014; Zhang et al., 2017; Kumar, 2021; Otero et al., 2022). For example, New York and Milwaukee may have 3 times their current average number of days warmer than 32°C (Patel et al., 2022) and the overshoot already observable in Chicago, Illinois (Patz, 2014). On the other hand, colder cities seem to be more affected by heat waves than warmer cities. Furthermore, cooler cities in northern Europe seem more vulnerable to heat waves, while cities in southern Europe seem better adapted (Ward et al., 2016).

In addition to increasing heat waves (Wang et al., 2021), anthropogenic emissions caused by man in the destruction of his environment are the cause of floods, air contamination, aeroallergens, droughts and vector-borne infections that directly or indirectly cause excessive morbidity and mortality (Hebbert and Jankovic, 2013; Kumar, 2021; Wang et al., 2021).

A whole list of diseases and problems related to climate change is presented in the literature. Several studies highlight the relationships between climate change, pollution and pandemics (e.g. respiratory complications caused by environmental pollutants and aeroallergens such as Covid-19 and asthma; Marazziti et al., 2021). Excessive daily heat exposures create direct effects, such as heat stroke (and possibly death) or thermal discomfort (Kumar, 2021), reduce labor productivity, and interfere with daily household activities (Kjellstrom et al., 2013). Furthermore, the increased frequency of disasters related to climate change can lead to post-traumatic stress disorder, adjustment disorder and depression (Padhy et al., 2015; Kumar, 2021).

2.3 Natural risks, natural disasters and urban territories

Natural disasters occur frequently around the world, economically affecting both developed and developing countries, although the level of vulnerability is not similar between the two groups of countries (Ashizawa et al., 2022). Therefore, the vast majority of lives lost or affected by natural disasters are in developing countries (Zorn, 2018; Botzen et al., 2019). Whether considered as single, repetitive or cumulative events of several local events, they negatively affect household sustainability and urban infrastructure (Ridha et al., 2022; Rahman et al., 2022). Although numerous, cities are exposed to natural hazards such as droughts, earthquakes, extreme temperatures, floods, landslides, storms, volcanic eruptions and forest fires (Julca, 2012; Chakraborty et al., 2016; Gu, 2019).

Like the adverse effects of climate change, natural disasters represent a serious risk to sustainable urban development, leading to escalating human and economic costs (Wamsler, 2014) and all projections related to climate change and variability show an increase in the frequency of natural disasters that will be distinguished by their scope and scale (IPCC, 2018; Kumar, 2021).

For example, large metropolises will not be spared because climate change projections indicate an increase in the frequency and intensity of short-lived extreme events, and indicate an increase in the number of days of heavy rain until the end century, further aggravating the problem of flooding (Haddad and Teixeira, 2015; Ridha et al., 2022).

In addition to the losses and inconvenience felt by residents, the floods produce damage that crosses city limits, affecting incomes and production in the metropolitan area as well as other parts of the state hitherto spared (example through sectoral and regional interdependencies, Mendoza-Tinoco et al., 2017) and the country (Rahman et al., 2022) and likely to disrupt all activities related to wealth creation by affecting local economic trends cities (Pan and Qiu, 2022).

The consequences of flooding in urban areas are relevant. Ranging from impacts on general human health (e.g. mental health and health-related quality of life, French et al., 2019) to effects on housing prices (Zhang, 2016; Zhang and Leonard, 2019; Shr and al., 2019), they also affect urban transport infrastructure (Habel et al., 2020) and coastal infrastructure due to sea level rise (Sanders and Grant, 2020).

Any disruption to the means of transport will have effects on the working time of citizens and the performance of companies (Kumar, 2021). Businesses located in the zone of influence of flood points may have to close temporarily and affect business performance (Coelli and Manasse, 2014). For example, the major flood in Germany of 2013, which caused damage of around €6-8 billion (Koetter et al., 2020) had a significant positive effect on the performance of small and medium-sized enterprises, which was not funded by increasing leverage or decreasing liquidity (Noth, 2019). The authors explain this effect for the following reasons. First, companies that have already experienced a major disaster of the same type may fare better after the 2013 crisis. Second, companies may reduce their investments and lay off employees due to the destruction of working capital. In addition, insurance payouts and government subsidies can help companies offset the negative effects. Finally, the replacement of old capital due to a disaster can improve productivity because it allows small and medium enterprises to modernize their capital stock (Noth, 2019).

In addition, damage to economic infrastructure can generate either a reduction in capital stocks available for production (Mendoza-Tinoco et al., 2017; Zhou et al., 2021), or, more frequently during floods, temporary disruptions to supply chain services, the retail network and public infrastructure (e.g. electricity circuits, roads, water services and telecommunications networks), also impacting negatively companies turnover and the regional annual gross value added (Haddad and Teixeira, 2015; Mendoza-Tinoco et al., 2017; Kumar, 2021).

The geographical position of cities plays an important role in determining their level of vulnerability during the occurrence of natural disasters, as evidenced by the work of Mazumder et al. (2022) on environmental equity assessment of flood risk and social vulnerabilities in the United States. For example, rapid urbanization under climate change, without efforts to increase resilience (Helderop and Grubesic, 2019), exposes cities around the world to enormous natural hazards, and especially cities built along rivers or near the coast (Kumar and Saroj, 2014; Allen et al., 2019; Kumar, 2021) for example the city of Tampa, Florida, and the city of Houston, Texas, both of which are at risk of flooding from sea level rise and extreme weather events induced by climate change (Mazumder et al., 2022).

Developing countries are more vulnerable to natural disasters because people live in areas at high risk of natural disasters in Asia (e.g. most coastal cities of Bangladesh, Honduras; Rahman et al., 2015) and Africa (e.g. countries like Benin, Ghana, Nigeria, Senegal and Sudan; Salami et al., 2017).

Contextually, coastal districts including Khulna, Chittagong and Barisal in Bangladesh have inadequate infrastructure (i.e. housing is poorly built, there is no sewage system in Khulna town and most areas have no water pipes or permanent drainage system) and can be easily damaged in the event of natural disasters (Rahman et al., 2015). For example, countries are not equipped with warning systems, and they have few assets and a weak social safety net to help them cope with disasters (Rahman et al., 2015; Salami et al. al., 2017; Zorn, 2018; Kumar, 2021).

By studying the exposure and vulnerability of 1860 cities and urban areas to 6 natural disasters (floods, cyclones, earthquakes, droughts, landslides and volcanic eruptions), Gu (2019) claims that more than half of the cities studied were exposed to at least one of the 6 hazards. The author argues that nearly 58% of the metropolitan areas studied were highly exposed to at least one of the six natural hazards. In addition, just under 14% and around 2% of cities were deeply exposed to more than two and three natural hazards, respectively (Gu, 2019).

Furthermore, the majority of the riskiest cities in the world are located in East Asia, China, Taiwan, the Philippines and Japan, based on their degree of exposure to natural hazards (Gu, 2019; Kumar, 2021) and most of them are coastal and threatened by floods, storms, earthquakes and other natural disasters (Rahman et al., 2015; Gu, 2019; Kumar, 2021).

The effects of natural disasters are not similar and vary according to the density of cities and their resilience capacities. They can also vary the number of occurrences and the damage caused monetarily. Thus, the work and results of Gu (2019) list the ten cities hardest hit by natural hazards around the world: Tokyo-Yokohama (Japan, 60), Manila (Philippines, 35), Pearl-River Delta (China, 35), Osaka-Kobe (Japan), Jakarta (Indonesia), Nagoya (Japan), Kolkota (Indonesia), Shanghai (China), Los Angeles (USA) and Tehran (Iran).

Obviously, the effects of a natural hazard in certain densely populated cities can be catastrophic (Debele et al., 2019; Kumar, 2021) and difficult to absorb in a context of global changes (Rahman et al., 2015).

Overall, floods, earthquakes and windstorms caused damage to 43.9%, 32.8% and 18.2% of urban dwellers in the cities cited above by Gu (2019), respectively, while an additional 5.2% of city dwellers were potentially devastated by storm surges and tsunamis (Gu, 2019; Kumar, 2021).

Each country through regions and territories must accommodate an appropriate urbanization model. This is why disaster risk planning and management is nowhere more urgent than in major metropolitan areas around the world (Kumar, 2021).

2.4 Economic consequences of climatic effects and natural disasters on urban territories

The consequences of climate change and natural disasters are increasingly frequent and complex (Suk et al., 2020) and it is difficult to assess the economic costs in an economy (Stern, 2008). For example, Franzke (2017) estimates that weather and climate extremes cause enormous economic damage and harm many lives each year (~35,000/year). In addition to direct deaths, populations that are victims of natural disasters become inactive and constitute an economic burden for society. Thus, people vulnerable to the effects of extreme weather, namely the poor, the elderly/disabled, children, prisoners and drug addicts, have experienced increased levels of mental, emotional and physical stress due to exposure to natural disasters (Benevolenza et al., 2019).

The results of Gu (2019) estimate that 76% of the 1,860 metropolitan areas studied were located in territories deeply vulnerable to flood-related mortality. The effects of climate change can easily cripple or slow down an entire national economy. To this end, natural hazards not only have a significant impact on human life and health, but they can also significantly disrupt the local economies of metropolitan areas and, in some cases, entire countries (Gu, 2019; Kumar, 2021).

The occurrence of disasters drastically guides the urban policies of cities in the construction of quality specialized infrastructure and also investments in certain sectors.

The cascading effects of natural disasters, such as earthquakes and floods, include outbreaks of infectious diseases (Suk et al., 2019). The projection that extreme weather events related to climate change will increase in Europe over the coming century highlights the importance of strengthening preparedness planning and measures to mitigate and control outbreaks in post-disaster situations (Suk and al., 2019).

The total economic loss for the Yorkshire and Humber region from the 2007 UK floods was high. According to the flood footprint analysis, it takes at least 14 months for the Yorkshire region's economy to return to its pre-disaster situation following the summer 2007 floods; this recovery involves both achieving economic balance and returning to pre-disaster production levels. The total economic loss is estimated at £2.7 billion, equivalent to 3.2% of the regional annual gross value added (Mendoza-Tinoco et al., 2017).

3 City adaptation and mitigation strategy in the face of climate change challenges

Scientific studies and perspectives are all unanimous on the fact that climatic events will increase in number and will be distinguished by their extent, pushing the quest to understand the level of vulnerability in urban areas (Sharifi, 2019; Zeng et al., 2022). Faced with these crucial challenges, cities and urban areas are developing adaptation strategies to mitigate potential climate shocks. As climate change progresses and becomes very evolutionary, the urban resilience of cities is nowadays becoming an important topic in scientific and political circles, which influence and help decision-making for future urban development.

3.1 Context of urban resilience

Faced with the effects of climate change and natural disasters, most geographical territories (continent, region, municipality, cities, etc.) have seen their flaws exposed because these events test their resilience. This notion of resilience is presented as a solution allowing cities to prepare in order to face the various uncertain and unpredictable climatic shocks (Ribeiro and Gonçalves, 2019). Urban resilience has its origins in the concept of ecological resilience which was first introduced by Holling in 1973 as "the ability of a system to absorb disturbances and reorganize itself while undergoing change to retain essentially the same function, structure, identity and feedbacks" (Holling, 1973; Tong, 2021). Beyond climatic shocks, cities can be confronted with shocks related to pandemics (example, covid-19) or socio-economic crises (example, the 2008 financial crisis) and many other problems related to changes in our societal environment (Rus et al., 2018).

In this context of global changes, urban resilience has become one of the fundamental principles of urban planning and urban development over the last decade to help territories better prepare for climate-related disasters (Meerow et al, 2016; Tong, 2021) and all other exogenous shocks (Rus et al., 2018; Wardekker et al., 2017).

As the frequency and severity of climate-related disasters increase, understanding how to improve urban resilience has become an important area of research (Tong, 2021) referring first to the contextualization of this phenomenon. Indeed, urban resilience and sustainability is an urgent issue to deal with hazards in an increasingly urbanized world (Zeng et al., 2022) in a context of rapid population growth (Sarker et al., 2020).

As mentioned earlier, resilience has emerged in ecological studies as a concept of strengthening a system against disturbances (Tong, 2021) and the first step to trigger the improvement of urban resilience to climate-related disasters is the assessment of current levels of resilience (Sharifi and Yamagata, 2016; Tong, 2021). Indeed, this scientific trend is driven by the increasing frequency and intensity of climate-related disasters affecting cities around the world and intensifying the need to assess urban resilience (Tyler et al., 2016; Tong, 2021).

Nowadays, researchers and scientists emphasize the resilience of cities, due to the increasing impacts of climate change and the occurrence of natural disasters, where the majority of daily interactions between humans and nature take place (Neuni et al., 2021). In other words, the promotion of urban resilience in the environmental, socio-economic and political domains is increasingly attracting the attention of researchers and local authorities (Ribeiro and Gonçalves, 2019).

3.2 Urban Resilience and Climate Change Framework

This subsection presents urban resilience through its characteristics and the different dimensions that allow it to be conceptualized and defined. It also presents the advantages of the existence of an urban resilience plan for cities and urban areas.

3.2.1 Characteristics of urban resilience

A multitude of definitions are available in the literature on urban resilience. Table 1 provides an overview of the different definitions of the concept of urban resilience. In their work, Zeng et al. (2022) provide a summary list of definitions associated with the concept of resilience in gray and scientific literature. We offer the following table of definition de la resilience in addition to other related definitions of the concept of resilience.

Authors (year)	Definitions of urban resilience
Godschalk (2003)	Resilience is a link between physical systems and human societies that is self-sustaining.
Pickett et al. (2004)	Resilience is the ability of a system to adapt to changing situations.
Campanella (2006)	Resilience is a city's ability to recover from a disaster.
IPCC (2007)	Resilience refers to the potential of a social or ecological system to absorb disturbances while retaining its essential structure and modes of functioning and its ability to self-organize and adapt to stress and change.
Alberti et al. (2008)	The degree to which cities accept change before reorganizing around a new set of structures and processes is resilience.
Lamond and Proverbs (2009)	Resilience encompasses the idea that cities should be able to recover quickly from major and minor disasters.
Wardekker et al. (2010)	A system that can tolerate disturbances (events and trends) through features or measures that limit their impacts, reducing or neutralizing damage and

	disturbances, and allowing the system to respond, recover, and adapt quickly to these disturbances.
Ernstson et al. (2010)	To maintain a certain dynamic regime, urban governance must also strengthen the capacity for transformation to cope with uncertainty and change.
Leichenko (2011)	The ability to withstand a wide range of shocks and stresses.
Romero-Lankao and Gnatz (2011)	A capacity of populations and urban systems to withstand a wide range of risks and stresses.
Tyler and Moench (2012)	Resilience encourages practitioners to consider innovation and change to help recover from predictable and unpredictable stresses and shocks.
Liao (2012)	The city's ability to tolerate flooding and to reorganize in the event of physical damage and socio-economic disruption, so as to prevent death and injury and maintain the current socio-economic identity.
Henstra (2012)	A climate-resilient city can withstand the stresses of climate change, respond effectively to climatic hazards, and recover quickly from residual negative impacts.
Wamsler (2013)	A disaster-resilient city can be understood as a city that has succeeded in: (a) reducing or avoiding current and future risks; (b) reduce current and future susceptibility to hazards; (c) put in place functioning mechanisms and structures for disaster response; (d) put in place operational mechanisms and structures for disaster recovery.
Coaffee (2013)	The ability to resist and bounce back from disruptive challenges.
Desouza and Flanery (2013)	Ability to absorb, adapt and respond to changes in urban systems.
Lu and Stead (2013)	The ability of a city to absorb disturbances while maintaining its functions and structures.
Thornbush et al. (2013)	A general quality of the city's social, economic and natural systems to be sufficiently future-proof.
Wagner and Breil (2013)	The overall capacity and ability of a community to withstand stress, survive, adapt and bounce back from a crisis or disaster and move on quickly.
Wilson (2013)	A disaster-resilient city can be understood as a city that has succeeded in: (a) reducing or avoiding current and future risks; (b) reduce current and future susceptibility to hazards; (c) put in place functioning mechanisms and structures for disaster response; (d) put in place operational mechanisms and structures for disaster recovery.
Asian Development Bank Manila (2014)	The ability of a city to function in such a way that its citizens and workers, especially the poor and vulnerable, can survive and thrive regardless of the stressors or shocks they face is referred to as urban resilience.
Bahadur and Thornton (2015)	For urban resilience, decentralized decision-making, systematic learning, simultaneous interaction with many shocks and pressures, appropriate urban planning, and recognition of the political underpinnings of risk and vulnerability are all needed.
HN-Habitat (2017)	Resilience is seen as a process, a state and a quality.
Zhang and Li (2017)	Urban resilience refers to the ability of an urban actor to cope or respond to the stress of hazards. Resilience refers to the ability of an individual or group to withstand the effects of a threat in terms of their economic, psychological, and physical well-being, as well as their maintenance systems.
Meerrow et al. (2016)	Urban resilience is defined as the ability of an urban system and all of its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly regain desired functions in the face of disturbance, to adapt to change and to rapidly transform systems that limit current or future adaptive capacity.

McGill (2020)	The ability of an urban area to resist disturbance and restore its condition after a disturbance is known as urban resilience.
Bruzzone et al. (2021)	A resilient urban community is able to manage unforeseen events and cope with pressures and shocks while preserving and developing its social, economic systems and infrastructure.
Wubneh (2021)	The ability of an urban system to adapt and function fully in order to maintain its form, structure and identity in the face of adversity is called urban resilience.
Saker et al. (2020)	Resilience represents the ability of a system to “bounce back” or return to a previous stable state after stressors caused by a hazard.
Masnavi et al. (2019)	Urban resilience is not necessarily the ability of a system to return to the previous state and equilibrium point while the system is experiencing the disturbance or shock. The previous state and the old equilibrium point may have disappeared or partially disappeared for various reasons, and alternative ways have probably emerged; So, it is necessary to note that all these scenarios and potential options can change the system path.
Kapucu et al. (2021)	Urban resilience is broadly defined as the ability of an urban system – and all of its constituent socio-ecological and socio-technical networks across temporal and spatial scales – to maintain or rapidly regain desired functions in the face of disruption, adapt to change and rapidly transform systems that limit current or future adaptive capacity.
Coaffee et al. (2018)	Resilience is a complex solution to a complex set of problems, including risks such as climate change, critical infrastructure failures, terrorist attacks, technological accidents, pandemics, etc.
Bautista-Puig et al. (2022)	Urban resilience is an emerging concept that is receiving increasing attention. Its definition is linked to the ability of an urban system to resist, maintain continuity and recover from all constraints while adapting and transforming towards sustainability.

TABLE 1. DEFINITIONS OF URBAN RESILIENCE

Although most definitions refer to the capacity of an urban area to cope with a shock, some definitions point directly to a single disaster, for example the definition of Lia (2012) which only refers to floods.

The most comprehensive definition that draws our attention is that given by IPCC (2007) and Meerrow et al. (2016) because to our knowledge, they evoke and consider affect all the dynamics around which a modern city is built and organized. According to the IPCC (2007), resilience is "the ability of a social or ecological system to absorb disturbances while maintaining the same basic structure and the same modes of functioning, the capacity for self-organization and the capacity to adapt to stress and change. Theoretically, these two definitions will be the basis of the methodological construction of our framework in the next section.

In other words, resilience is expressed in response to a shock or a disturbance of a complex system, but it can be considered as a latent property even in the absence of such a disturbance. Thus, strengthening urban climate resilience applied in the study by Tyler and Moench (2012) means: 1) strengthening infrastructures and ecosystems to reduce their fragility in the face of climate impacts and reduce the risk of cascading failures; 2) Strengthen the capacities of social agents to anticipate and develop adaptive responses, and to access and maintain favorable urban systems; and 3) Addressing institutional factors that limit the effectiveness of responses to system fragility or compromise the ability of agents to act.

3.2.2 Dimensions of urban resilience

The measurement and communication of climate performance around territories and urban areas also have important socio-economic and political dimensions. Overall, resilience questions these dynamics of evolution, their combinations and the resulting territorial trajectories. In other words, urban resilience involves multiple dimensions of urban ecosystems. Research should better integrate diverse fields of knowledge and a variety of approaches, through which academics and practitioners can collaborate to generate operational and actionable assessments (Tyler et al., 2016; Tong, 2021).

Moreover, the analysis of the interrelation between these domains can lead to actions aimed at strengthening the resilience of urban ecosystems (Tong, 2021). Therefore, each dimension focuses on several indicators that can represent the status of the specific dimension (Zeng et al., 2022) and the indicators selected and proposed should cover multiple dimensions of urban resilience (Sharifi and Yamagata, 2016; Tyler et al., 2016).

An urban area consists of a citizen, settlements and a built environment (Zeng et al., 2022; Sarker et al., 2020). As a result, it is necessary to capture or grasp these interactions between the citizen and his environment, both immediate and distant.

Authors (year)	Dimensions proposed et mobilized
Sharifi et Yamagata (2016)	Environmental materials and resources, society and well-being, economy, built environment and infrastructure, and governance and institution.
Smiciklas et al. (2017) / U4SSC	Economy (ICT, productivity, infrastructure), Environment (environment, energy) and Society & Culture (education, health and culture; safety, housing and social inclusion).
Zeng et al. (2022)	Adaptive capacity (education, health, food and water), Absorptive capacity (community support, urban green spaces, protective infrastructure, access to transport) and Transformative capacity (communication technology, multi-stakeholder collaboration, service delivery) government emergency, community-based urban planning).
City Protocol (2017)	Structure (environment, infrastructure et built domain), Interactions (Functions, economy, culture, information) et Society (Citizens et Government)
Bosch et al. (2017) /CityKeys (2017)	People (health, safety, access to services, education, diversity and social cohesion, quality of housing and the built environment), planet (energy & mitigation, materials, water and land, climate resilience, pollution & waste, ecosystem), prosperity (employment equity, green economy, economic performance, innovation, attractiveness & competitiveness), governance (organization, community involvement et multi-level governance) et propagation.
Giffinger et al. (2007)/European Smart City Ranking (2007)	Smart economy (innovative spirit, entrepreneurship, economic image & trademarks, productivity, flexibility of labor market, international, international embeddedness), smart people (level of qualification, affinity to lifelong learning, social and ethnic plurality, flexibility, creativity, cosmopolitanism/open-mindedness, participation in public life), Smart governance (participation in decision-making, public and social services, transparent governance), smart mobility (attractivity of natural conditions, pollution, environmental protection, sustainable resource management), smart living (cultural facilities, health conditions, individual safety, housing quality, education facilities, touristic attractivity and social cohesion)

Garau et Pavan (2018)	Use and fruition (accessibility, flexibility and functionality, minimum service provided), health and wellbeing (emotional wellbeing, quality of life and social wellbeing), Appearance (environment characteristics, built environment characteristics), management (efficiency of primary services), Environment (soil pollution), safety and security (security systems, smart crime prevention, risk of natural disaster)
Pira (2021)	Socio-cultural, economic, environmental and governance
Platform for Sustainable Cities (2018)	Governance and integrated urban planning (Vision and Long-term Strategic Planning, Stakeholder Participation , Data Management, Trend Analyses, Land Use and Zoning, Urban Growth Patterns, Informal Settlements, Transport and Mobility Integrated with Land Use, Cultural Heritage), Fiscal sustainability (Accountability and Transparency , Creditworthiness , Revenue and Financial Autonomy, Expenditure Management, Management of Debt and Other Obligations), urban economies (Economic Performance; Economic Structure; Business Climate, Innovation, and Entrepreneurship; Labor Force; Livelihood Opportunities; Income Equality and Shared Prosperity; Global Appeal; Connectivity and Global Links), Natural Environmental and resources (Ecosystems and Biodiversity, Air Quality, Water Resources Management, Solid Waste Management, Consumption and Production Patterns), Climate Action and Resilience (Greenhouse Gas Inventory, Energy Efficiency, Clean Energy,Climate Change Adaptation, Disaster Risk Reduction), Inclusivity and quality of life (Housing; Education; Poverty Reduction, Hunger Reduction, and Food Security; Drinking Water and Sanitation; Basic Physical Infrastructure; Health and Well-Being; Safety; Social Cohesion)
Pira (2021)	Environment (smart buildings, resources management, sustainable urban planning), mobility (efficiency transport, multimodal access, technology infrastructure), government (online services, infrastructure, open government), Economy (entrepreneurship and innovation, productivity), people (local and global connection, inclusion, education, creativity), living (culture and well-being, safety and health)
Ribeiro et Gonçalves (2019).	Dimension naturelle, dimension économique, dimension sociale, dimension physique et dimension institutionnelle.
OECD (2020)	Connectivity (% households equipped with internet, wireless broadband coverage; % of households who use digital apps or platforms to connect to local community) , mobility (% of smart traffic lights; % of public transport equipped with real-time information; number of users of sharing economy transportation per 100 000 population; % of public parking spaces equipped with e- payment systems), jobs and firms (% of job seekers who have access to e-career centres; expenditure in R&D), housing and built environment (Open-source cadastral data; digital land-use and building permits), health and safety (% of medical appointments conducted remotely; % of population registered with public alert systems for air and water quality; % of population with online access to their unified health file; % population equipped with real-time alert systems), education and skills (% of children who have access to e-learning platforms; number of computers, laptops, tablets, or other digital learning devices available per 1 000 primary school students), e-government (% of city services available online; number of municipal smart stations installed per 100 000 population; % of payments to the city that are paid electronically) et energy, water and waste (% of households equipped with smart energy meters; % of buildings with smart electricity meters; % of smart street lights; % of households equipped with smart water meters; % drinking water under water quality monitoring by real-time water quality monitoring station; % of buildings equipped with smart waste systems).
Masnavi et al. (2019)	Social dimension, institutional dimension, physical dimension and economic dimension

TABLE 2. DIMENSIONS OF URBAN RESILIENCE

Drawing on the existing literature on urban resilience assessment, Sharifi et al. (2016) provide a set of principles and indicators that can be used to develop an urban resilience assessment tool (e.g. selected indicators should cover multiple dimensions of urban resilience, Tong, 2021).

As such, they identify and propose five interdependent dimensions considered essential components of urban ecosystems to frame the assessment of urban resilience: environmental materials and resources, society and well-being, economy, built environment and infrastructure, and governance and institution (Sharifi et al., 2016; Tong, 2021).

It is obvious that neither urban resilience nor urban sustainability can be built on the basis of a single parameter or a single dimension. Resilience may simply replace sustainability as another term with widespread appeal despite (or perhaps because of) a lack of clarity (Davoudi, 2012; Shamsuddin, 2020). The requirement of a multitude of dimensions is more than necessary because due to the global changes that operate in our societies, capturing these notions in a single dimension or variable is possible but just without scientific relevance and this model will suffer from a lack of scientific rigor.

Indeed, resilience and sustainability are considered effective strategies to deal with all hazards and help the urban planning process (Pirlone et al., 2020; Zeng et al., 2022). Without an adaptation and mitigation strategy, the lack of urban resilience building has significant economic costs for cities. Rethinking urban resilience will allow territories and cities to make significant savings.

3.2.3 Economic costs of the inaction of cities and territories in the face of climate change.

Assessing the economic costs and damages of climate change in an economy remains very difficult. Most of the work has focused on assessing the effects of climate change on the agricultural sectors, particularly agriculture and food security. However, Stern (2008) and Nordhaus (1994) have already warned that the costs of inaction are generally higher than the damages. In particular, Stern (2008) calls for faster action to reduce the economic effects of climate change and action outweighs inaction in terms of the damage caused (Johnson et al., 2020).

Although there are some works (Terrin et al., 2015; UN Habitat, 2017; Coronese et al., 2019) on the effects of climate change and natural disasters on the urban environment, Dodman et al. (2019) argue that actions are not enough while calling for well-informed and meaningful action to reduce atmospheric concentrations of GHGs and enable cities to adapt to natural disasters and emerging climate risks.

Most discussions of climate change impacts in the urban environment have focused on storm and flood damage, heat impacts, water use, and human health and well-being. However, it is important to explicitly consider how current and potential changes have a direct and indirect impact on local economies (Kamal-Chaoui and Robert, 2009; Grislain-Letrémy, C., & Villeneuve, B. 2015).

A priori, some disasters cause significant economic damage that can be assessed at colossal sums. Having an idea of the costs allows municipalities and territories to prepare and mobilize strategies to mitigate and adapt to shocks (Nicklin et al., 2019). Therefore, the direct costs of climate change impacts can be extremely high, especially when linked to natural disasters and sea level rise (in the United States by Yohe et al. 1996; Titus et al. 1991; Dodman et al., 2019; Martinich et al., 2013; in Europe by Hinkel et al., 2010) and coastal flooding (Coronese et al., 2019).

Several examples can be cited in the context of damage management linked to climatic disasters. Recent projections for the contiguous United States (i.e. the lower 48 states) suggest over $230 billion in total undiscounted costs by 2100 under a rising level scenario. of the mid-range sea, i.e. 68 cm (Neumann et al. 2010; Martinich et al., 2013).

Another example cited by Kamal-Chaoui and Robert (2009) on coastal retreat in the United States indicates that its management costs between 270 and 475 billion dollars per meter of sea level rise. Similar costs are observable and even very high in developing countries, which can represent a third of annual GDP (Kamal-Chaoui and Robert, 2009; Martinich et al., 2013).

Economically, floods are one of the costliest disasters (Johnson et al., 2020) with severe societal consequences (Jongman et al., 2014). For example, a single flood in the year 2000 forced England to spend £1 billion to repair the damage (Kamal-Chaoui and Robert, 2009). In recent decades, major European and American cities have also experienced and recorded a multitude of floods. These floods vary in number and frequency: Prague, Dresden and several other cities (in 2002), Bern and several other cities (in 2005), New Orleans (2005), Copenhagen (in 2010, 2011 and 2014) and New York (in 2012), as well as regions such as Queensland (2010), the South West of England (2013-2014) and the Côte d'Azur (in 2015) in the South of France. In Europe alone, the average cost of flood damage between 2000 and 2012 has been estimated at around €4.9 billion per year. It is estimated that this figure could rise to around 23.5 billion per year by 2050, or +400% (Jongman et al., 2014; Sörensen et al., 2014).

In the past 10 years, 2010 ranks first in terms of the number of cities affected by floods in China and the total direct damage caused by floods. More than 250 cities were affected with a total direct damage of more than 350 billion RMB (or 46.9 billion Euros) that year (Zevenbergen et al., 2015).

Comparative costs and damages show that overall the effects remain significant for both developed and developing states. Unlike developed countries, developing countries are sorely lacking the substantial means to counteract the damage caused by natural and climatic disasters at the local level (Martinich et al., 2013).

Generally, climatic disasters can directly or indirectly disrupt all economic activities via the city's various interconnection channels. Furthermore, the economic and financial consequences on urban territories are proportional to the severity and height of climate shocks (Grislain-Letrémy and Villeneuve, 2015; Coronese et al., 2019).

Indirect impacts can also cripple local economic activity, when transport, commercial and industrial activities are disrupted due to severe weather events (Nicklin et al., 2019; Kamal-Chaoui and Robert, 2009; Grislain-Letrémy, C., & Villeneuve, B., 2015; Dodman et al., 2019). Therefore, economic impacts can have rebound effects on the labor market and reduce tax revenues (Alejos et al., 2018; Dodman et al., 2019).

These pressures on the local economy can limit investment opportunities (Fang et al., 2019) and deplete funds for infrastructure innovations, leaving cities more vulnerable to future changes (Kamal-Chaoui and Robert, 2009; Sheng and Xu, 2019; Fang et al., 2019). Ripple effects from outside the city can also incur costs. Declines in productivity or income outside the city can lead to lower demand and higher import prices which could in turn affect the profitability of many economic sectors in the city and the incomes of city dwellers, as well as the food security (Hallegatte et al., 2008; Sheng and Xu, 2019).

In general, the assessment of costs and damages takes the form of estimates in this type of context. Thus, most economic losses will take the form of "hidden" costs, such as the costs of re-routing traffic, loss of productivity, provision of emergency and continued assistance, relocation and retraining, loss heritage and damage to the urban ecosystem (Sheng and Xu, 2019; Onat et al., 2018).

The risks and effects related to climate change and natural disasters are very uncertain. Overestimating or underestimating potential effects induces costs related to uncertainty on disaster management by economic sector partners. For example, this situation of uncertainty can create additional costs to the insurance, banking, finance and investment sectors (Medders, 2017).

All the costs mentioned will potentially directly or indirectly affect the cities and therefore their territorial competitiveness, if the latter do not take any action in the face of the challenges of climate change. Cities will readjust their various expenditure items (Medders, 2017; Huang-Lachmann, 2019). Generally, the damage caused by pollution on health will push cities to increase their expenditure related to health and disease prevention. Therefore, a general idea can be given about estimating the economic costs of the effects of pollution on the level of economic growth of a country. China and the USA remain to this day the two biggest polluters on our planet. For example, air pollution has a significant negative impact on China's macroeconomic growth. Holding other factors constant, if the concentration of PM2.5 increases by 1%, the growth rate of GDP per capita will decrease by 0.05818 percentage points (Dong et al., 2021). Additionally, current estimates suggest that air pollution is having a negative impact on the US economy; the annual damage caused by PM 2.5 alone is around 790 billion dollars (Tschofen et al., 2019; Beaupied et al., 2022).

In the context of urban resilience, acting now, as recommended by Stern (2008), can effectively reduce the current and future damage of climate change. Immediate action will also reduce the costs of action because the more catastrophic the climate situation, the higher the costs of adaptation and mitigation will be. However, before acting, it is necessary to carry out a detailed diagnosis of the situation, in particular of the points of vulnerability which are dependent on the context. Quantitative assessment is one way to make such a diagnosis. However, as resilience is multidimensional, building an assessment framework involves bringing together a set of complementary indicators. The following section provides an overview of frameworks for assessing urban resilience within the scientific literature.

4 City assessment framework

Many studies have developed assessment methods, such as indices and frameworks, to measure urban resilience to climate-related disasters (Tong, 2021) and provide a description of urban ecosystems allowing quantification of the level of resilience through the use of indicators, indices or mathematical models (Rus et al., 2018). This section makes a state of the art on the different frameworks constructed and available both in the scientific literature and gray literature.

4.1 State of the literature

4.1.1 Gray literature

In the literature, a multitude of assessment frameworks and indicators are used to assess the resilience of cities and territories in the face of a multitude of man-made and natural disasters (Sharifi and Yamagata, 2016). The mobilization of executives depends on the objective sought by the study. One can for example characterize the urban sustainability (e.g. UN Habitat City Prosperity Index) of the city.

Although some research focuses on the development of integrated approaches combining these two constructs (e.g. the U4SSC framework), studies in this area remain very rare. In fact, some attempts have been made to build the global framework that can address the dimensions of the smart sustainable city (Janik et al., 2019) and other frameworks for the resilience of sustainable cities and territorial communities (example, ISO 37 123, ITU-T Y.4903 etc.).

Like urban resilience, the concepts of intelligence and sustainability have been the subject of several studies, but authors and scientists have provided different definitions for these different concepts and lack common definitions (Janik et al. 2019). Indeed, intelligence and sustainability are concepts of urban resilience. The table below gives an idea of the overview of the different definitions associated with these concepts.

Author(year)	Definition of a smart city
Harrison et al. (2010)	An instrumented, interconnected and intelligent city linking physical infrastructure, IT infrastructure, social infrastructure and commercial infrastructure to take advantage of the collective intelligence of the city.
Caragliu et al. (2011)	A city is smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with wise management of natural resources, through participatory governance.
Lazaroiu et Roscia (2012)	A city model where technology is at the service of the person and their improvement of the economic and social quality of life. A solution that considers the consumption of electricity, water and gas, as well as heating and cooling systems, public safety, waste management and mobility.
Marsal-Llacuna et al. (2015)	Smart city initiatives attempt to improve city performance by using data, information and information technology (IT) to provide more efficient services to citizens, monitor and optimize existing infrastructure, increase collaboration between different economic actors and encourage innovative business models in both the private and public sectors.
Dameri (2013)	A smart city is a well-defined geographical area, in which high technologies such as ICT, logistics, energy production, etc. cooperate to create benefits for citizens in terms of well-being, inclusion, participation, environmental quality and smart development; it is governed by a well-defined pool of subjects, able to set the rules and policy for the government and development of the city.
Kumar et al. (2018)	A city that focuses on the environmental, economic and social aspects of city life in a competent, practical and smart way to achieve quality of life through the fusion of smart and sustainable technologies.
Kitchin et al. (2014)	A smart city is increasingly composed and overseen by pervasive computing, and its economy and governance are driven by innovation and creativity driven by smart people.

TABLE 3. DEFINITION OF A SMART CITY

Author(year)	Definition of a sustainable city
United Nations (2013)	A city that relies on social development, economic development, environmental management and urban governance to ensure a "low ecological footprint" and eliminate the transfer of economic, social and environmental risks to other places and future generations.
Hiremath et al. (2013)	A city that has achieved a balance between urban development and environmental protection, including equality of income, employment, housing, basic services, social infrastructure and transport in urban areas.
Ibrahim et al. (2015)	A city that can provide the basic needs of city dwellers now and in the future such as infrastructure, civic amenities, health and medical care, housing, education, transportation, employment, good governance and ensuring that the needs of the people are met for the benefit of all sectors of society.

Gardner (2016)	A dynamic human settlement that offers many possibilities, in harmony with the natural environment, to create a dignified life for all citizens.
Bibri and Krogstie (2017b)	A desired state of the city in which urban society strives to achieve a balance between environmental protection and integration, economic development and regeneration, and social equity and justice within cities.
Wang et al. (2019)	A city where the quality of life has improved, including ecological, cultural, political, institutional, social and economic components without leaving a burden for future generations.

TABLE 4. DEFINITION OF A SUSTAINABLE CITY

According to Janik et al. (2019), the combination of smart city and sustainable city is conceptually difficult to describe and it has been less explored due to the multiplicity and diversity of existing definitions of smart city and sustainable city.

However, the term "smart and sustainable city" is generally used to refer to a city that relies on a ubiquitous presence and extensive use of advanced ICTs, which, in relation to various urban areas and systems and the way these are intertwined, allow cities to become more sustainable and offer citizens a better quality of life (Bibri and Krogstie, 2017a).

Author(year)	Definition of a smart and sustainable city
UIT (2014)	An innovative city that uses information and communication technologies (ICT) and other means to improve the quality of life, the efficiency of urban operations and services, and competitiveness, while ensuring that needs are met. present and future generations in terms of economic, social and environmental aspects.
Dhingra et Chattopadhyay (2016)	A city characterized as one whose following objectives must be achieved in an adaptable, reliable, scalable, accessible and resilient way: (1) improve the quality of life of its citizens, (2) ensure economic growth with better employment opportunities , (3) improve the well-being of its citizens by ensuring access to social and community services, (4) establish an environmentally responsible and sustainable approach to development, (5) ensure efficient delivery of basic services and infrastructure such as public transport, water supply and drainage, telecommunications and other utilities, (6) ability to deal with climate change and environmental issues, and (7) provide an effective local regulatory and governance mechanism ensuring fair policies.
Bibri et Krogstie (2017a)	A dynamic and complex interaction between scientific innovation, technological innovation, environmental innovation, innovation in urban design and planning, institutional innovation and political innovation. It represents and involves inherently complex socio-technical systems of all kinds of innovation systems. These systems, which focus on the creation, diffusion and use of knowledge and technology, are of various types (variants of innovation models), including national, regional, sectoral, technological and triple helix of university-industry-government relations.
Bibri (2018)	A holistic approach to urban development that seeks to explicitly bring together the sustainable city and the smart city as urban endeavors in a way that addresses and overcomes the major shortcomings of both classes of cities in terms of contributing to the Sustainable Development Goals.

TABLE 5. DEFINITION OF A SMART AND SUSTAINABLE CITY

4.1.2 Scientific literature

Contrary to the gray literature, few scientists and researchers have taken an interest in the construction of evaluation frameworks for cities and territories. For example, there are authors who have proposed evaluation frameworks for smart cities (Giffinger et al. 2007; Lombardi et al. 2012; Monfaredzadeh et al., 2015; Pira, 20121), sustainable cities (Estevez et al. al., 20016) and smart and sustainable cities (Garau and Pavan, 2018; Pira, 2021).

But most scientific studies are unanimous and argue that it is necessary to rely on tangible criteria to formalize a framework for evaluating cities and territories. For example, it has been concluded that urban resilience is based on four fundamental pillars: resist, recover, adapt and transform (Ribeiro and Gonçalves, 2019).

Some authors (Folke et al., 2010; Matya et al., 2015; Tong, 2021) mention the fact that urban resilience must consider the fundamental characteristics of urban resilience which are preparation, absorption, recovery, adaptability and transformability, and their relationship to the phases of resilience.

Along with the definition of urban resilience, five fundamental characteristics of urban resilience are generally used to describe the diverse and interdependent capacities of urban ecosystems through the phases of resilience (e.g. before, during and after an event, Sharifi, 2019; Serre, 2018; Tong, 2021).

Any framework that takes these dimensions into account gives more credibility to the framework constructed and above all more relevance to the evaluation of the city and to the various policy implications that may result from it.

4.1.3 Comparison of assessment frameworks

The comparison table of evaluation frameworks clearly shows that all frameworks have the same objectives, i.e. the evaluation of urban territories and cities. Furthermore, it should be noted that the majority of the indicators in the set are derived from existing urban indicator frameworks.

However, they differ in the number of dimensions and the number of indicators used. In other words, through these frameworks, it is trivial to understand that urban resilience covers a multidimensional aspect that each framework seeks to capture. For example, all frames have at least three dimensions. The last two columns give an idea of the shortcomings observed and the advantages of each of them. This synthetic analysis leads to the construction of the new framework proposed and justified in the following sections.

Focusing solely on dimensions does not make one frame better than another. However, this does not mean that it is the most comprehensive because the range of assessment methods depends mainly on the scope of the indicators which are listed at the lowest level of aggregation of the relevant components of the method (Janik and al., 2019).

Cities Assessment Framework	Descrirption	Dimensions	Indicators	Advantages	Disadvantages
City Protocol	City Protocol is a collaborative innovation framework that aims to foster city-centric solutions to improve efficient service delivery and the overall quality of life for citizens. In addition, this assessment framework includes all ISO 37120:2014 core and supporting measures with additional indicators of both types. It is composed of 53 CP core indicators, 49 ISO core indicators, 37 CP support indicators and 57 ISO support indicators (CPA, 2015).	3	196	It is a framework applicable to all cities in the world for the improvement and evaluation of performance in terms of environmental sustainability and the competitiveness of socio-economic services.	Absence of other important dimensions for the construction of a modern city and its evaluation.
CityKeys	CityKeys is a holistic performance measurement assessment framework prepared under the European project developed under the H2020 program whose main objective is to help smart cities strengthen their strategic planning and monitor and benchmark the implementation of smart city solutions. CityKeys is composed of 73 city indicators (Bosch et al., 2016).	5	73	A holistic performance measurement framework for harmonized and transparent future monitoring and comparability of the activities of European cities when implementing Smart City solutions.	Usable only for already smart and exclusively European cities.
U4SSC	U4SSC is a framework developed to provide cities with a consistent and standardized method to collect data and measure performance and progress towards achieving the Sustainable Development Goals. Therefore, the use of this framework is to enable cities to become a smarter city and a more sustainable city. Overall, this assessment framework consists of 54 core indicators and 37 leading indicators which indeed form the basis of the U4SSC Smart Sustainable City Index (U4SSC 2017).	3	91	Interesting framework offering a wide range of indicators for each dimension. Also proposing basic and monitoring indicators.	Absence of indicators capturing the vulnerability and resilience of territories and cities. The three current dimensions which are the economy, the environment and the social refer rather to the single notion of sustainability.
ETSI TS 103 463	It is a framework that is composed of key performance indicators for sustainable digital multi-service cities and brings together a selection of 76 indicators focused on monitoring a city's evolution towards a smarter city. The selection of indicators to assess a city was based on an inventory of existing city indicator frameworks, in particular the CITYkeys framework (ETSI, 2017).	4	76	The framework considers the wishes of cities and citizens.	Despite the addition of other indicators, the majority of indicators relate to smart cities.
European ranking of smart cities	The European ranking is based on the "intelligent" combination of endowments and activities of autonomous, independent and conscious citizens, developed and published by an international consortium led by the Vienna University of Technology. It includes 74 indicators comprising 33 factors describing 6 characteristics (Giffinger, 2007).	6	74	Several dimensions with an interesting number of indicators.	Framework orient only for smart cities.
ISO 37120:2018 Sustainable cities and communities	The ISO 37120 standard includes a set of indicators assessing municipal service performance management, service delivery and quality of life. It considers sustainability as its general principle, and smartness and resilience as guiding concepts in the development of cities. The standard consists of 45 core indicators, 59 supporting indicators and 23 profile indicators (ISO, 2018a).	17	127	Very interesting framework with a multitude of dimensions and indicators.	Although there are the variables of resilience, sustainability trumps all of the other indicators.
ISO /DIS 37123 – Sustainable cities and communities	Indicators for Resilient Cities – a standard defining a set of 73 indicators assessing resilience in cities. The condition for achieving sustainable development is the ability to maintain and improve city services and quality of life in the face of shocks and constraints. Therefore, it is assumed that this standard should be implemented in conjunction with ISO 37120 (ISO, 2021).	19	74	Very operational framework. Multiple and varied sizes.	The framework looks more at the vulnerability of socio-economic fundamentals and the configuration of cities.
UN Habitat Program Urban Indicators	These indicators constitute a framework comprising 20 key indicators, 9 checklists and 13 detailed indicators that measure and monitor performance and trends in the achievement of the habitat agenda and the Millennium Development Goals adopted by the United Nations (UN, 2004).	5	31	Very interesting framework that allows monitoring of the SDGs at the city level.	Absence of an urban resilience-oriented dimension.
UN Habitat City Prosperity Index	The index is a tool for measuring the sustainability of cities that conceptualizes prosperity in particular and identifies its most critical dimensions. It is a composite index based on 62 indicators used to measure how cities create and distribute socio-economic benefits and prosperity (UN, 2016).	6	62	Durability is considered with the latest dimensions.	Absence of variables related to urban resilience.

TABLE 6. COMPARISON OF DIFFERENT CITY ASSESSMENT FRAMEWORKS

4.2 New Improved Frame

As reported in recent works (Tong, 2021 and Amirzadeh et al., 2022) and as shown in the comparison table above (see section 4.1.3), old frameworks suffer from shortcomings and we think in the same sense of the fact that the establishment and use of a more holistic framework must allow an analysis of urban ecosystems as a whole and not only partially.

This section explains the importance of a holistic approach to quantifying the level of resilience and operationalizing urban resilience over time and space. Additionally, the limitations of this systematic review will be noted (Tong, 2021).

After the analyzes of the different assessment frameworks, our remarks and suggestions are in line with the suggestions of previous studies (Meerow et al, 2016; Sharifi et al., 2016; Tepes and Neumann, 2020; Tong, 2021) according to which more holistic approaches are needed to understand the complexity of urban ecosystems and their metabolism.

Starting from a simple approach, we first retain the U4SSC and note that it is marked by the absence of the “vulnerability” component which, in our opinion, remains an essential factor in the construction of urban resilience. Combined with the current body of knowledge on certain urban systems, a better analysis of the interdependencies, vulnerabilities and capacities of urban ecosystems can therefore be carried out. This would provide the information necessary for the decision-making process allowing cities and territories to provide adequate responses to the disturbances linked to the various shocks and global changes (Tong, 2021). Paraphrasing, we believe that understanding the dimensions and components of resilience is a complex issue because territories and urban areas differ in their geography, climate, culture, history, wealth and a host of other dimensions (Gardner, 2016).

4.2.1 Conceptual framework of the New Improved Framework

After the literature review presented in the previous sections, it is important to identify the principles and criteria related to resilience that should be integrated into the assessment framework for cities and territories. This section aims to introduce a set of criteria including the additional dimension to configure our new urban resilience assessment framework. For example, other authors have also added additional dimensions (institutional dimension for Estevez et al. 2016; dimensions size, shape, land uses, configuration and distribution of open spaces for Bibri and Krogstie, 2017b) on the dimensions of basis of the sustainable city which are economic, environmental and social.

Accordingly, a holistic approach to assessing urban resilience can facilitate a better understanding of the impact of climate-related disasters and the identification of needs and priorities in urban ecosystems, thus leading to a rigorous assessment of resilience across scales and territories (Tong, 2021) and resilience remains an ambiguous concept and that this could lead to theoretical and practical difficulties (Amirzadeh et al., 2022).

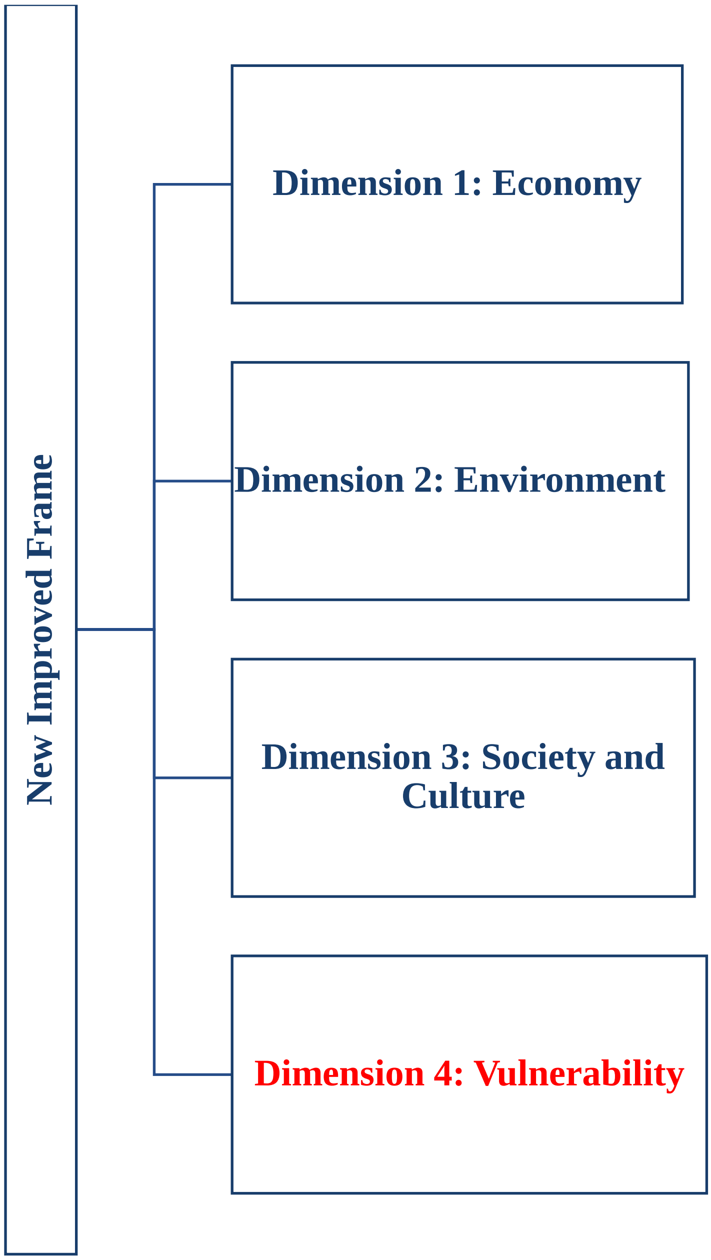

FIGURE 7. CONCEPTUAL FRAMEWORK AND DIMENSIONS OF THE NEW IMPROVED FRAMEWORK

Indeed, constructing a multidimensional assessment framework is technically sound because neither adaptation nor resilience can be measured directly. They are the result of complex systemic interactions (Tyler et al., 2016).

4.2.2 Indicators used

Mathematically, indicators are variables that summarize or otherwise simplify relevant information about the state of a complex system which may be environmental, socio-economic or climatic. Therefore, a correct evaluation stems from the choice of adequate "raw" data and the relationships between the "raw" data (Perotto et al., 2008).

As part of this work, the selection of indicators in each of the cities was guided by similar criteria: observable and verifiable; quantitative or qualitative; relevant to local decision-making; specific, measurable, actionable (meaning that the actions of the authorities should lead to changes in the value of the indicator), dynamic (change over relatively short periods of time), finally data availability. In other words, the verification and existence of data were criteria for selecting the indicators that make up our framework.

Representatives of the city teams were interviewed by the CREST team from France in order to collect data describing the process of generating the indicators. This question concerned firstly the existence or absence of data related to the U4SSC framework and then data related to the addition of a new dimension proposed after discussion between the different authors.

All cities through our partners have also independently reported on this process and the results of developing and applying their indicators. The authors were primarily responsible for these reports on the city's indicator development procedures in each case, and contributed to the main findings.

He had to find relevant indicators for which data was available, and then normalize this data if necessary, for two different periods. The Climate Resilience Framework has been used by all city working groups to explain resilience concepts, guide the development of indicators, and engage expert agencies in collaboration.

In this context of the proposed new assessment framework, we have chosen indicators that allow the development of indicators for planning and monitoring local climate resilience (Tyler et al., 2016). Therefore, the construction of an indicator also requires special attention (Perotto et al., 2008), especially the non-inclusion of certain data can be serious and can lead to under-reporting (Andrew and Cortese, 2011).

Technically and given the available data, the authors use single indicators or construct composite indicators for the formalization of all the indicators making up the different dimensions.

5 Conclusion

Our methodology consisted in basing ourselves on the abundant literature concerning urban resilience to carry out a work of synthesis which enabled us 1. To carry out a general view of the concept of urban resilience, and 2. To propose a New Improved Framework for assessment of a city's degree of resilience based on a set of indicators. Moreover, this methodology is intended to be synthetic and remains in a perspective of complementarity because it seeks to fill the gaps of the previous frameworks and indicators mobilized for the evaluation of urban resilience.

It is also necessary that natural hazard-specific vulnerability assessment tools are interpreted alongside or incorporate social, economic and political sources of danger to livelihoods and human health. For future-oriented policy relevance, tools are also needed to assess adaptive or adaptive capacity. This is essential for building a holistic approach to urban risk management (Pelling, 2006).

Thus, all the indicators of the U4SSC and ISO 37123 which will make it possible to build the methodology for the new improved assessment framework are presented in the tables in the appendix of the document.

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7 Annex

U4SSC

Dimension	Sub-dimension	Category	Indicator name
Economy	ICT	ICT Infrastructure	Household Internet Access
			Fixed Broadband Subscriptions
			Wireless Broadband Subscriptions
			Wireless Broadband Coverage
			Availability of WIFI in Public Areas
		Water and Sanitation	Smart Water Meters
			Water Supply ICT Monitoring
		Drainage	Drainage / Storm Water System ICT Monitoring
		Electricity Supply	Smart Electricity Meters
			Electricity Supply ICT Monitoring
			Demand Response Penetration
		Transport	Dynamic Public Transport Information
			Traffic Monitoring

ISO 37123

Dimension	Sub-dimension	Category	Indicator name
Economy			History of disaster losses as a percentage of urban product
			Average annual disaster losses as percentage of urban product
			Percentage of property insured against high-risk hazards
			Percentage of the total insured value compared to the total value exposed to risk in the city
			Concentration of jobs
			Percentage of labor force in informal employment
			Average household disposable income
Education			Percentage of schools that teach emergency preparedness and disaster risk reduction
			Percentage of population trained in emergency prepardeness and disaster risk reduction
			Percentage of emergency preparedness publications provided in foreign languages
			Disruption of schooling
Energy			Number of different electricity sources supplyng at least 5% of total energy supply capacity
			Electricity supply capacity as a percentage of peak electricity demand
			Percentage of critical facilities served by off-grid energy services

			Intersection Control
		Public Sector	Open data
			e-Government
			Public Sector e-procurement
	Productivity	Innovation	R&D Expenditure
			Patents
			Small and Medium-Sized Enterprises
		Employment	Unemployment Rate
			Youth Unemployment
			Rate Tourism Sector Employment
			ICT Sector Employment
	Infrastructure	Water and Sanitation	Basic Water Supply
			Potable Water Supply
			Water Supply Loss
			Wastewater Collection
			Household Sanitation
		Waste	Solid Waste Collection

Environment and climatic change			Magnitude of urban heat islan effects (atmospheric)
			Percentage of natural areas in the city that have undergone an ecological assessment for their protection services
			Area under ecosystem restoration as percentage of total city area
			Annual frequency of extreme precipitation events
			Annual frequency of extreme heat events
			Annual frequency of extreme cold episodes
			Annual flood frequency
			Percentage of city area covered by tree canopy
			Percentage of city area covered with high-albedo materials contributing to the reduction of urban heat islands
Finance			Annual expenditure for the modernization and maintenance of the heritage of services as a percentage of urban services as a percentage of the total budget of city
			Annual expenditures for upgrading and maintaining stormwater management infrastructure as a percentage of total city budget
			Annual expenditure allocated to ecosystem restoration within the city territory as a percentage of the total city budget
			Annual spending on green and blue infrastructure as percentage of total city budget
			Annual expenditure on emergency management planning as a percentage of total city budget
			Dépenses annuelles pour les services sociaux et de proximité en pourcentage du budget total de la ville/ Annual expenditure on social and community services as a percentage of the total city budget
			Total Disaster Reserve Fund Allocation as a Percentage of Total City Budget
Governance			Frequency of updating disaster management plans

		Electricity Supply	Electricity System Outage Frequency
			Electricity System Outage Time
			Access to Electricity
		Transport	Public Transport Network
			Public Transport Network Convenience
			Bicycle Network
			Transportation Mode Share
			Travel Time Index
			Shared Bicycles
			Shared Vehicles
			Low-Carbon Emission Passenger Vehicles
		Buildings	Public Building Sustainability
			Integrated Building Management Systems in Public Buildings
		Urban Planning	Pedestrian infrastructure
			Urban Development and Spatial Planning
Envi ron men t	Environment	Air quality	

			Percentage of essential urban services covered by a documented business continuity plan
			Pourcentage des données électroniques de la ville faisant l'objet d'un stockage de sauvegarde sécurisé et à distance Percentage of city electronic data in secure, remote backup storage
			Percentge of public meetings in the city dedicated to resilience
			Number of interjurisdictional disruption planning agreements as a percentage of total interjurisdictional agreements
			Percentage of essential service providers with a documented business continuity plan
Health			Percentage of hospitals equipped with emergency power supply
			Percentage of population with basic health insurance
			Percentage of population that is fully immunized
			Number of infectious disease epidemics per year
Accommodation			Capacity of designated emergency shelters per 100,000 population
			Percentage of buildings structurally vulnerable to high risk hazards
			Percentage of residential buildings not complying with buildings codes and standards
			Percentage of damaged infrastructure that has been "built back better" after a disaster
			Annual number of flooded residential properties as a percentage of the total number of residential properties in the city
			Percentage of residential properties located in high-risk areas

			Air pollution
			GHG Emissions
		Water and Sanitation	Drinking Water Quality
			Water Consumption
			Freshwater Consumption
			Wastewater Treatment
		Waste	Solid Waste Treatment
		Environmental Quality	EMF Exposure
			Noise Exposure
		Public Space and Nature	Green Areas
			Green Area Accessibility
			Protected Natural Areas
			Recreational Facilities
	Energy	Energy	Renewable Energy Consumption
			Electricity Consumption
			Residential Thermal Energy Consumption

Population and social conditions			Vulnerable population as a percentage of city population
			Percentage of population enrolled in social assistance programs
			Percentage of population at high risk from natural hazards
			Percentage of neighborhoods with regular and inclusive neighborhood association meetings
			Annual percentage of city population directly affected by natural hazards
Security			Percentage of city population covered by a multi-hazard early warning system
			Percentage of emergency responders who have received disaster first aid training
			Percentage of local hazard alerts issued each year by national agencies that are received in a timely manner by the city.
			Number of hospital beds in the city destroyed or damaged by natural hazards per 100,000 inhabitants
Solid waste			Number of active and temporary waste management sites available for rubble and rubble per square kilometer
Telecommunication			Percentage of emergency responders in the city equipped with specialized communication technologies able to function reliably during a disaster
Transport			Number of evacuation routes available per 100,000 inhabitants
Urban/local agriculture and food security			Percentage of city population that can be supplied by city food reserves for 72 hours in an emergency
			Percentage of city population living within one kilometer of a grocery store
Urban Planification			Percentage of city area covered by publicly available hazard maps

			Public Building Energy Consumption
Society and Culture	Education, Health and Culture	Education	Student ICT Access
			School Enrollment
			Higher Education Degrees
			Adult Literacy
		Health	Electronic Health Records
			Life Expectancy
			Maternal Mortality Rate
			Physicians
			In-Patient Hospital Beds
			Health Insurance / Public Health Coverage
		Culture	Cultural Expenditure
			Cultural Infrastructure
	Safety, Housing and Social Inclusion	Housing	Informal Settlements
			Housing Expenditure
		Social inclusion	Gender Income Equity
			Gini Coefficient

			Area of permeable land and public spaces constructed with porous and draining materials, as a percentage of city area.
			Percentage of the area of high-risk areas of the city where risk reduction measures have been implemented
			Percentage of municipal departments and utilities that carry out risk assessment as part of their business and investment planning
			Nombre annuel d'infrastructures critiques inondées en pourcentage des infrastructures critiques de la ville/ Annual number of flooded critical infrastructures as a percentage of the city's critical infrastructures
			Annual expenditure for water retention measures as a percentage of prevention measures budget
Water			Number of different water sources providing at least 5% of total water supply capacity
			Percentage of city population that can be supplied with drinking water by alternative methods for 72 hours

			Poverty
			Voter Participation
			Child Care Availability
		Safety	Natural Disaster Related Deaths
			Disaster Related Economic Losses
			Resilience Plans
			Population Living in Disaster Prone Areas
			Emergency Service Response Time
			Police Service
			Fire Service
			Violent Crime Rate
			Traffic Fatalities
		Food Security	Local Food Production

CONSORTIUM

CREST

D1.2 Impact and Monitoring assessment framework

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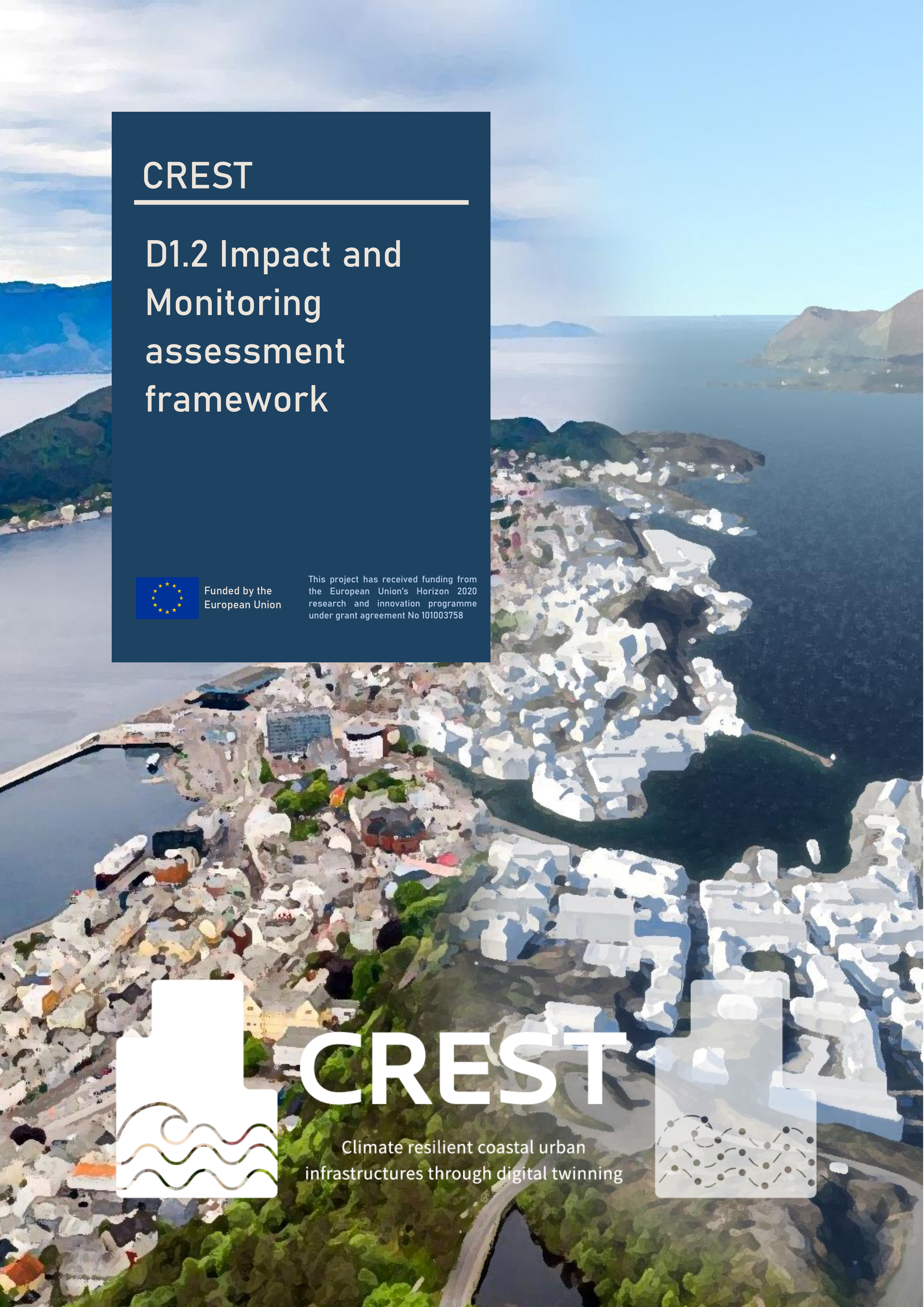

CREST

Climate resilient coastal urban infrastructures through digital twinning