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Title Page

Title : Urban Resilience operationalization issues in climate risk management: a review

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1
2 **Abstract**
3

4 This paper presents a review of existing strategies and tools aiming at facilitating the
5 operationalization of the concept of resilience into built environments. In a context of climate change,
6 increased risks in urban areas and growing uncertainties, urban managers are forced to innovate in
7 order to design appropriate new risk management strategies. Among these strategies, making cities
8 resilient has become an imperative. However, resilience remains complex to integrate into the
9 practices of urban planners and territorial actors. Its multitude of definitions and approaches has
10 contributed to its abstraction and lack of operationalization. This review highlights the multitude of
11 approaches and methodologies to address the bias of the lack of integration of the concept of resilience
12 in climate risk management. The limit is the multiplication of these strategies which lead to conceptual
13 vagueness and a lack of tangible application at the level of local actors. The challenge would then be
14 to design a toolbox to concentrate the various existing tools, conceptual models and decision support
15 systems in order to facilitate the autonomy and responsibility of local stakeholders in integrating the
16 concept of resilience into risk management strategies.
17

18 **Key words:** Resilience, urban environments, risk management, disaster risk reduction strategies
19

20 **1. Introduction**
21

22 Operationalizing urban resilience is a complex, even conflicting subject. Because of its
23 multidisciplinary origin and the multitude of approaches, resilience meanings are sometimes
24 contradictory (Davoudi et al., 2012). This contradiction is essentially due to the fact that resilience
25 belongs to many disciplines such as physics, psychology, ecology (Alexander, 2013). This conceptual
26 vagueness makes the use of resilience and its integration into risk management complex
27 (Weichselgartner and Kelman, 2015). Despite its growing use in official communications, the
28 operational relevance of the concept is therefore constantly being questioned.

29 The Hurricane Katrina (2005) marked a major turning point in the history of risk management
30 (Campanella, 2006; Cutter et al., 2008a, Hernandez, 2009). To prevent a similar event from happening
31 again, risk management has evolved to incorporate the concept of resilience. The objective is to use
32 this concept to best prepare populations and territories to increased risks in urban areas. The idea is no
33 longer to analyze the risks in a compartmentalized manner but to study the disruptive event and its
34 consequences as a whole. Several definitions and characteristics of resilience exist:

- 35 • Resistance capacity: Serre (2018) defined three capacities (resistance, absorption, recovery) of
36 resilience and defined the resistance ability to determine “*the physical damage to the network
37 as a result of the hazard*” (Serre et al., 2013). It is essential to know before any risk
38 management and actions plan the potential damages of a system, in order to adapt resilience
39 strategy. It is estimated that, more the technical system is damaged, greater is the possibility of
40 a malfunction of the system and more it will be difficult to restore it to service.
- 41 • Absorption capacity: UNISDR (2009) has define resilience as the “*ability of a system,
42 community or society exposed to hazards to resist, absorb, accommodate to and recover from
43 the effects of a hazard in a timely and efficient manner, including through the preservation
44 and restoration of its basic structures and functions*”. Cardona (2004) defined resilience as the
45 capacity of the damaged ecosystem or community to absorb negative impacts and recover
46 from these.
- 47 • Adaptive capacity: Pelling(2011) defends the idea that resilience is the ability of an actor to
48 cope with and adapt to hazards stress. . It refers to the “*ability of systems, institutions, humans
49 and other organisms to adjust to potential damage, to take advantage of opportunities, or to
50 respond to consequences*” (IPCC, 2014).
- 51 • Reaction capacity, linked to self-organization: Pickett et al. (2004) have defined resilience as
52 the “*ability of a system to adjust in the face of changing conditions*” and Ahern (2011) has
53 defend resilience as a “*capacity of systems to reorganize and recover from change and
54 disturbance*”.

- Ability to rebuild: Walker et al. (2004) developed the idea that resilience is the capacity to “reorganize while undergoing change so as to still retain essentially the same function, structure identity, and feedbacks”. It can also be understood from the ecological angle of “building back better” (Papathoma-Köhle et al., 2019)
- Learning capacity: The Resilience Alliance (Walker and Salt, 2006) defends that resilience is a combination of three capacities, absorb and remain within the same state, the capacity of self-organization and “the degree to which the system can build and increase the capacity for learning and adaptation” (Carpenter et al., 2001; Klein et al., 2003)
- Ability to bounce back: to some authors, there is one single-state equilibrium which implies to bounce back to equilibrium previous disturbance (Holling, 1996). On the contrary, others consider that we can observe multiple-state equilibrium which suppose that systems have different stable states (Davoudi et al., 2012; Holling, 1996)

Resilience is a multifaceted concept, involving a plurality of disciplines, definitions, etc. This diversity can be interpreted both as an opportunity but also as a difficulty in the operationalization of resilience. In the face of new risks linked to climate change, the evolution of urban areas and the concentration of issues, the concept of urban resilience represents both an essential concept but also full of operational limits (part 1). This is why a variety of methods have been developed to address the issue of its operationalization and appropriation by local actors (part 2). We will conclude by presenting the next steps needed to respond to the limits still present in the scientific and operational field.

2. Urban resilience: advances and limits

2.1 Urban system issues

Resilience in risk management is particularly relevant in addressing the increased vulnerability of urban environments. Urban areas are the territories most exposed to disasters. Today, nearly 3/5 cities, with 500,000 inhabitants, are at risk. However, urban areas produce between 70 and 80% of the world economy and are home to 55% of the world's population, with an increasing urban-rural drift expected to raise this value up to 68% by 2050 (UNDESA, 2019; Zevenbergen et al., 2010). Such a concentration of stakes increases the impact of disasters (Boin and McConnell, 2007) and raises questions on the future of cities. Beyond the increase in urban population and the concentration of issues, we are witnessing an over-vulnerability of these urban environments, linked to some critical elements. Urban space is made up of several infrastructures, some more essential than others. Critical Infrastructure (CI) concentrate all the functions (Pescaroli and Kelman, 2017) necessary for the proper functioning of a community. However, their potential destruction could weaken the entire defense and economic organization (Serre and Heinzlef, 2018) of a territory. However, these CIs interact with each other and thus create interdependencies (Serre, 2018) within the urban space. These interdependencies then play the role of a risk diffusion factor. According to the concept of the cascading effect (Bach et al., 2014; Nones and Pescaroli, 2016; Pescaroli and Nones, 2016; Serre and Heinzlef, 2018), some areas come to be impacted by the disaster, even if they were not located in the same area (Knabb et al., 2005; Mitigation Assessment Team Report, 2013; Kunz et al., 2013; Le Haut Comité Français pour la Défense Civile, 2013). Therefore, some damages are not caused by direct impacts but indirect impacts. In order to address these multiple complexities, it is necessary to broaden the risk assessment framework towards broader objectives related to the resilience of urban systems from a multi-hazard perspective (UN-Habitat, 2017). In the face of these growing uncertainties, risk management must evolve (Kappes et al., 2012; Rosendahl Appelquist and Balstrøm, 2014) by integrating new concepts.

2.2. Concept definitions

Urban resilience can be defined as the concept that studies urban systems faced to risks. It refers to a systemic approach that encompasses the multiple layers and structures that produce an integrated vision of the urban object. It would therefore be a utilitarian concept for analyzing the

106 complexity of the urban system and defining the different capacities of each element that defines this
 107 system in order to live and survive a disruptive event. The ability to define what is meant by resilience
 108 is an essential prerequisite for reducing the consequences of a disaster. Most research on
 109 operationalizing resilience focuses on a technical-functional approach. As a result, it is mostly the
 110 technical and material elements, such as urban networks, that are analyzed in these studies (Gonzva
 111 and Barroca, 2017; Lhomme et al., 2013; Serre, 2018, 2016). However, an urban system is made up of
 112 multiple components that are constantly interacting. There is no conceptual consensus in the scientific
 113 and policy community (Table 1) on the definition and objectives of urban resilience, which reinforces
 114 the lack of clarity in establishing resilient risk management strategies.
 115

Sources	Systems defined and used by authors	Definitions
Organisation for Economic Co-operation and Development, n.d	Cities	“Resilient cities are cities that have the ability to absorb, recover and prepare for future shocks (economic, environmental, social & institutional). Resilient cities promote sustainable development, well-being and inclusive growth”
C40 Cities, 2017	Cities	“Cities are at the forefront of experiencing a host of climate impacts, including coastal and inland flooding, heat waves, droughts, and wildfires. As a result, there is a widespread need for municipal agencies to understand and mitigate climate risks to urban infrastructure and services – and the communities they serve”
ICLEI Local Governments for Sustainability, n.d	Cities	“A resilient city is prepared to absorb and recover from any shock or stress while maintaining its essential functions, structures and identity as well as adapting and thriving in the face of continual change. Building resilience requires identifying and assessing hazard risks, reducing vulnerability and exposure, and lastly, increasing resistance, adaptive capacity, and emergency preparedness”.
Resilience Alliance, 2010	Cities	“A resilient city is one that has developed capacities to help absorb future shocks and stresses to its social, economic, and technical systems and infrastructures so as to still be able to maintain essentially the same functions, structures, systems and identity”.
Alberti et al., 2008	Cities	“The degree to which cities tolerate alteration before reorganization around a new set of structures and processes”
Campanella, 2006	Cities	“The capacity of a city to rebound from destruction”

Lamond and Proverbs, 2009	Cities	“Encompasses the idea that towns and cities should be able to recover quickly from major and minor disasters”
Lhomme et al., 2013	Cities	“The ability of a city to absorb disturbance and recover its functions after disturbance”
Urban Resilience Hub	Urban system	“The measurable ability of any urban system, with its inhabitants, to maintain continuity through all shocks and stresses, while positively adapting and transforming toward sustainability”
Koren and Rus, 2019	Urban system	“Urban resilience is a capacity of a complex urban system, composed of interacting physical and social components, to withstand an external stress and bounce back to a state of equilibrium or bounce forward to improved new states of equilibrium »
Holling, 1973	System	“The persistence of relationships within a system, a measure of the ability of systems to absorb changes of state variables, driving variables, and parameters, and still persist”
United Nations International Strategy for Disaster Reduction, 2009	System	“The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management”
100 Resilient Cities, n.d	System	“The capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience”
Pickett et al., 2004	System	“The ability of a system to adjust in the face of changing conditions”
Godschalk, 2003	Critical infrastructure networks	“A sustainable network of physical systems and human communities”
Serre et al., 2013	Critical infrastructure networks	“Urban resilience aims to maintain urban functions during the event and recover thanks to resistance capacities (assessing damages), absorption capacities (assessing alternatives) and recovery capacity (assessing accessibility)”

Cimellaro et al., 2010	Critical Infrastructure	“Resilience is defined as a function indicating the capability to sustain a level of functionality or performance for a given building, bridge, lifeline networks, or community, over a period defined as the control time that is usually decided by owners, or society”
Ouyang et al., 2012	Critical Infrastructure	“Resilience as the joint ability of infrastructure systems to resist (prevent and withstand) any possible hazards, absorb the initial damage, and recover to normal operation”
Longstaff, 2005	Community	“The ability by an individual, group, or organization to continue its existence (or remain more or less stable) in the face of some sort of surprise”
Adger, 2000	Community	“The ability of communities to withstand external shocks to their social infrastructure”
Ganor, 2003	Community	“The ability of individuals and communities to deal with a state of continuous, long term stress; the ability to find unknown inner strengths and resources in order to cope effectively, the measure of adaptation and flexibility”
Coles, 2004	Community	“A community’s capacities, skills and knowledge that allow it to participate fully in recovery from disasters”
Wagner and Breil, 2013	Community	“The general capacity and ability of a community to withstand stress, survive, adapt and bounce back from a crisis or disaster and rapidly move on”
Asprone et al., 2014	Community + City	“City resilience is based on the efficiency of hybrid networks composed by citizens and urban infrastructures.”
Heinzlef et al., 2020	Community +urban system	“The ability of populations, territories and infrastructures to put in place resources, skills and capacities in order to best experience a disruptive event so as to limit its negative impacts. Capacities can be both tangible (urban networks, supply of vital resources, etc.) and intangible (knowledge of risk, economic dynamics, institutional framework, etc.).”

116
117

Table 1: Comparison between different system to analyze urban resilience

118

119 Used by international, local or scientific institutions, urban resilience nevertheless comes up
120 against numerous limitations that prevent concrete actions in the evolution of risk management.

121 This multitude of uses (Emrich and Tobin, 2018) has turned resilience concept into a
122 buzzword (Reghezza-Zitt et al., 2012; Rufat, 2015) that complicates its understanding. A resilient
123 system is in turn defined as a system capable of stability but also of adaptation and evolution (Hegger
124 et al., 2016; Tempels and Hartmann, 2014). We speak of both "bouncing back" to a (potentially
125 anterior) equilibrium or "bouncing forward" to a new state of balance and harmony. Faced with this

126 ambiguity, or even contradiction, among the objectives and guidelines of resilience, actors and experts
127 come up against grey areas (Disse et al., 2020).

128

129 This conceptual vagueness has contributed to the political reappropriation (Béné et al., 2018;
130 Bahadur and Tanner, 2014; Béné et al., 2012; Cannon and Müller-Mahn, 2010; Duit et al., 2010).
131 Having become a political and management imperative, resilience has been transformed into a
132 political and crowd-unifying tool. Resilience can therefore be used more for political positioning or
133 institutions to strengthen their dominant governance model without necessarily leading to reflection on
134 processes of transformation or evolution that are generally necessary for the establishment of resilient
135 systems (Béné et al., 2018).

136

137 Furthermore, the cost of a resilient approach is often pointed out. Whether it is spatial
138 reorganization or the purchase of resilient development tools (Heinzlef et al., 2020a), local managers
139 are faced with a mismatch between the cost of approaches and their daily priorities. The fact also that
140 climate change and the associated risks are a more or less distant threat and hardly imaginable, makes
141 decision-makers less focused on the necessary evolution of risk management strategies through the
142 integration of resilience into the planning process (Leichenko et al., 2015).

143 Finally, the cultural dimension of risk management can also be seen as a barrier (Heinzlef et
144 al., 2020b) to the implementation of the concept of resilience (Heinzlef et al., 2019). At the level of
145 local actors (Amundsen et al., 2010; Dilling et al., 2015; Kettle and Dow, 2014; Mozumder et al.,
146 2011; Runhaar et al., 2012), it can be expressed through the culture of risk. It can be associated with
147 the historicity of disasters on a territory and therefore by the succession of management strategies put
148 in place to deal with them. Changing them can be complicated, especially if it requires new human and
149 financial investments. At the individual level, this cultural resistance is regularly linked to a lack of
150 awareness of the risks linked to climate change and a fear of changes in their habits and living
151 environment (Amundsen et al., 2010; Measham et al., 2011).

152 **3. Methods for integrating resilience into risk management**

153

154 The difficult consensus around the concept of resilience results in a complex transition from
155 theory to practice. However, this is the challenge posed by all studies on resilience, in order to use this
156 concept to build adequate risk management strategies. Several approaches have therefore attempted to
157 respond to these challenges by proposing methodologies that aim to operationalize resilience. We will
158 attempt to scan the approaches aimed at assessing resilience through the creation of indicators, models
159 proposing a conceptual framework or decision support systems, and then methodologies aimed at
160 creating collaborative work in order to operationalize resilience.

161

162 *3.1. Assessing urban resilience*

163

164 Measuring resilience has become an international priority in order to build strategies for the future
165 risk management (Winderl, 2014). The question of how to measure resilience is as old and as
166 important as the concept itself (Prior and Hagmann, 2014). Numerous indices and indicators of
167 resilience have been developed in various disciplines. In general, they are used for different purposes
168 and, as a result, they measure different things. An exploration of attempts to measure resilience reveals
169 the difficulty in establishing a measure that is both accurate and "*fit for purpose*" (Hinkel, 2011).
170 Measurement requires that a phenomenon be observable and allow for systematic attribution of value,
171 but the conceptual nature of resilience makes this difficult. Scientists are still disagree on specific
172 conventions for measuring resilience and, consequently, there is a substantial literature that discusses
173 both how and whether the phenomenon can and should be measured (Hinkel, 2011).

174 The identification of resilience requires planners to identify variables that trigger disturbances in a
175 city (a community, region or landscape), the frequency and intensity of these events, and the
176 mechanisms that enhance adaptability that can be activated to respond to (or avoid) these disorders. It
177 is need to assess the socio-economic dimensions of an urban area (Ahern, 2011). As established

178 previously, it is necessary to establish common denominators that induce vulnerability or strengthen
 179 resilience (Gonçalves, 2013). However, the difficulty essential is to measure these dimensions. The
 180 significant challenges in measuring the resilience lead either to imperfect quantified (Table 2)
 181 measurements or to a search for indicators of universal resilience (Hallegatte and Engle, 2019). Cutter
 182 et al. (2008) highlight this difficulty in believing that "*if we conceptually or sometimes intuitively*
 183 *understand the vulnerability and resilience, the devil is always in the details, and in this case, the devil*
 184 *is measurement*" (Cutter et al., 2008b).
 185

Models	References	Case study	Remarks
BRIC	(Cutter et al., 2014)	USA	<ul style="list-style-type: none"> • Resilience indicators to map the level of resilience across the USA • Resilience analyzed into 6 indicators: social, economic, community, institutional, infrastructural and environmental • Each variable has a positive or negative effect on community resilience • Possible to locate more or less finely the territories on which to focus efforts to increase territorial and social resilience • State-wide analysis • National data not always adequate for a fine-grained, contextualized analysis of resilience • No specific risk identified
DS3 Model	(Serre, 2018)	Hamburg	<ul style="list-style-type: none"> • 3 resilience capacities: resistance, absorption, recovery • neighbourhood level analysis • Identification of interdependent relationships between critical infrastructure • Identification of potential domino effects in case of disturbance • Focus on flood risk • Technical-functional approach to resilience centered around the analysis of the resilience of urban technical networks
Resilience Capacity Index	(Foster, 2012)	USA	<ul style="list-style-type: none"> • 12 indicators (regional economic, socio-demographic, and community connectivity attributes) • A broad analysis of the disaster (not only the natural disaster) • Integration of the notion of stress • Notion of vulnerability and resilience prior to the disruption • Visualization of resilience scores • Metropolitan Analysis Scale • Attempt to validate or at least

			<p>discuss the results</p> <ul style="list-style-type: none"> • Visualization of results on too large a scale that complicates decision making for urban actors • No specific risk identified
Community Disaster Resilience Index	(Peacock, 2010)	USA	<ul style="list-style-type: none"> • 75 indicators • Applied to 144 coastal or near coastal counties across the Gulf Coast • Data from 2000 to 2005 • Empirical validation (observations) • Doesn't work for the probability of fatalities • Visualization of results on too large a scale that complicates decision • No specific risk identified
Urban resilience index	(Suárez et al., 2016)	Spain	<ul style="list-style-type: none"> • 5 indicators • Quantitative and qualitative indicators • Tested in 50 spanish province capital • Not a generic approach • Very few indicators concentrated on food, land use and business • No specific risk identified
Community resilience assessment	(Fox-Lent et al., 2015)	Rockaway Peninsula, New York	<ul style="list-style-type: none"> • 16 indicators divided according to the temporality of the risk (preparation, absorption, recovery) • Adapted to a specific risk (flood) • Tested with a case study • Collaborative approach with stakeholders • Support decision-making • Possibility to combine this approach with others (model flexibility) • Need to develop a collaboration for several indicators (need to develop a long term approach)
The Peoples Resilience Framework	(Renschler et al., 2011)	Not known	<ul style="list-style-type: none"> • 7 indicators • Considering the interdependencies between the 7 dimensions • Crossing of scales between the individual and spatial scales • Qualitative and quantitative indicators • Consideration of resilience as a fluctuating variable • No identification of risks or

			<ul style="list-style-type: none"> specific disturbances No visualization of results No real measure of resilience but more a list of criteria to develop a resilient community
Hybrid method	(Heinzlef et al., 2019; Heinzlef et al., 2020a)	Avignon	<ul style="list-style-type: none"> Inclusive resilience approach 3 indicators: social, urban and technical resilience Administrative limits scale Collaborative approach Spatial decision support system Tool not 100% free access No validation of the methodology using a past event No long-term study of the impact of new urban projects on overall urban resilience

Table 2: Comparison between different resilient indicators models

186

187 These different indicator models demonstrate the multitude of possible methodological choices for
188 developing them. Some work at the national scale (Peacock, 2010; Foster, 2012; Cutter et al., 2014;
189 Suárez et al., 2016) others at the urban scale ((Fox-Lent et al., 2015; Heinzlef et al., 2019; Serre,
190 2018). The complexity of defining the concept of resilience also leads to diverse and varied choices
191 regarding the number of indicators constructed, some exceeding 10 indicators (Fox-Lent et al., 2015;
192 Peacock, 2010; Foster, 2012), others focusing on a more limited number (Cutter et al., 2014; Heinzlef
193 et al., 2019; Renschler et al., 2011; Serre, 2018; Suárez et al., 2016). This multitude can lead to an
194 overload of information, and therefore to a blurring of the knowledge acquired. Moreover, the
195 methodology chosen to build these indicators is not always clear, is it based on open data, is the
196 weight of each indicator always the same, can we reuse them or download the results, etc? Finally, the
197 understanding of risks is not identical everywhere, some specializing in one risk (Fox-Lent et al.,
198 2015; Heinzlef et al., 2019; Serre, 2018), others in more chronic risks (Cutter et al., 2014; Peacock,
199 2010; Renschler et al., 2011; Foster, 2012; Suárez et al., 2016).

200 3.2. Modelling resilience

201

202 As the concept of resilience is a complex subject to address and operationalize for local actors,
203 many tools have been created to simplify, define, measure and attempt to operationalize this concept.

204 For individuals, the visual context favors the acquisition of knowledge (Kwan and Lee, 2003;
205 Marzouki et al., 2017; Kurwakumire et al., 2019). The integration of visualization in the analysis of
206 geo-spatial data (Çöltekin et al., 2017) has led to geovisualization, a "set of visualization methods and
207 tools for interactively exploring, analyzing and synthesizing location-based data for knowledge
208 building" (Dykes and International Cartographic Association, 2007). Geovisualization combines
209 scientific visualization, information visualization, mapping, geographic information systems (GIS),
210 exploratory data analysis and many other methods to explore, analyze, synthesize and represent
211 geographic data and information (Nöllenburg, 2007). Several methodologies have produced tools to
212 clarify the concepts of resilience and vulnerability. These tools are spatial decision support systems
213 and have made it possible to dissect the concept of resilience (Table 3).

214

Models	References	Case study	Remarks
Social- infrastructural Interdependence Resilience (SIIR)	(Yang et al., 2022)	Nantes	<ul style="list-style-type: none"> Investigation of the interdependencies between 2 urban subsystems (social and

Framework			<p>infrastructural system)</p> <ul style="list-style-type: none"> • Tested to analyze the dependencies between Highway infrastructure and Emergency Medical service • Examples with different hazards • Is intended to be generic to other urban systems • Still conceptual
DOMINO	(Robert et al., 2008)	Montreal	<ul style="list-style-type: none"> • Modelling the spatial and temporal propagation of domino effects between critical infrastructure • City scale • Identify interdependencies • Collaborative approach • Dynamic interface • Technical-functional approach • Only interdependences issues • Centered around critical infrastructure
Web SIG	(Lhomme et al., 2010)	Dublin	<ul style="list-style-type: none"> • Study of the disturbances of critical infrastructure • Integration of interdependencies • Urban scale and critical infrastructure scale • Specific risk > floods • Prototype tool • Based only on urban networks
Coastal resilience mapping portal	Coastal Resilience https://maps.coastalresilience.org	Australia, Caribbean, Indonesia, Mexico and central America, USA	<ul style="list-style-type: none"> • Open access • Different case studies • Different elements represented (regional resilience projects, regional planning, community planning, future habitat, flood and sea level rise, risk explorer) • Interactive maps • Long term approach • No definition or measure of resilience • Too many information • Concentrated to coastal areas
StopDisaster	UNISDR https://www.stopdisastersgame.org	Virtual case studies	<ul style="list-style-type: none"> • Learn about risks and prevention methods through the online game • Understand what a major risk is and more specifically the notions of forecasting and prevention. • Adopt a responsible attitude towards risks • Different risks (tsunami, earthquake, hurricane, wildfire)

			<ul style="list-style-type: none"> and flood) No specific case studies Notions of resilience and vulnerability are not defined
ViewExposed	(Opach and Rød, 2013)	Norway	<ul style="list-style-type: none"> A tool for local authorities but also for residents Analysis of several vulnerabilities: physical, social vulnerability and a condensation of the two. Integrating the notion of vulnerability: local populations' capacities to resist Collaborative approach between scientists and local experts Creation of workshops Evolutionary platform The concept of resilience is not clearly integrated and identified
VisAdapt	(Johansson et al., 2016)	Nordic countries	<ul style="list-style-type: none"> Tool to visualize climate risks Scientific + Insurance Collaboration Intended users: private owners + planners Clear visualization of climate risks thanks to a dynamic interface Ease of use Advice and recommendations provided by the interface Buildings Frame Analysis Scale Not the same efficiency at each scale of analysis Limited characteristics of single-family homes Lack of precision Questionable Attractiveness

Table 3 Comparison between different geovisualization models

215

216 These different geo-visualization tools highlight the multitude of possibilities for representing risk
217 and resilience in dynamic and intuitive ways. While some are still conceptual models (Yang et al.,
218 2022), others are well and truly used by critical infrastructure managers (Johansson et al., 2016; Opach
219 and Rød, 2013; Robert et al., 2008). Some focus on the visualization of a risk such as flood (Lhomme
220 et al., 2010; Robert et al., 2008; Yang et al., 2022), while others address climate change in its globality
221 (UNISDR, n.d; Coastal resilience, n.d; Johansson et al., 2016; Opach and Rød, 2013). Their access
222 and target audience can also change, notably between access to the general public (UNISDR, n.d;
223 Coastal resilience, n.d; Johansson et al., 2016; Opach and Rød, 2013) or limited access to local actors
224 (Lhomme et al., 2010; Robert et al., 2008; Yang et al., 2022). The interactivity of the tool varies
225 greatly, depending on the audience for which it is intended. The Visadapt or Viewexposed tool have
226 an interactive, dynamic platform that allows for the selection of several viewing options and levels of
227 information. The StopDisaster tool has a rather old-fashioned design, which makes it somewhat
228 difficult to use. Finally, the Domino tool has a very limited representation, not very dynamic and

229 interactive, which limits its attractiveness and the pleasure of using the game. Finally, the scale is not
 230 always the same; between urban (Lhomme et al., 2010; Robert et al., 2008; Yang et al., 2022), national
 231 (Coastal resilience, n.d; Johansson et al., 2016; Opach and Rød, 2013) or fictitious scale (UNISDR,
 232 n.d), which sometimes complicates the implementation of risk management strategies afterwards.

233 *3.3. Integrating resilience into urban management through collaborative approaches*
 234

235 The United Nations International Strategy for Disaster Risk Reduction has developed 10 key
 236 points for creating resilient cities. The first point is to set up organizations to understand and reduce
 237 risks, based on the participation of local actors (UNISDR, 2015). The objective is to build local
 238 actions and alliances to ensure that actors understand their role in reducing and preparing risk
 239 reduction and resilience strategies (Heinzlef et al., 2020b; Gupta et al., 2010). Collaborative
 240 approaches are therefore essential levers in the process of involving, understanding and adopting the
 241 concept of resilience. Involving "local" people or people directly concerned by the issues studied does
 242 not appear to be new (Toubin et al., 2015) and even less original. The richness of having people from
 243 all walks of life interact with each other facilitates an exploration of possibilities, enriching
 244 discussions, encouraging cross-fertilization of views on the same subject, making it possible to be both
 245 more measured and more incisive in a specific area. The contribution of "profane" knowledge in
 246 thorny social and societal issues, as scientific knowledge cannot respond to all uncertainties, with the
 247 result that "expert" conclusions are called into question. Resilience, a social and thorny concept, is
 248 therefore a subject that would require the confrontation of views, knowledge, scientific and practical
 249 knowledge, perceptions and interpretations. However, although the population is often the first to be
 250 impacted by natural hazards and their inappropriate management, the fact remains that the inhabitants
 251 (Kuhlicke et al., 2011) and also the urban services (Toubin et al., 2015), which are nonetheless first-
 252 rate actors, are not sufficiently involved. The defended idea is that the creation of a hybrid knowledge
 253 (Djenontin and Meadow, 2018; Lemos and Morehouse, 2005; Schneider and Rist, 2014) allowing the
 254 involvement of all actors of the territory, from the inhabitant to the manager via the scientist, would
 255 make it possible to operationalize urban resilience thanks to an appropriation of the concept and stakes
 256 of urban risks. In fact, collaboration is mainly based on the appropriation of the different stakeholders
 257 of the same subject of tension and discussion. Collaboration therefore goes beyond the simple
 258 exchange of knowledge and information, but makes it possible to *"create a shared vision and*
 259 *articulated strategies for the emergence of common interests that extend beyond the limitations of*
 260 *each particular project"* (Chrislip, 2002). There are several examples of collaborative and/or
 261 participatory approaches that aim to integrate local actors in the process of operationalizing resilience
 262 (Table 4).
 263

Models	References	Case study	Benefits
Urban resilience through collaborative diagnosis	(Toubin et al., 2015)	Paris	<ul style="list-style-type: none"> • Involvement of critical infrastructure managers in resilience analysis • Development of a culture of resilience • Development of a cross-analysis between managers • Development of a common flood risk analysis • Confrontation between the different scales of analysis • No long-term reuse of the process • No utilitarian rendering for local actors beyond research • Analysis centered around the resilience of critical infrastructures and urban networks
A participatory	(Freeman et al.,	Mexico	<ul style="list-style-type: none"> • Freshwater issues • Identify with local stakeholders, resilience of

human-hydrologic systems approach	2020)		<p>what, to what; for whom and what can be done?</p> <ul style="list-style-type: none"> • Identify solutions and compromises between urban managers, political stakeholders and decision-makers • A shared narrow and adaptive approach • No long-term reuse of the process • No utilitarian rendering for local actors beyond research
The City Resilient Framework	(100 Resilient Cities, n.d.)	100 case study (New York, Paris, etc.)	<ul style="list-style-type: none"> • Integration of the different resilience themes: leadership, infrastructure and environment, health and well-being, economy and society • Integration of local actors • Metropolitan scale • Development of a local culture of resilience • Multi-risk approach (disasters natural + daily stress) • Approach to long-term resilience • No measurement of resilience • Very global conceptual framework
LittoSim	(Laatabi et al., 2022)	French coastal areas	<ul style="list-style-type: none"> • Participative simulation platform for local elected officials and technicians concerned by the management of the risk of marine submersion • Collaborative approach with local actors • Testing and validation of the game by and with the stakeholders • Interactive workshops • Dynamic and interactive platform • Long-term follow-up (before, during and after the game up to 2 years after the game) • No definition and measurement of resilience • Not yet adapted to different case studies
Narratives of change	(Marschütz et al., 2020)	Dordrecht	<ul style="list-style-type: none"> • Integration of stakeholders and citizens • Stimulate collaboration between authorities and citizens • Adaptation and resilience-building are locally meaningful • Elicit perceptions of past, present and future weather, water and climate • Contribution to an awareness and sense of urgency of some climate risks • No visualization or future use of results • Ask for a long and deep collaboration with stakeholders and citizens

Table 4: Comparison between different collaborative models

264

265

266 Not all models developing participatory approaches have the same methodology. Some approaches
267 rely on workshops, interviews, questionnaires with stakeholders (100 Resilient Cities, n.d.; Marschütz
268 et al., 2020; Freeman et al., 2020; Toubin et al., 2015), others develop visualization tools in
269 collaboration with stakeholders (Laatabi et al., 2022). The results are not always represented in a
270 uniform way (results of questionnaires, summary tables, etc.). On the other hand, the scale of analysis

271 is often urban, due to the complexity of data acquisition, which is more relevant on a fine scale.
 272 Finally, the common problem of collaborative approaches is the temporality of the project. A
 273 collaborative approach requires a long-term approach and the constant updating of data and results.
 274

275 4. From a multitude of methods to a resilience toolbox

276
 277 Several methodologies exist in order to operationalize resilience concepts and integrate it into
 278 urban risks strategies (Cutter et al., 2008; Heinzlef et al., 2020, 2019; Opach and Rød, 2013; Robert et
 279 al., 2008; Serre, 2018; Freeman et al., 2020; Toubin et al., 2015).

280 Indicators are helpful to define main resilience characteristics and to provide a measurement to
 281 analyze resilience potentialities. These indicators might be specific (Serre, 2018) or exhaustive
 282 (Heinzlef et al., 2020a). They have an important utility to urban managers to define low resilience
 283 areas and concentrate their strategies on it.

284 Geovisualization techniques are used to unbuilt resilience abstraction thanks to tools, interfaces
 285 and data which allow comprehension and facilitate resilience integration. Interactivity,
 286 communication, navigation, visualization lead to a precise resilience analyze. These tools are essential
 287 for knowledge construction.

288 Finally, collaborative approaches lead to local stakeholders' responsibilities to integrate resilience
 289 into risk strategies management. It is useful to create a shared vision on complex concepts and
 290 strategies between "experts" and "local actors". Their proper experiences lead to a territorialized risk
 291 and resilience strategies. It is also a long-term guarantee to resilience strategies adoption.
 292

293 The multitude of models for operationalizing resilience indicates the growing importance of the
 294 concept. They are essential to the transcription of the concept into a concept tool (Gonzva and
 295 Barroca, 2017). Going beyond the controversy over the exact definition of the concept, these models
 296 propose to operationalize resilience. The accuracy of their methodology then takes a back seat because
 297 what matters then is not that the model be rigorous, but that it be operational. However, not everyone
 298 has the same objective or goal (Table 5). While some apprehend urban resilience through the analysis
 299 of networks and through a technical-functional approach, others seek to develop hybrid, more
 300 exhaustive approaches that attempt to understand and analyze the diversity of the urban territory. The
 301 decision support approach also differs from one tool to another, with some advocating the usefulness
 302 of indicators, others justifying the need for visualization to lead to a process of understanding and
 303 decision making, and finally, some defending the need to integrate local actors at the beginning of any
 304 reflection on the concept of resilience.
 305

Models	Category	Identified Risk	Scale	Approach	Audience
BRIC (1)	Indicators	No	National	Global	Decision-makers and urban managers
DS3 Model (2)	Indicators	Yes	Urban	Technical	Critical infrastructure managers and urban managers
Resilience Capacity Index (3)	Indicators	Yes	National	Global	Risk researchers
Community Disaster resilience index (4)	Indicators	Yes	National	Global	Risk researchers
Urban resilience index (5)	Indicators	No	Urban	Technical	Risk researchers
Community	Indicators	Yes	Urban	Global	Risk researchers

resilience assessment (6)					
The Peoples Resilience Framework (7)	Indicators	No	None	Global	Risk researchers
Hybrid Approach (8)	Indicators	Yes	Urban	Global	Decision makers, urban managers and citizens
Social-infrastructural Interdependence Resilience (SIIR) Framework (9)	Spatial decision support system	Yes	Urban	Global	Decision makers, urban managers
DOMINO (10)	Spatial decision support system	Yes	Urban	Technical	Critical infrastructure managers and urban managers
WebSig (11)	Spatial decision support system	Yes	Urban	Technical	Critical infrastructure managers and urban managers
Coastal Resilience Mapping Portal (12)	Spatial decision support system	Yes	National	Global	Decision makers, urban managers and citizens
StopDisaster (13)	Spatial decision support system	Yes	None	Global	Decision makers, urban managers and citizens
ViewExposed (14)	Spatial decision support system	Yes	National	Global	Decision makers, urban managers, insurances and citizens
VisAdapt (15)	Spatial decision support system	Yes	Urban/Buildings	Global	Decision makers, urban managers, and citizens
Toubin et al., 2015 (16)	Collaborative approach	Yes	Urban	Global	Critical infrastructure managers and urban managers
Freeman et al., 2020 (17)	Collaborative approach	Yes	Urban	Global	Critical infrastructure managers and urban managers
The City Resilient Framework (18)	Collaborative approach	No	Urban	Global	Decision makers, urban managers

LittoSim (19)	Collaborative approach	Yes	Regional	Global	Decision makers, urban managers
Narratives Change (20)	Collaborative approach	No	Urban	Global	Decision makers, urban managers, and citizens

306

- | | | | |
|-----|----------------------------|-----|--------------------------------------------------------|
| 307 | (1) Cutter et al., 2014 | 318 | (12) Coastal Resilience, n.d. |
| 308 | (2) Serre, 2018 | 319 | (13) UNISDR (United Nations International Strategy for |
| 309 | (3) Foster, 2012 | 320 | Disaster Reduction), n.d. |
| 310 | (4) Peacock, 2010 | 321 | (14) Opach and Rod, 2013 |
| 311 | (5) Suárez et al., 2016 | 322 | (15) Johansson et al., 2016 |
| 312 | (6) Fox-Lent et al., 2015 | 323 | (16) Toubin et al., 2015 |
| 313 | (7) Renschler et al., 2011 | 324 | (17) Freeman et al., 2020 |
| 314 | (8) Heinzlief et al., 2020 | 325 | (18) 100 Resilient Cities, n.d. |
| 315 | (9) Yang et al., 2022 | 326 | (19) Laatabi et al., 2022 |
| 316 | (10) Robert et al., 2008 | 327 | (20) Marschütz et al., 2020 |
| 317 | (11) Lhomme et al., 2010 | | |

328

Table 5: Models' categories

329

330 Some models do not have the same technical maturity, development and use (Sadin et al.,
331 1989). In order to assess this maturity, the Technology Readiness Level (TRL) methodology,
332 developed by NASA, has been used. This methodology has been adapted in the European Union to
333 assess the outcome of EU-funded research and innovation projects (Sadin et al., 1989).

334

335 Some models presented are still at the prototype scale, others are directly used by actors
336 (Table 6). For example, the Web Sig developed by (Lhomme et al., 2010), has already been tested in
337 one field of study (Dublin), but its construction has not yet been completed to make it an efficient and
338 effective tool in other contexts. On the other hand, the DS3 Model developed by (Serre, 2018), has
339 already been tested and applied on different study sites (Hamburg, French Polynesia, Dublin, Paris),
340 with different issues and actors. Their usefulness in spheres other than academic can therefore be
341 discussed. However, operationalizing resilience tends to respond to the challenge of using the concept
342 in a concrete way through tools that meet the needs identified by local actors. However, their degree of
343 completion, as well as their technical specificities (indicators/geo-visualization/collaborative
344 approaches), their key audience (local actors, risk managers, infrastructure managers or researchers),
345 as well as their multiplication make their use very complex. The multitude of choices as well as the
346 sometimes too specific technicality lose the actors. Which tool should be chosen for which risk, which
347 use, which scale? These models are neither exhaustive nor exclusive and it is necessary to use them
348 jointly or at different times and phases in the construction of a resilience strategy. However, this
349 multitude does not promote the understanding and appropriation of a concept that is still abstract for
many local actors and managers.

350

Models/ TRL Levels	Basic princip les observ ed	Technol ogy concept formula ted	Experime ntal proof of concept	Technol ogy validat ed in lab	Technolo gy validat ed in relevant environ ment	Technolo gy demonstr ated in relevant environm ent	System prototype demonstra tion in operationa l environme nt	Syste m compl ete and qualifi ed	Actual system proven in operatio nal environ ment
BRIC (1)									V
DS3 Model (2)									V
Resilience							V		

Capacity Index (3)									
Community Disaster resilience index (4)									V
Urban resilience index (5)						V			
Community resilience assessment (6)									V
The Peoples Resilience Framework (7)			V						
Hybrid Approach (8)								V	
Social-infrastructural Interdependence Resilience (SIIR) Framework (9)							V		
DOMINO (10)									V
WebSig (11)							V		
Coastal Resilience Mapping Portal (12)									V
StopDisaster (13)				V					
ViewExposed (14)									V
VisAdapt (15)									V
Toubin et al., 2015 (16)									V
Freeman et al., 2020 (17)							V		
The City Resilient Framework (18)									V
LittoSim (19)							V		
Narratives Change (20)							V		

353	(3) Foster, 2012	363	(13) UNISDR (United Nations International Strategy for
354	(4) Peacock, 2010	364	Disaster Reduction), n.d.
355	(5) Suárez et al., 2016	365	(14) Opach and Rod, 2013
356	(6) Fox-Lent et al., 2015	366	(15) Johansson et al., 2016
357	(7) Renschler et al., 2011	367	(16) Toubin et al., 2015
358	(8) Heinzlef et al., 2020	368	(17) Freeman et al., 2020
359	(9) Yang et al., 2022	369	(18) 100 Resilient Cities, n.d.
360	(10) Robert et al., 2008	370	(19) Laatabi et al., 2022
361	(11) Lhomme et al., 2010	371	(20) Marschütz et al., 2020
362	(12) Coastal Resilience, n.d.		

372 *Table 6: Models' Technology Readiness Level based on (Sadin et al.1989)*

373

374 A tool that would allow all these options would be more efficient and relevant. A platform or
375 a toolbox, allowing the concentration of pre-existing data and the production of new data, the
376 development of collaborative approaches to ensure the sustainability of the use of the tool, the
377 integration of local risk strategies and the adequacy of the tool to local needs, as well as the
378 development of a methodology to visualize the results and test them on a dynamic and intuitive
379 platform, would respond to this bias of multiplication of tools and therefore loss of information. This
380 prototype would be to promote an inclusive approach that would bring together the different existing
381 approaches around the concept of resilience and to develop a framework for reflection and action
382 between local actors and scientific experts around the issue of operationalizing the concept. This type
383 of tool could be achieved through the design of a resilience observatory. Observatories are key tools to
384 support the observation, reflection, understanding and analysis of phenomena or territories. They have
385 to produce “*an understandable and operational collective representation of territories while at the*
386 *same time having to restore the inherent complexity of the systems they describe*” (Serre and Heinzlef,
387 2022). These tools, which are at the interface of reality and knowledge, are essential in the decision-
388 making process, allowing the acquisition of knowledge and data while taking the necessary distance to
389 have the most global vision possible of a phenomenon. These technical systems can “*acquire, store,*
390 *process, manage, and distribute the data, information and knowledge produced*” (Serre and Heinzlef,
391 2022). This kind of tool would allow the creation of a consensus between the production of indicators
392 and data, while developing visualization platforms and long-term collaborations (Fig.1). Such an
393 observatory is under construction at the scale of French Polynesia (Jessin et al., 2022; Serre and
394 Heinzlef, 2022). If some observatories already exist in France, as the National Observatory of Natural
395 Risks (ONRN) and the Regional Observatory of Major Risks (ORRM), they don't integrate the French
396 overseas territories. However, these territories are over vulnerable face to climate risks and are faced
397 to several limits such as a lack of scientific knowledge and dissemination, poor data quality, excessive
398 dissemination of models, data and approaches, etc. Such observatory should answer to multiple gaps
399 in French overseas risk management, and eventually to other territories.

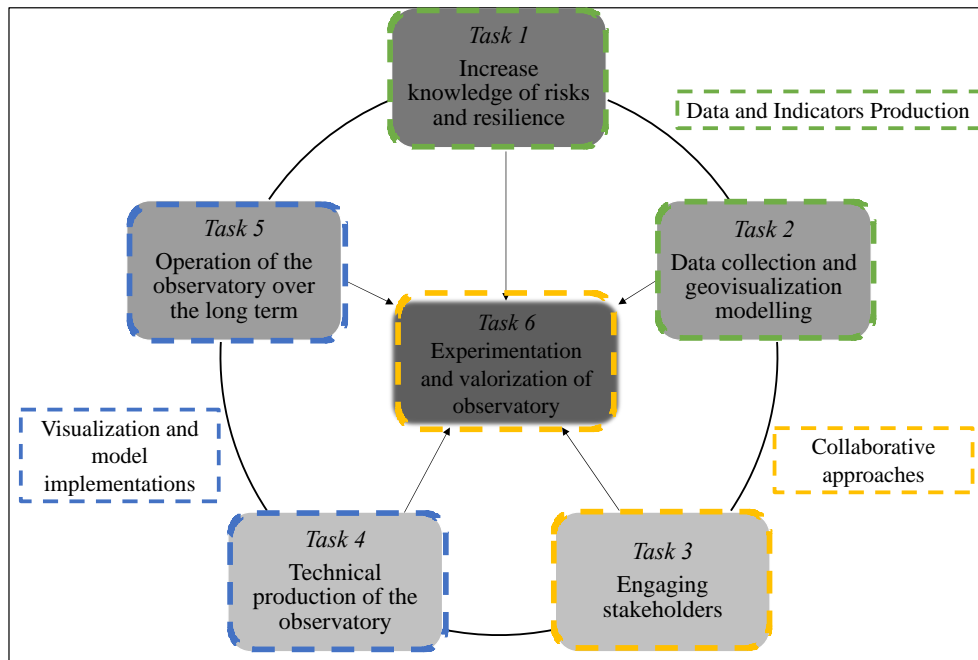


Figure 1: Observatory Tasks - Adapted from (Serre and Heinzlef, 2022)

400

401

402

403 The objectives are multiple and focus on increasing knowledge of territorial risks, the acquisition,
 404 storage and enhancement of data related to risks and resilience and finally the integration of
 405 stakeholders in the process of reflection and implementation of resilience strategies. This prototype
 406 observatory would be built around 6 steps. First, it is necessary to increase knowledge on risks and
 407 resilience. The awareness of the research around these themes is the dissonance of the terms in very
 408 actors (the different actors can all speak of "resilience" but do not put the same notions behind this
 409 concept). It is therefore necessary to develop a common vocabulary, evoking the same notions,
 410 resources, and issues. Secondly, it is necessary to gather pre-existing data. Data are multiple, are
 411 hosted on a multitude of platforms, are sometimes private or public. It is necessary to develop a tool
 412 that brings together all the pre-existing data in a single structure. This gathering allows to identify the
 413 missing data that it is necessary to produce in the most adequate way for the territory. The third step is
 414 to develop collaborative and sustainable approaches with local actors. As developed previously, these
 415 approaches are a guarantee of adoption of the tools and methods developed. In addition, they allow for
 416 a fusion between local knowledge and expertise and scientific knowledge. This step must be taken at
 417 several levels, from political decision-makers to critical infrastructure managers, to citizens. The
 418 fourth step must allow the technical construction of the platform. This platform must be built digitally:
 419 allow the storage and production of data and results, develop a geo-visualization tool (navigate on an
 420 interactive map to represent the necessary information), develop different accesses to resources and
 421 levels of confidentiality (depending on the status of the actor, certain data or results will be accessible
 422 or not), etc. The fifth step completes step 4. It ensures the sustainability of the tool and its relevance.
 423 To meet this challenge, the digital tool will be supplemented by a scientific and local team that will
 424 ensure that the observatory functions properly and is appropriate. Thus, regular workshops will be
 425 organized, as well as conferences to disseminate the results and fundraising. Finally, the sixth stage is
 426 the experimentation, adjustment, and validation stage. These stages are cyclical and continuous in time
 427 to ensure the adequacy of the observatory in relation to local needs and gaps.

428 This prototype can serve as a basis for reflection and suggestions for further progressive
 429 implementation of the concept of resilience in risk management strategies.

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433

434 5. Conclusion

435

436 This article has provided a review of the concept of urban resilience and its operationalization.
437 Confronted with a conceptual vagueness and a multiplicity of definitions, notions and associated
438 concepts, resilience loses its relevance and usefulness in risk management strategies. Yet this concept,
439 which encourages adaptability, evolution and flexibility, is perfectly adequate for the analysis of
440 climate change and the associated risks and uncertainties.

441 The current challenge, whether in the scientific community or in urban planners and decision-
442 makers sphere, is to work on its operationalization by promoting concept understanding and its
443 adoption by local actors. This need has led to a multitude of scientific positions, tools and
444 methodologies aimed at dissecting the concept of resilience and the concepts and capacities associated
445 with it. These operationalization strategies can promote the design of indicators to define and measure
446 resilience, develop spatial decision support systems to visualize territorial resilience or promote the
447 implementation of collaborative approaches to involve local stakeholders in the integration of the
448 concept in local risk management strategies. Although these methodologies in themselves provide
449 opportunities for reflection or even initiatives for resilience strategies, their contribution remains
450 modest and visible in a very short period of time.

451 Thinking about a new kind of tool for addressing resilience in the long term and an inclusive
452 approach to the concept and associated methodologies would make it possible to respond to these
453 current limitations. This tool, which would take the form of a resilience observatory, would make it
454 possible to develop a toolbox, bringing together conceptual and tangible advances related to the
455 operationalization of resilience.

456

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458

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