



1 Resilience issues and challenges into built environments: a review

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9 Abstract

10 This paper proposes a review of existing strategies and tools aiming at facilitating the
11 operationalization of the concept of resilience into built environments. In a context of climate change,
12 increased risks in urban areas and growing uncertainties, urban managers are forced to innovate in order
13 to design appropriate risk management strategies. Among these strategies, making cities resilient has
14 become an imperative. This injunction to innovation fits perfectly with the urban, economic, political,
15 social and ecological complexity of the contemporary world. As a result, the concept of resilience is
16 integrated into the issues of urban sprawl and the associated risks. However, despite this theoretical and
17 conceptual adequacy, resilience remains complex to integrate into the practices of urban planners and
18 territorial actors. Its multitude of definitions and approaches has contributed to its abstraction and lack
19 of operationalization. This review highlights the multitude of approaches and methodologies to address
20 the bias of the lack of integration of the concept of resilience in risk management. The limit is the
21 multiplication of these strategies which lead to conceptual vagueness and a lack of tangible application
22 at the level of local actors. The challenge would then be to design a toolbox to concentrate the various
23 existing tools, conceptual models and decision support systems in order to facilitate the autonomy and
24 responsibility of local stakeholders in integrating the concept of resilience into risk management
25 strategies.
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29 1. Introduction: several disciplines, definitions and associated concepts

30 Operationalizing resilience is a complex, even conflicting subject. Because of its multidisciplinary
31 origin and the multitude of approaches, interpretations of resilience and its operationalization are
32 sometimes contradictory (Davoudi et al., 2012). This contradiction is essentially due to the fact that
33 resilience belongs to many disciplines, physics, psychology, ecology or risk management. This
34 disciplinary and conceptual vagueness makes the use of resilience and its integration into risks . The
35 concept of resilience is faced with a problem of formalization which makes it difficult to move from
36 theory to practice (Weichselgartner and Kelman, 2015). Despite its growing success, the operational
37 relevance of the concept is therefore constantly questioned and questioned .
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40 1.1. Resilience, at the crossroads of several disciplines

41 Over the past 20 years or so, resilience has become an integral part of risk management (Heinzlef
42 et al., 2020a). However, its multidisciplinary use makes it a polysemic and abstract concept (Bahadur et
43 al., 2010). This concept is today over-used, solicited in many fields and linked to many notions (Emrich
44 and Tobin, 2018). From the Latin *resalire* (*re*, backwards; *salire*, jump), the term resilience is used for
45 the first time to illustrate the idea of 'bouncing' to refer to the noise that the echo makes while 'bouncing'.
46 The first meaning of the word resilience in the English language therefore means "to bounce" (Saunders
47 and Becker, 2015), "to straighten up". In French, the meaning of the word evolved during the Middle
48 Ages by taking on the meaning of to retract, to free oneself from a contract by a kind of jump backwards.
49 Nevertheless, this is the meaning of the Anglo-Saxon term that persists today linked to qualities of
50 elasticity, springiness, resourcefulness. The Latin root indicates quite clearly the interpretation of the
51 term: the capacity to untie/mitigate the impacts of a trauma. However, in view of the many definitions
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53 (Hosseini et al., 2016) and fields of use, it would be more accurate to begin by talking about resiliences
54 rather than resilience (Emrich and Tobin, 2018). This multitude of "resiliencies" (Bec et al., 2016) can
55 be explained by its origins but also by its diverse and varied uses (Gaillard, 2007; Klein et al., 2003).
56 Each actor can define the term resilience in different ways (Meerow et al., 2016). This diversity of
57 interpretation also makes it a weakness, which explains why translating this concept into action
58 strategies is difficult and laborious. From an innovative concept to a buzzword, resilience is a source of
59 enrichment, learning and improvement as an abstract word that few actors understand and integrate into
60 their risk management strategies. This is why it is necessary to understand the different definitions, and
61 therefore interpretations, that are related to this concept. While interdisciplinary can serve and enrich
62 the understanding of resilience, it can also serve it in its transition to operationalization.

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1.1.1. Concept of resilience in physics

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66 The first use of the concept of resilience in science is in the field of physics. In Thomas Tredgold's
67 Practical Treatise on the Strength of Cast Iron and Other Metals (1824), resilience refers to the elasticity
68 and strength of materials. In particular, it refers to the ratio of the absorbed kinetic energy required to
69 cause the rupture of a metal and therefore to the capacity of the metal to resist the impact while keeping
70 its initial shape (Campbell, 2008). Following a continuous pressure of a material under the effect of a
71 stress, the return to its initial state is the phenomenon of physical resilience. Resilience is therefore an
72 intrinsic - measurable - capacity.

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1.1.2. Resilience in psychology

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76 Psychological resilience is defined as an individual's ability to adapt in the face of tragedy, trauma,
77 disruption, threats or stress (Booth and Neill, 2017). The idea is to move beyond the difficult situation
78 (Cyrulnik and Jorland, 2012). Several approaches have followed, some defining psychological resilience
79 as a personal quality, others as a process, or as an ability, strength or aspiration that each individual
80 possesses. Today's established definition is that resilience represents positive adaptation in the face of
81 adversity (Luthar et al., 2000). Adaptation can be defined as significant and/or positive depending on
82 the situation (Luthar, 2015). In this case, resilience is not measured directly but is inferred from the
83 actions of individuals and evidence of adaptation. In this approach, risk or stress is required to
84 demonstrate resilience. Resilience is therefore distinct from normal development, i.e., undisturbed
85 individual development (Rutter, 1999, 1987; Rutter and Zigler, 2000).

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1.1.3. Resilience concept in ecology

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89 In 1973, Holling defined resilience as the ability of an eco "*system to maintain its qualitative*
90 *structure*" (Holling, 1973). This definition emphasizes the capacity of a system to maintain its qualitative
91 structure (Holling, 1973), to absorb a shock without changing behavior, function. It is therefore above
92 all the notion of persistence that is put forward. The idea is that the system has a constant evolution,
93 characterized by pendulum movements towards the initial state preceding the disturbance. However, the
94 idea that there is a single initial state of equilibrium for any element has been widely criticized, especially
95 when analyzing complex systems characterized by their evolution. This is why, several years later,
96 Holling evolved by introducing the idea of evolution without relying on necessarily on a return to a pre-
97 existing equilibrium. The resilience of an ecosystem can therefore be defined as the capacity to absorb
98 disturbances while reorganizing itself (Walker et al., 2004) in a feedback process. Gunderson and
99 Holling (Chelleri, 2012; Gunderson and Holling, 2002) have therefore innovated by using the panarchic
100 concept to illustrate the dynamics and multi-scale dimension of resilience. The Panarchy model sets up
101 a dynamic cycle combining a growth phase (exploitation phase), conservation (equilibrium phase),
102 collapse (release phase) and finally a reorganization phase.

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1.1.4. Resilience at the crossroads of disciplines for new risk management

105

106 The Hurricane Katrina disaster in New Orleans in 2005 marked a major turning point in the
107 history of the turning point in risk management (Campanella, 2006; Cutter et al., 2008a, Hernandez,



108 2009). To prevent a similar event from happening again, risk management has evolved to incorporate
109 the concept of resilience. The objective is to use this concept to best prepare populations and territories
110 to increased risks in urban areas. The idea is no longer to analyze the risks in a compartmentalized
111 manner but to study the disruptive event and its consequences as a whole. Three approaches and methods
112 stand out currently (Folke, 2006; Folke et al., 2010, 2002):

- 113 • The engineering approach assumes a steady state (Brand and Jax, 2007; Holling, 1973). The
114 idea is to evaluate the gap between the disturbed state and the steady state and the speed of
115 return. to a state of equilibrium after a disturbance. The hazard here represents an element
116 against which you have to protect yourself and avoid.
- 117 • The ecosystem approach (Carpenter et al., 2001; Gunderson and Holling, 2002; Walker et al.,
118 2004) does not imply a return to a previous equilibrium but acknowledges that several states of
119 equilibrium.
- 120 • The socio-ecological approach is defined as "*the capacity of a system to absorb disruptions and*
121 *to reorganize while undergoing change, so as to still maintain its overall function, structure,*
122 *and feedback loops, and by identity; in other words, the ability to change in order to maintain*
123 *the same identity. identity*" (Folke et al., 2010). This approach differs from the other two
124 because, while it integrates the idea of absorbing disturbances, it also incorporates the notions
125 of learning, adaptation, self-organization.

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128 The multiple disciplinary origins of the concept of resilience make it difficult to define. There are
129 many meanings behind this disciplinary identity, creating a lack of understanding between scientific
130 experts and/or local actors.

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132 1.2. Attempted resilience definitions

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134 While resilience belongs to so many different disciplines, there are many definitions related to
135 it. The main idea, however, is that when faced with a shock, a crisis, the system (whatever it is)
136 disappears or recovers. However, the question remains: when can it be determined that a system has
137 recovered from how many disturbances, changes and transformations it has undergone?

138 The various definitions belonging to these various disciplines refer to concepts such as:
139 recovery, reconstruction, restoration, renewal, return to a state of equilibrium, return to a previous
140 state, rebound, etc.

141 These different points of view then refer to resilience according to two currents of thought:

- 142 • Resilience is either a process or the result of this process: we evaluate the resilience capacity
143 of a post-crisis system (result), or the succession of solutions developed by this system to
144 recover from a shock (process). This vision of resilience can therefore only be assessed *a*
145 *posteriori*, in order to evaluate whether the system has been able to maintain itself beyond
146 a shock and to overcome it (Reghezza-Zitt and Rufat, 2016).
- 147 • Resilience is an intrinsic capacity of the system, a capacity that can be put forward at the
148 time of the shock. It can then be translated as an ability, a capacity, or even a capability.
149 This resilience can therefore be pre-existing to the shock, innate or acquired. This resilience
150 capacity can be declined according to several characteristics:
 - 151 ○ Resistance capacity: Serre (2018) defined three capacities of resilience and defined
152 the resistance ability to determine "the physical damage to the network as a result
153 of the hazard" (Serre et al., 2013). It is essential to know before any risk
154 management and actions plan the potential damages of a system, in order to adapt
155 resilience strategy. It is estimated that, more the technical system is damaged,
156 greater is the possibility of a malfunction of the system and more it will be difficult
157 to restore it to service.
 - 158 ○ Absorption capacity: For instance, the UNISDR (2009) has define resilience as the
159 "*ability of a system, community or society exposed to hazards to resist, absorb,*
160 *accommodate to and recover from the effects of a hazard in a timely and efficient*
161 *manner, including through the preservation and restoration of its basic structures*



- 162 *and functions*". Cardona (2004) defined resilience as the capacity of the damaged
163 ecosystem or community to absorb negative impacts and recover from these.
164 ○ Adaptive capacity: Pelling (2011) defends the idea that resilience is the ability of
165 an actor to cope with and adapt to hazards stress. It refers to the "*ability of systems,*
166 *institutions, humans and other organisms to adjust to potential damage, to take*
167 *advantage of opportunities, or to respond to consequences*" (IPCC, 2014). This
168 implies considering the entire pool of assets (social, physical, financial, natural,
169 human, and cultural) and resources (technological, knowledge and governance)
170 which can be mobilized to build resilience to climate change impacts. Socio-
171 technical and ecological aspects are equally targeted in a systemic perspective
172 (Whitney et al., 2017), including consideration of trade-offs among them to avoid
173 social-ecological traps which can risk conditions (Carpenter and Brock 2008).
174 ○ Reaction capacity, linked to self-organization: Pickett et al. (2004) have defined
175 resilience as the "*ability of a system to adjust in the face of changing conditions*"
176 and Ahern (2011) has defend resilience as a "*capacity of systems to reorganize and*
177 *recover from change and disturbance*".
178 ○ Ability to rebuild using internal and external forces: Walker et al. (2004) developed
179 the idea that resilience is the capacity to "*reorganize while undergoing change so*
180 *as to still retain essentially the same function, structure identity, and feedbacks*"
181 ○ Learning capacity: The Resilience Alliance (Walker and Salt, 2006) defends that
182 resilience is a combination of three capacities, absorb and remain within the same
183 state, the capacity of self-organization and "*the degree to which the system can*
184 *build and increase the capacity for learning and adaptation*" (Carpenter et al.,
185 2001; Klein et al., 2003)
186 ○ Ability to bounce back or reach a new state of equilibrium: to some authors, there
187 is one single-state equilibrium which implies to bounce back to equilibrium
188 previous disturbance (Holling, 1996). On the contrary, others consider that we can
189 observe multiple-state equilibrium which suppose that systems have different
190 stable states (Davoudi et al., 2012; Holling, 1996)

191
192 These different capacities can be self-sustaining or, on the contrary, contradict each other (such as
193 the capacities of resistance and adaptation). Faced with these different positions, the notions and
194 concepts associated with that of resilience accentuate the abstraction and incomprehension of the
195 concept.

196 197 1.3. Concepts associated to resilience perception

198
199 No doubt a victim of its multitude of disciplines and definitions, resilience has been continually
200 associated with or compared to related concepts. Resilience is regularly compared or associated with the
201 concepts of vulnerability and sustainable development (Romero-Lankao et al., 2016).

202 203 1.3.1. Resilience vs Vulnerability

204
205 The classic way of analyzing resilience and vulnerability is to contrast them: if you are resilient, you
206 are not vulnerable and vice versa (Folke et al., 2002). This clear opposition seems logical: if resilience
207 is the ability to adapt to a shock and vulnerability is defined as the propensity to damage, then the more
208 vulnerable a concept is, the less resilient it is (Pelling, 2003). So the equation is simple, reducing
209 vulnerability is the same as increasing resilience (Klein et al., 2003).

210 Yet this opposition has been widely contested. First of all, social vulnerability reflects the capacity
211 to face, anticipate and adapt to risks. These social capacities are largely integrated into the notion of
212 resilience (Cardona, 2004). Resilience can therefore be seen as an integral part of the concept of
213 vulnerability (Britton and Clark, 2000), being aimed "*to not only restore functionality but also correct*
214 *existing social, political, and economic structures that may have increased exposure and constrained*
215 *capacity to cope with the crisis*" (Patel and Nosal, 2016). Thus, the two concepts cannot be completely
216 opposed. Concerning the positioning aimed at qualifying the concept of vulnerability as "negative",



217 "positive" vulnerability provides a counter-argument. Vulnerability is considered positive when it leads
218 to a change that brings about a beneficial transformation (Gallopín, 2003). For example, in a situation
219 of vulnerability in a dictatorial political system, its collapse is positive. Seeing the collapse or paralysis
220 of an urban system following a flood can raise awareness and allow it to evolve towards more
221 appropriate functioning. Indeed, while in risk assessment vulnerability is in general hazard-specific,
222 certain factors - such as poverty, the lack of social networks and social support mechanisms, inadequate
223 governance structures - will aggravate or affect vulnerability levels irrespective of the type of hazard
224 (Prowse, 2003; UNEP, 2003). Such dimensions of resilience, which involve society and ecosystems as
225 a whole, can be used to identify cross-cutting vulnerability aspects to be tackled as high-level policy and
226 governance issues, linked e.g. to limitations in access to and mobilization of the resources of individuals
227 and institutions, as well as to the incapacity to anticipate, adapt, and respond to absorb the socio-
228 ecological and economic impact of hazards (Miller et al., 2010; UNISDR, 2011; Cardona et al., 2012;
229 EEA, 2016). Under these conditions, vulnerability and resilience are no longer in opposition but are part
230 of a whole. They can then be approached along a continuum. This new stance leads to the notion of
231 resilient vulnerability (Provitolo, 2012). This notion reflects the idea that *"vulnerability can be traversed
232 and modified by resilience considered from a global perspective, i.e. that this resilience can, on the one
233 hand, be directly linked to the vulnerability to which it applies and, on the other hand, have a positive
234 or negative effect depending on the scale at which the system is studied"* (Provitolo, 2012).

235 In conclusion, resilience and vulnerability are not dichotomously opposed. The two concepts are
236 equally adaptable to technical and/or social systems. Resilience and vulnerabilities overlap in their
237 approach to systems to provide a vision of exhaustive of the elements composing this one. Addressing
238 the two concepts leads to an analysis of the question of long-term risks. It is therefore necessary to learn
239 to live with the change and uncertainty and not seek short-term control of risks. Analyze together the
240 two concepts is like learning from crises (vulnerability approach) and innovate to adapt to risks
241 (resilience).

242 243 1.3.2. Resilience vs Sustainable development

244
245 Faced with increasing risks, stakeholders have identified two concepts (Saunders and Becker, 2015),
246 that of resilience (taking into account the management of disturbances) and that of sustainable
247 development (analyzing the balanced economic, social and environmental development of the territory).
248 For some, resilience is a necessary condition for sustainability (Folke et al., 2002; Klein et al., 2003).
249 For others, after studying the possible trajectories of ecosystems according to different initial states,
250 resilience is not sufficient, sometimes it is not even necessary.

251 However, Toubin et al. (2015) defend the fact that resilience can play a role in the realization of the
252 sustainable city (Elmqvist et al., 2019), an ideally functioning urban system. The urban resilience
253 enhancement approach is then defined as a means of managing the jolts of the urban system subjected
254 to numerous disturbances (short-time resilience) and maintaining it in the ideal trajectory of
255 sustainability (long-term resilience) linked to a system state indicator (economic growth, carbon
256 footprint, or demographics, for example). Resilience is thus presented as a means of achieving
257 sustainability (Toubin et al., 2015). Nevertheless, resilience may also *"run counter to sustainability
258 goals: for instance, efficiency reduces diversity and redundancy, both of which are key features of
259 resilience. This conflict is illustrated by high-density urban areas, which can be more efficient to run in
260 terms of, say, energy distribution, communications and waste collection. However, these areas can also
261 be vulnerable to extreme events such as flooding because they are less diverse (with few green areas,
262 for example) and have few redundancies (in the form of back-up facilities and disaster-management
263 processes)"* (Elmqvist, 2017).

264
265 Resilience as the capacity of a system to adapt to disturbances thus appears better able to satisfy the
266 need to operationalize the sustainable city. Indeed, the normative basis of sustainable development,
267 particularly in the expression of the major global principles, "freezes" the ideal model to be achieved,
268 while its subjective character raises many debates as to the - moral - values to be pursued. Conversely,
269 resilience seeks to free itself from norms in favor of descriptive magnitudes and ensure a better reactivity
270 of the urban system in the face of the unexpected. *"Improving resilience increases the chances of
271 sustainable development in a changing environment where the future is unpredictable and surprise is*



272 *likely*." (Folke et al., 2002). Developing a sustainable territory and community cannot therefore be
273 envisaged without a long-term resilience strategy.

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277 The concept of resilience is a multifaceted concept, involving a plurality of disciplines, definitions,
278 notions and associated concepts. This diversity can be interpreted both as a source of opportunity but
279 also as a difficulty in the operationalization of resilience and its lack of integration into risk management
280 strategies. In the face of new risks linked to climate change, the evolution of urban areas and the
281 concentration of issues (part 1), the concept of urban resilience represents both an innovative and
282 essential concept but also full of operational limits both at the international and local levels (part 2).
283 This is why a variety of methods, concepts and strategies have been developed to address the issue of
284 operationalization and appropriation of the concept by local actors in order to respond to these limits of
285 application (part 3). We will conclude on the notable advances in these approaches to integrate the
286 concept of resilience by presenting the next steps needed to respond to the limits still present in the
287 scientific and operational field.

288

289 **2. Urban risks: over-urbanization, cascading effects and multi-risk approach**

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291 The current climate change context has led to an increase in natural disasters of about 2% per year
292 for the past 15 years (Catastrophes Naturelles-Observatoire permanent des catastrophes naturelles et des
293 risques naturels, 2016). At the same time, the increase in the number of people and goods in urban areas
294 is making it more fragile, considerably the cities. Today, nearly three out of five cities, with 500,000
295 inhabitants, are at risk. However, urban areas produce between 70 and 80% of the world economy and
296 are home to 55% of the world's population, with an increasing urban-rural drift expected to raise this
297 value up to 68% by 2050 (UNDESA, 2019; Zevenbergen et al., 2010). Such a concentration of stakes
298 increases the impact of disasters and raises questions on the future of cities.

299 *2.1. Over-urbanization*

300 In 2008, half of the world's population lived in urban areas. This concentration is likely to accelerate.
301 Projections show that urbanization, combined with overall world population growth, could add an
302 additional 2.5 billion people to urban areas by 2050 (United Nations, 2018). The unplanned expansion
303 of urban areas to face to this rapid growth, combined with inappropriate land-use planning, a
304 geographical location at risk (river mouth, swampy areas, major river bed, etc.) and difficult regulation
305 of building standards, contributes to the over-vulnerability of urban territories and populations. Urban
306 areas in coastal regions are particularly exposed to sea level rise. Low-lying coastal areas - less than 10
307 metres above sea level - account for just 2% of the world's land but are home to 13% of the world's
308 urban population. In 2007, Africa had 37 cities with more than 1 million inhabitants, half of which are
309 located - at least in part - in the low-lying coastal zone.

310 However, this tendency to focus on a specific area can be observed on a global scale: cities occupy
311 only 1% of the world's territory (Angel et al., 2018). Developed countries have therefore never
312 concentrated more value added per km² than they do at present. This concentration of population on
313 such a small portion of the territory has increased spatial and social vulnerability through the exposure
314 of the issues. Indeed, it seems logical to consider that the more a population and its issues are
315 concentrated in a small area, the greater the damage will be. Flooding in an uninhabited area will not be
316 considered and apprehended in the same way as in a metropolis (Mitchell, 1999).

317 The example of storm Xynthia in France in 2010 is an example of the effects of over-urbanization
318 on the reality of the disaster. This storm is one of the deadliest disasters in France with 59 deaths. The
319 marine submersion, which reached 1.53 meters in La Rochelle, affected some communes up to 85% of
320 their surface area (Duvat, 2011). The magnitude of the disaster was due in particular to demographic



321 change and rapid urbanization in the area. Thus, between 1946 and 2007, urbanization in the lower areas
322 doubled or even tripled in some communes, leading to significant vulnerability. Indeed, the decline in
323 agricultural activities has had several effects, including the disappearance of risk culture and the over-
324 urbanization of land. Real estate developers and investors have seized land to build, on marshes or dunes,
325 subdivisions, which are vulnerable to the risk of flooding (Duvat, 2011). Some of these lands ended up
326 under a metre of water when the storm passed, trapping the inhabitants in buildings unsuited to the
327 hazards. The second factor of vulnerability is the progressive replacement of populations of farmers and
328 sailors by urban dwellers, tourists and pensioners. These populations live from discontinuously on the
329 territory and therefore lose the knowledge of the natural functioning of the territory, leading to a
330 vulnerability of the populations. Xynthia was thus such a dramatic event because of "*the modes of*
331 *occupation of space (which) gradually neglected the hazards of submersion and flooding*" (Duvat,
332 2011). It is therefore no longer only natural disasters that impact cities but urbanization that leads to
333 over-vulnerability, leading to a melting pot of opportunities for risk amplification (Mitchell, 1999).
334 Concentration is thus perceived as an aggravating factor in risk management. This concentration is
335 expressed by the density of population present in a given territory. It is established that the denser the
336 area, the more vulnerable it is, the greater the potential for loss. It is therefore established that in urban
337 areas, natural hazards tend to have more serious consequences (Mitchell, 1999).

338 Three risks have a particular impact on urban areas (CRED and UNISDR, 2018).

- 339
- 340 • The earthquake is the most dreadful hazard, as it is responsible for the largest number of victims
341 worldwide, averaging 130,000 a year (Sigma, Swiss Re., 2011). However, the number of
342 victims depends very largely on the nature of the buildings and the nature of the preventive
343 measures. At the same magnitude, the disaster in Port-au-Prince claimed 222,000 victims, but
344 only 500 in Santiago de Chile. As for material damage, given the very unequal insurance
345 coverage, the official estimate is reduced to \$10 billion in Haiti, but \$30 billion in Chile. In
346 addition to its direct destructive effects, the earthquake can trigger either fires by breaking
347 energy networks, such as the one that ravaged Tokyo in 1923, or tsunamis.
 - 348 • Flooding is also a major risk for large agglomerations that are located either in estuaries, on the
349 coast, in alluvial valleys or on slopes that have become unstable. Urban sprawl is often the most
350 vulnerable, due to poorly regulated urbanization, especially in areas where water is stagnant,
351 such as in Buenos Aires, Dhaka, Phnom Penh or New Orleans. It can also involve mudslides or
352 landslides on urbanized slopes such as the favelas of Rio de Janeiro. The urban dimension also
353 determines the extent of soil waterproofing, and therefore the extent of runoff. In addition to
354 these direct damages, there are also those related to the disorganization of services or the
355 degradation of equipment and industrial installations that are specific to any large urban area.
356 Climate change includes a new risk, that of the gradual rise in sea levels. As a consequence of
357 probable climate change, it threatens many of the world's port cities such as London, the Dutch
358 delta with Rotterdam/Amsterdam, but also Tokyo or New York.
 - 359 • Wildfires, which can occur in periods of drought and heat waves, can cause immeasurable
360 damage, as in Australia in 2019, resulting in the destruction of 3500 homes, 5852 outbuildings,
361 34 direct deaths and 417 by excess from smoke inhalation (Borchers Arriagada et al., 2020). In
362 Europe, forest fires in Greece in 2007 and in Portugal 2017 claimed 80 and more than 100 lives,
363 respectively. In 2018, 99 lives were lost in Greece, 2,500 people were evacuated in Portugal and
364 Spain, 50 people evacuated in UK, while Sweden had to face the most serious series of forest
365 fires in its modern history, although with no fatalities.

366

367 The over-vulnerability of these urban areas in the face of natural risks also leads to the emergence
368 of "urban" risks.



369 *2.2. Fragile urban spaces confronted with cascading effects*

370 Urban space is made up of several infrastructures, some more essential than others. Called Critical
371 Infrastructures (CI), these infrastructures concentrate all the functions (Pescaroli and Kelman, 2017)
372 necessary for the proper functioning of a community. The term critical infrastructure only appeared in
373 the United States in the 1990s following a succession of disasters, including the first attack on the World
374 Trade Center (1993), followed by that of Oklahoma City (1995) and the gas attack in the Tokyo subway
375 (1995). These infrastructures were then defined as vital to the point that "*their incapacity or destruction*
376 *would significantly weaken (US) defense or economic security*". Critical infrastructure is defined as
377 telecommunications, power generation systems, oil and gas storage and transportation systems, banking
378 and finance, passenger transportation, water supply and distribution, emergency services (medical,
379 police, fire), and those that ensure the continuity of government (Fekete et al., 2015). They are termed
380 "critical" because their potential destruction could weaken the entire defense and economic organization
381 (Serre and Heinzlef, 2018) of a country or city. Critical infrastructure can be natural; water supply, flood
382 water storage; or physical; energy networks, telecommunication networks, emergency services,
383 transport networks; or virtual systems such as cyber-information systems. However, these CIs interact
384 with each other and thus create interdependencies (Serre, 2018) within the urban space. These
385 interdependencies then play the role of a risk diffusion factor. According to the concept of the cascading
386 effect (Bach et al., 2013; Nones and Pescaroli, 2016; Pescaroli and Nones, 2016; Serre and Heinzlef,
387 2018) i.e. a chain reaction causing changes in a territory some areas come to be impacted by the disaster,
388 even if they were not located in the same area. directly in the flood hazard extension zone. As urban
389 areas are interconnected, infrastructure failure will impact the territories across geographic and
390 functional boundaries (Boin and McConnell, 2007). Because these components are connected at
391 multiple scales, CIs can have an impact on much larger territory than their first impact territory. For
392 example, floods can have an impact on a specific area, such as a road, but as the interconnected, the risk
393 will spread to other territories that should not have been interconnected. naturally be flooded (Lhomme
394 et al., 2013) by compromising power grids, supply of vital resources, etc. (Nones and Pescaroli, 2016).
395 Therefore, some damages are not caused by direct physical damage, but by through business
396 interruption. A distinction is made between direct and indirect impacts. The direct impacts are the
397 tangible impacts and refer to the damage of the elements. physical (furniture, buildings, stocks,
398 equipment, etc.). Indirect impacts occur when they are not caused by the disaster itself. Indirect impacts
399 can be related to interruption or damage to critical infrastructure service. These may occur outside the
400 area directly affected by the disaster and extend into the time after the shock (OECD, 2014).

401 *2.3. The contribution of urban networks to the spread of risks*

402 The role of urban networks is a good example for understanding and measuring what a CI failure
403 can lead to. Urban networks are an essential part of the urban system. In an interconnected world, urban
404 networks connect more and more people and territories and offer a wide variety of resources and
405 opportunities. However, they also create complex situations of interdependence. Public transport,
406 electricity, gas, telephone, heating, waste, etc. make the management of the urban system more complex.
407 While they are essential for creating dynamics, relationships, and opportunities, they also create
408 complex situations of interdependence. In addition to being a key component of the economy, these
409 networks are also extremely vulnerable in the event of a crisis. Because of their interconnectivity, all
410 urban operations depend on them. A single failure can have cascading effects affecting the entire
411 network and, due to a reticular urban system, the whole city. Some examples illustrate these effects:

- 412 • Hurricane Katrina (2005) highlights the devastating effects of CI failure and related domino
413 effects (Pescaroli and Kelman, 2017). The hurricane in August resulted in the breaching of
414 protective dykes causing the destruction of 300,000 homes and 1,833 deaths (Knabb et al.,
415 2005). The disaster was exacerbated by the domino effects that followed the destruction of the
416 dikes, which made relief operations more complex. Transportation such as highways and



417 bridges were affected, reducing the ability to deliver vital resources - such as water, food and
418 medical supplies. Medical facilities were, for the most part, damaged or destroyed. All of these
419 effects have made the territory and its inhabitants more fragile, making it more difficult for CIs
420 to be brought back into service, but also for social and spatial functioning to function properly.

- 421 • The aftermath of Hurricane Sandy in New York City in 2012 is a good example of these extreme
422 vulnerabilities aggravated by IC failures. Hurricane Sandy is one of the largest hurricanes ever
423 recorded in the Atlantic (Mitigation Assessment Team Report, 2013). New York University's
424 Langone Medical Center was evacuated after the generators failed due to flooding, causing the
425 transfer of 200 patients (Mitigation Assessment Team Report, 2013). The destruction of power
426 grids left 21.3 million people without electricity, and the blackout caused fires that destroyed
427 111 homes and damaged 20 others (Kunz et al., 2013). Daily life was severely disrupted by the
428 interruption of the metro, the breakdown of the heating network, security systems and
429 telecommunication services. In addition, alternative solutions such as emergency generators
430 could not be operated, as refineries were insufficient in number and unable to provide the
431 necessary fuel. While direct damage was estimated at 32.8 billion in repairs and restoration,
432 indirect losses cost the city and its citizens much more. The unpreparedness of managers and
433 citizens has considerably increased the impacts of the crisis. For example, the late evacuation
434 order and misinformation have resulted in the impossibility of evacuating certain institutions.
435 In addition, the crisis has put the vulnerability of sewer systems, poor anticipation of sewer
436 system failures, and the lack of network, the absence of a plan B for access to generators and
437 relay antennas, and the installation of the resistant flood barriers (Le Haut Comité Français pour
438 la Défense Civile, 2013) . In this case, the over-connected territory and society have created
439 new risks and made crisis and post-crisis management more difficult and complex

440

441 Societies and territories are therefore deeply vulnerable to potential functional disruptions due
442 to a crisis (Boin and McConnell, 2007). If the hazard persists (earthquake, flood, hurricane, etc.), it
443 is transformed by "*nature-society hybridization*" (Reghezza-Zitt et al., 2012), i.e. by the actions and
444 practices of humans in their environment. Thus, while natural hazards are not new, their impacts are
445 evolving due to climate change, urban growth and urban structural changes.

446 2.4. *The integration of the concept of multi-risk in the management of urban areas*

447 Due to the interconnection of territories and the emergence of cascading risks, risk management
448 must evolve from a single-risk to a multi-risk approach (Kappes et al., 2012) in order to understand the
449 diversity and consequences of interactions and interconnections. Whether due to a combination of
450 several natural risks, "*about 3.8 million km² and 790 million people in the world are relatively highly*
451 *exposed to at least two hazards, while about 0.5 million km² and 105 million people to three or more*
452 *hazards*" (Gallina et al., 2016) or as a result of cascading effects following a specific risk, or of man-
453 made disasters, territories and populations are exposed to a multitude of risks, forcing stakeholders to
454 innovate in traditional risk management. Furthermore, the climate change context increases the
455 likelihood of multi-risk exposure (Dilley et al., 2005; Komendantova et al., 2014). For instance, the
456 positioning of inter-tropical islands exposes them to a combination of risks such as storms, cyclones and
457 coastal erosion associated with the gradual rise of the oceans. If only one of these risks were analyzed
458 in a disconnected way from the others, the risk analysis, strategies and management established would
459 not be adequate and realistic to prepare these territories and their populations (Rosendahl Appelquist
460 and Balström, 2014).

461

462 Risk management must therefore focus on integrated management in order to address the multitude
463 of interconnected risks. This comprehensive approach will allow considering their short- and long-term



464 impacts, which can have cascading effects, and to innovate in solutions adapted to an interconnected
465 world (Garcia-Aristizabal et al., 2012). Multi-risk assessments and all-hazards approaches need to be
466 strengthened, overcoming the limitation of single-hazards assessments in defining suitable and cost-
467 effective resilience measures in regions potentially affected by multiple sources of natural hazards. From
468 an operational perspective, multi-risk and multi-level (vertical/horizontal) governance frameworks
469 shifting from a single (siloe) risk focus to embracing a multi-risk approach when working with
470 technical and political authorities should be co-developed and co-evaluated.

471

472

473 The context of over-urbanization has led to a situation of vulnerability of urban spaces to risks. At
474 present, half of all people live in urban areas, a rate that is expected to reach 70% by 2050. This
475 concentration of people and goods weakens territories in the face of the growing increase in urban risks.
476 Because of the inter-connected world, the interdependence between the different urban systems (virtual
477 and/or physical), accentuates the dependence and vulnerability of populations and spatial functioning.
478 Some infrastructures, essential to the proper functioning of the territory, are more targeted. Faced with
479 the potential disruption of one of these critical infrastructures, a chain reaction can occur and have a
480 lasting impact on territories that cross administrative borders. The city needs to be analyzed as “*a system*
481 *of systems, with each of those systems (e.g. communications, water, sanitation, energy, healthcare,*
482 *welfare, law and order, education, businesses, social and neighborhood systems) potentially having*
483 *separate owners and stakeholders*” (UNISDR, 2017). The collaborative process underlying an
484 assessment of systemic vulnerabilities emerging from such an interpretation lays the foundations for
485 expanding the risk assessment framework towards wider objectives linked to the resilience of urban
486 systems in a multi-risk perspective (UN-Habitat, 2017). In the face of these growing uncertainties, risk
487 management must evolve and provide local managers and decision-makers with the keys to solutions.
488 New concepts are therefore gradually being integrated into risk management in order to help territories
489 and populations adapt to climate change, growing risks and related uncertainties.

490

491 3. Urban resilience: advances and limits

492 Faced with these growing challenges related to risks in urban areas, risk management has therefore
493 evolved by adapting the concept of resilience to the analysis of risks in urban environments.

494 3.1. Urban resilience

495

496 Urban resilience can therefore be defined as the concept that studies urban systems, i.e. the
497 interactions between the different components that participate in the creation of the territory. Urban
498 resilience refers to a systemic approach that encompasses the multiple layers (built, social, political,
499 etc.) and structures that produce an integrated vision of the urban object. Urban resilience would
500 therefore be a tool for analyzing the complexity of the urban system and defining the different capacities
501 and capabilities of each element that defines this system in order to live and survive a disruptive event.
502 The ability to define what is meant by resilience is an essential prerequisite for reducing the
503 consequences of a disaster. Determining what is “at risk” in a specific area is an essential step in this
504 regard. But when we talk about urban resilience, aren't all elements are essential? Most research on
505 operationalizing resilience focuses on a technical-functional approach (Table 1). As a result, it is mostly
506 the technical and material elements, such as urban networks, that are analyzed in these studies (Gonzva
507 and Barroca, 2017; Lhomme et al., 2013; Serre, 2018, 2016). However, an urban system is made up of
508 multiple components that are constantly interacting. There is no conceptual and theoretical consensus
509 in the scientific and policy community (Table 1) on the definition and objectives of urban resilience,
510 which reinforces the lack of clarity in establishing resilient risk management strategies.

511



Sources	Systems	Definitions
OECD	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	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	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	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



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
UNISDR	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
100RC	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	Hybrid approach	City resilience is based on the efficiency of hybrid networks composed by citizens and urban infrastructures.
Heinzlef et al., 2020	Hybrid approach	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.).

512

Table 1: Comparison between different system of study to analyze urban resilience

513

3.2. A complex urban system...

514

515

One of the reasons for this lack of clarity is the complexity of current urban systems. The city is a complex object to define, describe and analyze. The urban components are and the models are struggling to analyze the urban system. Urban growth accompanied by urban, social, technical, political and economic changes are leading to a fragmentation of urban space. This fragmentation and increasing complexity does not and shared knowledge of urban space, which is a prerequisite for a global and shared vision and knowledge of the urban space. complicates risk management.

521

Since the 1970s, systems thinking has emerged to address complex systems. The difficulty of defining the city as an object emphasizes complexity and therefore suggests that we can consider the city as a system. A system can be defined as a set of elements and interactions between elements that form an organized whole, with the internal organization of the system constituting its structure and the behavior of the interacting elements defining its dynamics. Each system is defined according to a purpose and an objective.

527

This urban system (Bretagnolle et al., 2006) is defined by the interdependencies existing between the various components of the city, due to the multiple networks of relationships they have with each other. The systemic approach aims to observe, interpret and reconstruct the real world by putting forward hypotheses on the organization of cities (Paulet, 2009). The analysis of a system is therefore a construct and presupposes choices among the different variables of the system. The study of a city today therefore implies understanding and considering the interdependencies between cities and their components, and analyzing their connections.

534

The city thus first of all creates interweaving urban components, such as technical systems (such as urban networks and/or critical infrastructures) or public infrastructures (governance, education, health, police, justice, etc.) (Lhomme et al., 2013), but it also creates interrelationships with its environment, due to its open system characteristic. As an open system, it both transforms itself through intrinsic capacities but also receives resources through flows and information from their environment. Since it is not self-sufficient, the relationships between cities and countryside, between cities and towns, are essential and must be analyzed in the global study of an urban system. These interactions can therefore be considered as a source of wealth, more (food) resources, knowledge, techniques, but also a source of fragility (uncertainties, overproduction of waste, new urban risks, social risks, etc.). This non-exhaustive list nonetheless allows us to understand the fragility of urban environments, because their sources of growth, expansion and wealth can, at its peak, also be synonymous with vulnerability.

545

The city is therefore a complex object to apprehend and study. Because of its construction protean, the city is difficult to define and identify as a single object. The evolutions are constant and

546



547 vary according to the social, urban and technical components, environmental, political, economic, etc.,
548 of the urban space. Focusing on the issues at stake challenged by risk, cities are also concentrating
549 resources to deal with it. This is so in these spaces that urban systemic resilience must be analyzed and
550 operationalized.

551

552 3.3. ... Including some limits

553

554 Despite its growing importance and use in expert and policy discourse, the concept of resilience
555 faces many limitations.

556

557 3.3.1.A conceptual vagueness

558

559 The concept of resilience faces a conceptual confrontation in the multitude of definitions and
560 associated notions. This concept is today over-used, over-solicited in multiple fields (psychology,
561 ecology, political science, physics, geography, etc.) and related to many concepts (Emrich and Tobin,
562 2018). This multitude of uses has turned it into a buzzword (Reghezza-Zitt et al., 2012), a word
563 "suitcase" (Rufat, 2015) that complicates its understanding. A resilient system is in turn defined as a
564 system capable of stability but also of adaptation and evolution (Hegger et al., 2016; Tempels and
565 Hartmann, 2014). We speak of both "bouncing back" to a (potentially anterior) equilibrium or "bouncing
566 forward" to a new state of balance and harmony. Faced with this ambiguity, or even contradiction,
567 among the objectives and guidelines of resilience, actors and experts come up against grey areas (Disse
568 et al., 2020). Beyond these two characteristics, Brand and Jax (2007) analyzed the studies, definitions
569 and methodologies addressing the concept of resilience over the past 35 years and pointed to the abstract
570 trend of resilience. According to them, resilience must therefore be perceived and understood as a
571 perspective (of planning, risk management, spatial and social development) rather than as a concept or
572 tool to be clearly and unanimously defined (Kim and Lim, 2016).

573

574 3.3.2.A political reappropriation

575

576 This conceptual vagueness has contributed to the political reappropriation (Béné et al., 2018)
577 of the concept of resilience without resulting in clear strategies adapted to local actors and territories at
578 risk (Bahadur and Tanner, 2014; Béné et al., 2012; Cannon and Müller-Mahn, 2010; Duit et al., 2010).
579 Many scientists and experts have denounced the tendency to overuse and abuse the term resilience.
580 Having become a political and management imperative, resilience has been transformed into a political
581 and crowd-unifying tool. Resilience can therefore be used more for political positioning or institutions
582 to strengthen their dominant governance model without necessarily leading to reflection on processes
583 of transformation or evolution that are generally necessary for the establishment of resilient systems
584 (Béné et al., 2018).

585

586 Beyond limitations related to the lack of consensus on the concept of resilience, there are also
587 limits to its implementation in risk management strategies.

588

589 3.3.3.Financial limitations

590

591 The cost of a resilient approach or accommodations is often pointed out. Whether it is spatial
592 redevelopment (reworking urban density, refuge areas, critical infrastructures, risk areas, etc.) or the
593 purchase of so-called resilient development tools (Heinzlef et al., 2020), local managers and actors are
594 faced with a mismatch between the cost of this approach and their daily priorities. The fact also that
595 climate change and the associated risks are a more or less distant threat and hardly imaginable threat,
596 makes decision-makers less focused on the necessary evolution of risk management strategies through
597 the integration of resilience into the planning process (Leichenko et al., 2015).

598



599 3.3.4. Cultural barriers

600

601 The local cultural dimension of risk management can also be seen as a barrier (Heinzlef et al.,
602 2020b) to the implementation of the concept of resilience (Heinzlef et al., 2019a). This socio-cultural
603 dimension can be expressed at several levels.

604 At the level of local actors (Amundsen et al., 2010; Dilling et al., 2015; Kettle and Dow, 2014;
605 Mozumder et al., 2011; Runhaar et al., 2012), it can be expressed through the culture of risk. The risk
606 culture can be associated with the historicity of disasters on a specific territory and therefore by the
607 succession of management strategies put in place to deal with them. Changing them can be complicated,
608 especially if it requires new human and financial investments.

609 At the individual level, this cultural resistance or lack of understanding is regularly linked to a
610 lack of awareness of the risks linked to climate change and a fear of changes in their habits and living
611 environment (Amundsen et al., 2010; Measham et al., 2011).

612

613 3.3.5. Technical limitations

614

615 When resilience becomes an operational object, it often requires technical management tools.
616 However, the general bias for operationalizing resilience involves its quantification and representation.
617 Simply put, the tool must be able to conclude whether or not the territory is resilient. Numerous studies
618 have provided answers to this issue. After establishing the need for urban technical networks in the
619 functioning of urban territories, concluding that these networks contribute to the resilience of urban
620 areas becomes obvious. A great deal of research has therefore analysed resilience through the resistance
621 of urban networks (Barroca and Serre, 2013; Gonzva et al., 2017; Gonzva and Barroca, 2017; Lhomme
622 et al., 2013; Serre, 2018). These approaches focus on the resilience of networks, critical infrastructures
623 and the built environment, but very few address the concept in a global and systemic way. This technical-
624 functional positioning leads to a narrow vision of the systemic spatial complexity. As a result, they only
625 partially transcribe the spatial reality of urban dynamics and interconnections.

626

627

628

629

630

631

632 Faced with the difficult consensus around the concept of resilience, its operationalization is regularly
633 questioned. The difficult formalization, linked to the multitude of interpretations and approaches, results
634 in a complex transition from theory to practice. However, this is the challenge posed by all studies on
635 resilience, in order to use this concept to build adequate risk management strategies. Several approaches
636 have therefore attempted to respond to these challenges by proposing methodologies that aim to
637 operationalize resilience. This operationalization translates into the design of tools for measuring
638 resilience, spatial decision support systems or approaches that promote collaboration between experts
639 and local stakeholders. In this section, we will analyze some of these works, frameworks, structures and
640 methodologies. Some authors have attempted to synthesize all existing models (Constas et al., 2010;
641 Schipper and Langston, 2015) but the forty or so models mentioned (Bahadur et al., 2015) underline the
642 (over)abundance of approaches to resilience. We will attempt to scan the approaches aimed at assessing
643 resilience through the creation of indicators, models proposing a conceptual framework or decision
644 support systems, and then methodologies aimed at creating collaborative work in order to operationalize
645 resilience.

646

647

648

649



650 4. Methods and tools for evaluation, modelling and integrating resilience into risk management

651

652 A large part of operationalization involves determining how a concept can be measured (Adger
653 et al., 2004) and determining which indicators will be used to measure the concept in order to
654 generate data about it. The assessment of resilience therefore essentially involves its measurement
655 (Heinzlef et al., 2020a) and the creation of indicators.

656

657 4.1. Assessing urban resilience

658

659 4.1.1. Taking advantages from indicator sets

660

661 Indicators are quantitative variables intended to represent a characteristic of a system or concept.
662 They have been used to inform decision making, improve stakeholder participation, build consensus,
663 explore underlying processes, etc. (Parris and Kates, 2003). The objective of an indicator is to provide
664 information that should help actor to steer the course of action towards the achievement of an objective
665 or to enable him to evaluate the result. The indicator can be a parameter, a value, a data or an observation.
666 Its objective is to give indications or describe a phenomenon, a situation, an environment or a process.
667 It is necessary to define a preliminary objective to which the indicators will tend. An indicator can be
668 composed of a single variable or a combination of variables (Birkmann, 2006).

669

670 Regardless of the word used, the indicator primarily defines the compelling relationship between
671 the information contained in the indicator and the object pointed to by the indicator (Birkmann, 2006).
672 The function of the indicator is therefore to show, to place in space, and it is this spatializing nature that
673 makes it interesting as a geographical tool (Freudenberg, 2003). If the indicator in the primary sense of
674 the term does not analyze or define, it takes on its full meaning through the observer's reading of it.
675 Because of its eminently operational nature, it enables observations and results to be anchored in
676 practical reality. It answers directly to the question asked by the user confirming or not the initial
677 hypothesis. The hypotheses and judgements made when choosing the questions and data relevant to the
678 development of the indicator, as well as the evaluation of the usefulness of the indicator, require the
679 existence of objectives, implicit or explicit. An indicator collects data and information in order to
680 aggregate knowledge, which is essential for making the right choices (Wisner and Walter, 2005). For
681 this reason, indicators are fully involved in the decision support process (Tate, 2012).

682

683 However, despite its operational nature, the indicator is only an experience of reality and not a
684 proper experiment. It is therefore necessary to bear in mind that it is a practical image of reality but that
685 it is not objectively the reality of the territory. The indicator merely reproduces or reconstructs an image
686 of the geographical space, which makes the choice of indicator, variables and treatments very subtle and
687 complex. However, this choice is itself built around representational a priori, a socio-cognitive paradigm
688 that cannot be denied. It is therefore necessary to make the construction of these variables and indicators
689 as objective as possible in order to claim that the results are real. There are several "formats" of
690 indicators. Multiple indicators, for example, can be combined with unstructured composite indicators,
691 or indices, which attempt to distil the complexity of an entire system into a single measure. Social
692 indicators have been used since the 1960s, with applications to the environment (1970s), sustainability
693 (1990s), and more recently vulnerability (Birkmann, 2006; King and Macgregor, 2000) and resilience
694 (Cutter et al., 2010). The main global indices and recent regional studies that model various aspects of
695 vulnerability include the vulnerability index, the Human Development (UNDP), the Disaster Risk Index
696 (UNDP 2004) or the Disaster Risk Index (UNDP 2004). the Environmental Sustainability Index. The
697 Social Vulnerability Index (Cutter et al., 2003) is the best known index for evaluation at the national
698 level, with applications in the United States, Canada and the United States (de Oliveira Mendes, 2009;
699 Finch et al., 2010; Holand et al., 2011).

698

699 4.1.2. Resilience indicator challenges

700

701 Measuring resilience has become an international priority in order to build strategies for the
702 future. risk management (Winderl, 2014). The question of how to measure resilience is as old and as
703 important as the concept itself (Prior and Hagmann, 2014). Numerous indices and indicators of resilience
704 have been developed in various disciplines. In general, they are used for different purposes and, as a



705 result, they measure different things. An exploration of attempts to measure resilience reveals the
706 difficulty in establishing a measure that is both accurate and "*fit for purpose*" (Hinkel, 2011).
707 Measurement requires that a phenomenon be observable and allow for systematic attribution of value,
708 but the conceptual nature of resilience makes this difficult. Scientists do not have not yet agreed on
709 specific conventions for measuring resilience and, consequently, there is a substantial literature that
710 discusses both how and whether the phenomenon can and should be measured (Hinkel, 2011).

711 The identification of resilience requires planners to identify variables that trigger disturbances
712 in a city (a community, region or landscape), the frequency and intensity of these events, and the
713 mechanisms that enhance adaptability that can be activated to respond to (or avoid) these disorders. It
714 is need to assess the socio-economic dimensions of an urban area (Ahern, 2011). As established
715 previously, it is necessary to establish common denominators that induce vulnerability or strengthen
716 resilience (Gonçalves, 2013) . However, the difficulty essential is to measure these dimensions. The
717 significant challenges in measuring the resilience lead either to imperfect quantified measurements or
718 to a search for indicators of universal resilience (Hallegatte and Engle, 2019). Cutter et al. (2008)
719 highlight this difficulty in believing that "*if we conceptually or sometimes intuitively understand the*
720 *vulnerability and resilience, the devil is always in the details, and in this case, the devil is measurement*"
721 (Cutter et al., 2008b).

722

723 4.1.3.Examples of resilience indicators

724

- 725 • The Baseline Resilience Indicators for Communities (BRIC) (Cutter et al., 2014)

726

727 Cutter et al. developed BRIC (Baseline Resilience Indicators for Communities), which aims to
728 define resilience indicators to map the level of resilience across the United States. Dividing
729 resilience into six indicators - social, economic, community, institutional, infrastructural and
730 environmental - Cutter proposes to measure resilience (Cutter et al., 2014). Each indicator is divided
731 into sub-variables such as education, age, language proficiency, employment rate, immigration rate,
732 access to food, disaster training, social stability, access to health, access to energy, etc. (Cutter et
733 al., 2014). Each variable has a positive or negative effect on community resilience. Data acquisition
734 was an important issue. More than 20 data sets were obtained from the U.S. federal government
735 through online data portals. Four datasets were obtained from NGO websites, two through a contact
736 with the American Red Cross, and one from an open access data portal at a major press briefing.
737 One data source was the Dun and Bradstreet's Million Dollar Database and required a paid
738 subscription to acquire the data (Cutter et al., 2014). Once the data acquisition was completed, a
739 processing work, "cleaning" of the data was necessary. The chosen method of treatment was applied
740 to the Min-Max. The Min-Max normalization assigns a value of 0 to the minimum value and from
741 1 to the maximum value. All other values are scaled to between zero and one by subtracting the
742 minimum value and dividing by the range (minimum subtracted from the maximum). While this
743 method makes it much easier to compare between a large number of variables, the disadvantage
744 remains that the final score is not a measure absolute value of community resilience for a single
745 location, but rather a relative value of community resilience for a single location. in which several
746 locations can be compared. This is why the proposed work is done at the US level and not at a finer
747 scale or for an single year, not being a comparative work over several years.

748 This approach is a key work in the process of operationalizing the concept of resilience. In
749 addition to the definition of resilience criteria, it also makes it possible to locate more or less finely
750 the territories on which to focus efforts to increase territorial and social resilience. Its systemic
751 approach to the territory (considering the elements that make up the territory) is completely adapted
752 to risk analysis.

753

- 754 • The DS3 Model (Spatial Decision Support System) (Serre, 2018)

755

756 The DS3 Model has defined three capabilities to assess the resilience of urban networks to flood risk.
757 Resilience is defined here as the ability of a system to absorb a disturbance and subsequently recover its
758 functions. Three capabilities are assumed to determine the degree of resilience of these networks:

759



- 760 ○ The capacity to resist: this consists of determining the material damage following a risk.
761 It is considered that the more a network is damaged, the more likely it is that there will
762 be a slower and more complex return to service;
763 ○ The absorption capacity: it illustrates the fragilities and strengths of the network
764 allowing to build alternatives to it following a component failure;
765 ○ Recovery capacity: this represents the time required to return to service of the network
766 and its components.
767

768 These capabilities enable the resilience of a city's urban technical networks to be defined and
769 measured. The methodology was tested to assess the resilience capacity of the Hamburg district, Am
770 Sandtorkai/Dalmannkai. Each resilience capacity was analyzed according to the components of the
771 neighborhood, at its scale and then according to the interactions with its environment. Using this
772 technical resilience measurement tool, the case study analysis identified interdependencies and potential
773 domino effects at the neighborhood level. The definition of these three capabilities made it possible to
774 analyze resilience over a long period of time, before, during and after a disturbance. The systemic
775 approach here is defined by the analysis of inter-network interactions and interconnections in order to
776 assess cascading risks in urban environments.
777

- 778 • An hybrid approach (Heinzlef et al., 2020a)
779

780 This research made it possible to develop three indicators for defining and measuring resilience in
781 order to gain a comprehensive and exhaustive understanding of the concept. These indicators analyze
782 the urban, social and technical resilience of a city (Heinzlef et al., 2019a).
783

- 784 ○ The social resilience indicator illustrates a population's ability to adapt and recover from
785 disruption (Hutter and Lorenz, 2018). Many factors contribute to social resilience,
786 including age (Cutter et al., 2010), community and political investment (Voss, 2008),
787 socioeconomic status (Flanagan et al., 2011), knowledge and perception of risk, etc.
788 (Hutter and Lorenz, 2018). This methodology understands social resilience as
789 community resilience (Wilson, 2013) and not individual resilience (Hutter and Lorenz,
790 2018).
791 ○ The urban resilience indicator includes all urban dynamics, such as physical elements
792 (Norris et al., 2008; Opach and Rød, 2013) (age of the building, urban density,
793 building functions, critical infrastructure, etc.) or more virtual elements such as
794 economic dynamics through the creation or suppression of businesses or touristic
795 dynamism (Tierney, 2014).
796 ○ The technical resilience indicator includes urban networks (Serre, 2016). It is used to
797 analyze the diversity and accessibility of these networks within a radius of 100m
798 in order to assess their resilience and their impact on the territory in the event of a crisis
799 (Heinzlef et al., 2020a).
800

801 This study has been tested and validated in Avignon (France), and built with 90% open data in order
802 to allow the reuse of this methodology on other national case studies. The systemic approach is
803 illustrated by taking into account the multitude of elements that make up the urban territory in order to
804 have a global vision and approach to the territory, its population and its potential resilience.
805

806 807 4.2. *Modelling resilience*

808 809 4.2.1. The usefulness of space-based decision-support systems

810
811 As the concept of resilience is a complex subject to address and operationalize for local actors,
812 many tools have been created to simplify, define, measure and attempt to operationalize this concept.
813 The need to create decision-support systems makes sense in terms of the abstraction of the concept.
814 In risk management, taking is a complex combination of knowledge management and decision-making



815 processes. reasoning (Tacnet et al., 2014). Decision-support systems are defined as integrated computer
816 systems, designed for decision making. When territorial issues are addressed, these are referred to as
817 spatial decision Support System (DSS). They combine spatial and non-spatial data, functions analysis
818 and visualization of Geographic Information Systems (GIS) and decisions in order to construct, evaluate
819 and produce solutions (Keenan and Jankowski, 2019). These space-based decision support systems have
820 been developed to address the limitations of the GIS such as lack of modeling capabilities and lack of
821 flexibility of GIS for adapt to variations in the context or spatial decision-making process (Densham,
822 1991).

823

824 4.2.2. The integration of geo-visualization techniques

825

826 Indeed, current tools such as GIS are often inadequate in the face of the complexity of the real
827 issues facing users (Andrienko et al., 2007). For individuals, the visual context favors the acquisition of
828 knowledge (Kwan and Lee, 2003). There are many forms of data visualization that are primarily
829 scientific and information visualization (Marzouki et al., 2017). If data have a combination of spatial,
830 semantic and temporal dimensions, they are referred to as geographic data/information and geo-spatial
831 data (Marzouki et al., 2017). The visualization of these data then becomes specific, and goes beyond
832 simple scientific and information visualization (Kurwakumire et al., 2019). The integration of
833 visualization in the analysis of geo-spatial data has led to a transformation of traditional mapping
834 through the digital era (Çöltekin et al., 2017). This evolution of traditional mapping has led to
835 geovisualization, a "*set of visualization methods and tools for interactively exploring, analyzing and*
836 *synthesizing location-based data for knowledge building*" (Dykes and International Cartographic
837 Association, 2007). Geovisualization combines scientific visualization, information visualization,
838 mapping, geographic information systems (GIS), exploratory data analysis and many other methods to
839 explore, analyze, synthesize and represent geographic data and information (Nöllenburg, 2007). As a
840 result, many spatial decision support systems have been equipped with visualization techniques and
841 dynamic interfaces to combine technological capabilities with local interpretations and knowledge. Map
842 production is accessible and understandable through a visual interface to enable exploration,
843 understanding, analysis and reuse of a complex, geolocalized and heterogeneous database.

844 Thanks to a dynamic interface and a technical power capable of processing complex data,
845 geovisualization tools allow to communicate information about complex data necessary for the decision
846 support process. In addition, the interactivity of these tools allows the users to be actors in front of the
847 tool, by navigating, by making a visualization request, by downloading data or displaying information
848 as needed. The tools of are therefore both communication tools and tools for the production of
849 geovisualisation knowledge by being an integral part of the "*reflection/knowledge process*".
850 (MacEachren et al., 2004). As Bishop et al.(2013) point out, neuroscience has been a major contributor
851 to the development of the human brain. and has already demonstrated that visualization techniques are
852 essential to cognitive processes. leading to decision making (Padilla et al., 2018). Geovisualization thus
853 integral part of spatial decision support systems, as it allows to meet both scientific and societal needs
854 to initiate a process of reflection and thereby build and produce knowledge.

855

856 Several methodologies have produced tools to clarify the concepts of resilience and
857 vulnerability. These tools are spatial decision support systems and have made it possible to dissect the
858 concept of resilience. The objective of each of these approaches is to make the concept accessible by
859 creating links between scientific advances and territorial reality.

860

861 4.2.3. Examples of spatial decision support systems

862

- 863 • The DOMINO tool (Robert et al., 2008)

864

865 A tool for modelling the spatial and temporal propagation of domino effects between critical
866 infrastructures (CI) has been developed for the city of Montreal. It consists of a geographic database in
867 which organizations have entered relevant information about their dependencies on the critical resources
868 they use. Modules, created on the structure of the expert systems, combine information from different
869 organizations in order to identify interdependencies between them. A time simulator has also been



870 developed to visualize the propagation of potential domino effects following a failure. Being a geomatics
871 tool, it is possible to combine several layers of information in DOMINO. The partners' managers
872 (CI managers and emergency preparedness officials) have secure access to it, managed according to
873 levels corresponding to their user profile. Thus, each organization has access to its information, while
874 the results of the simulations are available to all the users. In terms of resilience, DOMINO allows
875 analyses on the different parameters of the resilience. Its establishment on a territory requires the various
876 organizations concerned to exchange information on their own disruption management capability. The
877 implementation of this information enables consistency analyses to be carried out on a given territory
878 and integrate broader community implications. The systemic dimension of this tool lies in the fact that
879 it analyses the interdependencies of critical infrastructures in an urban space and models potential
880 service disruptions.

- 881
- 882 • The ViewExposed tool (Opach and Rød, 2013)
- 883

884 A Norwegian study addressed the issue of vulnerability of territories s response to climate change
885 (Opach and Rød, 2013). In order to avoid an increase of local and national vulnerability, the researchers
886 have developed a ViewExposed tool, including the aim is to inform local authorities about the most
887 vulnerable areas of the territory Norway and also the causes of this vulnerability. The methodology used
888 is based on the work of SoVi (Cutter et al., 2003) and the University of South Carolina (Tate, 2012).
889 Several steps were necessary to create this tool:

- 890 ○ Creation of vulnerability indices for storms (StoVI), floods (FloVI) and landslides
891 (SliVi)
- 892 ○ Work on data and indices to create a compiled physical vulnerability index (PhyVI)
- 893 ○ Assessing Norway's social vulnerability and creating a Social Vulnerability Index
894 (SoVI)
- 895 ○ Compilation of the Physical and Social Vulnerability Indicator to create an Integrated
896 Vulnerability Index (IntVi)
- 897

898 The objective of IntVi is to focus on a municipality's exposure to natural hazards and to put it into
899 perspective with regard to the local population's capacity to resist them. For PhyVI, the exposure of
900 municipalities to natural risks is expressed as a percentage and depends on the work of Norwegian
901 insurers (Norwegian Natural Perils Pool). Based on the data, the researchers were able to determine that
902 during the period 1980-2010, 60% of the damage was caused by storms, 26% by floods, 7% by
903 landslides and 5% by storm surges (Opach and Rød, 2013). Concerning SoVI, the objective was to
904 assess the adaptive capacity of municipalities with regard to physical exposure. Thus, in the next step,
905 the SoVI was calculated using the methodological framework constructed for Norway by (Holand et al.,
906 2011). Finally, PhyVI and SoVI were compiled to create IntVI. To do so, the weights most correlated
907 with the Norwegian Natural Perils Pool claims data were used: 60% for PhyVI and 40% for SoVI. The
908 tool, which takes the form of an interface, has been created for professionals, local elected officials and
909 residents. It is the product of a collaboration between scientists and local experts through workshops
910 (Opach and Rød, 2013). The authors of the interface wished to answer two fundamental questions: Who
911 are the vulnerable people? And where do they live? The objective is therefore to identify regions with a
912 high level of social vulnerability to environmental risks in order to reduce it and thus help to improve
913 their resilience. In addition, the platform is open and scalable as any actor in the field can submit a
914 reflection using the "submit a comment" section of the interface. Although focused on the concept of
915 vulnerability, this tool also integrates the response of local managers and actors to natural disasters. It is
916 therefore both the vulnerabilities but also the resilience strategies that are integrated. In addition, this
917 tool proposes a collaborative and participatory approach between local actors and scientific experts.

918

919

920 *4.3. Integrating resilience into urban management through collaborative approaches*

921

922 The United Nations International Strategy for Disaster Risk Reduction (UNISDR) has developed
923 10 key points for creating resilient cities. The first point is to set up organizations or coordinations to
924 understand and reduce risks, based on the participation of citizens and civil societies (UNISDR, 2015).



925 The objective is to build local actions and alliances to ensure that each actor understands his or her role
926 in reducing and preparing risk reduction and resilience strategies (Heinzlef et al., 2020b; Gupta et al.,
927 2010).

928

929 4.3.1. Collaborative approaches, a key for operationalizing resilience

930

931 Involving "local" people or people directly concerned by the issues studied does not appear to be
932 new (Toubin et al., 2015) and even less original. The richness of having people from all walks of life
933 interact with each other facilitates an exploration of possibilities, enriching discussions, encouraging
934 cross-fertilization of views on the same subject, making it possible to be both more measured and more
935 incisive in a specific area. The contribution of "profane" knowledge in thorny social and societal issues,
936 as scientific knowledge cannot respond to all uncertainties, with the result that "expert" conclusions are
937 called into question. Resilience, a social and thorny concept, is therefore a subject that would require
938 the confrontation of views, knowledge, scientific and practical knowledge, perceptions and
939 interpretations. However, although the population is often the first to be impacted by natural hazards
940 and their inappropriate management, the fact remains that the inhabitants (Kuhlicke et al., 2011) and
941 also the urban services (Toubin et al., 2015), which are nonetheless first-rate actors, are not sufficiently
942 involved. The defended idea is that the creation of a hybrid knowledge (Djenontin and Meadow, 2018;
943 Lemos and Morehouse, 2005; Schneider and Rist, 2014) allowing the involvement of all actors of the
944 territory, from the inhabitant to the manager via the scientist, would make it possible to operationalize
945 urban resilience thanks to an appropriation of the concept and stakes of urban risks. In fact, collaboration
946 is mainly based on the appropriation of the different stakeholders of the same subject of tension and
947 discussion. Collaboration therefore goes beyond the simple exchange of knowledge and information,
948 but makes it possible to *"create a shared vision and articulated strategies for the emergence of common
949 interests that extend beyond the limitations of each particular project"* (Chrislip, 2002).

950

951 4.3.2. Examples of collaborative approaches

952

- 953 • Improving Urban Resilience through Collaborative Diagnosis (Toubin et al., 2015)

954

955 In her thesis, Marie Toubin develops a methodology to contribute to the improvement of conditions
956 of urban resilience and more particularly the resilience of urban networks. Her analysis of the
957 interactions and interdependencies of urban networks highlighted the intrinsic fragilities of urban
958 systems and their management in the event of a crisis. Faced with the challenges observed, the research
959 objective was therefore to develop methodological approaches and tools to help urban service managers
960 identify and characterize technical and organizational interdependencies in order to ensure service
961 continuity despite a disruption. The approach was built by integrating the main managers of the City of
962 Paris' urban services. The methodology made it possible to construct interviews to assess the criticality
963 of the resources required for the system to function properly. It was therefore possible to rank the
964 resources according to their importance and use. This research made it possible to draw up and analyze
965 the interdependencies of the Parisian urban networks. It highlights certain dependencies, particularly
966 those on electricity, telecommunications and travel. The collaborative approach made it possible to
967 involve managers in thinking about strategies to mitigate or at least manage these interdependencies.
968 Moreover, the collaborative process has illustrated the need to move beyond isolated approaches but
969 instead to foster a common vision. The interweaving of scales but also of services makes cooperation
970 and transparency between operators and decision-makers indispensable for the construction of a more
971 resilient city.

- 972 • Resilience by design in Mexico City: A participatory human-hydrologic systems approach
973 (Freeman et al., 2020)

974 The study developed by Freeman et al. (2020) in Mexico City highlights issues of building a
975 freshwater resilience of urban systems among several territories and stakeholders. In order to find a way
976 to manage systems of feedbacks and tradeoffs between stakeholders, Freeman et al. have developed a
977 Resilience by Design methodology (Brown et al., 2020). The aim of this methodology is to identify with



978 local stakeholders, resilience of what, to what; for whom and what can be done? Face to a complex
 979 issue, this methodology provides a planning and common framework to identify solutions and
 980 compromises between urban managers, political stakeholders and decision-makers. In this case study,
 981 Resilience by Design methodology revealed “*consistent stakeholder preferences for social (such as*
 982 *equity in water allocation among users) and economic performance*”, such as domestic, agricultural and
 983 industrial sectors. These common solutions guide to persistence, adaptation and transformations.
 984 Understandings and choices about how much “resilience of what, to what, for whom and at what cost”
 985 require a shared narrow and adaptive approach (Freeman et al., 2020). Thinking jointly about issues and
 986 related solutions helps to establish an understanding of the concept of resilience and established
 987 strategies over time. Actors must therefore debate and envisage solutions in an egalitarian and united
 988 manner in an evolving territory in order to tend to increase its resilience.

989
 990

991 Several methodologies exist in order to operationalize resilience concepts and integrate it into urban
 992 risks strategies. The main approaches are divided into three categories: (1) assessing resilience through
 993 its measure with indicators, (2) modeling resilience with geovisualization techniques and (3) developing
 994 collaborative approaches in order to lead to resilience understanding and adoption by stakeholders.

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

999 Geovisualization techniques are used to unbuild resilience abstraction thanks to tools, interfaces and
 1000 data which allow comprehension and facilitate resilience integration. Interactivity, communication,
 1001 navigation, visualization lead to a precise resilience analyze. These tools are essential for knowledge
 1002 construction and sharing and are part of the “reflection/knowledge process”.

1003 Finally, collaborative approaches lead to local stakeholders’ responsibilities to integrate resilience
 1004 into risk strategies management. It is useful to create a shared vision on complex concepts and strategies
 1005 between “experts” and “local actors”. Their proper experiences (local risk management heritage and
 1006 scientific knowledge) lead to a territorialized risk and resilience strategies. It is also a long-term
 1007 guarantee to resilience strategies adoption.

1008

1009 5. Discussion

1010

1011 The multitude of existing models for operationalizing resilience indicates the growing importance
 1012 of the concept. These models, as diverse and varied as they may be, are essential to the transcription of
 1013 the concept into a concept tool (Gonzva and Barroca, 2017). Going beyond the controversy over the
 1014 exact definition of the concept, these models propose to operationalize resilience. The accuracy of their
 1015 methodology then takes a back seat because what matters then is not that the model be rigorous, but that
 1016 it be operational. However, not everyone has the same objective or goal (Table 2).

1017

Names	Category	Approach	Systemic Approach	Intended Audience	Effective Appropriation
BRIC (1)	Indicators	Global approach	Yes	Decision-makers and urban managers	++
DS3 Model (2)	Indicators	Technico-functional approach	Yes	Critical infrastructure managers and urban managers	+
Hybrid Approach	Indicators	Global approach	Yes	Decision makers, urban	+++



(Avignon case study) (3)				managers and citizens	
DOMINO (4)	Spatial decision support system	Technico-functional approach	Yes	Critical infrastructure managers	++
ViewExposed (5)	Spatial decision support system	Global approach	No	Decision makers, urban managers, insurances and citizens	++
Toubin et al., 2015 (Paris case study) (6)	Collaborative approach	Global approach	Yes	Critical infrastructure managers and urban managers	+++
Freeman et al., 2020 (Mexico case study) (7)	Collaborative approach	Global approach	Yes	Critical infrastructure managers and urban managers	+

1018

- (1) Cutter et al., 2014
 (2) Serre, 2018
 (3) Heinzle et al., 2020
 (4) Robert et al., 2008

- (5) Opach and Rod, 2013
 (6) Toubin et al., 2015
 (7) Freeman et al., 2020

Table 2: Models' categories

The diversity of these models illustrates the interest and efforts developed to respond to the challenges of operationalizing the concept of resilience. While some apprehend urban resilience through the analysis of networks and through a technical-functional approach, others seek to develop hybrid, more exhaustive approaches that attempt to understand and analyze the diversity of the urban territory. The decision support approach also differs from one tool to another, with some advocating the usefulness of indicators, others justifying the need for visualization to lead to a process of understanding and decision making, and finally, some defending the need to integrate local actors at the beginning of any reflection on the concept of resilience. These models are neither exhaustive nor exclusive and it is necessary to use them jointly or at different times and phases in the construction of a resilience strategy. However, this multitude does not promote the understanding and appropriation of a concept that is still abstract for many local actors and managers. Whether it is due to the overly technical nature of the tools (such as for the DS3 Model), a lack of understanding of the concept or even a lack of knowledge of the tools themselves, local stakeholders have very little appropriation of the operationalization methodologies and therefore the concept of resilience.

A tool to define, measure, clarify and assist in decision-making would therefore be of significant interest. The objective of a new tool can be used as a basis for reflection and suggestions for further progressive implementation of the concept of resilience in risk management strategies. This prototype would be to promote an inclusive approach that would make it possible to bring together the different existing approaches around the concept of resilience and to develop a framework for reflection and action between local actors and scientific experts around the issue of operationalizing the concept. This type of tool could be achieved through the design of a resilience observatory. Observatories are key tools to support the observation, reflection, understanding and analysis of phenomena or territories. These tools, which are at the interface of reality and knowledge, are essential in the decision-making process, allowing the acquisition of knowledge and data while taking the necessary distance to have the most global vision possible of a phenomenon. Their usefulness in establishing monitoring of phenomena, territorial evolution and interaction, make them essential tools for apprehending events over



the long term, which is essential for establishing resilience strategies. A team based at the Oceanic Island Ecosystems joint research unit (UMR EIO) of the University of French Polynesia (Heinzlef et al., 2020, 2019b; Serre et al., 2019) has launched a prototype observatory on the islands of Tahiti and Moorea to analyze, measure and operationalize resilience. The objectives are multiple (Fig.1) and focus in particular on increasing knowledge of territorial risks, the acquisition, storage and enhancement of data related to risks and resilience and finally the integration of stakeholders in the process of reflection and implementation of resilience strategies.

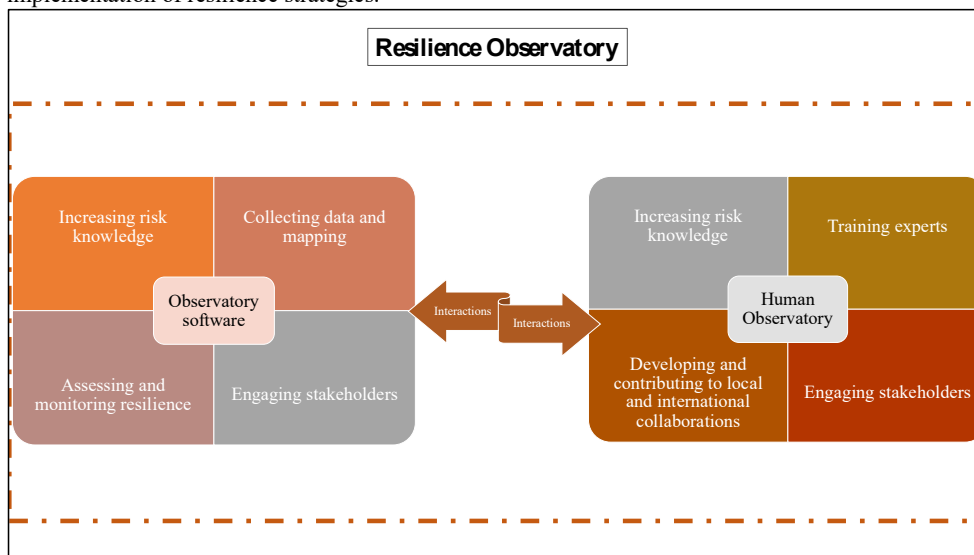


Figure 1: A Resilience Observatory Prototype

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

6. Conclusion

This article has provided a review of the concept of resilience and its operationalization. Confronted with a conceptual vagueness and a multiplication of definitions, notions and associated concepts, resilience loses its relevance and usefulness in risk management strategies. Yet this concept, which encourages adaptability, evolution and flexibility, is perfectly in line with climate change and the associated risks and uncertainties.

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

Thinking about a new kind of tool for addressing resilience in the long term and an inclusive approach to the concept and associated methodologies would make it possible to respond to these current limitations. This tool, which would take the form of a resilience observatory, would make it possible to



develop a toolbox, bringing together conceptual and tangible advances related to the operationalization of resilience.

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