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Urban resilience operationalization issues in climate risk management: A review

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ABSTRACT

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

1. Introduction

Operationalizing urban resilience is a complex, even conflicting subject. Because of its multidisciplinary origin and the multitude of approaches, resilience meanings are sometimes contradictory [1]. This contradiction is essentially due to the fact that resilience belongs to many disciplines such as physics, psychology, ecology [2]. This conceptual vagueness makes the use of resilience and its integration into risk management complex [3]. Despite its growing use in official communications, the operational relevance of the concept is therefore constantly being questioned.

The Hurricane Katrina (2005) marked a major turning point in the history of risk management [4–6]. To prevent a similar event from happening again, risk management has evolved to incorporate the concept of resilience. The objective is to use this concept to best prepare populations and territories to increased risks in urban areas. The idea is no longer to analyze the risks in a compartmentalized manner but to study the disruptive event and its consequences as a whole. Several definitions and characteristics of

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resilience exist:

- Resistance capacity: Serre [7] defined three capacities (resistance, absorption, recovery) of resilience and defined the resistance ability to determine "*the physical damage to the network as a result of the hazard*" [8]. It is essential to know before any risk management and actions plan the potential damages of a system, in order to adapt resilience strategy. It is estimated that, more the technical system is damaged, greater is the possibility of a malfunction of the system and more it will be difficult to restore it to service.
- Absorption capacity: UNISDR [9] has define resilience as the "*ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its basic structures and functions*". Cardona [10] defined resilience as the capacity of the damaged ecosystem or community to absorb negative impacts and recover from these.
- Adaptive capacity: Pelling [11] defends the idea that resilience is the ability of an actor to cope with and adapt to hazards stress. . It refers to the "*ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences*" [12].
- Reaction capacity, linked to self-organization: Pickett et al. [13] have defined resilience as the "*ability of a system to adjust in the face of changing conditions*" and Ahern [14] has defend resilience as a "*capacity of systems to reorganize and recover from change and disturbance*".
- Ability to rebuild: Walker et al. [15] developed the idea that resilience is the capacity to "*reorganize while undergoing change so as to still retain essentially the same function, structure identity, and feedbacks*". It can also be understood from the ecological angle of "building back better" [16].
- Learning capacity: The Resilience Alliance [17] defends that resilience is a combination of three capacities, absorb and remain within the same state, the capacity of self-organization and "*the degree to which the system can build and increase the capacity for learning and adaptation*" [18,19].
- Ability to bounce back: to some authors, there is one single-state equilibrium which implies to bounce back to equilibrium previous disturbance [20]. On the contrary, others consider that we can observe multiple-state equilibrium which suppose that systems have different stable states [1,20].

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

2. Urban resilience: advances and limits

2.1. Urban system issues

Resilience in risk management is particularly relevant in addressing the increased vulnerability of urban environments. Urban areas are the territories most exposed to disasters. Today, nearly 3/5 cities, with 500,000 inhabitants, are at risk. However, urban areas produce between 70 and 80% of the world economy and are home to 55% of the world's population, with an increasing urban-rural drift expected to raise this value up to 68% by 2050 [21,22]. Such a concentration of stakes increases the impact of disasters [23] and raises questions on the future of cities. Beyond the increase in urban population and the concentration of issues, we are witnessing an over-vulnerability of these urban environments, linked to some critical elements. Urban space is made up of several infrastructures, some more essential than others. Critical Infrastructure (CI) concentrate all the functions [24] necessary for the proper functioning of a community. However, their potential destruction could weaken the entire defense and economic organization [25] of a territory. However, these CIs interact with each other and thus create interdependencies [7] within the urban space. These interdependencies then play the role of a risk diffusion factor. According to the concept of the cascading effect [25–28], some areas come to be impacted by the disaster, even if they were not located in the same area [29–32]. Therefore, some damages are not caused by direct impacts but indirect impacts. In order to address these multiple complexities, it is necessary to broaden the risk assessment framework towards broader objectives related to the resilience of urban systems from a multi-hazard perspective [33]. In the face of these growing uncertainties, risk management must evolve [34,35] by integrating new concepts.

2.2. Concept definitions

Urban resilience can be defined as the concept that studies urban systems faced to risks. It refers to a systemic approach that encompasses the multiple layers and structures that produce an integrated vision of the urban object. It would therefore be a utilitarian concept for analyzing the complexity of the urban system and defining the different capacities of each element that defines this system in order to live and survive a disruptive event. The ability to define what is meant by resilience is an essential prerequisite for reducing the consequences of a disaster. Most research on operationalizing resilience focuses on a technical-functional approach. As a result, it is mostly the technical and material elements, such as urban networks, that are analyzed in these studies [7,36–38]. However, an urban system is made up of multiple components that are constantly interacting. There is no conceptual consensus in the scientific and policy community (Table 1) on the definition and objectives of urban resilience, which reinforces the lack of clarity in establishing resilient risk management strategies.

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

This multitude of uses [60] has turned resilience concept into a buzzword [61,62] that complicates its understanding. A resilient system is in turn defined as a system capable of stability but also of adaptation and evolution [63,64]. We speak of both "bouncing back" to a (potentially anterior) equilibrium or "bouncing forward" to a new state of balance and harmony. Faced with this ambiguity, or even contradiction, among the objectives and guidelines of resilience, actors and experts come up against grey areas [65].

This conceptual vagueness has contributed to the political reappropriation [66–70]. Having become a political and management imperative, resilience has been transformed into a political and crowd-unifying tool. Resilience can therefore be used more for political positioning or institutions to strengthen their dominant governance model without necessarily leading to reflection on processes of transformation or evolution that are generally necessary for the establishment of resilient systems [66].

Furthermore, the cost of a resilient approach is often pointed out. Whether it is spatial reorganization or the purchase of resilient development tools [58], local managers are faced with a mismatch between the cost of approaches and their daily priorities. The fact also that climate change and the associated risks are a more or less distant threat and hardly imaginable, makes decision-makers less

Table 1
Comparison between different system to analyze urban resilience.

Sources	Systems defined and used by authors	Definitions
[39]	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"
[40]	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"
[41]	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".
[42]	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".
[43]	Cities	"The degree to which cities tolerate alteration before reorganization around a new set of structures and processes"
[4]	Cities	"The capacity of a city to rebound from destruction"
[44]	Cities	"Encompasses the idea that towns and cities should be able to recover quickly from major and minor disasters"
[37]	Cities	"The ability of a city to absorb disturbance and recover its functions after disturbance"
[45]	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"
[46]	Urban system	"Urban resilience is a capacity of a complex urban system, composed of interacting physical and social components, to withstand an external stress and bounce back to a state of equilibrium or bounce forward to improved new states of equilibrium »
[47]	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"
[9]	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"
[48]	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"
[13]	System	"The ability of a system to adjust in the face of changing conditions"
[49]	Critical infrastructure networks	"A sustainable network of physical systems and human communities"
[8]	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)"
[50]	Critical Infrastructure	"Resilience is defined as a function indicating the capability to sustain a level of functionality or performance fora given building, bridge, lifeline networks, or community, over a period defined as the control time that is usually decided by owners, or society"
[51]	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"
[52]	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"
[53]	Community	"The ability of communities to withstand external shocks to their social infrastructure"
[54]	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"
[55]	Community	"A community's capacities, skills and knowledge that allow it to participate fully in recovery from disasters"
[56]	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"
[57]	Community + City	"City resilience is based on the efficiency of hybrid networks composed by citizens and urban infrastructures."
[58,59]	Community + urban system	"The ability of populations, territories and infrastructures to put in place resources, skills and capacities in order to best experience a disruptive event so as to limit its negative impacts. Capacities can be both tangible (urban networks, supply of vital resources, etc.) and intangible (knowledge of risk, economic dynamics, institutional framework, etc.)."

Table 2
Comparison between different resilient indicators models.

Models	References	Case study	Remarks
BRIC	[83]	USA	• Resilience indicators to map the level of resilience across the USA • Resilience analyzed into 6 indicators: social, economic, community, institutional, infrastructural and environmental • Each variable has a positive or negative effect on community resilience • Possible to locate more or less finely the territories on which to focus efforts to increase territorial and social resilience • State-wide analysis • National data not always adequate for a fine-grained, contextualized analysis of resilience • No specific risk identified
DS3 Model	[7]	Hamburg	• 3 resilience capacities: resistance, absorption, recovery • neighbourhood level analysis • Identification of interdependent relationships between critical infrastructure • Identification of potential domino effects in case of disturbance • Focus on flood risk • Technical-functional approach to resilience centered around the analysis of the resilience of urban technical networks
Resilence Capacity Index	[84]	USA	• 12 indicators (regional economic, socio-demographic, and community connectivity attributes • A broad analysis of the disaster (not only the natural disaster) • Integration of the notion of stress • Notion of vulnerability and resilience prior to the disruption • Visualization of resilience scores • Metropolitan Analysis Scale • Attempt to validate or at least discuss the results • Visualization of results on too large a scale that complicates decision making for urban actors • No specific risk identified
Community Disaster Resilience Index	[85]	USA	• 75 indicators • Applied to 144 coastal or near coastal counties across the Gulf Coast • Data from 2000 to 2005 • Empirical validation (observations) • Doesn't work for the probability of fatalities • Visualization of results on too large a scale that complicates decision • No specific risk identified
Urban resilience index	[86]	Spain	• 5 indicators • Quantitative and qualitative indicators • Tested in 50 spanish province capital • Not a generic approach • Very few indicators concentrated on food, land use and business • No specific risk identified
Community resilience assessment	[87]	Rockaway Peninsula, New York	• 16 indicators divided according to the temporality of the risk (preparation, absorption, recovery) • Adapted to a specific risk (flood) • Tested with a case study • Collaborative approach with stakeholders • Support decision-making • Possibility to combine this approach with others (model flexibility) • Need to develop a collaboration for several indicators (need to develop a long term approach)
The Peoples Resilience Framework	[88]	Not known	• 7 indicators • Considering the interdependencies between the 7 dimensions • Crossing of scales between the individual and spatial scales • Qualitative and quantitative indicators • Consideration of resilience as a fluctuating variable • No identification of risks or specific disturbances • No visualization of results • No real measure of resilience but more a list of criteria to develop a resilient community
Hybrid method	[58,72]	Avignon	• Inclusive resilience approach • 3 indicators: social, urban and technical resilience

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Table 2 (*continued*)

Models	References	Case study	Remarks
			• Administrative limits scale • Collaborative approach • Spatial decision support system • Tool not 100% free access • No validation of the methodology using a past event • No long-term study of the impact of new urban projects on overall urban resilience

focused on the necessary evolution of risk management strategies through the integration of resilience into the planning process [71].

Finally, the cultural dimension of risk management can also be seen as a barrier [59] to the implementation of the concept of resilience [72]. At the level of local actors [73–77], it can be expressed through the culture of risk. It can be associated with the historicity of disasters on a territory and therefore by the succession of management strategies put in place to deal with them. Changing them can be complicated, especially if it requires new human and financial investments. At the individual level, this cultural resistance is regularly linked to a lack of awareness of the risks linked to climate change and a fear of changes in their habits and living environment [73,78].

3. Methods for integrating resilience into risk management

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

3.1. Assessing urban resilience

Measuring resilience has become an international priority in order to build strategies for the future risk management [79]. The question of how to measure resilience is as old and as important as the concept itself [80]. Numerous indices and indicators of resilience have been developed in various disciplines. In general, they are used for different purposes and, as a result, they measure different things. An exploration of attempts to measure resilience reveals the difficulty in establishing a measure that is both accurate and "*fit for purpose*" [81]. Measurement requires that a phenomenon be observable and allow for systematic attribution of value, but the conceptual nature of resilience makes this difficult. Scientists are still disagree on specific conventions for measuring resilience and, consequently, there is a substantial literature that discusses both how and whether the phenomenon can and should be measured [81].

The identification of resilience requires planners to identify variables that trigger disturbances in a city (a community, region or landscape), the frequency and intensity of these events, and the mechanisms that enhance adaptability that can be activated to respond to (or avoid) these disorders. It is need to assess the socio-economic dimensions of an urban area [14]. As established previously, it is necessary to establish common denominators that induce vulnerability or strengthen resilience [82]. However, the difficulty essential is to measure these dimensions. The significant challenges in measuring the resilience lead either to imperfect quantified (Table 2) measurements or to a search for indicators of universal resilience [89]. Cutter et al. [5,90] highlight this difficulty in believing that "*if we conceptually or sometimes intuitively understand the vulnerability and resilience, the devil is always in the details, and in this case, the devil is measurement*" [90].

These different indicator models demonstrate the multitude of possible methodological choices for developing them. Some work at the national scale [83–86] others at the urban scale ([7,72,87]. The complexity of defining the concept of resilience also leads to diverse and varied choices regarding the number of indicators constructed, some exceeding 10 indicators [84,85,87], others focusing on a more limited number [7,72,83,86,88]. This multitude can lead to an overload of information, and therefore to a blurring of the knowledge acquired. Moreover, the methodology chosen to build these indicators is not always clear, is it based on open data, is the weight of each indicator always the same, can we reuse them or download the results, etc? Finally, the understanding of risks is not identical everywhere, some specializing in one risk [7,72,87], others in more chronic risks [83–86,88].

3.2. Modelling resilience

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

For individuals, the visual context favors the acquisition of knowledge [91–93]. The integration of visualization in the analysis of geo-spatial data [94] has led to geovisualization, a "*set of visualization methods and tools for interactively exploring, analyzing and synthesizing location-based data for knowledge building*" [95]. Geovisualization combines scientific visualization, information visualization, mapping, geographic information systems (GIS), exploratory data analysis and many other methods to explore, analyze, synthesize and represent geographic data and information [96]. Several methodologies have produced tools to clarify the concepts of resilience and vulnerability. These tools are spatial decision support systems and have made it possible to dissect the concept of resilience (Table 3).

Table 3
Comparison between different geovisualization models.

Models	References	Case study	Remarks
Social-infrastructural Interdependence Resilience (SIIR) Framework	[97]	Nantes	• Investigation of the interdependencies between 2 urban subsystems (social and infrastructural system) • Tested to analyze the dependencies between Highway infrastructure and Emergency Medical service • Examples with different hazards • Is intended to be generic to other urban systems • Still conceptual
DOMINO	[98]	Montreal	• Modelling the spatial and temporal propagation of domino effects between critical infrastructure • City scale • Identify interdependencies • Collaborative approach • Dynamic interface • Technical-functional approach • Only interdependences issues • Centered around critical infrastructure
Web SIG	[99]	Dublin	• Study of the disturbances of critical infrastructure • Integration of interdependencies • Urban scale and critical infrastructure scale • Specific risk > floods • Prototype tool • Based only on urban networks
Coastal resilience mapping portal	Coastal Resilience https://maps.coastalresilience.org	Australia, Caribeean, Indonesia, Mexico and central America, USA	• Open access • Different case studies • Different elements represented (regional resilience projects, regional planning, community planning, future habitat, flood and sea level rise, risk explorer) • Interactive maps • Long term approach • No definition or measure of resilience • Too many information • Concentrated to coastal areas
StopDisaster	UNISDR https://www.stopdisastersgame.org	Virtual case studies	• Learn about risks and prevention methods through the online game • Understand what a major risk is and more specifically the notions of forecasting and prevention. • Adopt a responsible attitude towards risks • Different risks (tsunami, earthquake, hurricane, wildfire and flood) • No specific case studies • Notions of resilience and vulnerability are not defined
ViewExposed	[100]	Norway	• A tool for local authorities but also for residents • Analysis of several vulnerabilities: physical, social vulnerability and a condensation of the two. • Integrating the notion of vulnerability: local populations' capacities to resist • Collaborative approach between scientists and local experts • Creation of workshops • Evolutionary platform • The concept of resilience is not clearly integrated and identified
VisAdapt	[101]	Nordic countries	• Tool to visualize climate risks • Scientific + Insurance Collaboration • Intended users: private owners + planners • Clear visualization of climate risks thanks to a dynamic interface • Ease of use

(continued on next page)

Table 3 (*continued*)

Models	References	Case study	Remarks
			• Advice and recommendations provided by the interface • Buildings Frame Analysis Scale • Not the same efficiency at each scale of analysis • Limited characteristics of single-family homes • Lack of precision • Questionable Attractiveness

These different geo-visualization tools highlight the multitude of possibilities for representing risk and resilience in dynamic and intuitive ways. While some are still conceptual models [97], others are well and truly used by critical infrastructure managers [98,100,101]. Some focus on the visualization of a risk such as flood [97–99], while others address climate change in its globality [100–103]. Their access and target audience can also change, notably between access to the general public [100–103] or limited access to local actors [97–99]. The interactivity of the tool varies greatly, depending on the audience for which it is intended. The Visadapt or

Table 4
Comparison between different collaborative models.

Models	References	Case study	Benefits
Urban resilience through collaborative diagnosis	[106]	Paris	• Involvement of critical infrastructure managers in resilience analysis • Development of a culture of resilience • Development of a cross-analysis between managers • Development of a common flood risk analysis • Confrontation between the different scales of analysis • No long-term reuse of the process • No utilitarian rendering for local actors beyond research • Analysis centered around the resilience of critical infrastructures and urban networks
A participatory human-hydrologic systems approach	[112]	Mexico	• Freshwater issues • Identify with local stakeholders, resilience of what, to what; for whom and what can be done? • Identify solutions and compromises between urban managers, political stakeholders and decision-makers • A shared narrow and adaptive approach • No long-term reuse of the process • No utilitarian rendering for local actors beyond research
The City Resilient Framework	[48]	100 case study (New York, Paris, etc.)	• Integration of the different resilience themes: leadership, infrastructure and environment, health and well-being, economy and society • Integration of local actors • Metropolitan scale • Development of a local culture of resilience • Multi-risk approach (disasters natural + daily stress) • Approach to long-term resilience • No measurement of resilience • Very global conceptual framework
LittoSIm	[113]	French coastal areas	• Participative simulation platform for local elected officials and technicians concerned by the management of the risk of marine submersion • Collaborative approach with local actors • Testing and validation of the game by and with the stakeholders • Interactive workshops • Dynamic and interactive platform • Long-term follow-up (before, during and after the game up to 2 years after the game) • No definition and measurement of resilience • Not yet adapted to different case studies
Narratives of change	[114]	Dortrecht	• Integration of stakeholders and citizens • Stimulate collaboration between authorities and citizens • Adaptation and resilience-building are locally meaningful • Elicit perceptions of past, present and future weather, water and climate • Contribution to an awareness and sense of urgency of some climate risks • No visualization or future use of results • Ask for a long and deep collaboration with stakeholders and citizens

Viewexposed tool have an interactive, dynamic platform that allows for the selection of several viewing options and levels of information. The StopDisaster tool has a rather old-fashioned design, which makes it somewhat difficult to use. Finally, the Domino tool has a very limited representation, not very dynamic and interactive, which limits its attractiveness and the pleasure of using the game. Finaly, the scale is not always the same; between urban [97–99], national [100,101,103] or fictitious scale [102], which sometimes complicates the implementation of risk management strategies afterwards.

3.3. Integrating resilience into urban management through collaborative approaches

The United Nations International Strategy for Disaster Risk Reduction has developed 10 key points for creating resilient cities. The first point is to set up organizations to understand and reduce risks, based on the participation of local actors [104]. The objective is to build local actions and alliances to ensure that actors understand their role in reducing and preparing risk reduction and resilience

Table 5
Models' categories.

Models	Category	Identified Risk	Scale	Approach	Audience
BRIC [a]	Indicators	No	National	Global	Decision-makers and urban managers
DS3 Model [b]	Indicators	Yes	Urban	Technical	Critical infrastructure managers and urban managers
Resilence Capacity Index [c]	Indicators	Yes	National	Global	Risk researchers
Community Disaster resilience index [d]	Indicators	Yes	National	Global	Risk researchers
Urban resilience index [e]	Indicators	No	Urban	Technical	Risk researchers
Community resilience assessment [f]	Indicators	Yes	Urban	Global	Risk researchers
The Peoples Resilience Framework [g]	Indicators	No	None	Global	Risk researchers
Hybrid Approach [h]	Indicators	Yes	Urban	Global	Decision makers, urban managers and citizens
Social-infrastructural Interdependence Resilience (SIIR) Framework [i]	Spatial decision support system	Yes	Urban	Global	Decision makers, urban managers
DOMINO [j]	Spatial decision support system	Yes	Urban	Technical	Critical infrastructure managers and urban managers
WebSig [k]	Spatial decision support system	Yes	Urban	Technical	Critical infrastructure managers and urban managers
Coastal Resilience Mapping Portal [l]	Spatial decision support system	Yes	National	Global	Decision makers, urban managers and citizens
StopDisaster [m]	Spatial decision support system	Yes	None	Global	Decision makers, urban managers and citizens
ViewExposed [n]	Spatial decision support system	Yes	National	Global	Decision makers, urban managers, insurances and citizens
VisAdapt [o]	Spatial decision support system	Yes	Urban/ Buildings	Global	Decision makers, urban managers, and citizens
[106] [p]	Collaborative approach	Yes	Urban	Global	Critical infrastructure managers and urban managers
[112] [q]	Collaborative approach	Yes	Urban	Global	Critical infrastructure managers and urban managers
The City Resilient Framework [r]	Collaborative approach	No	Urban	Global	Decision makers, urban managers
LittoSim [s]	Collaborative approach	Yes	Regional	Global	Decision makers, urban managers
Narratives Change [t]	Collaborative approach	No	Urban	Global	Decision makers, urban managers, and citizens

[a] [83].
[b] [7].
[c] [84].
[d] [85].
[e] [86].
[f] [87].
[g] [88].
[h] [58,59].
[i] [97].
[j] [98].
[k] [99].
[l] [103].
[m] [102].
[n] [100].
[o] [101].
[p] [106].
[q] [112].
[r] [48].
[s] [113].
[t] [114].

Table 6
Models' Technology Readiness Level based on [115].

Models/TRL Levels	Basic principles observed	Technology concept formulated	Experimental proof of concept	Technology validated in lab	Technology validated in relevant environment	Technology demonstrated in relevant environment	System prototype demonstration in operational environment	System complete and qualified	Actual system proven in operational environment
BRIC [a]									V
DS3 Model [b]									V
Resilience Capacity Index [c]							V		
Community Disaster resilience index [d]									V
Urban resilience index [e]						V			
Community resilience assessment [f]									V
The Peoples Resilience Framework [g]			V						
Hybrid Approach [h]								V	
Social-infrastructural Interdependence Resilience (SIIR) Framework [i]							V		
DOMINO [j]									V
WebSig [k]							V		
Coastal Resilience Mapping Portal [l]									V
StopDisaster [m]				V					
ViewExposed [n]									V
VisAdapt [o]									V
[106] [p]									V
[112] [q]							V		
The City Resilient Framework [r]									V
LittoSim [s]							V		
Narratives Change [t]							V		

[a] [83].
[b] [7].
[c] [84].
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strategies [59,105]. Collaborative approaches are therefore essential levers in the process of involving, understanding and adopting the concept of resilience. Involving "local" people or people directly concerned by the issues studied does not appear to be new [106] and even less original. The richness of having people from all walks of life interact with each other facilitates an exploration of possibilities, enriching discussions, encouraging cross-fertilization of views on the same subject, making it possible to be both more measured and more incisive in a specific area. The contribution of "profane" knowledge in thorny social and societal issues, as scientific knowledge cannot respond to all uncertainties, with the result that "expert" conclusions are called into question. Resilience, a social and thorny concept, is therefore a subject that would require the confrontation of views, knowledge, scientific and practical knowledge, perceptions and interpretations. However, although the population is often the first to be impacted by natural hazards and their inappropriate management, the fact remains that the inhabitants [107] and also the urban services [106], which are nonetheless first-rate actors, are not sufficiently involved. The defended idea is that the creation of a hybrid knowledge [108–110] allowing the involvement of all actors of the territory, from the inhabitant to the manager via the scientist, would make it possible to operationalize urban resilience thanks to an appropriation of the concept and stakes of urban risks. In fact, collaboration is mainly based on the appropriation of the different stakeholders of the same subject of tension and discussion. Collaboration therefore goes beyond the simple exchange of knowledge and information, but makes it possible to "*create a shared vision and articulated strategies for the emergence of common interests that extend beyond the limitations of each particular project*" [111]. There are several examples of collaborative and/or participatory approaches that aim to integrate local actors in the process of operationalizing resilience (Table 4).

Not all models developing participatory approaches have the same methodology. Some approaches rely on workshops, interviews, questionnaires with stakeholders [48,106,112,114], others develop visualization tools in collaboration with stakeholders [113]. The results are not always represented in a uniform way (results of questionnaires, summary tables, etc.). On the other hand, the scale of analysis is often urban, due to the complexity of data acquisition, which is more relevant on a fine scale. Finally, the common problem of collaborative approaches is the temporality of the project. A collaborative approach requires a long-term approach and the constant updating of data and results.

4. From a multitude of methods to a resilience toolbox

Several methodologies exist in order to operationalize resilience concepts and integrate it into urban risks strategies [5,7,58,59,72,90,98,100,106,112].

Indicators are helpful to define main resilience characteristics and to provide a measurement to analyze resilience potentialities. These indicators might be specific [7] or exhaustive [58]. They have an important utility to urban managers to define low resilience areas and concentrate their strategies on it.

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

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

The multitude of models for operationalizing resilience indicates the growing importance of the concept. They are essential to the transcription of the concept into a concept tool [36]. Going beyond the controversy over the exact definition of the concept, these models propose to operationalize resilience. The accuracy of their methodology then takes a back seat because what matters then is not that the model be rigorous, but that it be operational. However, not everyone has the same objective or goal (Table 5). 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.

Some models do not have the same technical maturity, development and use [115]. In order to assess this maturity, the Technology Readiness Level (TRL) methodology, developed by NASA, has been used. This methodology has been adapted in the European Union to assess the outcome of EU-founded research and innovation projects [115].

Some models presented are still at the prototype scale, others are directly used by actors (Table 6). For example, the Web Sig developed by Ref. [99], has already been tested in one field of study (Dublin), but its construction has not yet been completed to make it an efficient and effective tool in other contexts. On the other hand, the DS3 Model developed by Ref. [7], has already been tested and applied on different study sites (Hamburg, French Polynesia, Dublin, Paris), with different issues and actors. Their usefulness in spheres other than academic can therefore be discussed. However, operationalizing resilience tends to respond to the challenge of using the concept in a concrete way through tools that meet the needs identified by local actors. However, their degree of completion, as well as their technical specificities (indicators/geo-visualization/collaborative approaches), their key audience (local actors, risk managers, infrastructure managers or researchers), as well as their multiplication make their use very complex. The multitude of choices as well as the sometimes too specific technicality lose the actors. Which tool should be chosen for which risk, which use, which scale? 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.

A tool that would allow all these options would be more efficient and relevant. A platform or a toolbox, allowing the concentration of pre-existing data and the production of new data, the development of collaborative approaches to ensure the sustainability of the use of the tool, the integration of local risk strategies and the adequacy of the tool to local needs, as well as the development of a methodology to visualize the results and test them on a dynamic and intuitive platform, would respond to this bias of multiplication of tools and therefore loss of information. This prototype would be to promote an inclusive approach that would 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. They have to produce "*an understandable and operational collective representation of territories while at the same time having to restore the inherent complexity of the systems they describe*" [116]. 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. These technical systems can "*acquire, store, process, manage, and distribute the data, information and knowledge produced*" [116]. This kind of tool would allow the creation of a consensus between the production of indicators and data, while developing visualization platforms and long-term collaborations (Fig. 1). Such an observatory is under construction at the scale of French Polynesia [116,117]. If some observatories already exist in France, as the National Observatory of Natural Risks (ONRN) and the Regional Observatory of Major Risks (ORRM), they don't integrate the French overseas territories. However, these territories are over vulnerable face to climate risks and are faced to several limits such as a lack of scientific knowledge and dissemination, poor data quality, excessive dissemination of models, data and approaches, etc. Such observatory should answer to multiple gaps in French overseas risk management, and eventually to other territories.

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

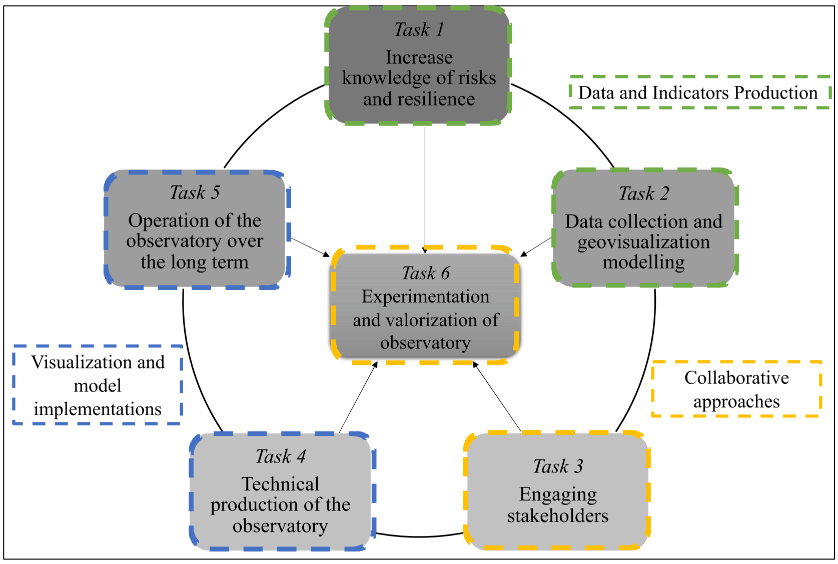

Fig. 1. Observatory tasks - adapted from [116].

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

5. Conclusion

This article has provided a review of the concept of urban resilience and its operationalization. Confronted with a conceptual vagueness and a multiplicity 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 adequate for the analysis of climate change and the associated risks and uncertainties.

The current 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.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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