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Operating urban resilience strategies to face climate change and associated risks: some advances from theory to application in Canada and France

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Abstract :

Faced with increasing urbanization and uncertainties linked to climate change, the scientific community has integrated the concept of resilience into urban management practices. Once revolutionary, now a buzzword, resilience is a concept that is difficult to transform into an integrated tool that stakeholders accept and adopt. This paper offers a perspective on the different interpretations of resilience, its difficult implementation and the tools that seek to operationalize it. The underlying questions are how these tools are appropriated by urban managers and territorial decision-makers, and how the theoretical concept can be translated into resilient urban development. This research paper reviews the work on resilience and investigates its use and operationalization, comparing two different approaches - organizational (Canada) and holistic (France) - that aim to clarify and operationalize resilience. These theoretical approaches have been combined to create workshops for urban managers so they can move from theoretical results to practical applications.

Keywords : Resilience issues, Climate Change, Collaborative workshops, Spatial-decision support systems

1 Introduction

Between 1995 and 2015, climate-related hazards became more frequent and intense (UNISDR and Center for Research on the Epidemiology of Disasters (CRED), 2015). The Center for Research on the Epidemiology of Disasters (CRED) Emergency Events Database recorded 6,457 weather- or climate-related disasters during this period, claiming 606,000 lives and affecting 4 billion people (UNISDR and CRED, 2015). It is well known that climate change has increased both the frequency (14% greater than in the decade 1980–1989) and the severity of certain extreme weather-related events such as heavy precipitation, storms and floods, and this trend is projected to continue (European Environment Agency, 2017).

The impacts of this situation are significant, both for the populations affected and for current or future economic, urban, international, and political challenges. Floods represent 47% of all weather-related disasters (with an average of 171 per year in the period from 2005 to 2014, up from an annual average of 127 in the previous decade) and affect 2.3 billion people (UNISDR and CRED, 2015). Among other things, this dramatic trend can be explained by the changing nature of floods, with flash floods and coastal floods becoming increasingly frequent. Moreover, urbanization has led to an increase in flood runoff, affecting urban areas where the stakes are particularly high. In addition to creating new kinds of risk, urbanization has important implications for exposure and vulnerability to extreme events (Field and Intergovernmental Panel on Climate Change, 2012).

Moreover, modern threats and risks are transboundary (Boin et al., 2010), as globalization is creating a connected world, where interactions between territories, societies and issues lead to many interdependencies (Serre, 2018; Serre and Heinzlef, 2018). The interconnected architecture of modern cities' economic, social, political, commercial, administrative and other activities and the globalized world are creating interdependent networks, both formal (technical networks) and informal (functioning in interrelated societies). According to the concept of the domino effect (Nones and Pescaroli, 2016; Pescaroli and Kelman, 2017; Pescaroli and Nones, 2016; Robert et al., 2008; Serre and Heinzlef, 2018) – a chain reaction causing changes in a territory – some areas may be affected by a flood, for example, even if they are not located directly in the risk area. Indeed, in the interconnected space of modern cities, risks have impacts beyond spatial boundaries. Globalization, the increase in flows, social, economic and political exchanges, the interdependence of networks (urban, social, political and economic networks), etc., has redefined the spatial boundaries of risks. Finally, the presence of critical infrastructures (CI) in cities complicates their functioning and crisis management. These critical infrastructures (CIs) are defined as vital to the point that their destruction or incapacity would significantly weaken defense, economic security or overall functioning on the territory. These infrastructures can be physical (buildings such as hospitals, urban networks, etc.), virtual (economic, social, political flows, etc.), service infrastructures (first aid service, defence service, food distribution, etc.), etc (Serre and Heinzlef, 2018).

Faced with this rapid urbanization and the emergence of these new risks, managers must deal with a series of uncertainties. These uncertainties, linked to climate change (Adger and Brooks, 2003), urbanization, system complexity, and the emergence of new actors and new risks complicate urban risk management. How should these uncertainties be managed? Our incomplete understanding of the natural systems associated with human behavior makes it more difficult to understand risks. Aware of these growing uncertainties, experts and scientists have questioned risk management strategies and graduallyintegrated the concept of resilience. In recent years, resilience has become a major focus in such fields as politics, economics, sports and natural disaster management (Comfort et al., 2010). However, the transition between these different themes has transformed this innovative concept into a mere buzzword (Brand and Jax, 2007; Linkov et al., 2014), used everywhere and by everyone. The overuse of this concept can be explained by its diverse academic roots (De Bruijne et al., 2010); it is applied in domains as varied as physics, psychology, ecology and risk management. The many uses of the concept (Cyrulnik, 2004; Holling, 1973; Koffi, 2014) have made it seem more abstract. However, despite the multitude of definitions (Meerow et al., 2016), the concept is applied in many political, ecological and risk management discourses, as an injunction to systems to be resilient.

In the chaos of these growing uncertainties, the concept of resilience is an interesting approach to understanding the responses of systems and actors to the challenges posed by natural disasters (Fuchs and Thaler, 2018). Resilience can be defined as the ability of populations, territories and infrastructure to develop the resources, skills and capacities needed to best experience a disruptive event in order to limit its negative impacts. In many ways, urban resilience seems to be an appropriate response to the uncertainties associated with increased risk in urban areas. It provides a sufficiently flexible framework for action to encourage innovation in all its forms. However, this flexibility – this richness of interpretation – undermines the concrete application of the concept. Few managers, decision-makers or urban stakeholders (planners who are focused on the city growth and managers who are in charge of increasing the service life of assets through optimum use) actually use the concept to influence how they act on the territory. This is why some researchers have examined the difficulty of operationalizing the concept.

The objective of this article is to present two approaches that aim to address the biases (such as the confusion between the concept of vulnerability and the concept of resilience, the different interpretations according to the temporalities of crisis and resilience, etc.) and limitations of the theoretical concept of resilience by working to operationalize it through decision support tools, on one hand, and collaborative approaches, on the other hand, in order to enhance the use and performance of spatial decision support systems and improve resilience conditions. These tools protect organizational resilience, in the case of a tool developed in Quebec (Canada), and holistic resilience, in the case of a tool developed in Avignon (France), in areas subject to flood risk. Through a collaborative approach to understanding local managers' needs and habits, the aim is to enrich and adapt these decision support tools and integrate resilience into local stakeholders' risk management strategies, so they can adapt better to climate change. These two case studies were selected for different reasons. First, in the spring of 2017, Montreal was violently hit by flooding. The 2017 spring flooding in Quebec is a weather event of exceptional flooding of rivers in the southern part of the province of Quebec, Canada, due to the spring snowmelt, to which were added numerous rainfall events that resulted in abnormally high accumulations for April and May. The final toll was very heavy: 261 municipalities affected, 5,371 homes flooded, 4,066 people evacuated and 557 roads affected. The costs were estimated at several hundred million Canadian dollars, and the number of troops mobilized for this operation was greater than in any other operation underway worldwide for the Canadian Armed Forces at the same time. The floods were ranked the third most significant weather event in Canada in 2017 by the Meteorological Service of Canada. At the same time, Avignon suffered heavy flooding in the fall of 2016, which is part of a continuum of floods that weakened the urban area (1993, 1994, 2002, 2003, 2016, 2019).

Secondly, with this very particular climatic context, the research teams of the École Polytechnique de Montréal and the University of Avignon have launched a joint reflection on risk management and the challenges of operationalizing the concept of resilience. While one approach has focused its research on an organizational methodology (Canadian approach), the other has developed a more holistic methodology. The common point between these two approaches to operationalizing the concept remains a collaborative approach. The objective is to evaluate the different advances in the process of operationalizing the concept of resilience and the different results related to the appropriation of the concept by local actors.

We will first analyze the two strategies for operationalizing resilience – organizational and holistic – tested in Canada and France, and then examine the collaborative process designed to integrate scientific and local expertise in order to promote the adoption of the concept of resilience in risk management strategies.

2 Spatial decision support systems design for organizational and holistic resilience assessment

Starting from the observation that the implementation of resilience because of the lack of clarity about how to define it, some projects have sought to define and delimit the issues in order to identify specific objectives. We propose to compare two theoretical and concrete attempts to clarify the concept of resilience: at the holistic level, in Avignon (France), and at the organizational level, in Quebec (Canada).

2.1 French spatial decision support system for holistic resilience

2.1.1 Climate and risk issues in France's Mediterranean region

In Europe, extreme events will lead to increased costs. Floods, and especially the risk of coastal flooding, should increase significantly. Consequently, the current average damages of €3 billion per year will be multiplied by a factor of at least 5 by the end of the century and in the worst case scenario will reach €38 billion (Centre Européen de Prévention du Risque d'inondation, n.d.).

In France, flood risk is the most frequent (60% of natural disasters) and damaging (60% of damages) of all risks. Approximately, 17 million people (26% of the French population) and 9 million jobs are located in flood-prone areas (Larrue et al., 2016). Currently, the International Disaster Data Base ranks France as the European country with the second greatest exposure to very serious natural events. Damages are projected to increase because of the increasing exposure of both populations and assets (Bouwer et al., 2010). The Mediterranean region is warming faster than most of the rest of the world: compared to the global average increase of 1°C since pre-industrial times, the average temperature has already increased by 1.4°C. And if, hypothetically, the objective of maintaining the average global temperature rise at +1.5°C were met, the Mediterranean area would still be an average +2.2°C warmer (Cramer et al., 2018). Furthermore, a report by the French Ministry of the Environment estimates that there is an average of 10 deaths per year in the 12 departments (regions) along the Mediterranean coast due to specific floods. The loss ratio is therefore concentrated primarily in south-eastern France, and in particular in the Gard and Vaucluse regions. In addition, based on the proportion of the population estimated to live in floodplains, the Vaucluse, with 42%, is among the most exposed French departments (regions) , as all of its municipalities are affected by flood risk. For example, in June 2010, storms hit southeast France and the heavy rain led to flash flooding. The rainfall amounts were exceptional for the time of year; 400 mm of rain fell in less than two days in Provence, an amount that had not been seen in the previous 50 years. Hundreds of homes were flooded in the department of Var, causing several deaths (Met Office, 2011).

Avignon, in Vaucluse prefecture, is faced with physical (confluence of the Rhône and Durance rivers) and human tensions (such as a feeling of injustice on the part of people living in flood zones who feel that they are not taken into account by planners and decision-makers (Gentric and Langumier, 2009)). According to the Preliminary Flood Risk Assessment on the Avignon Flood Risk Territory (TRI):

- the permanent population in flood-prone areas is about 400,000 people, or 67% of the estimated total population of the TRI;
- about 185,000 jobs are based in flood-prone areas, or 76.2% of the total jobs identified within the TRI (Directive Inondations Bassin Rhône-Méditerranée, 2014).

In 2010, it was estimated that, in Avignon, 768 inhabitants and a maximum of 606 jobs would be affected in the case of a frequent flooding scenario and 73,820 inhabitants for a maximum of 72,198 jobs in the case of an extreme scenario (Fig.1). With large but rare floods (the most recent major one was in 2003), Avignon’s risk culture, prevention strategy and resilience operationality are in doubt.

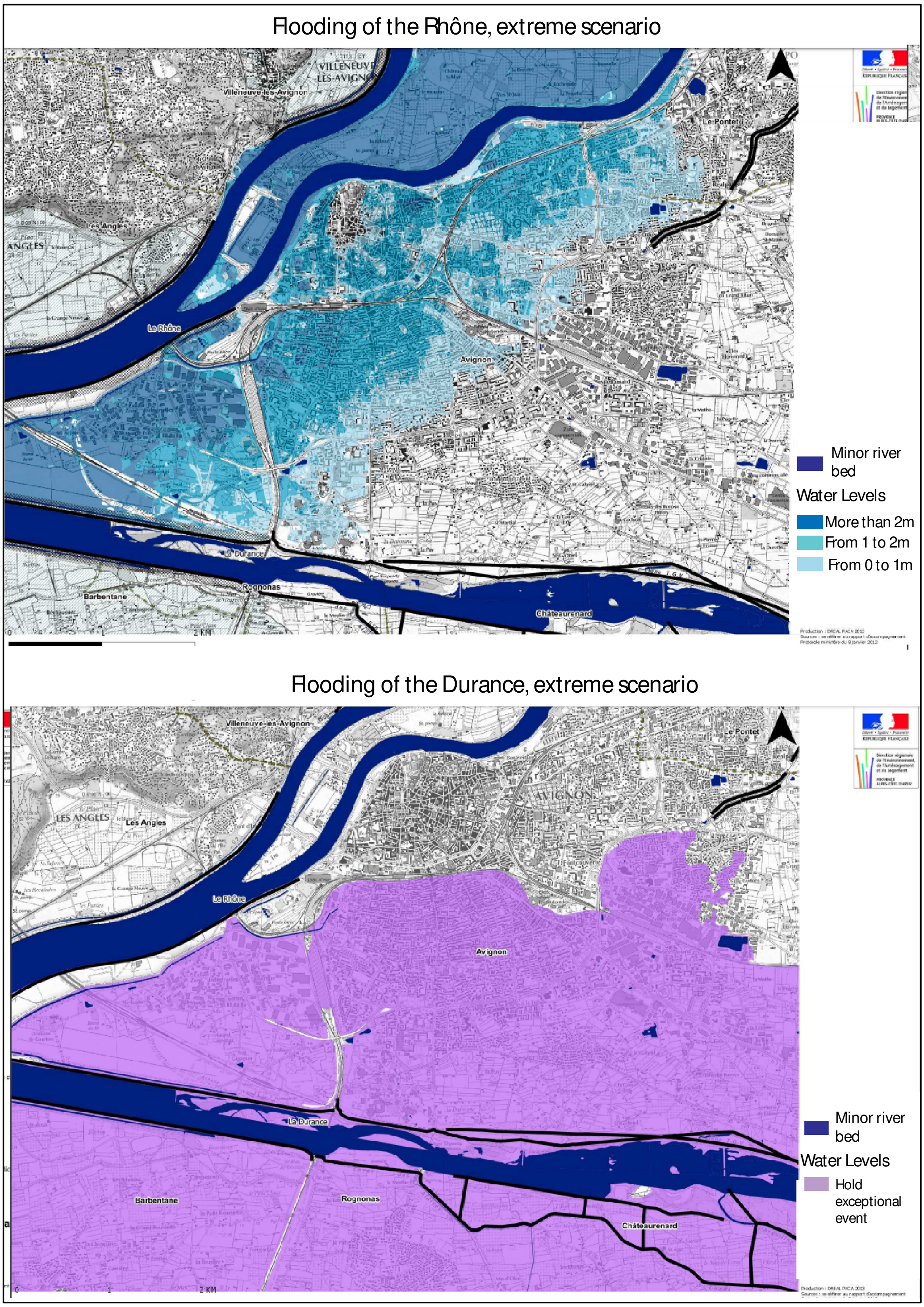

Figure 1: Extreme Flood Scenario, Avignon Scale, inspired by © DREAL PACA (Heinzlef, 2019)

Thus, there is a crucial need for a spatial decision support system to integrate the concept of resilience into practice. It has been set up in partnership with Avignon’s urban and technical service departments. Although the city already has communication and protection tools, the concept of resilience is, as previously noted, hardly integrated into its systems. The main objective of this project was therefore to address the theoretical and practical biases of operationalizing resilience by co-constructing a decision support tool. Indeed, the PACA region suffers each year from events related to river overflows. Each event raises the question of territorial strategy with regard to events that are (or will be) increasingly intense and recurrent according to the forecasts of the IPCC (Intergovernmental Panel on Climate Change). However, local elected officials, managers and decision-makers are sometimes powerless on the strategies of territories to be developed both in the short and long term. At the same time, development operations are continuing in high-risk areas but without necessarily developing management strategies. Given the regional context related to flood risk and land issues, it is urgent that local decision-makers can therefore integrate resilience strategies into their territorial perspectives. The tool developed in this study therefore aims to provide a basis for discussion on risk and resilience issues.

The socio-economic partnership developed with the City of Avignon and its GIS services has resulted in the exchange of data necessary for the study of the territory and daily support for the development, integration and processing of geographical data. The City's interest in this work is explained by its geographical location, at the confluence of the Rhône and the Durance rivers. Most of this territory is subject to the influence of these two rivers and has already suffered from numerous floods. The life of the community and urban developments is totally conditioned by this critical environment. Being able to offer decision support tools to integrate urban resilience has several advantages such as providing specific knowledge about the territory and participating in the preparation and anticipation of the city of tomorrow.

2.1.2 A holistic approach to resilience

In this approach, the idea is that urban resilience embodies the ability of a city and its population to put measures in place before, during and after a disruptive event in order to limit its negative impacts. This scientific approach makes it possible to analyze urban resilience as a continuum, highlighting proactive capacities that the urban system must develop in order to (re)act in response to the disaster, and thereby developing learning and anticipation skills. This analysis also considers that resilience is intrinsic to the urban and human environment, and that a shock is therefore not necessarily negative or even necessary to develop resilience capacities, which may be pre-existing skills. Resilience factors can then be identified over a long period of time, in order to study and develop the potential for resilience.

A decision support tool for integrating this notion into urban practices is extremely innovative and useful for a flood-prone community. This collaborative project enriches theoretical research work by integrating it into the social, urban, architectural, political and economic needs of the community. It is therefore positioned on the border between the practical – professional application – and theoretical research. Researchers and practitioners will increase their understanding of urban risk in all "its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment" (UN General Assembly, 2015), as well as resilience capacities. In the last decade, methods based on indicators have been used in the field of risk, specifically to measure the vulnerability of territories and populations at risk (Cutter et al., 2008*)*. A vulnerability indicator can be defined as a tool able to provide data about a system's susceptibility, fragility, vulnerability, adaptability and resilience (Birkmann, 2006). To give concrete form to the notion of resilience on the territory, three indicators – urban, technical and social resilience (Fig.2) – have therefore been cocreated thanks to this study conducted with the Avignon GIS department to measure pre-existing resilience (Serre and Heinzlef, 2018). Co-construction has been established around data exchange, the pooling of processing tools and the sharing of information and knowledge.

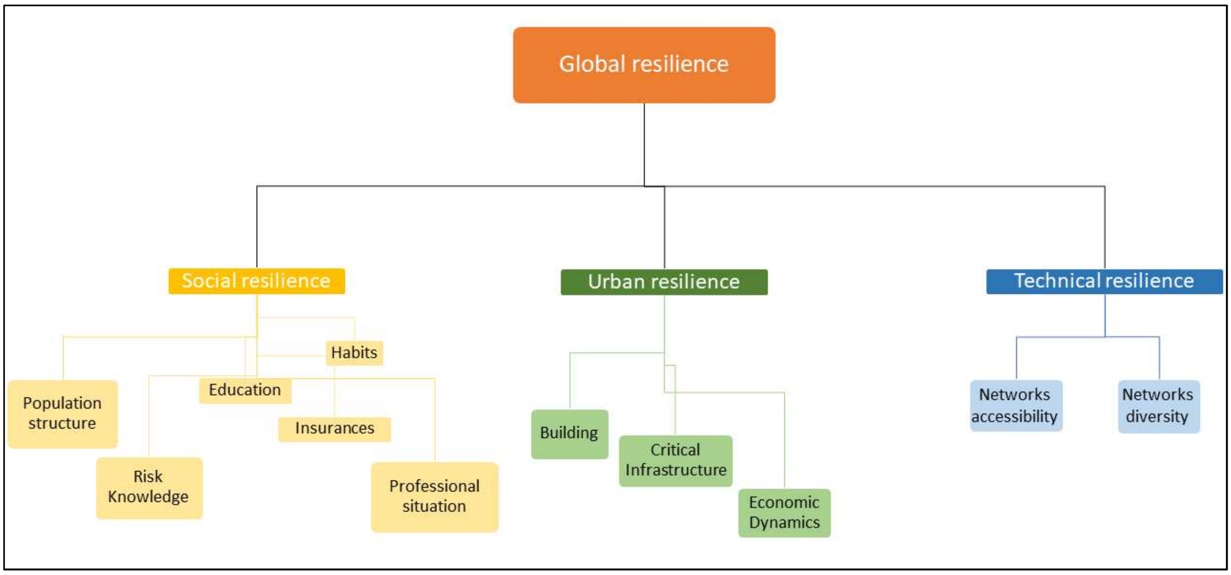

Figure 2: Resilience index built around three resilience indicators, social, technical and urban. Each indicator is divided into sub-variables to analyze the potential resilience of the territory.

We used variables to study both inherent vulnerability and inherent resilience of a society and its territory (Serre and Heinzlef, 2018). These variables indicate a *potential* for resilience in order to revive a social, economic, urban, or systemic activity after a disruption (Heinzlef and al., 2019). The variables for each indicator were based on an analysis of the scientific literature in order to identify the different social (age of the population, level of education, knowledge of risk, etc.), urban (urban structure, economic dynamics, state of structures, etc.) and technical components of the territory. The scientific consensus that resilience is multidisciplinary led to the selection of data on social, economic, institutional, infrastructure and community factors (Cutter et al., 2008).

Then, each variable was placed on a positive or negative resilience curve. This definition of the parameters corresponds to a unique form of deviation (Holand et al., 2011) for each variable, thus making it possible to vary the overall value of the resilience per indicator. In order to create a generic tool that can be used by different players, all the indicators were built using open-source national data (e.g., the Sirene database maintained by INSEE, France’s National Institute of Statistics and Economic studies). The resiliency calculation for each variable and indicator was built using a Data Management Engine (ETL), the Feature Manipulation Engine, used by French cities’ GIS departments. Maps and analyses were created on the QGIS platform. The spatial scale of analysis was local, given the desire to work with local stakeholders in order to respond to their management problems in dealing with the risk of flooding. Thus, urban projects at the neighborhood level were analyzed in terms of their contribution to the intrinsic resilience of a larger area. Projects at this neighborhood or urban scale, which has not been much explored, allow one to act directly on the territory, innovate, experiment and test new practices directly with managers. As a result, the main scale of study chosen to assess urban resilience must be as accurate as possible, namely at the IRIS scale (Regrouped Ilots for Statistical Information). This scale is located between the 200 x 200 m grid (INSEE) and the District Council level. Each computation is therefore multiscalar but also multitemporal. Indeed, resilience to risks must be conceived of according to a multitemporal paradigm: stakeholders need to act before the crisis, or anticipate (urban planning), and to recover from the event afterward (rebuild, restore an activity, adapt) (Barroca et al., 2013).

Preliminary results, based on the social and urban resilience indicator, make it possible to analyze Avignon’s social structure according to the capacity of the various populations and urban structures to support and recover from an event. Because each indicator (urban, technical and social) is independent of the others, politicians and managers find it easier to work on variables with low levels of resilience and identify areas to be redeveloped and/or reintegrated in urban dynamism. The impact of this study has been at several levels. Firstly, the concept itself has been clarified through the definition and co-construction of indicators with local actors. This made it possible to associate scientific advances in the field with the legacy of local risk management. In addition, the mapping, at a sufficiently fine scale, of resilience according to the different indicators has made it possible to develop a better knowledge of the territory. What was the intrinsic vulnerability of the territory of Avignon, according to social, technical and urban criteria, and on what spatial scale? The construction of a new database (quantitative and qualitative) has made it possible to develop an anchor point in the evaluation of the territory's resilience capacities but also to provide a focus for debate for potential future urban projects. The results are more visible in the medium and long term and are more reflexive than economic. The idea is to develop a regular evaluation every 2-3 years to understand the use of this tool and assess its impact on local planning and investment decisions.

2.2 Canadian spatial decision support system for organizational resilience

2.2.1 Climate and risk issues in the province of Quebec

In the past few decades, Quebec's climate has changed significantly. Average daily temperatures in southern Quebec have increased by from 0.2°C to 0.4°C per decade (Québec (Province) and Mnistère du développement durable, 2013). In winter, by 2050, average temperatures are predicted to increase by 2.5°C to 3.8°C in southern Quebec and 4.5°C to 6.5°C in the north. In summer, average temperatures are expected to increase between 1.9°C and 3.0°C in the south and between 1.6°C and 2.8°C in the north.

It is accepted that the impacts of temperature changes under the 1.5°C, 2°C and 4°C global warming scenarios will lead to more frequent flood events. In fact, floods are projected to increase on all continents under all considered warming levels, leading to a widespread rise in the flood hazard (IPCC, 2018). Climate change will result in more frequent and more intense extreme weather events (winter storms, high winds, heavy rains, etc.). These events may well lead to various natural hazards such as floods, erosion, etc. Expected increases in the duration, frequency and intensity of rainfall will have a significant impact on the frequency of sewer overflows and their indirect effects (backflows, overflows in the natural environment, flooding of urban areas) and on erosion caused by water runoff. These phenomena also pose a risk to municipal urban drainage infrastructure and drinking water intakes. The Quebec floods in 2017 were a harsh reminder of the reality of this risk (Commission de l'Aménagement, 2017; Ministère de la Sécurité publique Québec, 2017). From late February to June 2, 2017, floods occurred in 15 administrative regions, affecting an unprecedented total of 291 municipalities. These proven and expected climate changes have prompted managers and scientists to address the challenges of operationalizing resilience (Borie et al., 2019).

2.2.2 An organizational resilience approach

Crises are becoming increasingly complex, largely due to the many interdependencies between critical systems and their infrastructures in urban societies. A mode of operation that promotes interorganizational collaboration is much more effective than a "silo" model, especially when key relationships are established before the crisis itself. But few known partnerships have made it possible to develop operational mechanisms for preventive mobilization related to intersectoral interdependencies and the prevention of domino effects (Robert and Morabito, 2009). Identifying resilience as an objective to achieve is beneficial, but the manager of an organization still has to implement this objective on a daily basis. The first task is to assess the organization's resilience potential based on the flexibility the manager has to make internal decisions. Various approaches exist to characterize and assess this resilience, but they fail to capture the full specificity of an organization (resilience engineering, ecosystem resilience, community resilience). In an organizational context, the objectives are always essentially the same:

- ensure acceptable operation;
- adapt to different changes in the environment, both internal and external;
- restore operations in the event of an interruption.

The operationalization of these objectives requires the integration of emergency measures and business continuity plans by both private and public organizations. It is then possible to assess an organization's ability to manage disruptions and thus measure its potential for resilience. In Quebec, the *Centre Risque & Performance* (CRP) at *Polytechnique Montréal*, in conjunction with the Ministère de la Sécurité publique, has defined resilience as "the ability of a system to maintain or restore an acceptable level of operation despite disruptions or failures" (Robert et al., 2008). In partnership with more than 15 ministries and key networks, indicators have been developed to assess an organization's potential for resilience, paving the way for diagnoses and recommendations for action to strengthen this potential. The concept of resilience is perceived as being rather theoretical and complex. Given that the assessment of resilience must become an important decision-making tool for organizations, it is therefore crucial to integrate it into their culture, even though the transition from theory to practice is difficult. The first way to act concretely in an organization to operationalize all these concepts and make it more resilient is to integrate the notion "Accept – Anticipate – Plan" (Robert et al., 2017). The cement that binds these concepts and builds the system's resilience is the continuous evaluation of the coherence between all elements of knowledge, anticipation mechanisms and planning rules within the system, as well as its coherence with its environment.

The capacity of CIs to function despite disruptions is the core of community resilience. Modern societies depend more and more on essential resources (telecommunications, energy, drinking water, etc.); organizational management is increasingly based on lean and just-in-time principles; and the service sector (financial transactions, postal services, information networks, social media, etc.) relies increasingly on immediate access to remote information. In parallel with this growth in needs, CIs are subject to new risks associated with major changes in their environment (climate change, technological change, social change, etc.), which require them to be very adaptable. In addition to society's dependency on the resources provided by CIs, we must consider the complexity of these infrastructures' functioning and the many interdependencies between them. The result is that all the conditions are in place to ensure that any disaster may assume unsuspected proportions, with consequences that directly affect communities' health, safety and socioeconomic activities.

Thus, when a disaster occurs, community resilience depends greatly on the resilience of these organizations, that is to say, their ability to maintain a certain acceptable level of service and, especially, to restore it as quickly as possible. Knowledge of the issues facing each stakeholder is key to ensuring resilience. Such knowledge makes it possible to understand the various issues based on different possible levels of acceptance and anticipation of the consequences, but also on the variability of the numerous planning and crisis management tools. To meet this knowledge sharing challenge, it is necessary to implement a collaborative mechanism (Robert et al., 2008). The guidance of this collaborative mechanism is rooted in a consequence-based risk management approach. Unlike traditional risk management approaches (which start with a triggering event), this approach focuses on the consequences associated with the failure of an infrastructure, and not with the causes of that failure. This makes it possible to conduct all the necessary analyses of the dependencies among CIs. The results are shared in the form of dependency curves (Fig.3) that use a color code to indicate the various organizations' dependency on the resources they use (changes in the state of the system based on the duration of outages). These curves provide results that are more concrete, realistic and reliable and that better meet organizations' real needs; consequently, organizations are more likely to accept them and take ownership of the results faster (Robert et al., 2015). The knowledge related to these curves enables CI managers to determine acceptability thresholds for certain durations of possible failures, anticipate the consequences for other CIs, and integrate these parameters into their measurement tools (emergency measures, business continuity and asset protection plans). Although the resilience parameters of these independent organizations exist, the concept of capacity means that the coherence of these parameters throughout a community's territory must be assessed dynamically.

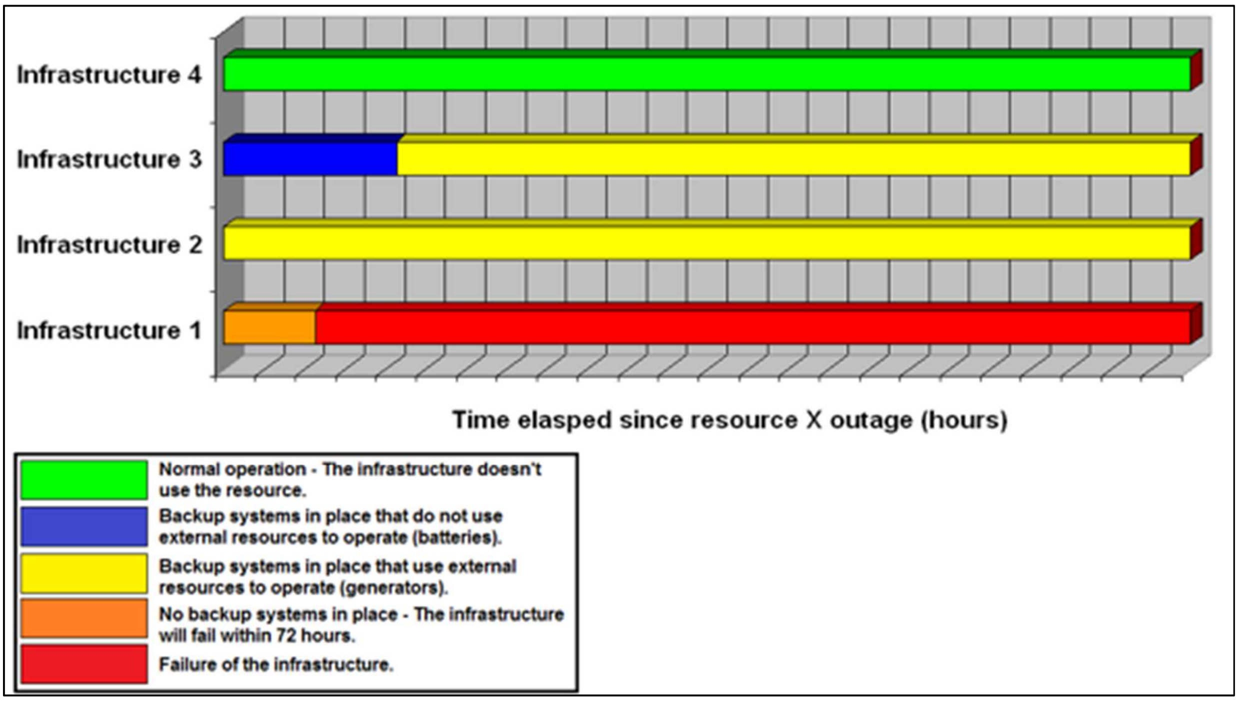

Figure 3: Some example of infrastructure dependency types to external resources to operation abilities.

2.3 Comparative analysis of the holistic and organizational resilience approaches

This work on defining the issues and characteristics of resilience has made it possible to develop two approaches intended to clarify a concept that is still very abstract for urban managers. Both the organizational approach focused on the vulnerability of CIs in a context of climate change and the holistic approach based on urban, technical and social resilience tested in Avignon have made it possible to reconsider the practical integration of resilience into risk management strategies. Because they clarify the concept and define its challenges and characteristics, these tools are essential to the work of appropriating and building resilience strategies. While they are the first step toward these resilience strategies, there is a limit to their use by local managers and elected officials.

The tool developed with the organizational approach allows CI managers to understand the evolution of a situation likely to generate domino effects. Its primary role is therefore to identify CIs and areas potentially impacted by these domino effects. The information provided by this tool allows organizations to make better and faster decisions. This makes it possible to increase the capacity for collective response by promoting coherence among all the stakeholders' actions. Although essential and innovative in its modeling and information approach, this tool examines only the resilience of CIs, which greatly limits the analysis of the resilience of the urban territory and its population. In addition, certain technical limitations make this tool more difficult for managers to use and adapt. Several technical challenges remain to be addressed, including the automation of certain tasks and the interface and the integration of new options for considering natural hazards and industrial risks. Other challenges are organizational. For example, it will be necessary to determine who should have access to this system and who will be responsible for managing and updating it. It is also necessary to define interorganizational communication mechanisms and adopt a structure that allows 24/7 access to the system. The system should be hosted by a monitoring organization with an existing foundation such as a government monitoring center. On the other hand, the partner networks require the system manager to be neutral so that the tool and the data that feed it are not used for any purpose other than emergency management.

The holistic approach attempts to address the challenges of a systemic approach to resilience by assessing it from an urban, technical and social perspective. The collaboration with the GIS departments of the city of Avignon attempted to address the limitations affecting appropriation and operationalization of urban resilience in risk management strategies. Although this collaboration has provided some interesting results, and more are anticipated, the question of the autonomy of urban managers may ultimately arise at the end of the project. How and to what extent will this tool be used in risk management practices once the study itself is completed?

This is why, on the basis of these interesting and innovative tools, we propose an approach built *a posteriori* to understand managers' habits and functioning, in order to better understand their needs. This collaborative, participatory approach aims to enrich both approaches and adapt them to the needs of managers, so that resilience strategies for risk management can be developed.

3 Improving Canadian and French spatial decision support systems with collaborative workshops

In order to diversify the approaches and, above all, to take stock of the results of the implementation of resilience in practice, we decided to organize participatory workshops to understand and test the appropriation of these two different tools and approaches by urban, CI and risk managers, with a view to adapting our scientific approaches and improving the construction of these tools so they become easier to integrate into resilience strategies and policies.

3.1 Objectives

As part of a scientific analysis and a joint exercise between two regions – the province of Quebec (Canada) and the city of Avignon (France) – we decided to analyze flood risk management systems. These strategies, designed by the various actors and managers of a community, are intended to contribute to a territory's resilience.

We have therefore sought to understand how these strategies are constructed and, above all, shared by the various stakeholders in the territory. The objective was to analyze the different actions envisaged by the participants in each organization according to the various plans at their disposal and then to analyze the coherence of these planned and unplanned actions.

Indeed, collaboration mainly involves the various stakeholders buying in to common goals. Collaboration therefore goes beyond the simple exchange of knowledge and information but allows stakeholders to "create a shared vision and articulated strategies to bring out common interests that go beyond the boundaries of each particular project" (Chrislip, 2002). However, it would be beneficial to build this shared vision and commitment around the concept of resilience, an approach that would also allow a transition in how cities are designed, and risks understood in urban environments. We therefore propose to develop strategies to integrate resilience so that they can be co-constructed with municipal stakeholders, both so that they invest directly in the process and so that they apply this strategy before and during a crisis (Serre et al., 2013).

3.2 Comparative approaches in the city of Avignon and in two Quebec RCMs

3.2.1 Avignon, France

The first workshop was held in Avignon (Vaucluse, France), the territory on which a decision support tool is being built to integrate “holistic” resilience into flood risk management approaches. The objectives of the workshop were very clear. The research team wanted to identify and address several issues such as the appropriation of the concept by managers and the operationalization of the concept in order to make it sufficiently interesting and useful for users. To meet these objectives, it was necessary to define expectations, objectives and issues and to identify the various stakeholders’ capacities for individual and joint action and consider their long-term risk management strategies (Tab.1).

Type of actors/ Services	Attending stakeholders
Urban Managers	VEOLIA (Water management) GRDF (Gas network) ENEDIS (Electricity network)
City of Avignon (Avignon Scale)	Art and Hydraulic Dams Dyke Management Traffic lights GIS service
Agglomeration scale	Management of Aquatic Environments
Academics	University of Avignon Montreal Polytechnic

Table 1: Avignon's workshop stakeholders

In particular, we sought to analyze flood risk management systems. These strategies, designed by the various actors and managers in a community, are supposed to contribute to its resilience. It was therefore necessary to understand how these strategies are constructed and shared by stakeholders and to analyze their coherence.

To prepare for this technical workshop, we created a preparatory questionnaire to initiate an initial reflection process on flood risk management by CI managers and municipalities. The purpose of this form was to stimulate discussion between the various actors on the following points:

1. The issues at stake in the Avignon area;
2. The CIs concerned;
3. The vulnerability of CIs.

During the discussions among stakeholders, several topics that were associated with tension and limits were highlighted. Firstly, the “long-term” horizon, set at 2030 by the urban managers and city officials, is already obsolete. At a minimum, management plans should posit a 2050 horizon. Then, communication between the different decision-making levels is very difficult: for example, the prefecture has a list of CIs, but the municipal government is not aware of them. Another limit is the valve-based flood protection system, which is almost entirely dependent on the power grid; only two valves are manual. In the event of a power failure due to flooding, the valves cannot be operated. The system of manual cofferdams and gates depends on the number of people on duty when a flood strikes (accessibility of flooded areas, availability of workers, etc.). The natural gas distribution system is dependent on human assistance when it is recommissioned. Indeed, the need to deal with each customer individually lengthens the restoration of the electricity system, slowing down other services. The electricity system does not seem to have planned any preventive actions to avoid the impact of a flood on the network (no early shutdown is envisaged). The water and waste management company’s systems do not seem to consider the amount of human and other waste produced by a flood and has no management system. This waste, in addition to blocking streets and thus limiting accessibility to certain areas, can cause disease. Finally, the hospital is a source of tension. It is accessible only by a single dead-end road. How is such a building to be evacuated or kept running? In addition, the hospital, located right in a flood-prone area, only has emergency generators if the power system should become unusable. Therefore, the question arises as to these plan B systems’ capacity for use (are operations possible?) and duration (a few days, a week?).

Despite these limitations, which stakeholders mentioned in their speeches, while the academics in charge of building a decision-making tool to integrate resilience into urban practices were present, urban managers and decision-makers remained essentially focused on their achievements related to the experience or legacy of risk management in the Avignon area rather than moving forward toward collaboration between academics and territorial players. There is a clear lack of communication, cohesion and collaboration, which is all the more striking as the University of Avignon and the city are partners in numerous research projects to overcome the lack of tools and plans and the increased uncertainties related to flood risk in a context of climate change and urban population growth.

Thus, despite the joint research projects and the creation of a decision support tool to inform managers about holistic resilience, the workshop further demonstrated the limits of such collaborations and especially the current lack of autonomous appropriation of the resilience tool, or even the concept.

3.2.2 Quebec, Canada

Two exercises were carried out in Quebec concerning a more general problem related to water, namely risks to the drinking water supply. This problem is interesting at many levels. In the short term, it makes it possible to investigate the level of preparedness and emergency measures. In the long term, combined with climate change, it shows the importance of implementing measures to protect this resource (Janke et al., 2014). The long-term view also highlights the importance of considering future uses in relation to current decisions.

The exercises were done in the course of a research project on the vulnerability and resilience of regional territories' CIs in a context of climate change. The project is being executed in two regional county municipalities (RCMs, or groups of municipalities) in the province of Quebec. Case studies were done in each RCM. The goal is to better understand the challenges related to communities' resilience in connection with their dependency on the various CIs that exist on their territory.

These case studies made it possible bring together close to 30 participants, from numerous essentially public organizations (Tab.2) in each RCM. To orient these case studies, all participants were asked to do some preliminary work to identify the first management measures they would apply in case of a shortage of drinking water. Ideally, these measures should be supported by emergency measures, business continuity and asset protection plans. In a plenary session, these actions were presented and discussed in order to identify possible disparities among these decisions but also, and most importantly, to identify the relevant organizational interdependencies. An assessment was done of the possible integration of concepts related to climate change in decision-making.

Type of actors/ Services	Attending stakeholders
Urban Managers	General manager Fire department Public work department Water management Wastewater management Infrastructure management General administration
RCM	General manager's GIS expert
Government	Ministère de la Sécurité publique du Québec Ministère de l'Environnement et Lutte contre les changements climatiques Ministère des Affaires municipales et Habitation
Academics	Montreal Polytechnic The University of Public Administration
Experts	OURANOS consortium

Table 2: Quebec's workshop stakeholders

In terms of results, there was no disparity in the analyses carried out in the two RCMs, despite the differences in the occupation of the territory and socioeconomic issues. Several findings emerged regarding the analysis of the resilience of the communities on these territories in the face of CIs. The concept of knowledge immediately became salient. Many stakeholders did not have adequate knowledge of the concept of CI, even when their own organization was considered to be one. All decisions were made in a single-organization context, without considering possible dependencies on other CIs. The corollary is that crisis management planning tools do not take account of these dependencies, given that they are not widely known. Finally, most planning tools are centered on management based on the security of the population over a period of several days, but there is practically no consideration of the socioeconomic consequences for the territory over a longer period.

4 How do collaborative workshops improve risk management perspectives in France and Canada?

4.1 Advantages and disadvantages of collaborative workshops

The results of the workshops are mixed. A significant lack of coordination and cohesion between stakeholders was highlighted. Both for tools meant to integrate organizational resilience into the various stakeholders' operations in the territory and for tools codesigned with the players in the territory to increase holistic resilience, the gap between the scientific approach and managers' appropriation of the concept is still a large one.

Some advice and suggestions can already be made to improve cohesion between players facing a common risk. In the case of Avignon, risk management measures should be put in place that consider specific time frames. For instance, it is necessary to measure the duration of CI autonomy. For instance, can the hospital generators' autonomy be measured in hours, days or weeks? Particular attention should be paid to how to initiate joint discussions of business continuity plans. What if electricity is not available for more than a week? Which spatial areas will be impacted? And what part of the population will be most vulnerable? The most important weakness that will have consequences in the short, medium and long term remains the lack of coordination, cohesion and communication among the various stakeholders, departments and managers. Efforts must therefore focus first and foremost on this point. With this in mind, the academic team that worked on the Avignon decision support tool to increase resilience took several actions to contribute to improving this weakness. In order to achieve a global, co-constructed vision, the academic team sought to feed this collaboration – first of all by bringing together local players and students to discuss the flood risk and planning. This kind of association allows students to be involved in projects on the territory where they live and gives them a chance to put their theoretical learning into perspective based on the realities on the ground. The idea is to make this collaboration a long-term one in order to allow different points of view to come into contact, to track changes in the territory and its policies, as well as the theoretical advances that the students represent. In addition, following the discussions at the workshop, certain city departments (mobility, waterworks, etc.) specifically asked to work together with local stakeholders and researchers on the challenges of increased flooding, development and resilience. This extremely positive result shows the growing need for territories to acquire strategies and tools to operationalize urban resilience, but also demonstrates the feasibility and usefulness of this type of approach.

Regarding follow-up after the workshop held in Quebec, ongoing work has been arranged. Individual and/or subgroup meetings are in progress in the coming months to clearly identify the issues and create a portrait of the situation. The number and diversity of the actors involved also explain the need to work in subgroups in order to develop trusting discourse and address the issues subject to debate in more depth; this is impossible if stakeholders cannot or do not feel free to express themselves, particularly because of tensions between organizations.

The French study is being continued by means of weekly meetings with the city service departments in order to work jointly on a short- and long-term strategy to integrate resilience into communal services and vulnerable populations (particularly by means of interventions with schools in flood zones). The concrete outcome of this collaboration process will be the construction of an official operational document, as well as some scientific work (participation in joint presentations). The aim is to develop a “toolbox” that managers can use to work through the various time frames of flood risk, in order to be proactive in dealing with growing uncertainty. This toolbox includes the mapping tool but expands the approach with a more general reflection process intended to determine the premises for a resilience observatory, for which the test territory would be Avignon; this observatory would be the outcome of a scientific analysis and managers’ practice and experience on the territory.

The findings of the two Canadian workshops echo those of a previous workshop held on the city of Montreal. Planning (emergency measures, business continuity, asset protection) exists but it is not uniform. The levels of acceptance of the consequences and failures are not uniform either. The anticipation thresholds of failures and alert levels are highly variable. On the other hand, the stakeholders agreed that knowledge of CIs and organizations’ dependency on those CIs is the core of resilience. To improve the capacity to manage disruptions, it is important to be familiar with the territory and the CIs that exist on it. This knowledge can then be integrated into numerous planning tools and exercises.

To reach this conclusion, it is important to properly characterize the territory in terms of CIs. More operational exercises regarding the real-life capacity to manage disruptions must be done. The act of working on a case of a shortage of drinking water – a situation that changes over time and quickly affects the population, as well as industrial activity – highlighted the need to link CI failures to their economic consequences.

From the point of view of following up on these workshops and developing a strategy in accordance with managers' needs, the Canadian research work continued with the definition and mapping of CIs on the test territories, with the managers' agreement. To identify and characterize CIs on the RCMs' territories, the concept of key elements was used. An element deemed to be key is one on which a CI manager's or owner's management, operating, exploitation and control activities depends. If this element becomes unavailable, the operation or management of the CI will be disrupted or interrupted. For each CI for which the key elements have been identified on the territory, all the stakeholders must establish an overall level of consequences on the territory in the event of a service interruption. The assessment of these consequences must incorporate a temporal parameter that assigns an order of magnitude to their appearance.

For this reason, each key element that is mapped is linked to a CI for which the consequences on the territory were evaluated by consensus. This knowledge, which is the heart of resilience, will directly enable the many organizations involved to enhance their ability to manage disruptions related to CIs. This knowledge must be integrated into:

- The creation of climate risk maps;
- The management of short- and medium-term climate risks;
- The management and development of the territory;
- The updating of municipal and regional emergency measures plans;
- The updating of business continuity plans;
- Etc.

Although the results of the first workshops have revealed the gap between scientific progress and its appropriation by managers, the continuation of these discussions, particularly by backtracking to engage in primarily informative work (definition, location and mapping) on CIs, has made it possible to keep the discussions active, ask further questions about the status of territorial knowledge related to risk, and advance together to creating a knowledge base and a tool based on managers' and urban decision-makers' practices.

4.2 Potential for spatial decision support systems use and appropriation

The creation of and reflection on these tools highlighted the challenges of operationalizing resilience. Although these tools have advanced the understanding, definition and appropriation of the concept of resilience, its operationalization by urban managers so far has been limited, to say the least. This limitation was explained in particular by the lack of support and autonomy in the use of these tools, which received very limited practical use by managers. The workshops highlighted the advances but also the technical and theoretical limitations of these tools (general lack of knowledge of tools, too specific technicality of the tools, inadequacy of the tools in the face of local risk management knowledge and practices, partial misunderstanding of the vocabulary used; etc.). This reflection and collaboration process has made it possible to restart the debate on the concept of resilience, its definition, and the criteria for integration into risk strategies. Integrating the points of view, experiences and subtle reflections of the different actors involved in risk management (both managers and citizens) leads to a profound questioning of these tools and their adoption by local stakeholders.

Therefore, a paradigm shift must take place in order to integrate stakeholders. Although this transition may seem insurmountable to some people and unproductive to others, it has nevertheless been proven that the construction of a base of knowledge common to experts and lay people makes it possible to reduce complexity, take each party's interests into account, and encourage the acceptance and appropriation of solutions (Toubin, 2014). Thus, despite the necessary efforts to build this trust, collaboration and common dialogue, the result is better integration and acceptance of the work of the experts. In addition, since these subjects, such as environmental issues, urban risks and climate change, affect and involve all stakeholders, integrating them not only makes it possible to address new points of view and approaches but also to build knowledge equity. Thus, the integration of the various players has a doubly positive impact: it makes it possible to meet the objectives of an urban project by improving the proposals but is also an objective in itself by respecting the wishes underlying the consultation process.

Managers need to be flexible so they can adapt and negotiate so they can convince (Joerin, 1997). In that way, right from the outset of a project, they can formalize a vision and ensure knowledge co-construction among the different actors. As a result, the outcome will be more legitimate and relevant. Thus, through dialogue, compromise and individual awareness, environmental strategies and adaptation strategies in response to risks will have a greater chance of having a real positive impact on a territory and its population.

Briefly, the operationalization of resilience necessarily requires the involvement of multiple actors in order to propose coherent urban planning and adaptation strategies that will best respond to the threat of increasing risks in urban areas.

5 Conclusion

In a context of climate change, with the increasing frequency and intensity of natural disasters, resilience emerged in the 2000s as an innovative concept in risk management. As an innovative concept – at the political, urban, architectural and social levels – resilience has struggled to respond to the challenges of growing climate uncertainties and to urban managers' questions. While strategies now exist to attempt to address the biases of this concept by working on its operationalization – notably through the creation of simulation (Robert et al., 2017) and measurement tools (Serre and Heinzlef, 2018) – the appropriation of the concept of resilience and its translation into risk management strategies are still very limited. This is why, after working on tools to define and operationalize the concept, we focused on the need to work through collaborative approaches with urban managers and decision-makers to address climate change issues, climate and urban uncertainties, and resilience strategies.

This paper emphasizes the difficulty of operationalizing resilience. It presents two approaches that are intended to be innovative, both in their theoretical underpinnings (organizational approach and holistic approach) and in their implementation (collaboration with local actors). Nevertheless, the results of workshops to determine whether flood risk management strategies and systems integrate resilience are extremely mixed. Although the concept itself is known and mentioned in official and individual speeches, its operationalization and integration into objectives, actions, strategies in the short, medium and long term, has barely begun.

Nevertheless, setting up these workshops enabled us to make tangible progress toward improving resilience tools. While they are generally known in scientific circles, their appropriation by managers is not yet fully effective. Although the results in themselves are mixed, they have made it possible to build a common approach over the long term.

These workshops allowed academic conceptions and practical realities to come face to face in dealing with the issue of resilience and climate change. Awareness of the limits that still persist today will allow communities to deepen their understanding of the challenges involved in integrating the concept of resilience into their urban practices. In that way, they may be able to face climate uncertainties and also to address some of the issues observed during these exchanges. As a result, these decision support tools may become as relevant as possible in dealing with practical realities and the concerns and practices of stakeholders. Ultimately, they may help to build a bridge between scientific advances and the real-world experiences of urban managers.

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