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Application of the DS3 model to the stormwater sewerage system at the neighborhood level

Application du modèle DS3 au système d'assainissement pluviale à l'échelle du quartier

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RÉSUMÉ

Des changements récents dans les villes et leur environnement causés par une urbanisation rapide couplé à un changement climatique, augmentent la probabilité et l'impact des inondations. Par conséquent, il est nécessaire pour toutes les villes de s'adapter aux changements climatiques et socio-économiques en développant des nouvelles stratégies de gestion du risque d'inondation. Suite à un changement de paradigme des approches traditionnelles vers des approches plus intégrées, et en considérant les incertitudes liées au futur développement urbain, une des tâches le plus important pour les gestionnaires de la ville devient le développement des villes résilientes. Cependant, le sens du concept de résilience et son opérationnalité reste encore vague. L'objectif de cette recherche est d'étudier la façon dont les disciplines de génie et conception urbaine pourraient améliorer la résilience des quartiers face au risque d'inondation. Cet article présente le modèle DS3, lequel nous considérons pertinent pour analyser et puis implémenter la résilience à travers la conception du quartier. En utilisant ce modèle, nous analysons le système d'assainissement des eaux pluviales à l'échelle du quartier dans deux sites spécifiques : Rotterdam et la Nouvelle-Orléans.

ABSTRACT

Recent changes in cities and their environments caused by rapid urbanization and climate change have increased both the flood probability and the severity of flooding. Consequently there is a need for all cities to adapt to climate and socio-economic changes by developing new strategies of flood risk management. Following a risk paradigm shift from traditional to more integrated approaches, and considering the uncertainties of future urban development, one of the main emerging tasks for city managers, becomes the development of resilient cities. However, the meaning of resilience concept and its operability is still not clear. The goal of this research is to study how the urban engineering and design disciplines can improve the resilience to floods in urban neighborhoods. This paper presents the DS3 model that we consider relevant to analyze and then implement resilience into the neighborhood design. Using this model, we analyze and discuss the stormwater sewerage system at the neighborhood scale in two specific sites: Rotterdam and New Orleans.

KEYWORDS

DS3 model, Neighborhood, Stormwater sewerage system, Urban resilience

1 INTRODUCTION

The resilience concept as applied to risk management has emerged to meet the needs not satisfied by the current measures and strategies. The concept of resilience is shown through actions that reduce the consequences due to disturbances, considering that these disturbances can lead to a more sustainable urban development opportunity (Serre, 2011). Rebuilding risk management modes by means of resilience concept imposes creative thinking and innovations that modify current strategies to focus on a dynamic, systemic and an integrated approach. This takes all dimensions of the city and its interactions into account, in an organized and multi scalar manner (Serre et al., 2012).

However, the meaning of resilience and its operability in risk management, and particularly in flood risk management, remains vague (Lhomme, 2012). Relative to urban design, several ongoing or already executed projects and/or measures have been defined as “resilient”, allowing improved flood resilience of the city. Nevertheless, a framework to analyze and to justify how a specific action of urban design can contribute to improving resilience does not yet exist.

In our research, the concept of resilience is defined as « the ability of a system to absorb a disturbance and recover its functions following the disturbance » (Lhomme, 2012). Indeed, in the resilience context, the object studied is a system. Assuming that the city can be considered as a system, the resilience definition can be transposed to the urban context as: « the ability of a city to operate in a degraded mode and recover its functions while some urban components remain disrupted » (Lhomme, 2012).

The goal of our research is to investigate how the resilience concept can be incorporated into the urban design at the neighborhood scale. By focusing on the physical dimension of the neighborhood, we aim to specify how it can be designed and/or renovated to achieve the desired level of flood urban resilience while retaining the urban qualities required for a sustainable operation. For this purpose, we are going to use the DS3 (Spatial Decision Support System for resilience capacities enhancement) model which previously has only been applied to study the resilience of urban networks.

In this article we present the application of the DS3 model to the stormwater sewerage system at the neighborhood level using two particular sites: Rotterdam and New Orleans. Using this model we analyze how different engineering and design actions relative the stormwater sewerage system at the neighborhood scale can contribute to improved resistance, absorption or recovery capacities, and consequently urban resilience to floods in particular.

2 METHODOLOGY

2.1 The DS3 model

Lhomme (2012), according to its urban resilience definition, has developed a conceptual model to analyze the resilience of urban networks: the DS3 model. In this model, three capacities have been defined as essential to study the resilience of urban networks (Serre, 2011): resistance, absorption and recovery. The Lhomme (2012) approach is based on the performance of the urban system at the city level and focuses on a physical urban dimension, particularly on technical aspects. Because our research is also based on the urban system’s performance, we consider that the DS3 model can also be relevant and be adapted to our study.

To date, the DS3 model has only been applied to studying and assessing the resilience of urban networks. Using the model we aim to analyze how different urban design actions can contribute to improved resistance, absorption or recovery capacities, and consequently urban resilience to floods in particular. The idea is to develop resilience criteria to guide a neighborhood’s design by integrating flood resilience in its performance. Each capacity and its adaptation at the neighborhood level are presented below.

2.1.1 *Resistance capacity*

In the context of the resilience concept, the resistance capacity of a system begins with a system damage analysis. Resistance capacity should be considered as the starting point for any resilience analysis. It is necessary to know the potential damages so that the failure which the system must be able to absorb and from which it needs to recover. Thus, in order to study the resistance capacity of a neighborhood, it should be analyzed its damage and how this could be reduced, thereby improving its

performance during a flood.

2.1.2 Absorption capacity

On the other hand the absorption capacity is an action that involves the assimilation of something (in this particular case, a disturbance) that needs to accommodate the disturbance rather than to oppose it, thereby introducing the disturbance in the system's performance. The study of the absorption capacity refers to the alternatives that can be offered by the system following the failure of one or more of its components (Serre, 2011). This requires studying its redundancy properties. Indeed, the redundancy is defined as one of the properties characterizing the resilience of different systems (Clarke et al., 1998) (Bruneau et al., 2003) (Ahern, 2011). Usually, if a component of a system ceases to work (it does not achieve its function), a redundant system can mitigate this failure with an alternative (Serre, 2011). Regarding the absorption capacity of a neighborhood, we are going to analyze the alternatives that can be offered by the physical characteristics of the neighborhood following the failure of one or more of its components.

2.1.3 Recovery capacity

Finally, the recovery capacity is the most representative of the resilience concept (Serre, 2011). Recovery does not mean returning to a previous state, but rather a functional recovery of the system. The recovery leads the system to recover a state, a structure or a property (Lhomme, 2012). The recovery capacity of a neighborhood could be the time required for the function recovery of the components damaged to return to an operational state. Consequently, we are going to analyze how the physical dimension of the neighborhood can contribute in order to recover to an acceptable level of performance of the neighborhood as soon as possible.

The logic of the DS3 model when applied at the neighborhood level is shown in the figure 1.

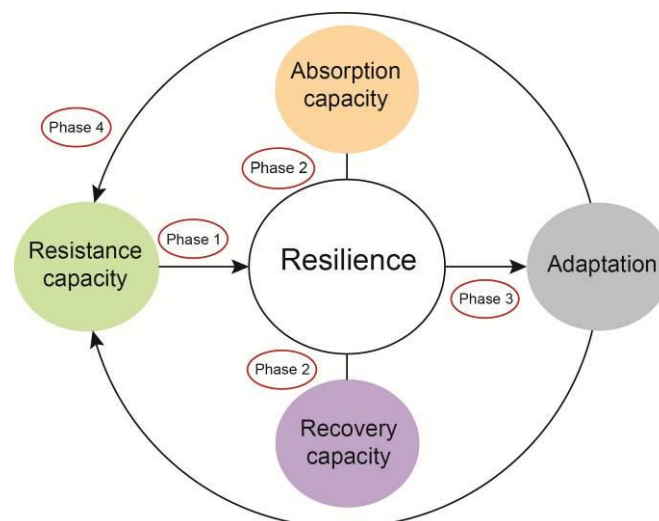


Figure 1: DS3 model representation

The resistance capacity or the physical damage (failure) of the neighborhood is the basis to start the resilience analysis (phase 1). Then the neighborhood resilience draws on its resources (phase 2) for a purpose: the adaptation of the neighborhood to floods (phase 3). Such adaptation requires a return to the resistance capacity (phase 4) because it can change disturbances, inducing new or different disturbances.

2.2 Particular case studies

Rotterdam and New Orleans are both located in Deltas, exposed the both to rising sea levels and to increasing extreme precipitations, both as consequences of climate change. A really important characteristic of these cities is their topographic elevation which is both cause and effect of the geology, pedology and hydrology of the cities. Indeed, the average elevation of the cities is below sea level, 4 meters in Rotterdam and between 1 and 0'5 meters in New Orleans.

As a consequence of these characteristics and their existing stormwater sewerage system, Rotterdam and New Orleans have significant problems associated with flooding during heavy rains. Flooding from

internal waters is really common in in both cities, and even this kind of flooding leads to extensive damage to the urban networks, homes and businesses.

Even if the solution to deal with this problem could be changing the completely stormwater sewerage system, the amount of money and the period of time that would represent rebuilding such system makes this solution impossible. However, other options and solutions have been already considered in both cities.

2.2.1 Rotterdam

The main sewerage system in Rotterdam is a combined system which transports both urban runoff and wastewater in single pipelines to the wastewater treatment plants (WWTP). The pipelines do not have sufficient capacity to transport rainwater during intense rainstorms. As a result of the insufficient capacity there are combined sewer overflows (CSO's) into the surface water (De Graaf, 2009). Thus, different possible ways to avoid this problem have been developed and implemented throughout Rotterdam (Tab. 1).








ROTTERDAM stormwater sewerage system			
Project/Measure	Description	Examples	Functions
Green and water roof 	During heavy rainfall events, these green and water roofs are a highly valuable solution for temporary water storage	Green roof at the Westblaak building	Temporary storage water Absorb water Infiltrate water
Water plaza 	These water plazas fill up in a controlled manner during heavy rainfall, preventing surrounding streets from flooding. They can be used as a playground in normal weather conditions	Water plaza Benthemplein	Temporary storage capacity Collect water
Multifunctional car park 	The car park will be equipped with an underground water storage. The water will be stored in a reservoir at the base of the structure	Car park near the Museumpark (it will carter for 1200 cars and 10000 m ³ meters of water)	Temporary storage water
Separated sewer systems 	Two conduits are constructed which transport runoff to the urban surface water system and wastewater to the treatment plant. Stormwater is usually discharged direct to the nearest watercourse	In new urban areas and renewal areas	Collect water Convey water
Reopening culverts 	Culverts tend to increase flood risk, especially if they are either too narrow in diameter or become blocked by debris. Compared with an open stream, access for maintenance of culverted watercourses is also limited		Collect water Convey water
Gardens 	Gardens can be used as infiltration and to absorb rainwater	Gardens in several neighborhoods	Infiltrate water Absorb water
Over flow system 	Over system can increase the collection capacity of individual houses		Collect water Convey water

Table 1: Stormwater sewerage system measures at the neighborhood scale in Rotterdam

Table 1 informs about projects and/or measures concerning the stormwater sewerage system at the

neighborhood level in Rotterdam. It shows projects and/or measures with a brief description, specific examples and the functions that they perform.

2.2.2 New Orleans

New Orleans has a separate stormwater and sanitary sewer systems; stormwater runoff and wastewater are not conveyed in single pipelines to the treatment plant. The stormwater (or drainage) runoff is transmitted to large drainage pumping stations and the overwhelming majority of it is pumped into Lake Pontchartrain, it is not treated in any way. During a rainstorm, periods of heavy rain can far exceed the capacity of the drainage systems, even when they are functioning at full capacity. The insufficient capacity of the drainage system causes runoff back into the streets, and sometimes into the homes and businesses. Thus, to deal with it, several projects and/or measures have been developed throughout New Orleans (Tab. 2).








NEW ORLEANS stormwater sewerage system			
Project/Measure	Description	Examples	Functions
Extensive tree canopy 	Establish planting and maintenance programs to provide an extensive tree canopy that shades each neighborhood's streets		Detain water Absorb water Infiltrate water
Shape existing parks with berms and low areas 	It will be used for water storage so that excess runoff from a neighborhood street can be safely retained	Wally Pontiff Park is a neighborhood-scale water retention area	Retain water Temporary storage water
Pedestrian corridors and pocket parks 	Use vacant lots and other underutilized spaces, including infrastructural rights of ways to create stormwater corridors and storage areas where water can be held and allowed to soak in our soils		Detain water Temporary storage water
Vegetated roadside swales 	Vegetated roadside swales to collect and filter stormwater at the street edge	Raingardens on Portland street detain water before it reaches the drainage system	Absorb water Infiltrate water Detain water
Pervious paving in low-traffic areas 	Pervious paving in low-traffic areas to reduce runoff and treat stormwater		Absorb water Infiltrate water
Curb cuts in the street 	Curb cuts in the street to divert water from storm drains into neutral grounds and street-side rain gardens instead, so that road runoff can be stored and treated	Some neighborhood's streets	Infiltrate water Detain water
Water detention basin next to a sidewalk 	The water detention basin would delay a portion of peak-flow discharge extends the capacity of the existing drainage system	Water detention basin at the Aviators Street. During dry conditions it would function as a flexible performance	Infiltrate water Temporary storage water

Table 2: Stormwater sewerage system measures at the neighborhood scale in New Orleans

Table 2 informs about projects and/or measures concerning the stormwater sewerage system at the

neighborhood level in New Orleans. It shows projects and/or measures with a brief description, specific examples and the functions that they perform.

3 RESULTS AND DISCUSSION

3.1 Results of the analysis

Using the DS3 model presented earlier and considering the different engineering and design actions concerning the stormwater sewerage system at the neighborhood scale in both Rotterdam and New Orleans, we can then proceed to study how these actions can contribute to improving resistance, the absorption or recovery capacity of the neighborhood, and consequently its urban resilience to floods.

By applying these capacities to the stormwater sewerage systems of the neighborhood, three main research questions have been formulated:

- Do stormwater sewerage systems contribute to reducing the damage of the neighborhood by improving its performance during a flood? How does it contribute?
- Do stormwater sewerage systems contribute to the alternatives that the neighborhood can offer following the failure of one of its components? How does it contribute?
- Do stormwater sewerage systems provide factors that allow the neighborhood to recover to a level of acceptable performance as soon as possible? Which are factors are involved?

We aim to answer these three questions through the tables we present as follows for each city (Tab. 3 and Tab. 4). The table 3 and table 4 show how each project and/or measure at the neighborhood scale contributes to improving resistance, absorption or recovery capacity. We show a positive contribution with a green arrow and when there is no contribution with a red arrow.

3.1.1 Rotterdam results

In Rotterdam (Tab. 3), the resistance capacity is improved by measures performing the function of rainwater absorption (green and water roofs, gardens...), rainwater temporary storage (water plaza, car park...) and rainwater conveyance (separated sewer systems, over flow system...) in the neighborhood. The absorption of rainwater diminishes the surface runoff, reducing possible physical damage to the neighborhood and so improving its performance during a flood. The temporary storage and conveyance of rainwater take pressure off the pipelines, thereby avoiding the overflow and damage of the pipelines, and improving the performance of the neighborhood during a flood.

On the other hand, the absorption capacity is enhanced by the measures such as temporary rainwater storage (green and water roof, water plaza, car park...) in the neighborhood. Indeed, the temporary storage of rainwater provides an alternative to the neighborhood when the pipelines capacity is overflowed, allowing the failure mitigation.

Finally, the measures for rainwater collection (water plaza, car park), rainwater temporary storage (water plaza, car park) in the neighborhood and the measures which can be easily maintained (culverts reopened), contribute positively to enhance the recovery capacity. The collection and the temporary storage of rainwater reduce surface runoff enabling an earlier recovery of an acceptable neighborhood performance.

3.1.2 New Orleans results

In New Orleans (Tab. 4), the resistance capacity is improved by the measures that achieve the following functions: rainwater absorption (tree canopy, vegetated roadside swales...), rainwater detention (pedestrian corridors and pocket parks, curb cuts...) and rainwater temporary storage (parks with low areas, water basin...). The absorption of rainwater diminishes the surface runoff reducing possible physical damage of the neighborhood and improves its performance during a flood. The detention and the temporary storage of rain water take pressure off the pipelines, avoiding the overflow and damage to the pipelines, and thereby improving the performance of the neighborhood during a flood.

The absorption capacity is enhanced by various measures including measures achieving the function

of temporary rainwater storage (Parks with low areas, curbs cuts...) in the neighborhood. The temporary storage of rainwater provides an alternative to the neighborhood when the capacity of the pipelines is exceeded, allowing the mitigation of this particular failure.

The recovery capacity is improved by the measures performing the function of rainwater temporary storage (parks with low areas, water basin...) in the neighborhood. The temporary storage of rainwater reduces surface runoff which allow for an earlier recovery of a neighborhood operation.








ROTTERDAM stormwater sewerage system			
Project/Measure	Resistance capacity	Absorption capacity	Recovery capacity
Green and water roof 	<p>↑ It improves the performance of the neighborhood because it absorb water, reducing possible damage</p> <p>↑ It improves the performance of the neighborhood because it allow temporary water storage and to take pressure off the pipelines (not overflow the pipelines capacity)</p>	<p>↑ It provides an alternative to the neighborhood when the pipelines capacity is overflowed, because it allow temporary water storage, it allow mitigate the failure</p>	<p>↓ No significant contribution</p>
Water plaza 	<p>↑ It improves the performance of the neighborhood because it allow temporary water storage and to take pressure off the pipelines (not overflow the pipelines capacity)</p>	<p>↑ It provides an alternative to the neighborhood when the pipelines capacity is overflowed, because it allow temporary water storage, it allow mitigate the failure</p>	<p>↑ It contributes to recover an acceptable performance of the neighborhood because it allow water collection and temporary water storage reducing runoff</p>
Multifunctional car park 	<p>↑ It improves the performance of the neighborhood because it allow temporary water storage and to take pressure off the pipelines (not overflow the pipelines capacity)</p>	<p>↑ It provides an alternative to the neighborhood when the pipelines capacity is overflowed, because it allow temporary water storage, it allow mitigate the failure</p>	<p>↑ It contributes to recover an acceptable performance of the neighborhood because it allow water collection and temporary water storage reducing runoff</p>
Separated sewer systems 	<p>↑ It improves the performance of the neighborhood because it allow more water conveyance reducing possible damage of wastewater pipelines</p>	<p>↓ No significant contribution</p>	<p>↓ No significant contribution</p>
Reopening culverts 	<p>↑ It improves the performance of the neighborhood because it avoids the damage of the pipelines produced by a high water pressure</p>	<p>↓ No significant contribution</p>	<p>↑ It contributes to recover an acceptable performance of the neighborhood because it can be easily maintained</p>
Gardens 	<p>↑ It improves the performance of the neighborhood because it absorb water, reducing possible damage</p>	<p>↓ No significant contribution</p>	<p>↓ No significant contribution</p>
Over flow system 	<p>↑ It improves the performance of the neighborhood because it allow water conveyance and to take pressure off the pipelines (not overflow pipelines capacity)</p>	<p>↑ It provides an alternative to the neighborhood when the pipelines capacity is overflowed, because it allow temporary water storage, it allow mitigate the failure</p>	<p>↑ It contributes to recover an acceptable performance of the neighborhood because it allow water collection reducing runoff</p>

Table 3: Rotterdam capacities analysis








NEW ORLEANS stormwater sewerage system			
Project/Measure	Resistance capacity	Absorption capacity	Recovery capacity
Extensive tree canopy 	<p>↑ It improves the performance of the neighborhood because it absorb water, reducing possible damage</p>	<p>↓ No significant contribution</p>	<p>↓ No significant contribution</p>
	<p>↑ It improves the performance of the neighborhood because it detain water, slowing down runoff which gives the water a change to soak into the soils</p>		
Shape existing parks with berms and low areas 	<p>↑ It improves the performance of the neighborhood because it allow temporary water storage and to take pressure off the pipelines (not overflow the pipelines capacity)</p>	<p>↑ It provides an alternative to the neighborhood when the pipelines capacity is overflowed, because it allow temporary water storage, it allow mitigate the failure</p>	<p>↑ It contributes to recover an acceptable performance of the neighborhood because it allow temporary water storage reducing runoff</p>
	<p>↑ It improves the performance of the neighborhood because it detain water, slowing down runoff which gives the water a change to soak into the soils</p>		
Pedestrian corridors and pocket parks 	<p>↑ It improves the performance of the neighborhood because it detain water, slowing down runoff which gives the water a change to soak into the soils</p>	<p>↑ It provides an alternative to the neighborhood when the pipelines capacity is overflowed, because it allow temporary water storage, it allow mitigate the failure</p>	<p>↑ It contributes to recover an acceptable performance of the neighborhood because it allow temporary water storage reducing runoff</p>
	<p>↑ It improves the performance of the neighborhood because it allow temporary water storage and to take pressure off the pipelines (not overflow the pipelines capacity)</p>		
Vegetated roadside swales 	<p>↑ It improves the performance of the neighborhood because it absorb water, reducing possible damage</p>	<p>↓ No significant contribution</p>	<p>↓ No significant contribution</p>
	<p>↑ It improves the performance of the neighborhood because it detain water, slowing down runoff which gives the water a change to soak into the soils</p>		
Pervious paving in low-traffic areas 	<p>↑ It improves the performance of the neighborhood because it absorb water, reducing possible damage</p>	<p>↓ No significant contribution</p>	<p>↓ No significant contribution</p>
	<p>↑ It improves the performance of the neighborhood because it detain water, slowing down runoff which gives the water a change to soak into the soils</p>		
Curb cuts in the street 	<p>↑ It improves the performance of the neighborhood because it detain water, slowing down runoff which gives the water a change to soak into the soils</p>	<p>↑ It provides an alternative to the neighborhood when the pipelines capacity is overflowed, because it allow temporary water storage, it allow mitigate the failure</p>	<p>↑ It contributes to recover an acceptable performance of the neighborhood because it allow temporary water storage reducing runoff</p>
	<p>↑ It improves the performance of the neighborhood because it allow temporary water storage and to take pressure off the pipelines (not overflow the pipelines capacity)</p>		
Water detention basin next to a sidewalk 	<p>↑ It improves the performance of the neighborhood because it allow temporary water storage and to take pressure off the pipelines (not overflow the pipelines capacity)</p>	<p>↑ It provides an alternative to the neighborhood when the pipelines capacity is overflowed, because it allow temporary water storage, it allow mitigate the failure</p>	<p>↑ It contributes to recover an acceptable performance of the neighborhood because it allow temporary water storage reducing runoff</p>
	<p>↑ It improves the performance of the neighborhood because it detain water, slowing down runoff which gives the water a change to soak into the soils</p>		

Table 4: New Orleans capacities analysis

3.2 Discussion

The conceptual DS3 model has been used in this research to analyze how different engineering and design actions relative to stormwater sewerage system at the neighborhood scale contribute to the improvement of urban resilience to floods in Rotterdam and New Orleans.

The results suggest that most of the measures developed at the neighborhood scale in Rotterdam as well as in New Orleans contribute positively to enhancing resistance, absorption and recovery capacities. It highlights that these capacities are not affected similarly by the measures. Indeed, the resistance capacity is the most improved; all measures contribute in some way to improve this capacity.

Even if we realize that the functions allowing improving capacities are very similar in both Rotterdam and New Orleans, the measures performing these functions are not the same. For example, in Rotterdam the measures which achieve the function of rainwater temporary storage are green and water roofs, water plazas and a car park. In New Orleans the measures used to achieve this function are parks with berms and low areas, pedestrian corridors and pocket parks and water basins next to the sidewalk. The measures used in New Orleans are much more natural and certainly less expensive than those used in Rotterdam, where significant infrastructures enhancements have been developed. Even though both Rotterdam and New Orleans face similar physical and environmental conditions, the socio-economic challenges in both cities are very different. Certainly, the lack of density of New Orleans makes less expensive solutions suitable.

Finally, we want to emphasize the robustness of the DS3 model in this research. We consider that it provides a good qualitative analysis of how the stormwater sewerage systems, at the neighborhood scale, contribute to improve urban resilience to floods. However, the model has only been applied to study the stormwater sewerage system of two particular sites. Thus, more sites need to be studied for the complete validation of the model. Specially, it would be interesting to analyze other sites with different topographical, geological and hydrological features. Nevertheless, the results obtained to date, already suggest that the DS3 model can be a relevant conceptual tool to implement resilience in existing and/or new neighborhoods.

4 CONCLUSION

The meaning of urban resilience concept and its operability in flood risk management is not clear. As regards urban engineering and design disciplines, no framework has been developed to analyze and justify how specific engineering and design actions can contribute to improve urban resilience relative to floods.

The DS3 model as defined in this research and applied to stormwater sewerage system at the neighborhood scale seems to be appropriate for analyzing how this system can improve the resilience of the neighborhood to floods, using three essential capacities to study resilience: resistance, absorption and recovery.

The results from these two particular case studies (Rotterdam and New Orleans) show the importance of the stormwater sewerage system at the neighborhood scale to improve urban resilience to floods. Consequently, this system should be seriously considered when designing flood resilient neighborhoods.

In conclusion, even if in this research we only applied the DS3 model to the stormwater sewerage systems, we aim also to integrate in our study all urban technical components (infrastructures, buildings, protective systems...) to finally achieve a holistic and complete analysis of the neighborhood urban resilience to floods.

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