Analysing urban resilience through alternative stormwater management options: application of the conceptual Spatial Decision Support System model at the neighbourhood scale

M. Balsells, B. Barroca, J. R. Amdal, Y. Diab, V. Becue and D. Serre

ABSTRACT

Recent changes in cities and their environments, caused by rapid urbanisation and climate change, have increased both 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 for 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 the resilience concept and its operability is still not clear. The goal of this research is to study how urban engineering and design disciplines can improve resilience to floods in urban neighbourhoods. This paper presents the conceptual Spatial Decision Support System (DS3) model which we consider a relevant tool to analyse and then implement resilience into neighbourhood design. Using this model, we analyse and discuss alternative stormwater management options at the neighbourhood scale in two specific areas: Rotterdam and New Orleans. The results obtained demonstrate that the DS3 model confirmed in its framework analysis that stormwater management systems can positively contribute to the improved flood resilience of a neighbourhood.

Key words | DS3 model, neighbourhood scale, stormwater management system, urban resilience

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INTRODUCTION

Flood events consistently demonstrate the need to question the preparedness of cities for flooding, especially considering the backdrop of population growth, trend towards climate change. The causes of floods are shifting and their impact is accelerating (Schefault *et al.* 2011). Indeed, during the last few years extremely damaging floods have occurred around the world: Thailand 2011, United States and United Kingdom 2012, Australia, Central Europe and China 2013, etc.

The recent shift in flood risk management accepts that floods cannot be prevented, but the impacts on and vulnerability of risk prone urban systems can be reduced. Today, several studies are looking at the concept of urban resilience as a new approach, which leads to projects and strategies that better integrate water and flood risk into city planning and disaster preparedness (Serre 2011). The concept of resilience is presented as one means for urban systems to cope with unexpected shocks and to achieve sustainability over time. Reorienting risk management by using the concept of resilience introduces creative thinking and innovations into current strategies focusing on a dynamic, systemic and an integrated approach. This takes all the dimensions of the

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city and its interactions into account, in an organised and multi-scale manner (Serre *et al.* 2013).

Even if resilience applied to the urban context overcomes conceptually and methodologically sectorial analyses, it is difficult to make it operational because urban resilience provides multiple translations in terms of issues and methodology development (Toubin *et al.* 2012). Indeed, the definition of urban resilience is open to debate and this makes it difficult to apply it in practice. However, with regard to flood risk management, several current studies (e.g. De Brujin (2005); Colten *et al.* (2008); Ahern (2011); Sajaloli *et al.* (2011); Barroca *et al.* (2012); Gersonius (2012); Khaimi & Perera (2012); Lhomme *et al.* (2013); De Graaf *et al.* (2013)) and projects (e.g. FRC – Flood Resilience City project (www.floodresiliencity.eu); FloodProBE project (www.floodprobe.eu); SMARTeST project (www.floodresilience.eu); FREEMAN project (www.feem-project.net); CORFU project (www.corfu7.eu); Resilis project (www.resilis.fr)) seek to make the concept of urban resilience operational through different approaches, according to the different urban dimensions (social, economic, physical) or spatial scales involved. Certain models, factors, indicators, etc. have already been developed in order to analyse and/or assess urban resilience to floods.

This literature review highlights the fact that to date, almost no references can be found concerning studies focused on operationalising urban flood resilience at the neighbourhood level. For example, relative to urban design, several ongoing or already executed projects and/or measures have been defined as contributing to improve urban flood resilience. Nevertheless, this statement is not based on a conceptual framework or tool allowing its justification.

In our research, the concept of urban resilience is defined as 'the ability of a city to operate in a degraded mode and recover its functions while some urban components remain disrupted' (Lhomme *et al.* 2013). The main goal of our study is to investigate how the flood resilience concept can be incorporated into urban design. By focusing on the physical dimension of a neighbourhood, we aim to specify how it can be designed and/or renovated to achieve the desired level of flood resilience, while retaining the urban qualities required for sustainable operation.

In this paper, we first describe a model we have identified as being relevant for adaptation and use as an analysis tool at the neighbourhood scale: the conceptual Spatial Decision Support System (DS3) model (Serre 2011). We then present its application to the stormwater management system using two particular areas: Rotterdam and New Orleans. We analyse and justify how alternative engineering and design options relative to stormwater management systems at the neighbourhood scale can contribute to improved urban flood resilience.

METHODOLOGY

The conceptual DS3 model adapted at the neighbourhood scale

Serre (2011), according to his urban resilience definition, has developed an analysis tool to study the resilience of urban networks: the conceptual DS3 model. In this model, three capacities have been defined as essential to analyse the resilience of urban networks: resistance, absorption and recovery. The Serre (2011) approach is based on the operation of urban interconnected systems at the city level and focuses on the physical dimension, particularly on technical aspects.

A neighbourhood, in the same way as a city, can be represented as an open and complex system that is characterised by exchange processes within its environment and is continuously changing and developing. Under flooding conditions, high dependencies and interdependencies between some of the neighbourhood components can become real issues. Lhomme *et al.* (2013) have demonstrated that among urban components, urban networks play a major role in urban flooding; they are a good example of critical infrastructure (CI).

CI represents the infrastructure that is essential for the functioning of society, whose failure would seriously affect many people (Heilemann *et al.* 2013). Indeed, a CI is generally defined by the impact that its incapacity or destruction would cause. Even if there is no single definition of CI (Galland 2010), the most common urban components associated with the term are: electricity networks, water supply and drainage networks, communication-related infrastructure, roads, schools and hospitals, banks, financial institutions, gas supply, nuclear power plants, etc. However, the meaning of 'criticality' and which components are therefore included, differs according to different parameters, such as the spatial and the temporal context, the type of hazard, stakeholders, etc. For example, an infrastructure considered critical at the city scale will not necessarily be critical at the regional or national scale (Figure 1). Moreover, for the same type of infrastructure, the elements considered should match the urban scale.

In our research, CI includes all networks and buildings (Figure 1) that are essential for the functioning of society, whose incapacity or destruction could have an important

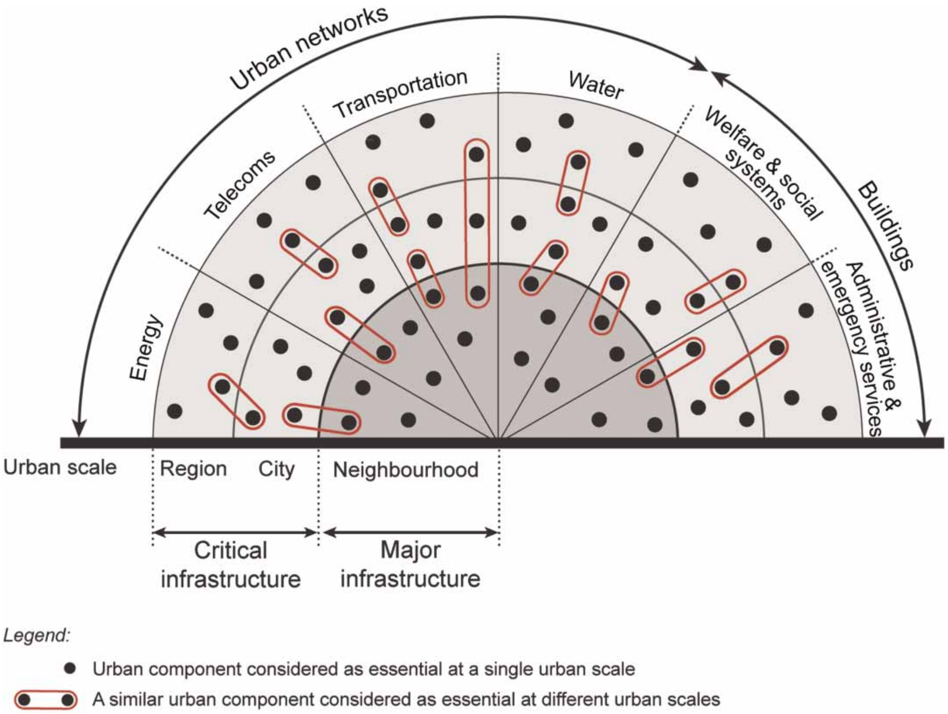


Figure 1 | Critical Infrastructure and MI across urban scales.

effect on many people over a long time. However, this concept is not applied at local urban scales such as the neighbourhood scale. Indeed, because the flow and exchange processes characterising the urban system operation are less important at the neighbourhood scale than at larger scales (e.g., city, region, etc.), the people and urban functions involved in its operation are minor. Hence, the concept of major infrastructure (MI) has been developed in our research in order to define those urban components that are essential for the proper operation of a neighbourhood, whose failure would have a serious impact on its inhabitants. An MI could also correspond to a CI so that its incapacity could have an impact on larger scales than the neighbourhood scale (Figure 1). Thus, even if among these components urban networks play an important role, other components can also be considered.

Because our research approach is also focused on the urban system operation, we consider that the DS3 model can be relevant and can, therefore, be adapted and used as an analysis tool in our study. Yet, based on what has just been quoted above, the logic of the DS3 model adapted to our research is founded on the MI damage in order to argue for the integration of flood resilience in the neighbourhood operation through its urban design (Figure 2). Each capacity and its adaptation for our research is presented below.

- **Resistance capacity.** In the context of the resilience concept, the resistance capacity of a system begins with a system damage analysis. It is necessary to know the potential damage and, hence, the failure that the system must be able to resist. In our research, we have defined improving the resistance capacity of a neighbourhood as aiming to reduce the damage of its MI. Thus, we are going to study how neighbourhood design can contribute to this end.
- **Absorption capacity.** The study of absorption capacity refers to 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. 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. Improving the absorption capacity of a neighbourhood will consist of increasing the alternatives that can be offered by the neighbourhood following the failure of one or more of its MI. Consequently, we are going to analyse how the neighbourhood design can contribute to creating alternatives.
- **Recovery capacity.** Recovery is most representative of the resilience concept (Serre 2011). Recovery does not mean returning to a previous state, but rather, to a functional

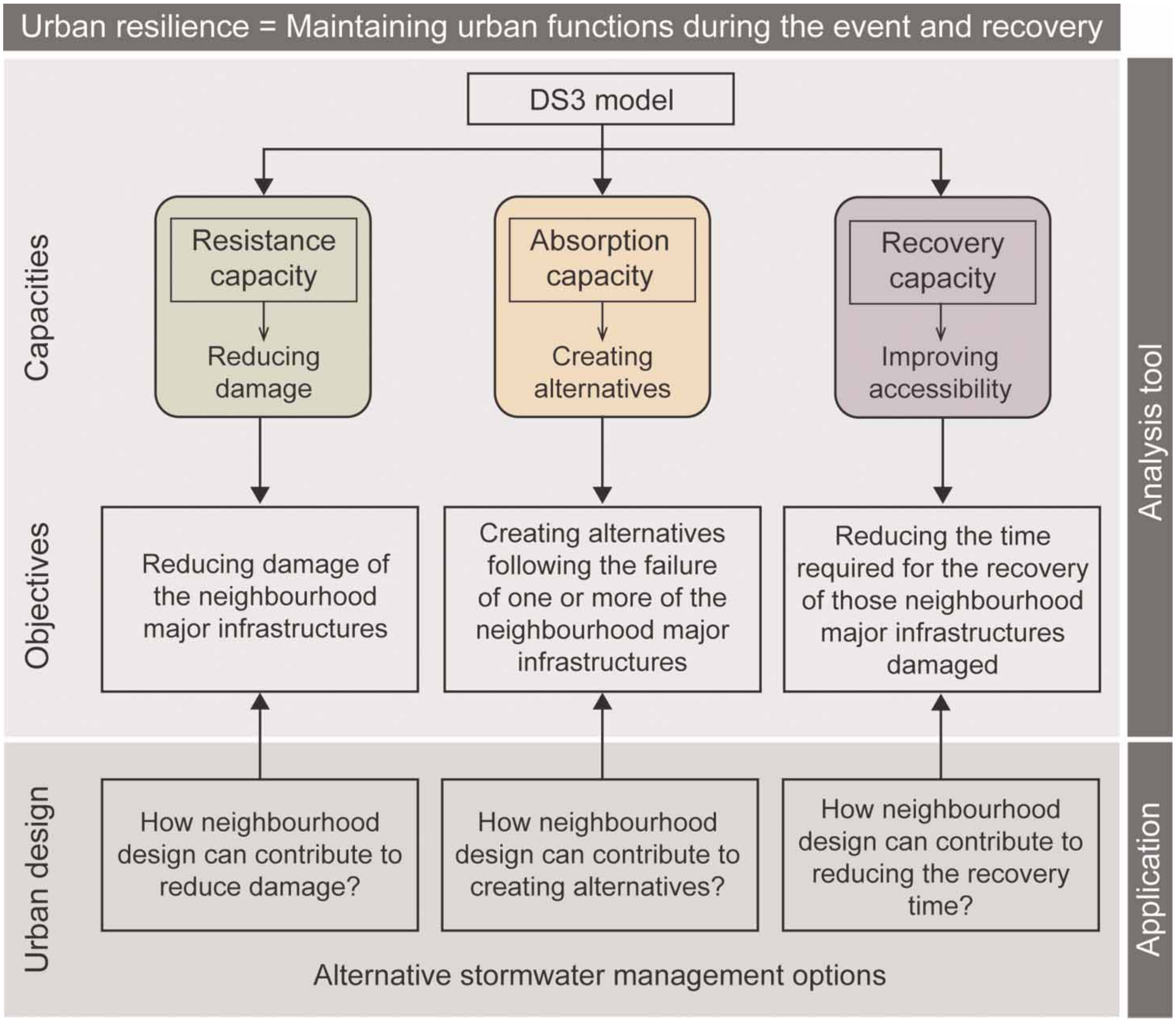


Figure 2 | Research methodology.

recovery of the system. The recovery capacity of a neighbourhood will be improved by reducing the time required for the functional recovery of those MIs that incur damage. We are going to study how neighbourhood design can contribute to recovering an acceptable level of performance as soon as possible by improving accessibility.

Since this particular study focuses on the stormwater management system, we are going to use the model to analyse how alternative stormwater management options contribute to reducing damage, mitigating failures with alternatives and recovering to an acceptable performance level as soon as possible. Figure 1 synthesizes the research methodology described, including the DS3 model used as an analysis tool.

Finally, it is important to highlight that the result of using the analysis tool is not going to be a quantitative assessment, but rather a qualitative analysis, allowing for the identification of engineering and design actions or measures contributing to integrating flood resilience in the neighbourhood operation.

The case studies

Rotterdam and New Orleans are located in deltas and are both exposed 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 a cause and effect of the geology, pedology and hydrology of the cities (Campanella 2006). Indeed, the average elevation of the cities is below sea level, 4 metres in Rotterdam and between 1 and 0.5 metres in New Orleans.

As a consequence of these characteristics and their existing stormwater sewerage systems, Rotterdam and New Orleans have significant problems associated with flooding during heavy rains (De Graaf 2009; Meyer & Waggonner 2009). Flooding from internal waters is really common in both cities, and even this kind of flooding leads to the extensive damage of urban networks, homes and businesses.

Even if the solution for dealing with this problem was completely changing the stormwater sewerage system, the amount of money and the period of time that would represent rebuilding such systems makes this solution impossible. However, alternative stormwater management options have been already considered in both cities.

Rotterdam

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

New Orleans

New Orleans has 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 majority of it is pumped into Lake Pontchartrain without treatment. 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 homes and businesses (Meyer & Waggonner 2009). Thus, to deal with it, alternative stormwater management options have been developed throughout New Orleans (Table 2).

RESULTS AND DISCUSSION

Results of the analysis

Using the conceptual DS3 model as an analysis tool, and considering different alternative stormwater management options at the neighbourhood scale in both Rotterdam and New Orleans, we have then proceeded to study how these actions can contribute to improved flood resilience. Tables 3 and 4 show the contribution of each measure/project to improving resistance, absorption and recovery capacity. A positive contribution is represented with a green arrow, and when there is no contribution, with a red arrow.

Rotterdam results

In Rotterdam (Table 3), resistance capacity is improved by measures performing the function of rainwater absorption (green and water roofs, gardens, etc.), rainwater temporary storage (water plaza, car park, etc.) and rainwater conveyance (separated sewer systems, overflow system, etc.). The absorption of rainwater diminishes the surface runoff, reducing possible damage to the neighbourhood's MIs, hence improving its performance during a flood. The temporary storage and conveyance of rainwater takes pressure off the pipelines (considered as an MI), thereby avoiding overflow and damage of the pipelines, and improving performance of the neighbourhood during a flood.

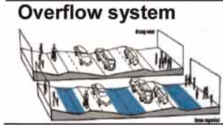
On the other hand, absorption capacity is enhanced by measures such as temporary rainwater storage (green and water roofs, water plaza, car park, etc.). Indeed, the temporary storage of rainwater provides an alternative to the neighbourhood when pipeline capacity is overwhelmed, allowing for failure mitigation. That is, it can offer an alternative following the failure of a neighbourhood MI.

Finally, measures for rainwater collection (water plaza, car park), rainwater temporary storage (water plaza, car park), and measures which can be easily maintained (culverts reopened) (Chammah 2007), contribute positively to enhance recovery capacity. The collection and temporary storage of rainwater reduce surface runoff enabling accessibility in the neighbourhood and therefore an earlier recovery of an acceptable neighbourhood performance.

New Orleans results

In New Orleans (Table 4), resistance capacity is improved by measures that achieve the following functions:

Table 1 | Alternative stormwater management options at the neighbourhood scale in Rotterdam

ROTTERDAM's alternative stormwater management options			
Project/Measure	**Description**	**Examples**	**Functions**
Green and water roofs 	During heavy rainfall events, these green and water roofs are a highly valuable solution for water absorption and temporary water storage.	Green roof at the Westblaak building	Temporary water storage 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 water storage Collect water
Multifunctional car park 	This car park is equipped with underground water storage tanks or reservoir.	Car park near the Museumpark (it will cater for 1200 cars and 10,000 m^3 of water	Temporary water storage
Separated sewer systems 	Two conduits are constructed to transport runoff to the urban surface water system and wastewater to the treatment plant. Stormwater is usually discharged directly to the nearest watercourse.	In new urban areas and renewal areas	Convey water
Reopening culverts 	Culverts tend to increase flood risk, especially if they are either too narrow in diameter or become blocked by debris. Moreover, compared with an open stream, the access for the maintenance of culvert watercourses is limited.		Collect water Convey water
Gardens 	Gardens can be used for infiltration and absorption of rainwater	Gardens in several neighbourhoods	Infiltrate water Absorb water
Overflow system 	Overflow system can increase the collection capacity of individual houses		Collect water Convey water

rainwater absorption (tree canopy, vegetated roadside swales, etc.), rainwater detention (pedestrian corridors and pocket parks, curb cuts, etc.) and rainwater temporary storage (parks with low areas, water basins, etc.). The absorption of rainwater diminishes the surface runoff, reducing possible damage of the neighbourhood's MI, thereby improving its performance during a flood. The detention and temporary storage of rain water take pressure off the pipelines (considered as an MI), avoiding possible overflow and damage, which also improves neighbourhood performance.

Absorption capacity is enhanced by various measures, including measures acting as temporary rainwater storage (parks with low areas, curb cuts, etc.). The temporary storage of rainwater provides an alternative for the neighbourhood when the capacity of the pipes is exceeded, allowing the mitigation of this particular failure. It can offer an alternative following the failure of a neighbourhood MI.

Recovery capacity is improved by measures acting as rainwater temporary storage (parks with low areas, water basins, etc.). The temporary storage of rainwater reduces

Table 2 | Alternative stormwater management options at the neighbourhood scale in New Orleans

NEW ORLEANS's alternative stormwater management options			
Project/Measure	**Description**	**Examples**	**Functions**
Extensive tree canopy 	Establish planting and maintenance programmes to provide an extensive tree canopy that shades each neighbourhood streets.	Throughout New Orleans neighbourhoods	Detain water Absorb water Infiltrate water
Shape existing parks with berms and low areas 	Used for water storage so that excess runoff from a neighbourhood street can be safely retained.	Wally Pontiff Park is a neighbourhood-scaled water retention area	Temporary water storage
Pedestrian corridors and pocket parks 	Use vacant lots and other underutilized spaces, including utility rights of ways to create stormwater corridors and storage areas where water can be detained soaked in the soils.	Throughout New Orleans neighbourhoods	Detain water Temporary water storage
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 drive water from storm drains into neutral grounds and street-side rain gardens so that road runoff can be stored and treated.	Some neighbourhood's streets	Infiltrate water Detain water Temporary water storage
Water detention basin next to a sidewalk 	The water detention basin delays a portion of peak-flow discharge thereby increasing the capacity of the existing drainage system.	Water detention basin at Aviators Street. During dry conditions it would function as a multi-functional performance space	Infiltrate water Detain water Temporary water storage

surface runoff, enabling accessibility in the neighbourhood and an earlier recovery of its damaged MIs.

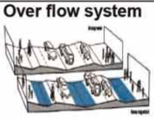
Discussion

The conceptual DS3 model has been adapted and then used in this research as an analysis tool to study how alternative engineering and design actions, relative to stormwater management systems at the neighbourhood scale, contribute to the improvement of urban resilience to floods in Rotterdam and New Orleans.

The results suggest that most of the alternative measures developed at the neighbourhood scale in Rotterdam, as well as in New Orleans, contribute positively to enhancing resistance, absorption and recovery capacities. Furthermore, it highlights that these capacities are not affected similarly by the measures. Indeed, resistance capacity is the most improved since all measures contribute in some way to this capacity. It may be due to the fact that this capacity is the easiest to develop into already existing urban areas.

Even if we realise that the functions allowing improved capacities are very similar in both Rotterdam and New

Table 3 | Rotterdam results provided by the analysis tool

ROTTERDAM's alternative stormwater management options			
Project/Measure	**Resistance capacity**	**Absorption capacity**	**Recovery capacity**
Green and water roofs 	↑ It improves the performance of the neighbourhood because it **absorbs water,** reducing possible damage from surface runoff. ↑ It improves the performance of the neighbourhood because it allows **temporary water storage** and takes pressure off the drainage system.	↑ It provides an alternative to the neighbourhood when the pipeline's capacity is overflowed because it allows **temporary water storage**; it offers a mitigation option.	↓ No significant contribution
Water plaza 	↑ It improves the performance of the neighbourhood because it allows for the **temporary storage of excess water** and reduces the pressure on the drainage system.	↑ It provides an alternative to the neighbourhood when the pipeline capacity is overflowed because it allows for **temporary water storage**, it offers a mitigation option.	↑ It contributes to recovering acceptable performance levels of the neighbourhood because it enhances **water collection** and **temporary water storage,** thereby reducing runoff and improving accessibility in the neighbourhood.
Multifunctional car park 	↑ It improves the performance of the neighbourhood because it allows for **temporary water storage** and reduces the pressure of the drainage system.	↑ It provides an alternative to the neighbourhood when the drainage system's capacity is exceeded because it allows for **temporary water storage** and helps to mitigate the potential failure.	↑ It contributes to recovering acceptable performance levels of the neighbourhood because it allows **temporary water storage,** thereby reducing runoff and improving accessibility in the neighbourhood.
Separated sewer systems 	↑ It improves the performance of the neighbourhood because it allows more **water conveyance** thereby reducing possible damage to wastewater pipelines.	↓ No significant contribution	↓ No significant contribution
Reopening culverts 	↑ It improves the performance of the neighbourhood because it **avoids damage** to the pipelines produced by high water pressure.	↓ No significant contribution	↑ It contributes to recovering acceptable performance levels of the neighbourhood because it can be **easily maintained** and it enhances **water collection.**
Gardens 	↑ It improves the performance of the neighbourhood because it **absorbs water runoff** and reduces potential damage.	↓ No significant contribution	↓ No significant contribution
Over flow system 	↑ It improves the performance of the neighbourhood because it allows for greater **water conveyance** and reduces pressure on the drainage system.	↑ It provides an alternative to the neighbourhood when the pipeline's capacity is exceeded because it allows **temporary water conveyance** which increases mitigating options.	↑ It contributes to recovering acceptable performance levels of the neighbourhood because it allows for greater **water collection,** thereby reducing runoff and improving accessibility in the neighbourhood.

Orleans, the measures performing these functions are not the same. For example, in Rotterdam the measures that 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 infrastructure enhancements have been implemented. 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 population density in New Orleans makes less expensive solutions more suitable.

Furthermore, we want to emphasize the robustness of the conceptual DS3 model for use as an analysis tool in this research. We consider that it provides an interesting qualitative analysis of how alternative stormwater management options contribute to improved flood resilience at the neighbourhood level. However, the tool has only been applied to the study of two particular areas and more

Table 4 | New Orleans results provided by the analysis tool

NEW ORLEANS's alternative stormwater management options			
Project/Measure	**Resistance capacity**	**Absorption capacity**	**Recovery capacity**
Extensive tree canopy 	↑ It improves the performance of the neighbourhood because it **absorbs water** reducing possible damage. ↑ It improves the performance of the neighbourhood because it **detains water**, slowing down runoff which gives the water a chance to soak into the soil.	↓ No significant contribution	↓ No significant contribution
Shape existing parks with berms and low areas 	↑ It improves the performance of the neighbourhood because it allows for **temporary water storage** and reduces pressure of the drainage system.	↑ It provides an alternative to the neighbourhood when the pipeline's capacity is exceeded because it allows for **temporary water storage** increasing mitigation options.	↑ It contributes to recovering acceptable performance levels of the neighbourhood because it allows for **temporary water storage,** thereby reducing runoff and improving accessibility in the neighbourhood.
Pedestrian corridors and pocket parks 	↑ It improves the performance of the neighbourhood because it **detains water** and slows down runoff which gives the water a chance to soak into the soils. ↑ It improves the performance of the neighbourhood because it allows for **temporary water storage** and reduces pressure of the drainage system.	↑ It provides an alternative to the neighbourhood when the pipeline capacity is exceeded because it allows for **temporary water storage** allowing the mitigation of the potential failure.	↑ It contributes to recovering acceptable performance levels of the neighbourhood because it allows for **temporary water storage,** thereby reducing runoff and improving accessibility in the neighbourhood.
Vegetated roadside swales 	↑ It improves the performance of the neighbourhood because it **absorbs water** thereby reducing possible damage. ↑ It improves the performance of the neighbourhood because it **detains water** and slows down runoff which gives the water a chance to soak into the soil.	↓ No significant contribution	↓ No significant contribution
Pervious paving in low-traffic areas 	↑ It improves the performance of the neighbourhood because it **absorbs water** and reduces possible damage.	↓ No significant contribution	↓ No significant contribution
Curb cuts in the street 	↑ It improves the performance of the neighbourhood because it **detains water** and slows down runoff which gives the water a chance to soak into the soil. ↑ It improves the performance of the neighbourhood because it allows for **temporary water storage** and reduces pressure of the drainage system.	↑ It provides an alternative to the neighbourhood when the pipeline capacity is exceeded because it allows for **temporary water storage** and thereby offers a mitigation option.	↑ It contributes to recovering acceptable performance levels of the neighbourhood because it allows for **temporary water storage,** thereby reducing runoff and improving accessibility in the neighbourhood.
Water detention basin next to a sidewalk 	↑ It improves the performance of the neighbourhood because it **detains water** and slows down runoff which gives the water a chance to soak into the soil. ↑ It improves the performance of the neighbourhood because it allows for **temporary water storage** reducing pressure of the drainage system.	↑ It provides an alternative to the neighbourhood when the pipeline capacity is exceeded because it allows for **temporary water storage** and adds a mitigation option.	↑ It contributes to recovering acceptable performance levels of the neighbourhood because it allows for temporary **water storage,** thereby reducing runoff and improving accessibility in the neighbourhood.

sites should be studied for the complete validation of the model. Specifically, it could be interesting to analyse other sites with different topographical, geological and hydrological features in order to be able to compare the results.

Finally, even if this particular paper only presents the application of the DS3 model to the stormwater management system, we aim to integrate all of the neighbourhood's urban components (infrastructures, buildings, protective systems, etc.) in our study to finally achieve a holistic and complete analysis. Through the study of several particular neighbourhoods, the final goal is to develop resilience criteria in order to guide the design of neighbourhoods integrating flood resilience into their operation.

CONCLUSION

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

The conceptual DS3 model, as adapted to this research and applied to stormwater management systems at the neighbourhood scale, seems to be appropriate for analysing how alternative stormwater management options can improve the flood resilience of a neighbourhood by using three essential capacities: resistance, absorption and recovery.

The results from the two particular case studies presented in this paper (Rotterdam and New Orleans) emphasise the importance of the stormwater management system, and particularly of the alternative stormwater management options to integrate flood resilience in a neighbourhood. Consequently, revisions to this system should be seriously considered when designing or renovating flood-resilient neighbourhoods.

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