International Conference on Flood Resilience:
Experiences in Asia and Europe
5-7 September 2013, Exeter, United Kingdom

METHODOLOGY FOR FLOOD RESILIENCE INDEX

Jelena Batica[1,*], Philippe Gourbesville[1], Fang-Yu Hu[2],

[1] University of Nice - Sophia Antipolis / Polytech'Nice-Sophia / Innovative City lab, France, [2] AREPville, France
[*] *930 Route des Colles, 06903 Biot, France; Tel: +33 (0) 4 92 96 51 36; E-mail: batica@euroaquae.eu*

ABSTRACT

The number of people affected by flooding increases, the disruption of physical environment and urban communities by flood causes significant damages. It is understood that floods can not be stopped, but the reduction of damages and vulnerability of risk prone communities can be done. The need for a shift to a new approach within flood risk management resulted with integrated flood risk management. The shift from traditional flood risk management put a vulnerability of community in the focus. The way forward is leading to resilience, having in mind all challenges that are obstructing implementation of this new approach. The urban flood resilience methodology brings a new light on existing flood related problems that are urban communities face nowadays. This paper takes a first step in bringing resilience in integrated flood risk management through a framework that is employing five dimensions in order to evaluate the level of disturbance and ability to preserve and functioning during and after the flooding processes on one side and relief, resist, response, recovery and reflect (5R) on the other side. The methodology presented in this paper is done within CORFU project.

KEYWORDS
Flood resilience index, functional analysis, urban systems, urban flooding.

1. INTRODUCTION

Flooding is one of the most frequent natural hazards. The number of people affected by flooding increases and the disruption of physical environment and urban communities by flood causes significant damages. It is understood that floods can not be stopped, but reducing damages and the vulnerability of risk prone communities is possible. (e.g. Bharwani et al., 2008; Krywkow et al., 2008; Vis et al., 2003). The need for a shift to a new approach within flood risk management resulted with integrated flood risk management. The shift from traditional flood risk management put a vulnerability of community in the focus. The new approach deploys a set of measures that bring changes in social and economic drivers in urban systems as well as improved risk management. The way forward is leading to resilience, having in mind all challenges that are obstructing implementation of this new approach. Based on this view, the shift is done from typical technical solutions that is provided by pure engineering science to a concept of understanding the conditions associated with human actions, economic change and institutional capacity. This paper takes a first step in bringing resilience in integrated flood risk management through a framework that is employing five dimensions in order to evaluate the level of disturbance and ability to preserve and functioning during and after the flooding processes on one side and Relief, Resist, Response, Recovery and Reflect (5R) on the other side. The methodology presented in this paper is done within the Collaborative Research of Flood Resilience in Urban Areas (CORFU project). The CORFU project is a part of the Seventh Framework Programme (FP7) of the European Union. The project looks at advanced and novel strategies to provide adequate measures for improving flood management and flood resilience in cities.

2. RESILIENCE AND VULNERABILITY

The pressures of urban development and increased vulnerability have encouraged urban communities to move towards a risk culture and the development of their ability to accept a certain level of flooding. The ability to accept and be able to reorganize introduces a new concept, resilience. Level of acceptance of flooding with certain damage is expressed through carrying capacity.

Assessing the flood risk in urban systems brings three concepts: **carrying capacity, vulnerability and resilience** (Burton, 1983). The concept of *carrying capacity* identifies the maximum tolerable damage that a community or a city could bear. The concepts of vulnerability and resilience serve to measure and to assess the **carrying capacity** of a community or a city. The vulnerability expresses the impact of disturbance of a system; the resilience is to describe the capacity of a system to absorb the shock.

2.1 Vulnerability

There is a need to tell the difference between vulnerability and resilience. Vulnerability presents a pre-event characteristic of a social system that has a potential to harm. Vulnerability is in a function of exposure or sensitivity of a system to disturbance. This is explained through answer on question who or what is at risk? **Vulnerability** is defined as the conditions determined with physical, social, economic, or environmental factors or processes which are increasing the weakness of community to the impact of hazard (UN/ISDR, 2004).

2.2 The resilience concept

Resilience, represents the capacity of an urban system or community exposed to hazard to adapt by resisting or changing in order to reach an acceptable level of functioning, organization and structure (UN/ISDR, 2004). Trying to look for a sustainable solution in solving flooding problems in urban areas, the definition of vulnerability and resilience to flooding processes are important. Looking from ecological aspect resilience is defined as the ability of a system to absorb changes of variables and parameters, and still persevere (Holling, 1973). Holling was one the first scientist who introduces the concept of resilience of ecological systems. Ecological resilience is focused on systems far from any equilibrium steady state, where the system could turn over into another regime of behaviour. In other words the system from an ecological point of view doesn't need to define the conditions which will provide some functionality. On the other hand urban systems need to have in advance defined 'conditions' in order to have the proper level of functioning.

Resilience doesn't have a general definition although it is increasingly used in integrated urban drainage management, (Ashley *et al.*, 2007; De Bruijn 2004; Klein *et al.*, 1998; Sayers *et al.*, 2003; Sendzimir *et al.*, 2007; Vis *et al.*, 2003;). The term resilience is often left open to debate. The diverse interpretations of resilience reflect the complexity of this concept and made it 'difficult' in implementation of integrated urban drainage management. Accordingly it implies that the definition of what is vulnerable and what is building the resilience should be clear. Initial understanding of the various definitions that are nowadays present with its determinants is significant. Broader view of existing resilience approaches is described in Table 1 (Folke, 2006).

Table 1: Existing resilience approaches (Carpentner et al, 2001)

Resilience concept	Characteristic	Focus on	Context
Engineering	Return time, efficiency	Recovery, constancy	Proximity of a stable equilibrium
Ecological/ecosystem resilience	Buffer capacity, withstand shock, maintain function	Persistence, robustness	Multiple equilibrium, stability landscapes
Social/ecological system resilience	Interplay disturbance and reorganization, sustaining and developing	Adaptive capacity, transformability, learning innovation	Integrated system feedback, cross scale dynamic interactions

According to Walker at all., (2004) resilience is defined as the ability of a system to absorb disturbance and to reorganize up to the level of changes that allows the same function, structure, characteristics and feedback. If ecosystem resilience is taken into consideration the first part of the definition is fulfilled in the sense that ecosystem will accept disturbance by the level that allows persistence. In social resilience for example, the definition, by Adger (2000), relates to the ability of human communities to tolerate to external stress to services and mechanisms that ensure health care, education, community progress, profit distribution, employment and social welfare. Disturbance in the system depends on system reorganization possibilities. This process has spatial and temporal scale.

Resilience concept brings adaptation, learning and self organization in addition to the general ability to persist interruption.

In opposite to general resilience, **specified resilience** – resilience “of what to what” (Carpenter *et al.*, 2001) – is more concrete and open to the evaluation. It can be defined by identifying what system attributes are to be resilient, and to what kind of disturbances. Specified resilience in the context of Integrated Urban Drainage Management (IUDM) has often been defined in a restricted sense to express the ability of the whole system to recover from the reaction of flood waves (Klein *et al.*, 1998; Sayers *et al.*, 2003; De Bruijn, 2004). Suitable definition for resilience adopted for the research in this paper is proposed by the United Nations’ International Strategy for Disaster Reduction (UNISDR). In the context of urban flooding, resilience can be defined as follows:

“*Resilience is the capacity of a system, community or society potentially exposed to hazards to adapt, by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organising itself to increase this capacity for learning from past disasters for better future protection and to improve risk reduction measures*”.

From this wide sense the concept provides a perhaps more suitable background framework to develop and assess integrated approaches to flood risk management. Resilience is therefore specified here in respect to the broader social–ecological context as the capacity of the whole-system to absorb flood waves in annual variability, and to reorganize while undergoing change in flood wave frequency and severity in the long term, so as to enable it to function normally. The resilience approach is aiming to prevent the urban system as whole to move to an undesirable state from which is not possible to recover due to extreme flood impact, etc. These preventions are in following directions:

1. Adjusting the thresholds of a system in respect to changes in response to flood waves;
2. Defining the level to which system is capable of self organizing;
3. Define the level to which system is able to build and increase capacity for learning and adaptation.

This defines the resilience thinking, a different point of view for guiding and organizing of urban systems. The defined terminology of vulnerability and resilience is very important in the analysis of urban areas and their existing flood risks but there should be a distinction between the flood vulnerability and flood resilience of people on one side and the urban structure on the other side.

3. ADDING RESILIENCE TO FLOOD RISK MANAGEMENT

The resilient urban systems and urban communities have ability to accept, resist, recover and learn from the events. Capacity of urban systems and communities is improved in each part of the flood risk management cycle. It covers actions related to preparedness, response and recovery. Within this research the five elements of flood risk management are developed: **relief, resist, response, recovery and reflect**.

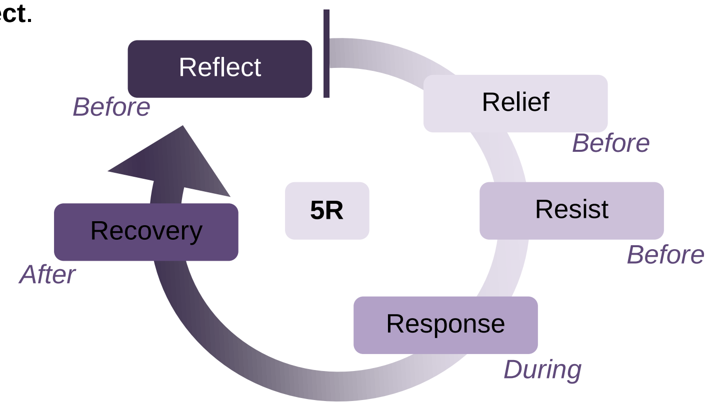

Figure 1: Elements for flood risk management cycle – CORFU project

- Relief – A buffer element. The use of using existing structures and urban functions for collection of flood water (green areas, different playgrounds...) is dominant. Measures implemented before a flood. Implementation of physical, technical, non-structural and procedural measures relates to the concept “living with floods”, such as wet flood proofing.
- Resist – Prevention of flood risk if possible, threshold capacity; measures implemented before a flood. Limiting flood damage and easing recovery by planning and adapting buildings, infrastructure, surfaces and economic activity relate to the concept of resistance
- Response – Measures taken during the flood. Actions focus on crisis management coping capacity. Flood impact is reduced by implementation of physical, technical, non-structural and procedural measures relates to the concept “living with floods”.
- Recovery – Providing support to recovery processes and engaging and building capacity in communities enable to cope with the impacts after flooding events.
- Reflect – Actions focus on increasing awareness and adaptive capacity, learning from past event and/or preparation for an uncertain future. Enhancing the awareness and engagement in all aspects of flood risk and the means of managing it at the policy level (politicians/decision makers), professionals (of the involved authorities and elsewhere) and at the public participation (people, companies, developers, insurance companies).

Actions and measures are directly connected with flood resilience. They are related to strong intent to increase capacity building of human resources, better land use management, increased flood preparedness and emergency measures that are taken during mostly usually and after a flood event.

Capacity building of human resources refers to increasing awareness of flood risk among key stakeholders in urban systems. The awareness among the population is assessed through presenting the brochures, short public presentations, creating internet portals that with useful information’s. Constant communication with population and education are also one of elements for capacity building of human resources. This is achieved with face-to-face learning and training also. In present urban systems these measures are in developing stage since they were not considered under traditional flood risk management.

Land use management refers to spatial planning and building regulations in order to create more space for water. The new buildings come up with improved shapes that are able to accept a certain amount of flood water and have minimal flood damage. The land use management contributes prevention to flood where possible.

Adapting to flooding by floatable building and buildings on piles, dry and wet proofing of buildings contributes to increased flood preparedness and contributes to mitigate the effects of flooding.

The measures that refer to preparation to flooding processes are financial preparedness, voluntaries, shelter management, improving flood insurance schemes, evacuation and rescue plans, etc. These measures are to be tested during the flood event.

4. METHODOLOGY

The new methodology of urban diagnostic is facing an urban flood risk issue. The approach is based on the development of urban flood vulnerability and resilience assessment tools with indicators which can provide a comprehensive overview of vulnerability and resilience of a city and community. Therefore the evaluation of flood risk considers different spatial scales for analysing and highlighting the components and flux of urban system.

The new urban environment has to be changed in a way that it has the ability to accept flooding with limited damages. The reshaped, adapted and prepared urban environment is one of the solution for minimizing flood impact. Urban environment has two components, a physical and social system and they have to be analysed together. The use of systemic approach provides the possibility to analyse urban environment as a complex system that requires numerous regulations be stable. These regulations enable, at all times, to re-establish urban functions after the disturbance of external events such as natural hazard. In this light, flood risk could be considered as one of the elements which activate regeneration of urban systems.

Therefore the flood risk is not only a threat to the city and its inhabitants, but also one of the essential components of urban structure and the evolution of its urbanisation. For that reason, it is necessary to analyse flooding processes in the context of urban spatial development. The development of methodology and analysis of urban systems through different scales and components can provide essential information for the transformation of the urban spatial organization.

The relationship between the nature of interaction and the structure of an urban system is fundamental. City systems - urban systems - are very complex. Their function is providing different services for the residents. This complexity of urban systems can be analysed using functional analysis that provides a description of the structure of the city as well as the implementation of measures. The main interest in this approach is to provide indicators that could be used to characterize urban resilience regarding flooding issues.

4.1 Scales for analysis

A city is the spatial expression of a system based on functional actions, processes, operations that must perform in order to achieve addressed outputs. Performing activities such as transportation of people, assets, food, providing residential areas, energy supplies to residential areas, etc. are some of addressed outputs that urban system has to achieve. The shape of urban systems is changing over time since urbanization is also a dynamic process. Change of urban systems over time does not imply just physical change of landscape. The change of system in social dimension is significant as well e.g. population density.

The boundaries of urban systems are influenced by many factors. Spatial evolution of urban system changes environment and existing natural water courses. Scaling of urban system allows recognition of main urban patterns. The urban system is mapped with respect to its objective – to provide the necessary service to the community. The urban functions are components and services are presented as flux of an urban system.

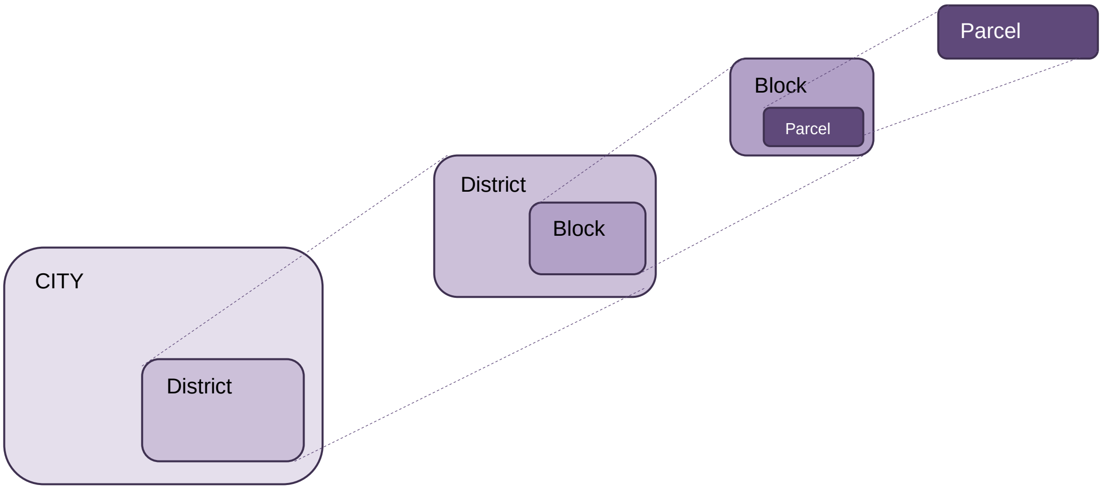

Figure 2: City system represented through scales (city, district, block and parcel)

Different spatial scales provide better assessment of flooding issues. Within presented spatial scaling of urban system the individual parcel presents the smallest unit for analysis. A group of parcels contoured with streets represent block. Third level of organization represents a district (group of blocks or administrative unit) and the final organization ring is the city itself (Batica, Gourbesville 2011) (Figure 2). Above presented is scaled urban system with four entities: *city, district, block and parcel* (Batica and Gourbesville 2011).

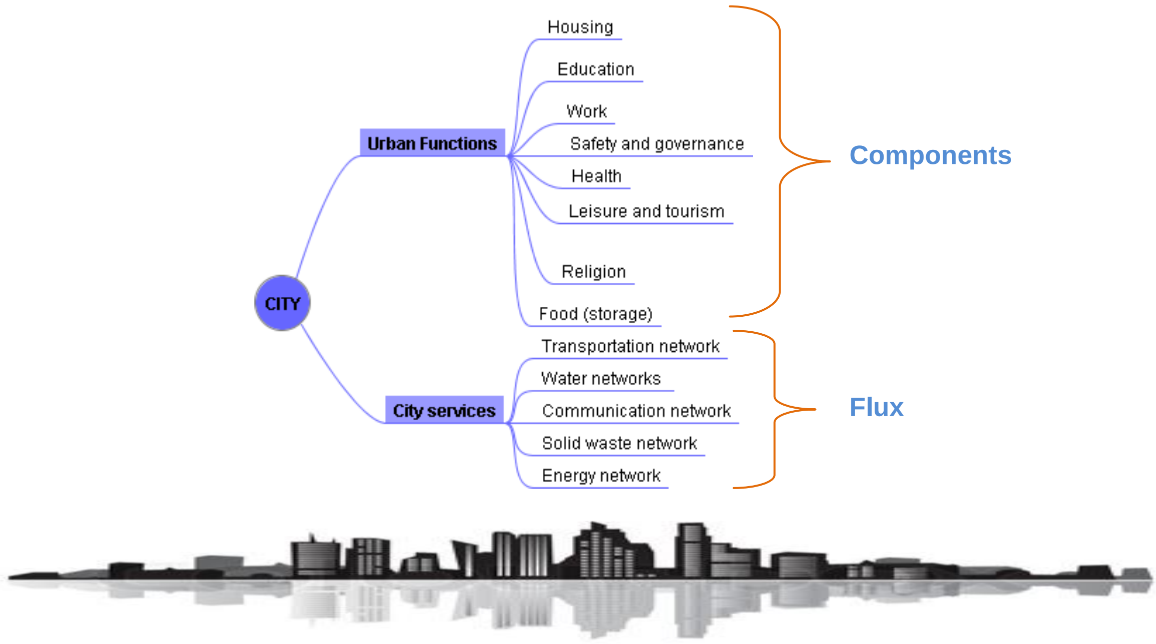

Figure 3: Mapping of the city according to urban functions and services

Components of urban systems provides an investigation of connections and *dependencies* within the system during flooding processes. Common for each urban system is to have the necessary elements in order to be able to function. By breaking down the structure of urban patterns it is possible to map system elements to physical components and map the elements to systems requirements (Daniell, et all, 2005). This allows listing all necessary tasks that urban system is performing. Components of the systems are urban functions and services. The functions and services (figure 3) of urban system are buildings, streets, parks, water distribution network, shops, industrial buildings, electricity network, religion areas, etc. Urban functions represent assets that the city needs to have in order to perform while services provide connections between different system components. Urban functions of a city are defined as components that urban system need to provide as fundamental needs to residents.

The urban functions have spatial extension and they are expressed through units (m^2). There are eight main urban functions that urban system needs to have in order to fulfil requirements related to integral needs provided to residents. They are: **housing** (individual or collective), **education** (for local and non-local education services), **food supply** (area for food storing and providing), **working** (areas of industry and areas for non-industrial activities), **safety** (police, fire brigade and rescue services at local level) and **governance**, **health** (hospitals on local and non-local level), **leisure** and **tourism** (on local and non-local level) and areas for **religious** activities (churches and cemeteries). Connectivity between physical components is done through services. Services in urban system gives functionality and interconnectivity to urban functions (e.g. The function of a house is to provide space for living). They represent a **flux** of urban system.

Hence the urban environment is mapped with the functions and services it is important to highlight the 'strategic' urban functions. They have vital importance for society. The strategic urban function is following: power stations, water treatment plants, the control centre of public transport, waste water treatment plants, firefighting stations and hospitals. If any of these strategic urban function experience failure it will trigger major damages for society and the economy. For this reason, it is necessary to **identify** these functions and develop potential protection technologies.

4.2 Flood Resilience Index

Evaluation of urban flood resilience is done through flood resilience index (FRI). The index is represented as a **level of flood resilience assessment in the analysed area for certain flood characteristics**. This is with respect that resilience is a characteristic by definition and represents **ability to accept** a disturbance up to some level. This ability is defined up to the level where the system is able to organize itself and preserve the structure and function. Reflected in urban systems this means that resilience is defined up to the level that urban structure and urban community are able to accept disturbance, preserve the 'level of functioning', organize and recover from it.

4.2.1 Critical assumptions

The presented method is a simplification of reality. The method is addressing the flooding processes in urban systems. The focus is on specified resilience, the flood resilience at the city scale. Interconnection between natural, physical, economic, social and institutional system exist and their separation is arbitrary.

4.2.2 Evaluation of urban flood resilience

A majority of assessment techniques is based on quantitative analysis. The urban system is considered through five dimensions: natural, physical, economical, social and institutional. Within each dimension the set of major indicators is chosen. The set of indicators or variables is taken because it is very difficult to quantify resilience in absolute terms. The indicators are chosen according to the following criteria:

- Sensitivity
- Availability
- Affordability and
- Relevance

The methodology is set to take into account different spatial scales. Looking at a city through different spatial scales it is more likely to asses' present issues regarding urban flooding. The evaluation of the FRI on parcel/building and the block scale focuses on urban function. The evaluation of FRI for the city and district/block scale is done through five dimensions: natural, physical, social, economic and institutional.

4.2.3 FRI on parcel/building scale

Physical components of urban system have a unique building topology. As presented above there are eight different urban functions. Each urban function has different typology. The analysis considers the examination of requirements for urban functions and for city services.

The characteristics of urban functions are defined with respect to their type. The requirements are divided on: requirements necessary for a building as a construction and requirements with respect to availability of different services (water, energy, transportation, communication, solid waste).Setting the requirements for urban functions is done in respect to flooding processes. The main purpose is to investigate "*is the particular function operational during and after the flood?*". Operational characteristic of urban function during and after a flood is defined by two different sets of requirements:

- Services (related to external dependencies)
- Safety of urban function (related to the safety for users)

Under services the set of external dependencies are listed: communication, electricity, water (distribution and waste), transportation, solid waste network. With services all external connections for urban function are satisfied. On the other hand the 'safety of urban function' is related to the safety of users (people). Following a set of question are raised while evaluating 'is the UF safe for users':

- Is there enough food in the house for residents during the flood and if necessary after flood?
- Is the house safe for residents to stay during and if necessary after the flood?
- Is the house secured to be a potential shelter not just for residents (has access to transportation, water, energy, communication....)

In accordance, this indicates that if these two sets of requirements are satisfied (external and internal) with respect to different level of availability the urban function has *a certain level of functioning* during and after flooding processes. Further, the two sets of requirements provide the criteria for operationality of urban function. Different levels of functioning during and after flooding processes indicate a different level of flood resilience. In this context the set of two requirements stands as an adequate instrument to measure a functionality of urban function. Setting up an availability level with respect to different flooding conditions there are sufficient data to measure flood resilience for urban function.

Different levels of availability are marked from 0 – the requirement is not provided to 5 – the requirement is fully provided. There is a six availability levels that are describing accessibility. The table below describes those levels.

Table 2: Availability levels of urban functions

Availability level	Description
0	Not available
1	Poor availability – major interruptions
2	Low availability – interruptions provide minimum availability
3	Medium – small interruptions that are tolerable for small flood durations
4	Medium-high – interruptions that are tolerable for long flood durations
5	Requirement fully provided

The flood resilience is respectively: very low, low, medium and high for a building.

Table 3: Evaluation of FRI for building scale

Requirements for urban function	Availability level (0 – 5)	FRI (parcel/building scale)
EXTERNAL SERVICES		$FRI(building) = \frac{\text{Availability level}}{8}$
Energy	1,2,3,4,5	
Water	1,2,3,4,5	
Waste	1,2,3,4,5	
Communication	1,2,3,4,5	
Transport	1,2,3,4,5	
INTERNAL SERVICES		
Food availability	1,2,3,4,5	
Occupation of urban function	1,2,3,4,5	
Access to the urban function	1,2,3,4,5	

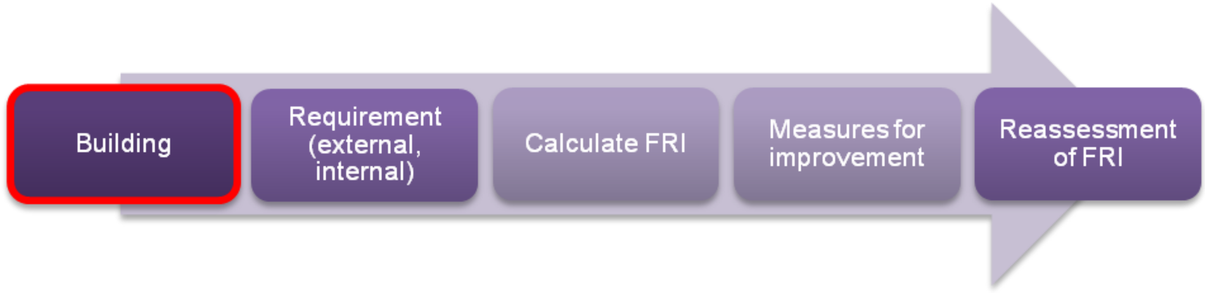

Figure 4: Synthetic view of evaluating flood resilience index for building scale

4.2.4 FRI for block scale

Evaluation of FRI for block scale focuses on city services and flood impact on them. The block is defined as a set of buildings or parcels surrounded by streets. The path for calculating RI on the block scale follows the path presented in figure 6. Both, flooded and non-flooded blocks are analysed. Different urban functions are within one block. In this case the dominant urban function is chosen. As shown in figure 5 the evaluation is done using the same set of requirements like it is presented for FRI evaluation on parcel scale. Here, two cases are analysed. The first case is evaluation of FRI for flooded block. In that case the evaluation is done for dominant urban function located in the flooded block. According to chosen dominant urban function the availability of internal services is evaluated as presented in table 3. The second case with non-flooded block the internal availability have scored 5 while an examination is only focused on the availability of external services. .

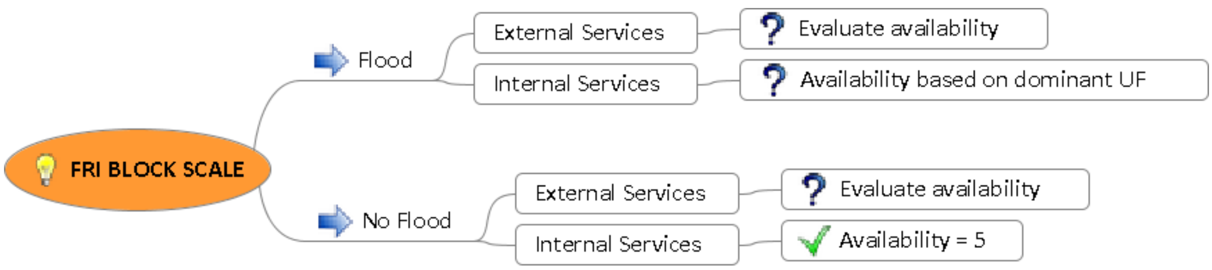

Figure 5: FRI for a block scale with two cases: flooded and no flooded block

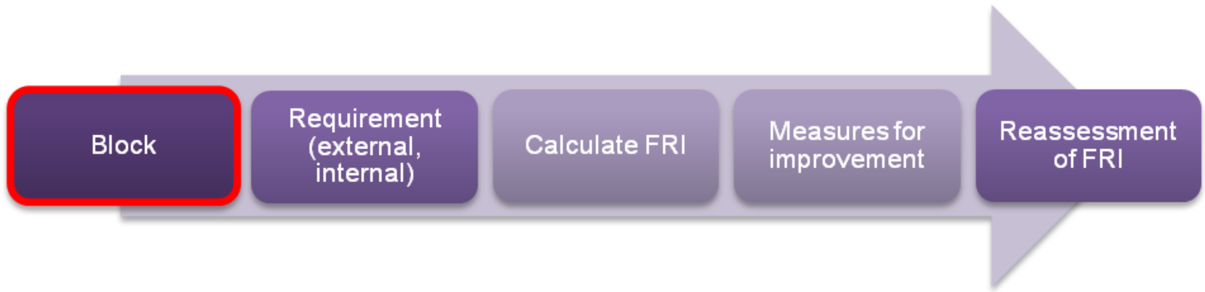

Figure 6: Synthetic view of evaluating flood resilience index for block scale

4.2.5 FRI for city/district scale

Resilience assessment is an overall analysis of urban system (usually city and district scale) looking at its natural, physical, economical, social and institutional dimensions. Each dimension contributes to the evaluation of the flood resilience index for the particular urban system. Dimensions are composed with different variables. The approach brings resilience into flood risk management through 5R concept.

FRI represents overall flood resilience for different scales of urban systems. The assessment of FRI on the parcel and block scale is focused on the building (urban function) while for the bigger scale (city/district) the evaluation of FRI is done through five dimensions (natural, physical, economical, social and institutional). These five dimensions describe the physical and social attributes of urban systems. One of the main objective criteria was to evaluate is the urban community able to accept certain disturbance and recover from it. This is done after reassessment of FRI after implementation of the measure.

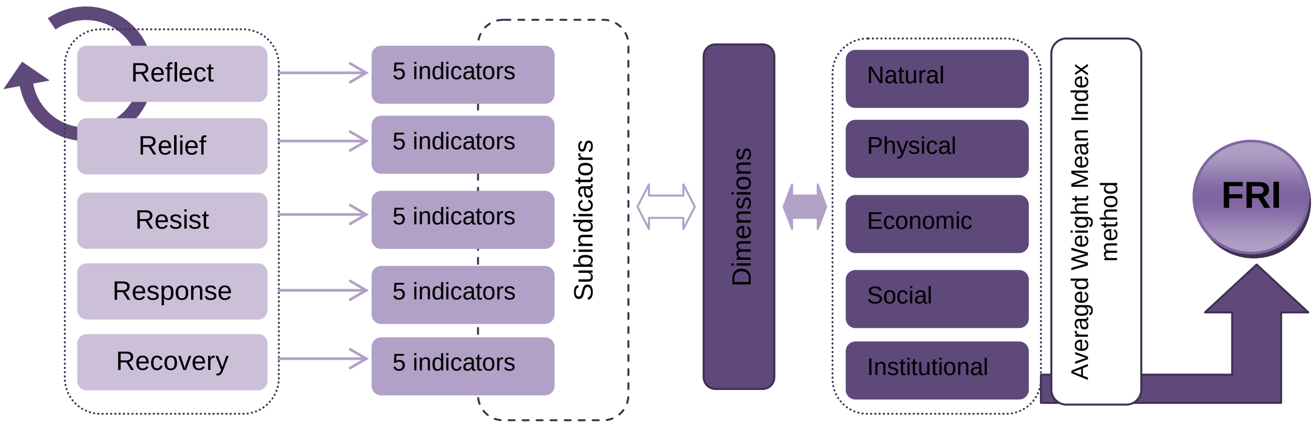

Figure 7: Schematic presentation of FRI evaluation of city/district scale

- **Natural dimension** – Describes the space where urban area is located with different ranges for variables: available water bodies, percentage of existing slope or flat areas, drainage density, rainfall duration, existing watershed
- **Physical dimension** – For each sub variable the variable availably is evaluated according to: Structural measures protection, communication network (telephone, internet, transport…), human safety (ex. emergency shelter), equipment for service and available networks in building location
- **Economic dimension** – Increase of households is line with population growth rates. Employment is direct link to economic growth of area and also triggers urban growth.Implies that long term benefits of planning policies, disaster management and mitigation plans are important tools for increasing resilience and reducing losses
- **Social dimension** – Also explore available resources, health status, knowledge and flexibility as well as connections within the community.
- **Institutional dimension** – Existence of flood management plans, policies, regulations, evacuation plans.. Is the population in this area taken into account for existing migration plans for the emergency situation.

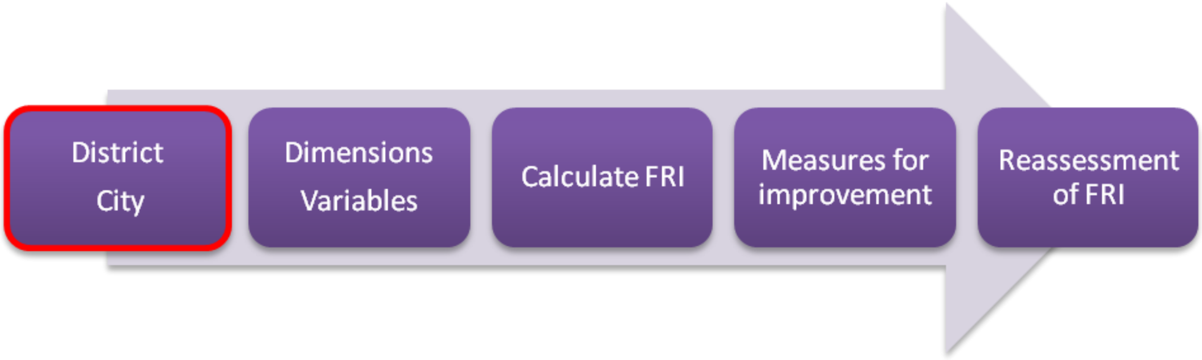

Figure 8: Scheme of Flood Resilience Index evaluation of city/district scale

Constructions of a rating scale with weights for all variables need to be done using weighted indexes. Aggregate Weighted Mean Index or AWMI (for each dimension) will be calculated using Weighted Mean Index (WMI) method (Rajib Shaw and IEDM Team (2009). The calculated averaged WMI of one dimension is the FRI for that dimension. Rating scales corresponds to *very low, low, medium, and high* respectively. The scale is presented in the table bellow.

Table 4: Scales for Flood Resilience Index

Very low 0-2	The activities are not clear and coherent in an overall flood risk management (5R). Awareness is very low on the issues and motivation to address them. Interventions have a short-term character. Actions limited to crisis response.
Low 2-3	Awareness of the issues and motivation to address them exist. Capacity building of human resources remains limited. Capacity to act is improved and substantial. Interventions are more numerous and long-term. Development and implementation of solutions.
Medium 3-4	Integration and implementation of solutions is higher. Interventions are extensive, covering all main aspects of the 'problem', and they are linked within a coherent long-term strategy.
High 4-5	A ''culture of safety'' exists among all stakeholders, where the resilience concept is embedded in all relevant policies, planning, practice, attitudes and behaviour.

4.3 Limitations of the proposed index

In this study we developed flood resilience index with ability to objectively assess all indicators. The outcome indicators were developed from actions in flood risk management cycle. The flood resilience index still depends on some assumptions. The proposed measurement of indicators relies on weights (assign for each indicator). Some limitations related to providing a quality measure of the process are possible since weights are used to intensify the scores in the assessment.

5. CONCLUSION

The flood resilience concept brings a new philosophy to urban systems, 'living with floods'. The approach transforms the existing structure of urban system and creates a system that is accepting the water with minimal damages, system that is able to recover in a minimum time frame and system that is able to have a certain level of functioning during the flood. The approach in this paper is based on functional analysis and provide a better presentation of urban systems.

The imperative is to acknowledge the importance of social, institutional and economical component when managing flood risk. The FRI represents a tool for stakeholders and decision makers. Different weights in matrix for evaluation FRI on the city / district scale highlights the most important variables that are contributing higher level of resilience for the certain case study area.

The resilience of a system could be improved by using diverse regulations such as institutional, urban planning and design, architectural design, public participation, financial stimulation, etc. Most of flood risk management (FRM) strategies are based on historical events by depending on resistance measures.

Currently the focus is on minimizing the consequences of flooding where flood risk management strategies are based on concept ‘living with floods’. Urban communities are moving to the risk culture and accepting the resilience. This trend of development in resilience evolution is graphically presented in figure 9. The presented flood resilience curves for urban system highlight the nonlinear characteristic of the whole resilience concept. This theoretical curve tends to present how development of urban system has influenced flood risk.

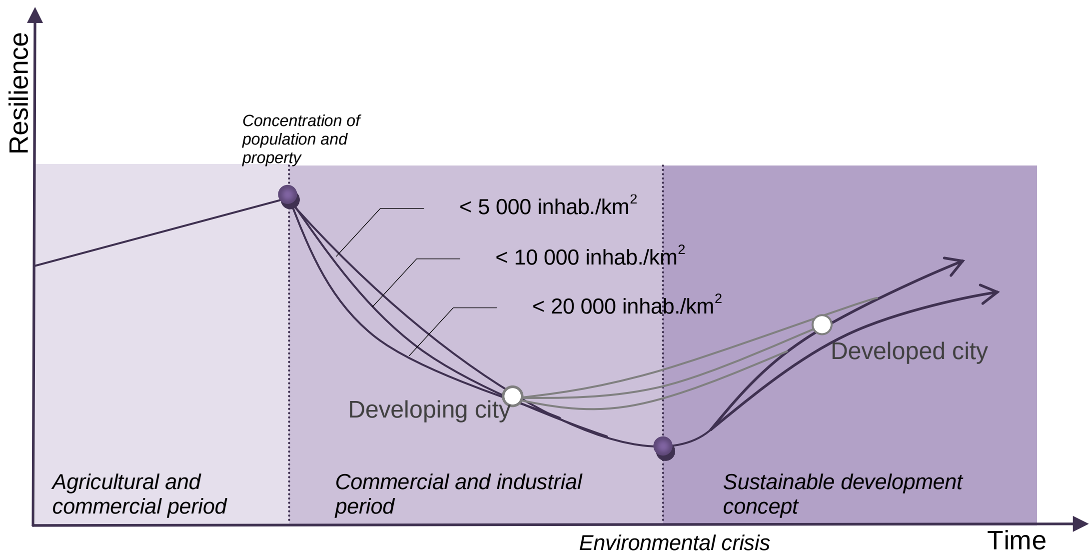

Figure 9: Evolution of flood resilience curve

It starts with agricultural age where the resilience is constant due to not signify development of assets, landscape and concentration of population. With the beginning of industrial time the changes in the landscape are significant. The assets becoming more sophisticated which contributes to higher concentrations of people. The structure of urban system starts to change and big challenges are posed to original landscape. Flood risk starts to increase and strategies were developed to reduce flood frequency and flood hazard. The theoretical curve is presented in figure 9. The expansion of urban landscapes on behalf of environment started to be more dominant. The flood vulnerability becomes higher and the urban communities realized that the way forward is in increased flood resilience. The risk culture is introduced to urban communities and they move to resilience concept.

In conclusion, the importance is in the possibility to use experience from flood resilience urban systems and avoid huge flood damages and dysfunction. The developing urban systems can find a good practice and good paths towards flood resiliency without reaching a low level of functioning.

6. ACKNOWLEDGEMENT

Research on the CORFU (Collaborative research on flood resilience in urban areas) project was funded by the European Commission through Framework Programme 7, Grant Number 244047.

7. REFERENCES

Adger W N. (2000). Social and ecological resilience: are they related? Prog. Hum. Geogr. 2000: 24; 347.

Ashley R.M., Blanksby J., Cashman A. and Newman R. (2007): An adaptable approach to flood risk management for local urban drainage. Defra Flood and Coastal Erosion Conference, York, 2007.

Batica, Gourbesville – Methodology for Flood Resilience Index Development – IAHR congress – June 2011, Brisbane, Australia

Bharwani, S., Magnuszewski, P., Sendzimir, J., Stein, C., Downing, T.E., 2008. Vulnerability, Adaptation and Resilience. Progress Toward Incorporating VAR Concepts into Adaptive Water Resource Management Report of the NeWater Project – New Approaches to Adaptive Water Management under Uncertainty. Report of the NeWater Project. Stockholm Environment Institute, Oxford Centre.

Bruijn K.M. de (2004). Resilience indicators for flood risk management systems of lowland rivers. International Journal of River Basin Management, 2(3), 199-210

Burton I. (1983), "Vulnerability and resilience in the evolution of cities: a methodological framework and research plan", Toronto: Institute for Environmental Studies, University of Toronto

Carpenter S., Walker B., Anderies J.M. and Abel N. (2001). From metaphor to measurement: Resilience of what to what? Ecosystems, 4, 765-781.

Carpenter S., Walker B., Anderies J.M. and Abel N. (2001). From metaphor to measurement: Resilience of what to what? Ecosystems, 4, 765-781.

Daniell, K.A. et all (2005) – Integrated urban system modelling: methodology and case study using multi-agent systems

Folke C. (2006). Resilience: The emergence of a perspective for social–ecological systems analyses. Global Environmental Change, 16, 253-267.

Holling C.S. (1973). Resilience and stability of ecological systems. Annual Review of Ecology and Systematics, 4, 1-23.

IPCC - Pacharui et al. (Eds) (2008), Fourth Assessment Report: Climate Change 2007: Sythesis Report, 104 p.

Klein R.J.T., Smit M.J., Goosen H. and Hulsbergen C.H. (1998). Resilience and Vulnerability: Coastal Dynamics or Dutch Dikes? The Geographical Journal, 164(3), 259-268.

Krywkow, J., Filatova, T., van der Veen, A., 2008. Flood risk perceptions in the Dutch province of Zeeland: does the public still support current policies? In: Samuels, P., Huntington, S., Allsop, W., Harrop, J. (Eds.), Flood Risk Management: Research and Practice, CRC Press/Balkema Proceedings and Monographs in Engineering, Water and Earth Science. Taylor & Francis Group, London, pp. 1513–1521.

Shaw, R. and IEDM Team (2009) – Climate Disaster Resilience: Focus on Coastal Urban Cities in Asia (Downloadable at http://www.unescap.org/idd/events/2009_EGM-DRR/Japan-Rajib-Shaw-CLIMATE-DISASTER-RESILIENCE.pdf)

Sayers P., Gouldby B.P., Simm J.D., Meadowcroft I. and Hall J. (2003). Risk, Performance and uncertainty in flood and coastal defence – A review. R&D Technical report FD2302/TR1.

Sendzimir J., Magnuszewski P., Flachner Z., Balogh P., Molnar G., Sarvari A. and Nagy Z. (2007). Assessing the resilience of a river management regime: informal learning in a shadow network in the Tisza River Basin. Ecology and Society, 13(1): 11. [online] URL: http://www.ecologyandsociety.org/vol13/iss1/art11/

UN-ISDR(2004), http://www.unisdr.org/we/inform/terminology

Vis M., Klijn F., de Bruijn K.M. and Buuren M. van (2003). Resilience strategies for flood risk management in the Netherlands. International journal of river basin management, 2003/1, 33-40.

Vis, M., Klijn, F., De Bruijn, K.M., Van Buuren, M., 2003. Resilience strategies for flood management in the Netherlands. International Journal of River Basin Management 1 (1), 33–40.

Walker B., Holling C.S., Carpenter S.R. and Kinzig A. (2004). Resilience, adaptability and transformability in social–ecological systems. Ecology and Society, 9(2): 5. [online] URL: http://www.ecologyandsociety.org/vol9/iss2/art5/