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Review article: current approaches and critical issues in multi-risk recovery planning of urban areas exposed to natural hazards

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Abstract. Natural hazard disasters recovery has been addressed in the literature by different sectoral perspectives and scientific communities. Nevertheless, studies providing holistic approaches to recovery, integrating reconstruction procedures and socio-economic impacts, are still lacking. Furthermore, recovery has been only marginally explored from a pre-disaster perspective, in terms of planning and actions for better recovery before disasters occur.

This paper provides a critical review of existing literature and guidelines on disaster recovery with the twofold aim of identifying current gaps and providing the layout to address multi-hazard recovery planning tools for decision-making. Disaster recovery literature is investigated in the paper by focusing on: the definition of the recovery phase and its separation or overlapping with other disaster risk management phases; the different destinations and goals that an urban system follows through recovery pathways; the requirements to implement a holistic resilience-based recovery roadmap; the challenges for shifting from single hazard to multi-hazard recovery approaches; the available tools for optimal decision making in the recovery planning. Finally, the current challenges in multi-risk recovery planning are discussed.

This review can be a ground basis for new research directions to help stakeholders in decision-making and optimise their pre-disaster investments to improve the urban system's recoverability.

1 Introduction

The frequency of natural hazards and consequent disaster events has increased in recent decades (CRED, 2022). Moreover, the extent of these events' impact, in terms of both the economy and humankind, has shown exponential growth (Cerè et al., 2017). Additionally, by 2050, cities would house more than 70% of the world's population, making them global centres of human settlement and capital accumulation and the locations most exposed to natural hazard events (Goldstone, 2010). To cope with natural hazard event impacts, planning and procedures that anticipate extreme events, mitigate possible damages, and allow for the speedy restoration of key services and recovery are required (Berke et al., 2009).

In the last decades, resilience planning has started to have a central role in disaster risk management, with the goal of reducing direct and indirect impacts in communities facing natural hazards (Leichenko, 2011). 22/03/2023 12:17:00The origin of the modern resilience theory and its application to natural ecosystems back to (Holling, 1973). Holling used the resilience term to describe the system's capability to remain functional and "persist" after changes that might happen.

Holling's writing was the basis for establishing an interdisciplinary research network for developing the resilience concept and its application in understanding the complex system's performance encountering disturbances (Walker et al., 2004; Gunderson and Holling, 2002). Folke (2006) strives for elaboration on the concept and provides the resilience theory not just restricted to the extent of a system characteristic but as a mindset. Over time, the comprehensive resilience concept has been extended to various fields and domains, including natural hazards and risk management (Coaffee, 2008; Cutter et al., 2008; Klein et al., 2003; Bruneau et al., 2003), climate change adaptation (Nelson et al., 2007; Tanner et al., 2009) and planning (Davoudi et al., 2012; Wilkinson, 2012).

As one of the most complex systems exposed to natural hazards, cities have also been included in this concept's extent, linking resilience to Disaster Risk Management (DRM). Urban resilience has been defined variously in the literature. Specifically, both the terms ‘urban’ and ‘city’ vary from one discipline to the other, and even in the urban resilience context, researchers have not agreed on a unique definition of an urban system.

‘Complex system’ is one of the city's most common descriptions in the urban resilience literature (Brugmann, 2012; da Silva et al., 2012). Some authors (Desouza and Flanery, 2013; Lhomme et al., 2012) refer to urban systems as a series of interconnected tangible and intangible networks through which services and goods are provided. Other authors (Ernstson et al., 2010; Godschalk, 2003; Romero-Lankao and Gnatz, 2013) divide the urban system into social, ecological, and technical (or physical) networks or components and describe the interlinkage between them using various terminology.

Among the many different definitions of urban resilience available in the literature, one of the most comprehensive is the one provided by Meerow et al. (2016): “Urban resilience refers to the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity.” The phrase "ability to return" stands out in this definition. The fundamental concern that arises, however, is how to ensure that the city, as a complex system with various components and interconnected networks, has the ability to return or recover after a disaster occurs. On the other hand, the term "maintain" can be seen in Meerow et al. (2016) definition as a reference to the ability of a resilient urban system to preserve what currently exists, which is more closely tied to the concepts of disaster risk preparedness and response.

As pointed out by Rus et al. (2018), the resilience concept can be reflected in preparedness, response, recovery, and adaptation actions, depending on the temporal domain. However, studies on the system recovery phase are lacking in this field, and research that evaluates the relationships and implications of these various DRM cycle phases one on another in resilience-based urban planning are still absent (Rus et al., 2018). This lack in the literature is reflected also in the confusion felt by stakeholders involved in the resilient urban planning process. Indeed, decision-makers do not know how to choose an investment direction among the various phases of the risk management cycle (Kawasaki and Rhyner, 2018). Are they supposed to protect and strengthen the system, work to make it more recoverable, or even set aside funds for disaster recovery?

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When disruptions arise in a variety of sorts and categories, with the potential for interaction, the problem becomes more complicated. In that circumstance, the system must be resilient to many types of risks, embracing a multi-risk perspective, and as a result, this issue will present additional challenges in decision-making regarding recovery and all other phases of the DRM cycle (Ward et al., 2022).

Although the resilience of an urban system is not solely determined by its ability to restore from a disruptive event, the recovery process represents one of the most critical and significant aspects contributing to the overall system resilience. To corroborate this perspective, Manyena et al. (2019) indicate that, since 1980 the terms "return to equilibrium," "bounce-back," "recover," "restore," "bounce-forward," "rebound," "rebuild," and "reorganize", which all have the connotation of recovery, have been frequently used in the different resilience definitions provided in the literature. According to McEntire et al. (2002), the term "resilience" emerged as a reaction to or alternative for the term "resistance". The key difference between these two concepts is that contrary to the resistance idea that prevention is the main strategy, natural hazard events inevitably occur in resilience discourse and disaster avoidance is not always achievable. As a result, the main issue in resilience is the need to focus on recovering from them as quickly and effectively as feasible (McEntire et al., 2002). Indeed, different researchers have used indicators such as the system's ability to function during recovery, the speed of recovery, the quality of recovery, and the area under the recovery curve to measure the system's resilience (Bruneau et al., 2003; Rus et al., 2018; Soltani-Sobh et al., 2016; Zhang and Wang, 2016).

This study analyses the existing disaster recovery literature and guidelines in the realm of natural hazards with the dual goals of identifying current inadequacies and laying the groundwork for developing multi-hazard decision-making tools for recovery planning in the urban areas. The needs and present limits of building a multi-risk tool for recovery planning are addressed. The final goal is to outline new research directions to enable stakeholders in making decisions and optimising their investments in the pre-disaster phase to improve urban areas recoverability. It is crucial to emphasize that, while urban recovery planning encompasses various actions and aspects, in this research we focus on decision-making concerning investments prioritization to improve resilience of physical elements at the urban scale.

In this study, we used a critical literature review (Grant and Booth, 2009; Snyder, 2019) approach. The literature on disaster recovery includes a broad group of researchers from several disciplines who have produced a large body of work. We sought a balanced and critical assessment of the literature (versus a systematic mapping of all relevant literature (Wong et al., 2013)), generating and responding to precise questions (Boaz et al., 2002).

Specifically, the critical literature review focuses on natural hazards and aims to identify the most pressing challenges in multi-hazard recovery so that they can be incorporated into the development of a multi-hazard decision-making tool. The review has been guided by the following questions:

i. What is the relationship between the recovery and the other DRM cycle phases?
ii. What is the final goal of the recovery process, and how can an increase in the urban system resilience be ensured?
iii. What are the most important physical prerequisites for the urban system to begin and sustain recovery in a multi-risk environment?

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iv. What are the methods and models currently used for prioritizing the investments in physical elements to improve disaster recovery from natural hazards in urban areas?

The questions have been answered considering the following constrains and assumptions:

- *Recovery is analysed through the lens of resilience, considering specifically how the disaster recovery can contribute to improving urban resilience.* Given that resilience is not just tied to recoverability, it is vital to understand how the recovery phase of DRM interacts with other phases. Considering this, questions (i) and (ii) have been raised. Addressing these two questions would necessitate understanding both the phenomenology of the recovery as well as its role, beginning, and end points within the DRM context.
- *The primary focus of this research is on urban physical assets*, and how investments prioritization can increase their resilience from multiple hazards and facilitate the recovery process. This is the core issue that should be considered when trying to answer the first two questions, which in turn would cause the second and third questions to emerge. More specifically, question (iii) addresses this issue understanding how to address pre-disaster recovery in a multi-risk environment, and question (iv) is posed to understand and analyse the decision-making methods for investments in physical elements and the strengths and weaknesses of each method.

The review has included relevant publications found in the Google Scholar and Scopus databases and the material available in the International Recovery Platform (International Recovery Platform, 2022), all explored using a series of selected keywords (recovery requirements, post-disaster needs, resilient recovery, the difference between recovery and emergency, multi-risk recovery, recovery optimization models, recovery planning, pre-disaster recovery planning, socio-economic aspects of disaster recovery). These searches yielded approximately 250 papers/documents, of which we used roughly 130 to inform the findings in this paper. The remaining 130 papers have been selected for the following reasons:

- The recovery phase and its activities are the key topics and are addressed in detail.
- The publications address specifically only natural hazards or in combination with other types of hazards, such as technological or human-made hazards.
- Recovery is addressed at the urban scale.
- The publications focus on the physical elements and their function for the urban area's recovery (this has been considered specifically in answering research questions (iii) and (iv).

The obtained results have been clustered into a series of research issues, each one discussed in a separate session of the manuscript:

- *Issue 1*: Recovery and its role in the risk management cycle (Sect. 2).
- *Issue 2*: Recovery challenges and requirements in the current world setting, including multi-risk conditions (Sect. 3).
- *Issue 3*: Decision making models and methods for investment in physical elements to improve recovery in urban areas (Sect. 4).

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To be more specific, Issue 1 corresponds to Research Questions (i) and (ii), whereas Issues 2 and 3 relate to Research Questions (iii) and (iv), respectively.

Then, the current challenges in implementing multi-risk recovery planning, as a result of the literature review, are discussed in Sect. 5. The final outcomes of this critical literature review will set the basis to outline the new research directions and help stakeholders in improving the urban system's recoverability (Sect. 6).

The examined references together with their critical classification are reported in the supplementary material of the paper to provide a comprehensive overview to the reader.

2 Issue 1: Recovery and its role in the risk management cycle

2.1 What is recovery?

Despite disaster recovery having been studied from several perspectives, there was a lack of theory explaining recovery in the literature until the early twenty-first century (Chang, 2005). Early definitions of recovery included some recognizable activities that should be completed in a timely order, with the result being a return to normalcy (Haas et al., 1977). Occasionally some evolutionary notions were added, such as risk reduction or decreased vulnerability (Whyte, 1979). However, these first definitions completely neglected to consider socio-economic aspects affecting the complex recovery processes, and oversimplified recovery as a well-defined and uniform path in all societies or even all scales of a single society (Holton, 2000; Sullivan, 2003). A selection of definitions provided by different authors that illustrate the evolution of the recovery concept is given in Table 1 (the full table is provided in the supplementary material).

Recovery, according to Nigg (1995), is more than just reconstructing the built environment, and the activities that shape this process can be influenced by pre- and post-disaster circumstances. Smith and Wenger (2007) proposed a more holistic definition of recovery that considers the various groups' differential recovery steps and the socioeconomic aspects of the process while also emphasising the importance of pre-disaster planning.

The definitions of recovery found in the literature can be separated into two groups (Winkworth, 2007):

i. Definitions that focus on recovery as a desired outcome per se.
ii. Definitions that consider recovery as a process that leads to one or more desired outcomes.

In the second group, i.e., definitions that see recovery as a process, recovery refers to coordinated efforts in terms of decisions and actions to aid communities in returning to their pre-disaster state or even regenerating them to become less risky than before the disaster (Independent Evaluation Group, 2006). Recovery, according to Mileti (1999), for example, “is not just a physical outcome but a social process that encompasses decision-making about restoration and reconstruction activities”.

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Table 1. Recovery definitions given by nine different sets of authors reported from the less to the most recent (the complete table is available in the supplementary material)

Author(s)	Definition
Rubin and Barbee (1985)	"Long-term recovery (i.e., the reconstruction process) is characterised by attention to rebuilding and new construction; restoration of major urban services; and review of pre-disaster land uses, especially insofar as they include consideration of local hazards in the recovery plans for the affected area."
Quarantelli (1989)	"Disaster recovery implies that everything works out fine after the disaster."
Nigg (1995)	"Recovery is a social process that begins prior to disaster impact and encompasses decision making concerning restoration."
Emergency Management Australia (1996)	"The coordinated process of supporting disaster-affected communities in reconstruction of the physical infrastructure and restoration of emotional, social, economic and physical well-being."
Mileti (1999)	"Process of interaction and decision-making among a variety of groups and institu-tions, including households, organisations, businesses, the broader community and society."
Winkworth (2007)	"Recovery comes to signify an active process of integrating traumatic events associated with a disaster so that destructive impacts are minimised and so that individuals, communities and governments are able to move forward into a post-disaster future in which the world has changed."
Smith and Wenger (2007)	"The differential process of restoring, rebuilding, and reshaping the physical, social, economic, and natural environment through pre-event planning and post-event actions."
Smith et al. (2018)	"The differential process of restoring, rebuilding, and reshaping the physical, social, economic, and natural environment through pre-event planning and post-event actions that enhance the resilience and adaptive capacity of assistance networks to effectively address recovery needs that span rapid and slow-onset hazards and disasters."
UNDRR (2020)	"The restoring or improving of livelihoods and health, as well as economic, physical, social, cultural, and environmental assets, systems and activities, of a disaster-affected community or society, aligning with the principles of sustainable development and 'build back better', to avoid or reduce future disaster risk."

In its terminology, the UNDRR (2020) distinguishes between 'reconstruction' and 'recovery'. The recovery definition is provided in the last line of Table 1. Reconstruction is defined as "the medium- and long-term rebuilding and sustainable

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restoration of resilient critical infrastructures, services, housing, facilities, and livelihoods required for the full functioning of a community, or a society affected by a disaster, aligning with the principles of sustainable development and 'build back better', to avoid or reduce future disaster risk." The fundamental distinction between the two definitions is the statements' objects, which are more tangible elements in the reconstruction definition. Even though some of the nouns, such as 'services' and 'livelihoods,' do not appear to be purely physical, the definition's verbs, including 'rebuilding', imply the physical structures that support supplying these subjective functions. Objects, on the other hand, are made up of a broader array of functions and (sub)systems of a meta-system such as a community or society in the recovery definition. The direct pointing to 'activities' is remarkable in the recovery notion. Because this emphasises the fact that recovery encompasses more than the rebuilding of physical components of the systems. In addition, while both definitions of reconstruction and recovery from UNDRR contain advice about aligning with build back better principles to reduce future risk, the recovery definition emphasises 'improvement.' Based on the definitions, it can be argued that full community functioning is the main goal of reconstruction, while in recovery the main goal is improvement in all areas. In fact, reconstruction goals may come true much sooner than what we anticipate for recovery.

By comparing the definitions, reconstruction can be regarded as a part of the recovery process, dividing all recovery activities into two primary domains:

i. Physical reconstruction
ii. Non-physical reconstruction-oriented activities, which we will refer to as 'socio-economic activities'

The socio-economic activities encompass local business recovery efforts, community participation, building social connections, psychological support, activation of NGOs and voluntary groups, and institutionalisation, among others.

The functional recovery zone is depicted in panel (a) of Fig. 1 as a common area between two different types of activity domains. Although functional recovery will be defined in greater detail in Sect. 5, we may state here that what is referred to as functional recovery in this study is a type of recovery whose primary purpose is the maintenance of community functions throughout and after recovery. Functional recovery would be impossible if the focus was solely on physical reconstruction while the socioeconomic aspects of recovery were ignored. The importance of considering socio-economic recovery and its relationship with physical reconstruction and their impact on each other will be discussed in greater depth in Sect. 3, based on literature.

In an ideal recovery process, the intensity of physical reconstruction and socio-economic activity remains at their maximum level during the recovery time to maximise the functional recovery zone. However, this would not be possible. As will be discussed in Sect. 2.2, resource allocation and concentration on the disaster area will not remain constant during the whole recovery period. External support would decline, and the intensity of reconstruction activities could decrease. Nevertheless, because socioeconomic recovery is dependent on physical structure, the intensity of related recovery activities may be raised with the repair of some of the damaged facilities, while at the initial stage of the recovery, it might not be so high due to the damaged structures and infrastructures.

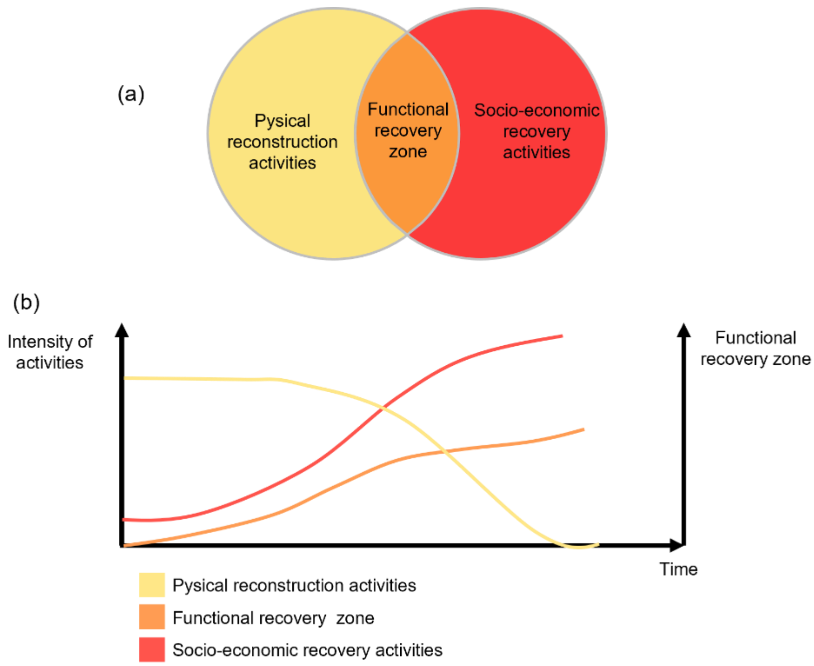

Figure 1. Panel (a): The relationship between physical (in yellow) and socio-economic (in red) activities in the recovery process, as well as their interaction zone (in orange), is called the functional recovery zone. Panel (b): Changes in the intensity of physical and socio-economic recovery activities over time, and the resulting changes in the functional recovery zone. The reader is referred to the web version of this article for an interpretation of the references to colour in this figure.

As shown in panel (b) of Fig. 1, by increasing the intensity of socio-economic recovery activities, the common zone (functional recovery) could be preserved or even increased during the recovery period. Furthermore, the intensity of socio-economic recovery activities could be increased without external support in a disaster community. These cooperatively evolving activities enable people to take part in the restoration of their communities independently. For instance, as more enterprises of all sizes become involved in the economy, people will be more capable of actively participating in the economic recovery of their community. Setting this balance between physical reconstruction and socioeconomic recovery would be possible if the disaster area needs assessment (see Sect. 3) is considered.

Assessing system performance and the effectiveness of investments made in various sectors throughout the process of recovery following a disaster, as well as evaluating quantitatively recovery plans for upcoming events, has always been a challenge for decision-makers and researchers. Although many frameworks and metrics have been developed to evaluate recovery efforts following a disaster in various aspects, such as physical reconstruction (Charles et al., 2021; Labadie, 2008), economic (Marshall and Schrank, 2014; Yamaguchi et al., 2016), and social recovery (Bahmani and Zhang, 2021; Dwyer and Horney, 2014), measuring the recoverability of various communities by evaluating their recovery plans, pre-disaster investments and resilience has received less attention (Berke et al., 2014). Additionally, diverse groups in urban systems may not experience recovery at the same rate (Fussell, 2015), and recovery measurement on various scales (e.g., individuals, groups, communities, cities, etc.) would necessitate the use of ad-hoc indicators and methodologies (Chang, 2010).

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2.2 Recovery in the DRM cycle

The definition of the starting time of the recovery process represents a controversial issue in the literature. According to Rotimi et al. (2009), recovery is the phase just after the initial response to a disaster, while for UNDP (Arenas et al., 2016) recovery activities begin immediately after a disaster, during the relief phase, and continue until full recovery is accomplished. More specifically, coordination and recovery planning are the two main activities to start immediately after a disaster and concurrently with the response phase (Arenas et al., 2016).

Empirical data and previous experiences show a disparity in allotted resources, organisation, and contributions between the response and recovery phases (Ali et al., 2020). Therefore, these two phases should be treated as separate and consecutive. However, it should be noted that experience indicates that addressing the short-term requirements of affected populations during the response phase has an influence on meeting the needs of the population during long-term recovery and addressing these two types of needs should be done in an integrated way (Garnett and Moore, 2010).

As emergency requirements settle and the media spotlight fades, consideration is given to the long-term implications of loss. Nonetheless, the longer and more costly phase of disaster recovery rarely receives the same level of support compared to the response, even though it may influence a community's future well-being for years to come (Choi et al., 2019; International Recovery Platform, 2007; Raju and Becker, 2013).

Transitioning from the response to the recovery phase has not been adequately addressed in the literature (Levine et al., 2007). The questions of how, when, and who will organise, finance, and manage this transition process remain unanswered (Ali et al., 2020; Muskat et al., 2014). Trying to answer this question, the UNDP (Arenas et al., 2016) strategy entails breaking down recovery into stages, named as early, medium, and long-term recovery, respectively. Early recovery occurs during the transition period from emergency relief to long-term restoration. More specifically, early recovery begins with quick interventions like financial support or food for reconstruction; medium-term interventions focus on rebuilding shelters, infrastructure, and livelihoods; and long-term recovery concerns strengthening government capacity and lowering the risk of future disasters (Arenas et al., 2016) (Fig. 1).

Analogously, with the goal of evaluating the success of the recovery initiatives, Bahmani and Zhang (2021) separated the recovery process into three distinct time domains: short-term, medium-term, and long-term. For each time domain, they identified a series of critical success factors. Short-term critical success factors refer to the ability to answer people's emergency requirements, which should primarily be addressed during the response phase (Bahmani & Zhang, 2021). As a result, the short-term recovery phase as defined by Bahmani and Zhang (2021) basically coincides with the response phase.

The practice of dividing recovery into sub-phases is not new. Kates and Pijawka (1977) proposed a four-phased sequential description for recovery, which included an 'emergency', 'restoration', 'replacement and reconstruction', and a 'commemorative, betterment, and developmental reconstruction' period. Even though their model has been referenced and used in several publications (Hill and Keys-Mathews, 2005; Kates et al., 2006; Platt and So, 2017), it has some flaws (Sobhaninia and Buckman, 2022; Rubin, 2009). Sobhaninia & Buckman, (2022) criticised the Kates & Pijawka model for

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not considering pre-disaster statutory and different types of disasters. As an alternative, they presented a reconfigured model based on Kates and Pijawka's approach, emphasising anticipation, equity, and resilience. They incorporated in their model phases' overlaps and varying durations of sub-phases (emergency, restoration, replacement, and reconstruction) that are not always consecutive for all communities, as well as pre-disaster vulnerability and equity and their impact on recovery. Furthermore, by including the resiliency notion in their model, they considered the recovery effect on pre-disaster conditions, making it a cyclic procedure (Sobhaninia & Buckman, 2022).

The recovery in L'Aquila following the earthquake in 2009 is a good illustration of how the boundaries between the various stages of recovery are not always clear and can be fuzzy. Several years after the earthquake, early recovery actions are still in place, executed simultaneously with development actions (Contreras, 2016; Contreras et al., 2014).

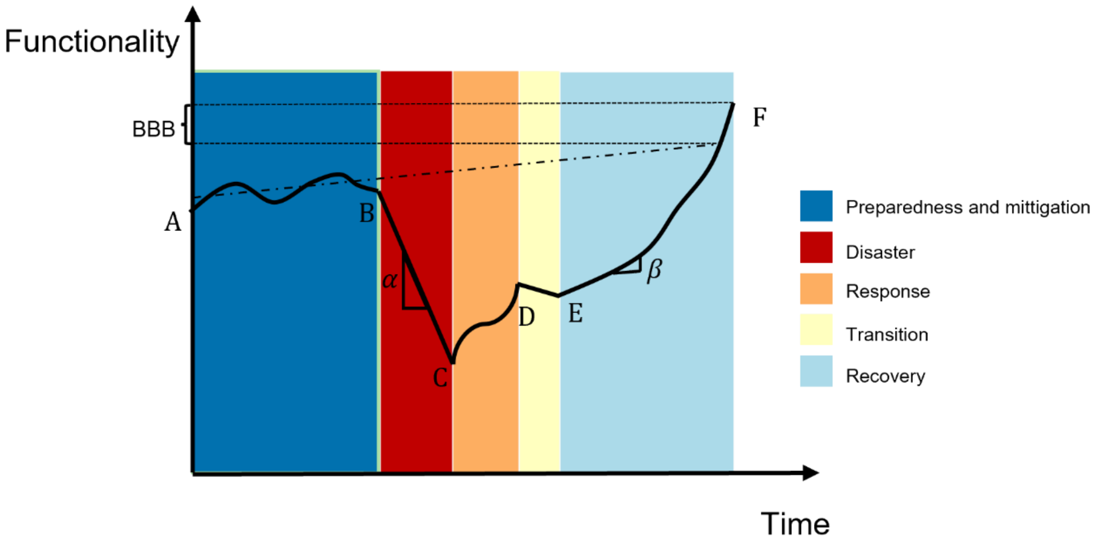

Figure 2. Urban system state behaviour in terms of functionality in different DRM phases includes: the dynamic fluctuation of functionality due to the lack of maintenance or mitigation activities that are conducted with various intensities during preparedness time according to the stakeholders' decision (segment A-B); the abrupt decline in functionality as a consequence of a disaster occurrence with a given slope α which depends on system preparedness and robustness in pre-disaster (segment B-C); increase in the urban system's functionality in a short time and with a noticeable slope due to the external contribution and sources during the response phase (segment C-D); transition phase between response and recovery and a slight decrease in functionality of the urban system due to the lifting of external support and public attention fading (segment D-E); recovery phase and increase in system's functionality with a given average slope β which depends on pre-disaster and post-disaster planning and activities (E-F); final urban system's functionality level (point F), which could be higher than its initial value in pre-disaster time (point B).

Fig. 2 depicts how the functionality of an urban system affected by a disaster may change over time. The phases of the disaster risk management cycle are depicted in the background, with the system behaviour in each phase indicated by a black line. According to Zhang et al. (2021), the system can have a dynamic behaviour in the pre-disaster period (segment A-B) depending on the decisions made by stakeholders, and the general trend could be ascending or descending. In the hypothetical example provided in Fig. 2, before the disaster, stakeholders are attempting to improve the system's functionality. Immediately after the disaster, there would be a reduction in functionality (segment B-C), and then a consequent increase due to the actions that may be carried out during the response phase (segment C-D).

A slight decline in functionality is expected during the transition period due to the removal of external support (Choi et al., 2019; International Recovery Platform, 2007; Raju and Becker, 2013), followed by an upward trend in functionality during the recovery phase. A noticeable point is that pre-disaster decisions and actions influence $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$, which are the slope of the decreasing and increasing functionality during the disaster and recovery respectively (Sobhaninia and Buckman, 2022).

The dynamic represented in Fig. 2 is commonly used in the literature to describe the urban system’s functionality (Choi et al., 2019; Fang et al., 2016; Ghorbani-Renani et al., 2020; Zhang et al., 2021). Nevertheless, such a representation does not consider the nonlinear increase of functionality during recovery. As previously stated, the recovery actions are not always carried out in a sequential manner, and therefore the functionality is not necessarily increasing as continuous line, as is shown in Fig. 2 (Rubin, 2009). This current issue underlies the need for functionality models able to capture non-sequentially behaviour in the recovery process.

2.3 The final goal of the recovery process

Researchers did not agree on where the recovery process should lead and conclude (Ganapati and Mukherji, 2014; Ismail et al., 2014; Sadiqi et al., 2017). Defining the recovery procedure's goal depends on many factors and doing so without considering the system's condition in terms of functionality in the different phases of the DRM cycle can lead to simplistic or useless results. The least that may be expected from the recovery is a return to pre-disaster conditions(Quarantelli, 1999; Su and Le Dé, 2020; Whyte, 1979). However, there is no certainty that this will be achieved. Unawareness of different options in defining objectives for recovery procedures and the lack of participation of all stakeholders in the recovery decision-making stages may result in the community's inability to return to pre-disaster conditions, or worse yet, increase their exposure and vulnerability (Smith and Wenger, 2007). Poor reconstruction as a result of focusing solely on a quick recovery, job losses, a reduction in affordable housing stocks, and the inability to assist the disadvantaged classes of the community in their recovery are just some of the possible repercussions of the bad recovery that results in an urban system that is even more vulnerable than it was before the disaster (Bolin and Bolton, 1986; Peacock et al., 1997; Vale, 2005).

In the field of economic studies, the recovery endpoint is defined ‘a-priori’ as the condition that would have been attained if the disaster had never happened. This method highlights the impact of ongoing trends outside of the disaster on indicators like unemployment rates and house prices (Cheng et al., 2015).

As illustrated in Fig. 2, the endpoint of the recovery process (point F) can even be higher than its initial value in pre-disaster time, highlighting how the recovery can represent an opportunity for improvement in urban systems. The notion of disaster as an opportunity has progressively gained traction in different fields, such as technological, economic, and social. Shaw et al. (2003) have demonstrated that meaningful change is possible under the right circumstances after a disaster. Most of the time, the savvy communities that survive after a disaster have the chance and ambition to work toward improving the citizens' economic, environmental conditions, and quality of life (Smith and Wenger, 2007). Instead of perceiving recovery

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as a return to the status quo, the viewpoint of disaster as an opportunity laid the groundwork for the rise of concepts like 'new normal' as the final stage of recovery, which may be viewed as an adaptive process that negotiates the conflicts between re-establishment of pre-disaster systems and considerable transformation of those systems (Smith and Wenger, 2007; Tierney and Oliver-Smith, 2012).

For example, considering the GDP per capita as an index, Chhibber and Laajaj (2007) propose certain long-term scenarios concerning the index's behaviour. Instead of using the exact amount of GDP prior to the disaster's occurrence, they used other criteria. They used the pre-disaster GDP growth rate to linearly extrapolate the GDP the community would have reached at the recovery endpoint if the disaster had not occurred. They claim that even though a disaster will inevitably result in a decline in GDP per person due to the extensive damage to the capital stock, it is still possible to use the disaster as an opportunity to achieve a higher GDP per capita at the end of recovery.

In a report titled "Key Propositions for Building Back Better", former US President William Clinton first introduced the 'Build Back Better' (BBB) approach to disaster recovery in 2006 (Clinton, 2006). Since then, BBB has become the catchphrase of post-disaster reconstruction programs, to the point where the second half of Priority 4 of the Sendai Framework for Disaster Risk Reduction 2015–2030, was designated to BBB. According to the UNDRR (2020) terminology, BBB initiatives include incorporating disaster risk reduction strategies into the recovery of physical infrastructure and societal systems, as well as the revitalization of livelihoods, economies, and the environment with the aim of increasing the resilience of nations. Given that the provided definition's object relates to different structures and subsystems with various functions in the urban system, the 'better' adjective has undergone numerous interpretations and, in some cases, alternative substitutions depending on stakeholders' perspectives have been proposed (Fernandez and Ahmed, 2019; Kennedy et al., 2008). Safer, greener, more environmentally friendly, more aesthetically appealing, more oriented toward livelihoods, more resistant to natural hazards, faster, stronger, and more equitable are some examples of researchers' 'better' interpretations (Hinzpeter and Sandholz, 2018; Kennedy et al., 2008; Kim and Olshansky, 2014). Moreover, measuring quantitatively the success of the BBB is another controversial issue (Thomalla et al., 2018; Fernandez and Ahmed, 2019). Therefore, Tatham and Houghton (2011) question still needs to be answered: "Who decides what 'better' actually means?".

In Fig. 2, BBB at the end of recovery has been determined using the economists' notion as mentioned above, considering the pre-disaster trend in terms of functionality growth. While this idea may appear ambitious for a progressive urban system in terms of functionality, considering the advantage of using the external resources that would enter the system during the recovery, reaching such a position would be feasible.

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3 Issue 2: Recovery challenges and requirements in the current world setting

3.1 Recovery requirements

Recovery is a long-term process that might take years or decades to complete (Dunford and Li, 2011; Olshansky, 2006), and ignoring socio-economic aspects of the involved urban systems throughout this time will impede comprehensive community development while and after recovery (Oliver-Smith, 1990). Some early studies (Rubin and Barbee, 1985) on recovery equated socio-economic recovery with physical reconstruction. Socio-economic recovery necessitates the restoration of some physical structures to offer spatial conditions for shaping social and economic linkage and communication. Restored socio-economic connections, on the other hand, can influence and improve the physical recovery process. As a result, while these two realms have mutual effects, they are clearly distinct and are characterised by different requirements and actions in the recovery process (Tierney and Oliver-Smith, 2012).

Paying attention to people's needs in recovery decisions is essential for moving toward a holistic approach that addresses socio-economic and physical recovery in constructive connection with each other. However, prevalent recovery practices have shown that mostly governmental assistance programs draw more attention to physical recovery planning than systematic identification of community needs (Kartez, 1991).

Comprehension of community needs integrates visions into recovery plans toward building long-term resilience in disaster-affected communities and making them capable of facing upcoming events (Chandrasekhar, 2012; Iuchi et al., 2015). On the other hand, community needs, and capacity assessment is also required for recognizing and delivering solutions to problems that can and should be tackled at the community level (Gaillard and Mercer, 2013; Horney et al., 2016; Bolin and Stanford, 1998).

As a result, as shown in Fig. 3, community involvement might occur in two types of interventions during the recovery process:

i. *In needs and capacity assessment*, to properly integrate community needs and planning recovery accordingly

ii. *In recovery activities*, using the existing capacity to tackle the problem at the community level and efficiently employ local resources

Furthermore, community involvement can be intensified as much as the disaster recovery process is able to address their needs (Iuchi, 2014; Sovacool, 2017). As illustrated by the arrow that connects the 'new system state' to the 'Community Involvement' in Fig. 3, the more the recovery activities are directed toward meeting the needs of the community, the more the population will find the recovery process effective and will be encouraged to participate because they find themselves as an important part of decision-making process (Mutch, 2014). As a result, since the community's resources and capacity would be mobilized in an efficient and influential manner toward progressive recovery, it could be noted that while the need assessment initially appears to slow down the recovery process by delaying tangible actions, it ultimately speeds it up in the long term (Chandrasekhar et al., 2014).

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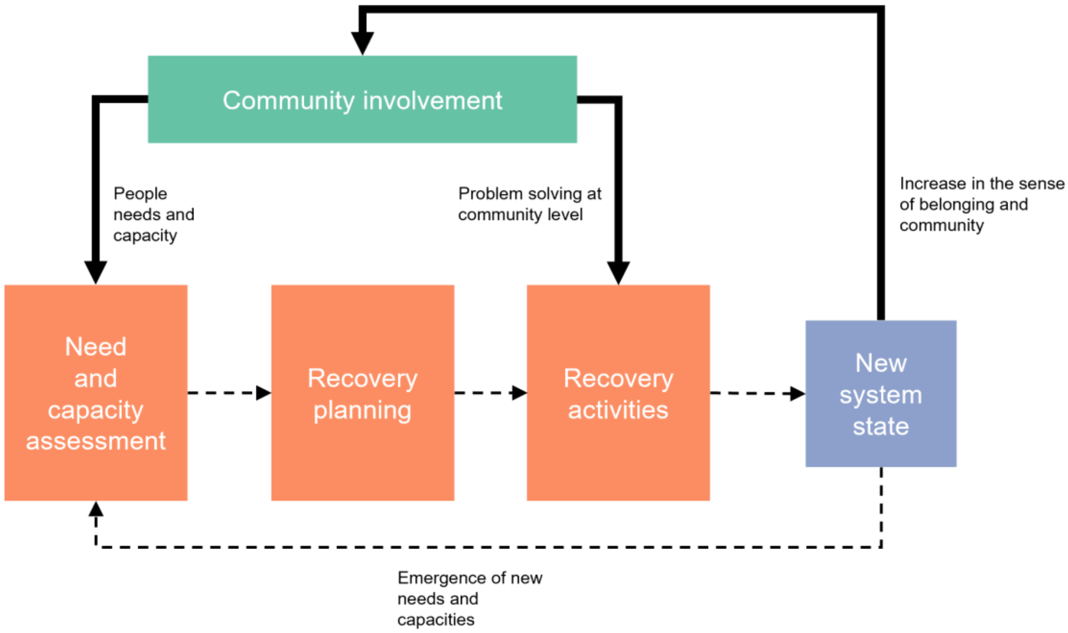

375 **Figure 3. Role of community involvement in need and capacity assessments, recovery planning, and recovery activities. The need and capacity assessment represents a key element in forming and preserving the dynamic process of recovery and the incremental participation of the community in the process.**

Table 2 reports a series of post-disaster need assessment approaches presented by different authors in the literature. It tried to find studies that followed, established, or reviewed applicable methodologies for needs identification and assessment and applied it to at least one real-world case study. The papers that only discuss recovery or early recovery are chosen for this collection. If a paper just addresses institutional or other forms of shortages, it is not considered because the chosen papers tackle needs that require physical assets to be addressed. Moreover, the articles included deal with prioritizing and comparing community needs rather than exclusively locating resources to address a particular need in a specific area. While a complete table is provided in the supplemental material, Table 2 attempts to focus on selection of studies mainly including stakeholder participation. Malilay et al. (1996) used quantitative cluster-sampling to conduct a rapid needs assessment in the aftermath of disasters, focusing on population-based data including remaining population and the number of people with specific health needs. In assessing the needs, their model considered disaster damage, the number and types of specific health needs, and the number of housing units. To assess the post disaster health needs consequent to the 1999 Chi-Chi earthquake in Taiwan, Chen et al. (2016) adapted this cluster-sampling technique to the community needs assessment and morbidity and mortality surveillance, which mainly considered population data and infrastructure functionality after damage in the quake areas.

The United Nations Development Group (UNDG), the World Bank (WB), and the European Union (EU) worked on the development of a Post-Disaster Needs Assessment (PDNA) tool (The European Commission et al., 2013). This tool provides an objective, thorough, and government-led assessment of post-disaster damages, losses, and recovery needs, setting the path

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for a consolidated recovery framework. The PDNA Guide (The European Commission et al., 2013) gives step-by-step guidance on planning for and implementing a PDNA, drawing on and incorporating several assessments and planning methodologies such as the Damage and Loss Assessment (DaLA) and the Human Recovery Needs Assessment (HRNA). The tool has been implemented in several case studies (Hinzpeter and Sandholz, 2018; The European Commission et al., 2016, 2017).

Considering the different studies reported in Table 2, it is possible to see that most of the approaches and methodologies for the recovery needs assessment are qualitative, relying on interviews and document surveys, and many of them focus on earthquake disasters. Most of the studies emphasised employment, jobs, and housing as primary concerns. Stakeholders and researchers all around the world have been debating whether housing or employment should take precedence over other recovery priorities, and they have yet to agree on which should be prioritised (Dunford and Li, 2011; He, 2019).

Prioritisation should not lead to decision-makers ignoring other essential concerns in recovery and directing all resources to meet only the most demanding needs. For example, if a community identifies housing as their primary need, focusing on new housing construction and allocating most recovery resources to this sector may lead to a misunderstanding of recovery progress and the withdrawal of government aid and intervention before true recovery in all sectors, including the economy, occurs (Lyons, 2009). Shortening reconstruction projects by directing all financial resources toward physical reconstruction may result in growing construction-related businesses and temporary jobs for locals. Consequently, it would appear to decision-makers that the economic recovery is advancing. However, after the reconstruction is complete, neglecting sustainable economic growth would present a new challenge that would be more difficult to deal with due to the allocation of the majority of financial resources earlier to physical reconstruction (Dunford and Li, 2011). Furthermore, the needs are interconnected, and treating one may result in the solution of another need, or the sort of answer offered to a need may lead to the formation of new demands (He, 2019; Zhang, 2016).

Moreover, as the perception and needs of the affected people change in the aftermath of a disaster, the solutions offered by the decision-making for recovery should change as well (Chandrasekhar, 2012; Kurosaki, 2017). For instance, relief and short-term recovery efforts are critical and urgent, with the goal of shortening the time it takes for people to reclaim a safe home and secure livelihood. However, redevelopment policies should be carefully developed based on comprehensive, site-based risk and vulnerability assessments, as well as ongoing consultations with all stakeholders (Downing, 2002; Ingram et al., 2006).

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Table 2. Post disaster need assessment approaches conducted in eight different publications (the complete table is available in the supplementary material)

Author(s)	Assessment target	Method	Input data / considered factors	Hazard	Main priorities amongst the needs	Involved stakeholders
He (2018)	Community needs	Semi-structured interviews and focus groups	-Disaster impacts -Disaster public perception -Local capacity -Expected external aids	Earthquake	-Productive living and development issues -Permanent ownership of land -Gain of employability for overseas job-hunting	Earthquake-resettled households and community leaders
He (2019)	Community needs	Semi-structured interviews and focus groups	-Disaster public perception -Expected external aids	Earthquake	-Safe land for reconstruction -Constructive conversation with the government -Permanent housing -Land grants	Earthquake-resettled households and community leaders
He et al. (2019)	-Evaluation of the current living conditions (compared to the pre-disaster)	-Semi-structured interviews and focus groups -Documentary and field investigations	-Physical living conditions -Off-farm job availability -Living expenses - Place attachment -Expected external aids	Earthquake	Non-agricultural employment	Households
Kurosaki (2017)	Assessment of the level of household recovery	Panel survey	-Preliminary disaster damage assessment -External aids received -Changes in the productive assets	Flood	Productive assets functionality	Households
Deen (2015)	-Vulnerable households and undermined informal coping strategies - Government's capacity	-Review and analysis of the existing literature and documents - Interviews	- Reducing vulnerability - Sustainable development goals	Flood	-Public health services - Sustainable shelter - Restoration of on and off-farm -Incomes (agriculture and livestock) - Public administration - Infrastructure - Education services	Key government officials
Honjo (2011)	Life recovery assessment	Workshops	Citizens' happiness	Earthquake	Permanent housing	Citizens

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All this implies that determining recovery needs is a dynamic process that should be continued throughout the recovery period. As illustrated in Fig. 3, one of the major components of the recovery plan should be the needs and capacity assessment of the community, and after each recovery cycle, and reaching a new system state in terms of functionality, a new need assessment should be undertaken to identify newly emerging needs.

The L'Aquila C.A.S.E. reconstruction project is an excellent example of the mismatch between people’s needs and priorities during the early-recovery phase and in the long term. Specifically, the project was initially conceived as ‘temporary housing’ but later resulted in a permanent housing solution that failed to meet the residents' long-term needs (Alexander, 2010a). According on the population's needs changing during various phases of recovery, some urban subsystems may need to operate differently. For instance, during long-term recovery, the health system should place more of its effort on treating chronic diseases and mental illnesses rather than providing emergency care which is the focus area of these systems during emergency and early recovery phase (Runkle et al., 2012).

In addition, post-disaster transformational changes (Blackburn, 2018) should be constructive or would cause dissatisfaction among the target group. This is the case of post-disaster relocation programs, in which people are typically resettled in another location unwillingly without regard to their pre-disaster socioeconomic status (Shanmugaratnam, 2005), which mainly leads to a sluggish recovery process (Charny and Martin, 2005). People are unwilling to alter their living habits to reduce their exposure to a natural hazard if it increases their vulnerability to other threats like economic insecurity. Therefore, exposure reduction should be one of the top priorities for choosing the location of the resettlement but not the only one (Davidson et al., 2007; Degg and Chester, 2005; Shanmugaratnam, 2005). In the case of L'Aquila post-earthquake recovery, population relocation without consideration of issues such as sufficient urban facilities (Forino, 2015), spatial connectivity (Contreras et al., 2013), social fragmentation, lack of functional living, and questionable ecological values (Alexander, 2010a; Özerdem and Rufini, 2013) resulted in an incomplete and slow recovery process and eventually a not resilient city (Contreras et al., 2017). Other flaws in L'Aquila recovery include focusing solely on meeting the population's quantitative needs while ignoring the quality of life of the afflicted population (Alexander, 2010b) in housing and deferring the reconstruction of the historical areas while ignoring their role in the city and citizens' identity (Contreras et al., 2014).

3.2 Single hazard and multi-hazard risk recovery

The interrelationship of multiple hazards and their impacts, as well as the implications of DRM decisions on different economic sectors and regions, and the diverse impact of disaster risk reduction measures on different risks, make recovery in multi-hazard environments challenging (Ward et al., 2022).

Among the different types of multi-hazard interaction mechanisms that can lead to a disaster such as compound, triggering, or cascading, (Gill and Malamud, 2014; Marzocchi et al., 2009; Tilloy et al., 2019), the occurrence of consecutive disasters is specifically challenging for the recovery process. Consecutive disasters are two or more disasters that occur in succession and whose direct impacts overlap spatially before the recovery from the prior event is considered complete (de Ruiter et al., 2020). The results of the interaction between the impacts generated by two consecutive hazards depend on the time interval

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between them, the rate of recovery of the system or the asset, or a combination of them (De Angeli et al., 2022; Marzocchi et al., 2012).

Table 3. A selection of seven publications presenting multi-hazard approaches in recovery or resiliency analysis (the complete table is available in the supplementary material)

Author(s)	Considered hazards	Included territorial element(s)	Spatial scale	Aim of the research	Multi-hazard approach
Der Sarkissian et al. (2020)	-Earthquakes -Wildfires -Floods -Windstorms -Landslides	Road network	Country	Assess road network resilience to natural hazards.	Multiple hazards are considered in a separate way (i.e., without considering any interaction) and compared.
Gentile et al. (2019)	-Earthquakes -Tsunami	Schools	City	Prioritisation for DRR measures	The considered hazards are combined in a multi-hazard index
Cheng et al. (2021)	-Earthquake -Heavy wind -Cyber-attack	IEEE 9-bus as an abstract and approximation of country power grid system	Country	Quantifying the resilience of engineered systems under random multi-hazard by employing availability as an effective performance indicator and assessing the system's availability across time, based on which resilience is quantified w.r.t. system robustness and recovery ability.	interdependent hazards are considered and their interdependences characterized by the copula, joint distribution, and Markov models. Cascading failures have taken into account.
Argyroudis et al. (2020)	-Flood -Earthquake	Multi-span highway bridge	Structure	Life-cycle assessment of the resilience of infrastructure, by taking into account all the possible events that may affect the system during its design lifetime.	Physical vulnerability surface that includes both hazards and accumulated damage due to the occurrence of the second hazard before complete recovery from the first one.

In the case of consecutive disasters, the exposed elements could remain in an unrecovered state due to the limited time interval between two hazards, and as a result, the second hazard's occurrence would cause greater impacts than it would have generated without previous damage (De Angeli et al., 2022; de Ruiter et al., 2020; Gill and Malamud, 2016; He et al., 2018). Furthermore, the response and recovery processes from the initial disaster would also become more demanding, if

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overlapped with the emergency response of the second disaster. On the other hand, if there is enough time and commitment for a successful recovery from the first disaster, the vulnerability of the urban system may be reduced, as an example through changes to building standards (i.e., 'built back better') (Fernandez and Ahmed, 2019; Kennedy et al., 2008). In such a case, the occurrence of a second hazard, even if it has the same characteristics as the first, may result in less damage (De Angeli et al., 2022). Despite the efforts made by researchers to quantify the losses of a structure exposed to multiple hazards (Jaimes et al., 2015), available multi-hazard risk or impact methodologies usually do not model recovery dynamics or residual damage due to consecutive disasters (De Angeli et al., 2022). Furthermore, the effectiveness of Disaster Risk Reduction (DRR) measures is usually not investigated from a multi-hazard perspective. While a DRR intervention can help in decreasing the risk of a single hazard type, it can also have unwanted effects on other hazard risk typologies, such as an increase in the vulnerability (Crosti et al., 2011; Li et al., 2012). These effects are referred to as "asynergies" of DRR measures (de Ruiter et al., 2021).

Table 3 includes a selection of studies that illustrate the key strategies for recovery planning in a multi-risk context. Only four studies were included in this table as representative of the main multi-hazard approaches available in the literature. The complete table of the analysed approaches is available in the supplementary material. It should be noted that only the papers that addressed the recovery in a multi-hazard environment were considered. Hence, even though there are many more studies that account for multi-risk assessment or multi-risk resilience evaluation, they are disregarded because they do not address recovery specifically or because they do not clearly discuss the application of their methods in recovery planning. As can be seen some researchers tackled multi-risk issue in recovery planning through prioritising one of the hazards over the others in order to implement DRR measures based on risk comparisons (Der Sarkissian et al., 2020). Gentile et al. (2019) and Sevieri et al. (2020) integrated two risk indices to create a single index for decision-making and prioritising among various DRR measures that could be taken regarding a building portfolio. However, they did not consider asynergy or accumulated damage because of the multi-risk situation. (Argyroudis et al. (2020) considered the recovery dynamics and accumulated damage due to the multi-risks in their analysis but focused on a single infrastructure (i.e., a bridge) to perform resilience assessment without providing any suggestion to contribute to stakeholders' decision making concerning DRR measures. In their analysis, Cheng et al. (2021) considered a simplified representation of a real-world power grid. Although they considered the likelihood of the second hazard occurring during the period of recovery following the first one, they neglected to account for the interaction between these two types of hazards and the consequently greater impact on the system when compared to the occurrence of single multiple hazards. As a result, the development of a comprehensive tool that can account for asynergies, cumulative damages, recovery dynamics, and any other interaction at various levels (hazard, vulnerability, exposure, or DRR measure) is required to assist decision-makers in long-term recovery planning and DRR measures implementation to increase the resilience of the urban system (de Ruiter et al., 2020; Durham, 2003).

A comprehensive representation that shows how multiple hazards can influence the functionality of an urban system in the different phases of the DRM cycle (pre-disaster, during disaster, and post-disaster) is presented in Fig. 4. During the disaster phase (represented by the red time frames in the "DRM phase" timeline of Fig. 4), most of the response actions facing various hazards are carried out. If certain measures, such as propping damaged buildings, which primarily overlap with early recovery actions, are not correctly completed, or ignored entirely in this DRM phase, the system's functionality will continue to decline even after the disaster has occurred, as illustrated in panels A, B, and C in Fig. 4. Additionally, events of any size, no matter how severe, that occur after a destructive event may result in the system's functionality being reduced because the system will be more vulnerable than it was prior to the big event, due to the damages that have been imposed by the first big event. This pattern may be seen in the panel C of Fig. 4, where the effects of shocks and landslides following an earthquake are depicted.

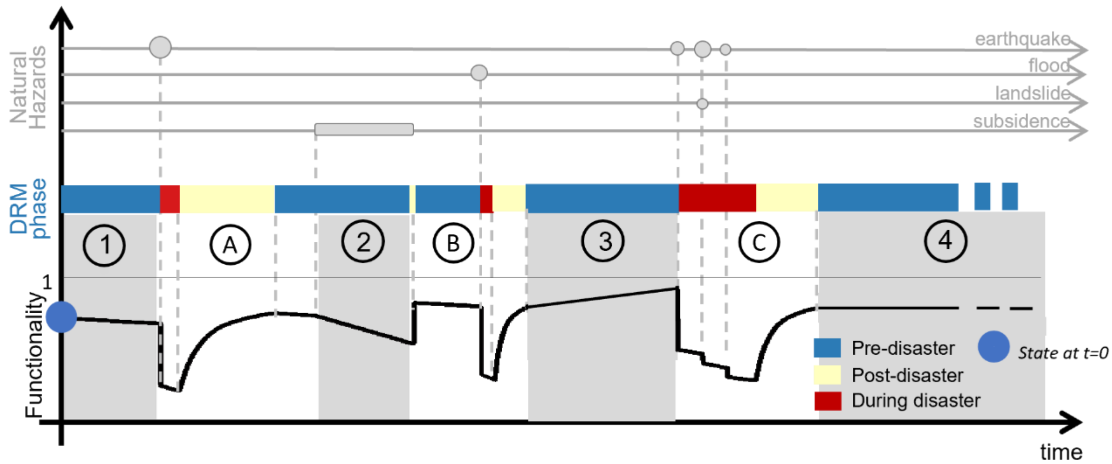

Figure 4. Possible evolution of the urban system functionality in a multi-risk environment divided into three phases (pre-disaster, during a disaster, and post-disaster) , considering different types of hazards (rapid onset: earthquake, flood, and landslide; slow onset : subsidence) consecutively with various time intervals between them and different trends in pre-disaster (ascending n. 3, descending n. 1 and 2, and steady n. 4) as a result of mitigation, lack of maintenance, and slow-onset hazards and their interaction with each other.

Furthermore, the pre-disaster phase has a great effect on system functionality and plays a crucial role in the system state also during the other phases. By increasing the functionality in pre-disaster, it is possible to reduce the loss caused by an upcoming disaster and prevent the system from reaching a very low level of functionality, from which it would be hard to recover. To investigate the role of the pre-disaster system's functionality, four different types of behaviour are identified in Fig. 4 by the grey time slots numbered from 1 to 4. In time slots 1 and 2, a gradual descending trend can be observed due to the lack of maintenance or the presence of slow-onset hazards (e.g., subsidence or coastal erosion). In time slot 3 the effect of mitigation and activities to increase the system's robustness has been depicted as having an ascending trend in the system's functionality. Time slot number 4 shows steady behaviour of the urban system's functionality because of the compensatory effect of the above-mentioned activities.

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4 Issue 3: Decision making models and methods for investment in physical elements to improve recovery in urban areas

One of the main concerns of the decision-makers has been how to take cost- and time-effective resilience measures considering the resource restrictions (Ghannad et al., 2020). Making sure that the urban system runs to its full potential and that none of the stakeholders or system components are malfunctioning because of the absence of necessary services that the other system components should be providing is a further concern that can aid in the efficient use of resources (Almoghathawi and Barker, 2019). Decision-making for investments to improve recovery of widely diversified and broadening urban systems is especially challenging, which is why researchers have developed optimisation models that can help decision-makers in directing their resources (Zamanifar and Hartmann, 2020). Although there are many other types of optimization models that support allocating investments to various sectors to boost recovery, or descriptive framework for recovery planning that focused on different aspects of the system (Bozza et al., 2015; Choi et al., 2019), in this section, optimization models refer only to models that distribute resources to the system's physical elements. Optimization models for recovery planning available in the scientific literature, can be divided into three classes (pre-disaster, post-disaster, and pre & post-disaster models) as shown in Table 4, according to the phase where the planned actions should be applied.

As can be seen, the models were pursuing three different objectives (cost minimization, recovery time reduction, and serviceability maximisation), with some of them seeking two of these goals. It should be noted that for assigning the objectives to the models that have been addressed, constraints that were considered by the authors in developing their optimisation model have not been regarded but the main goals of the optimization model were considered as the objective.

The territorial elements with which the models were concerned were also factored in classifying them. As a result, lifeline infrastructure networks (electricity, water, gas, telecommunications, and roads) are the most frequently applied territorial elements in optimization models. Given that the value of lifeline infrastructures in the recovery phase is primarily determined by their ability to provide service to residents and that they are the most covered territorial elements in the investigated models, serviceability is the most common objective in evaluated research. Although there have been many previous studies on some of the territorial elements, such as road networks, for which Zamanifar and Hartmann (2020) published a specific review on the recovery optimization model, in this study it was attempted to select papers to cover a diversity of territorial elements.

Interdependencies play a crucial role in the functioning of critical structures and infrastructural systems (Ouyang, 2014), which is why we have included this factor in our evaluations. Even though different studies proposed various types of interdependencies (physical, cyber, geographical, spatial, mutual, collocated, etc.) (Dudenhoeffer et al., 2006; Rinaldi et al., 2001) in urban system modelling, we only considered the presence of any type of interdependency in modelling in our analysis, and if interdependencies existed between more than two subsystems or networks, we recognized the study to be one that included interdependency in its modelling and optimization disregarding the type and depth of the interdependency consideration.

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Recovery improvement action planning		Author(s)	Urban Element(s)							Objective(s)		
			El	Wt	Gs	Tr	Tc	Gp	Fb	S	T	C
	Pre-disaster Actions	(Y. Fang & Zio, 2019)	■		■						■	■
		(Der Sarkissian et al., 2020)				■				■		
		(Du & Peeta, 2014)				■				■		
		(Rosato et al., 2021)	■	■	■		■		■	■		
		(Soltani-Sobh et al., 2016)				■					■	■
		(Bozza, Asprone, & Manfredi, 2017)							■	■		
		(Y.-P. Fang & Zio, 2019)	■		■						■	■
	Pre and post disaster Actions	(Ghorbani-Renani et al., 2020)	■		■					■	■	
		(X. Liu et al., 2021)				■					■	■
		(Ouyang et al., 2012)				■					■	
		(Ouyang et al., 2019)	■	■	■		■		■	■		
		(Blagojević et al., 2022)				■				■	■	
		(Almoghathawi & Barker, 2019)							■	■	■	
	Post disaster Actions	(W. Liu et al., 2020)	■		■					■		
		(Der Sarkissian et al., 2022)				■				■		
		(Rosenheim et al., 2021)				■				■		
		(Cha & He, 2019)	■	■	■		■		■	■		
		(Y.-P. Fang et al., 2016)				■				■	■	
		(Mudassir, 2020)							■	■		
		(Almoghathawi et al., 2021)	■		■						■	■
		(Ghannad et al., 2020)	■		■					■		■
		(Mudassir & Di Marco, 2021)				■				■		
		(Bristow, 2019)				■				■	■	
		(Guidotti et al., 2019)	■	■	■		■		■	■		
		(Cavallaro et al., 2014)				■				■	■	
		(Xu et al., 2020)							■	■	■	
		(Yu & Baroud, 2020)	■		■						■	

Urban Elements	Acronym
Electricity network	El
Water network	Wt
Gas network	Gs
Transportation network	Tr
Telecommunication network	Tc
Good production	Gp
Urban facility building	Fb

Objective	Acronym
Cost minimization	C
Recovery time minimization	T
Serviceability maximization	S

Interdependency	Authors' name background color
Interdependency considered	(grey)
Interdependency not considered	(white)

565 **Table 4. Optimization models for recovery planning are grouped into 3 matrices (pre-disaster, pre and post disaster, post-disaster actions) according to the DRM phase where the planned actions should be applied. In each matrix, for each of the selected approaches, it is reported: (i) the urban elements covered by the model; (ii) the goal of the optimization; (iii) if interdependencies are modelled or not (the complete table is available in the supplementary material).**

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More than 60% of studies were completed after 2019, and more than 80% of papers published prior to 2019 did not consider interdependencies. Other studies conducted resilience assessments using different indices while considering the recovery phase were explored in our literature study (Aroquipa and Hurtado, 2022; Dong et al., 2021; He and Cha, 2021; Liu et al., 2017; Pant et al., 2014; Zhang et al., 2021), but since they do not address recovery specifically or because they do not clearly discuss the application of their methods in recovery planning, they were not included in Table 4. Also, nine other studies—most of which were conducted before 2019 and which overlooked the interdependencies among systems—are considered in the analysis, which is reported in the supplementary material.

5 Key challenges in multi-risk recovery planning

In this final session, the current challenges in implementing multi-risk recovery planning are summarised, as a result of the main issues identified in Sect. 2-4.

Stakeholders' decision-making process for selecting an investment direction to increase urban resilience and improve multi-risk recovery planning is complex and often confusing for them. This confusion is exacerbated by the fact that the emerging concepts of resilience, recovery, multi-risk, and built-back-better, among others, have been increasingly included in real-world decision-making processes, but a shared and applicable definition of these terms is still lacking, together with an understanding of the links and relationship among them.

The current challenges and issues in the field of disaster recovery have been extensively analysed in the previous sections of this manuscript, with a specific focus on recovery phenomenology (Sect. 2), its requirements (Sect. 3), and available methodologies for disaster recovery planning (Sect. 4).

From the analysis of these three main issues, a series of key challenges and gaps have emerged. These challenges represent the main current criticalities and gaps in the field of recovery planning, from a multi-risk perspective, and represent the background to define the required future research development in the field. Each of the ten identified challenges is reported and discussed hereafter.

1. Current disaster recovery approaches do not evaluate how pre-disaster (i.e., prevention, preparedness, and mitigation) activities can influence the capability of urban systems to recover efficiently and timely from disasters. Recovery from disasters does not only encompass post-event actions, but also pre-event planning, as it is well underlined in some of the definitions of recovery reported in Sect. 2.1. According to the literature, pre-disaster actions play a significant role in determining the speed of the recovery process (Sect. 2.2). Nevertheless, there are only a few approaches in the literature (Sect. 4) that consider both pre- and post-disaster activities as well as how they relate to and affect recovery. These studies are all focused on specific infrastructures. Since the concept of resilience encompasses a range of time domains from pre-disaster to post-disaster and recovery, an evaluation of the relationship between the different phases of the disaster risk management cycle, considering the activities that are carried on in each phase, is important for taking measures to increase

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the resilience of the urban system. This issue is not sufficiently addressed so far, specifically by considering socio-economic aspects of the urban system.

2. The recovery process involves a heterogeneous group of stakeholders, characterised by different capabilities, shortages, and expectations. Decision-making in the recovery process is challenging due to the heterogeneity of the engaged groups. Indeed, stakeholders rarely agree on recovery goals (Sect. 2.3). If the different options in defining the objectives for the recovery procedures are not considered and the participation of all stakeholders is not promoted, the outcomes could be detrimental to one or more groups, leading to greater inequality in the community. Stakeholders' heterogeneity can be seen as a resource in the different stages of the recovery planning (e.g., needs and capacity assessment, or the implementation of the recovery actions) since it would bring different skills, mindsets and capabilities which would enrich and improve the overall process (Sect. 3.1).

*3. Rather than viewing recovery as a process, it is mainly addressed by focusing on the outcome***.** Most definitions of recovery, even the less recent ones, referred to disaster recovery as a process (Sect. 2.1). However, it emerged from experience that while planning for recovery, the main emphasis was on the outcomes. This issue has led stakeholders to think about recovery mainly out of a static mindset, even in identifying the needs and scopes (Sect. 3.1). Moreover, stakeholders usually compare the states of the system before the disaster and at the end of the recovery process, while it has been outlined that it would be better to compare the trends that the system exhibits in each time domain to determine whether the system was improved or not (Sect. 2.3). Therefore, even though the need to view recovery as a process rather than a product has been highlighted in theory, this approach mostly has not been executed in practice.

4. Physical reconstruction has been the focus of recovery plans. The planning for other recovery activities that support the restoration of urban socio-economic institutions has been only partially explored in the literature. Reconstruction and recovery are different even in definition (Sect. 2.1). Insufficient research has been conducted on the interaction between physical reconstruction and socioeconomic recovery efforts, as well as the coordination of these two types of activities so that they would be carried out with the same objectives and in line with each other (Sect. 2.1).

5. Current literature does not provide a clear distinction between response and recovery phases, while communities in these two phases have different needs and goals. Additionally, from response to recovery, capacities and external contributions may change significantly. Therefore, the transition between the two phases needs to be managed effectively so that stakeholders and decision-makers would not become confused by abrupt changes (Sect. 2.2). Moreover, in a multi-risk environment, it is possible for the community to be in the recovery phase of one risk while in the response phase of another. Therefore, planning and actions in these two phases should be coordinated to not conflict with one another (Sect. 3.2).

6. Recovery is a dynamic and non-linear process, characterised by different paces and parallel activities. Different communities and even different groups within the same community may experience varying rates of recovery, depending on their equipment capabilities, willingness to participate in the recovery process, and recovery objectives (Sect. 2.3 and 3.1). In addition, past experiences indicate that recovery efforts would not be carried out in every community in the same pattern and order, since the built environment components could be damaged at different levels depending on their significance to the

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functioning of the urban system. Therefore, it is not a realistic approach to prescribe and demonstrate an ordered linear recovery roadmap for all communities (Sect. 2.2 and 3.1).

7. Disasters are not seen as an opportunity to improve the urban system's resilience. Planning and investments for recovery are concentrated mainly on getting the system back to its pre-disaster state (Sect. 2.3 and 4). There are not enough plans and strategies that view recovery from disasters as a springboard for achieving sustainable development goals or making cities more resilient. The BBB concept has been in existence for years, but it is still ambiguous. All the components of this concept ('build', 'back', and 'better') are still controversial and there is disagreement amongst stakeholders on a practical definition of the terms (Sect. 2.3).

8. Community needs are not always incorporated into the recovery planning and reconstruction process. Therefore, the physical reconstruction of a built environment after a disaster is not always compatible with stakeholders' expectations and needs and eventually results in the malfunctioning of the system. Needs are changing constantly and answering one need leads to the emergence of another (Sect. 3.1).

9. Multi-risk recovery planning approaches are still lacking. Neglecting synergies, cumulative damages, recovery dynamics, and any other interactions at different levels (hazard, vulnerability, exposure, or DRR measure) might result in recovery plans that would strengthen the system's resilience regarding a particular hazard but leave it vulnerable, or even increasing its vulnerability to other hazards (Sect. 3.2).

10. Recovery planning requires a multi-objective optimization including maximisation of the socio-economic benefit of the community. The socio-economic importance of the urban assets and their contribution to the overall system functionality has been neglected in the planning and orientation of the investment for the recovery process. Only cost and time minimization and in some cases maximising serviceability of specific infrastructures were the main objectives in current optimization models. Moreover, socio-economic interdependencies amongst urban assets (e.g., buildings, critical infrastructures, lifelines, etc.) are ignored so far in urban system modelling for recovery (Sect. 4).

6 Conclusions

In this paper, a critical review of the existing natural hazard disaster recovery literature and guidelines has been performed with the dual goals of identifying current challenges and laying the groundwork for future research on multi-hazard recovery planning for urban resilience and decision-making tools development.

Disaster recovery literature has been investigated with a specific focus on: how we can define recovery and its role in the risk management cycle (Issue 1, Sect. 2), what is the final goal of the recovery process and what are the most important physical prerequisites for the urban system to begin and sustain recovery in a multi-risk environment (Issue 2, Sect. 3), and what are the available disaster recovery planning models and methods (Issue 3, Sect. 4).

What emerged from the review is that disaster recovery has been largely addressed by different sectoral perspectives and scientific communities. Nevertheless, studies providing holistic approaches to recovery, not only focusing on physical

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reconstruction but also including socio-economic impacts, are still lacking. Furthermore, recovery is mainly approached from a single-risk perspective, neglecting synergies, cumulative damages, recovery dynamics, and any other multi-risk interaction. Moreover, recovery has been only marginally explored from a pre-disaster perspective, in terms of planning and actions for better recovery before disasters occur.

Recovery planning requires a multi-objective optimization, where not only time and money are minimised, but also the socio-economic benefit of the community is maximised. Nevertheless, community needs are not always incorporated into the recovery planning and reconstruction process, and stakeholder heterogeneity is not exploited as a source of richness, but as a limit in identifying optimal solutions.

Stakeholders' decision-making process for selecting an investment direction to increase urban resilience and improve recovery planning is still complex and confusing. This confusion is exacerbated by the fact that applicable definitions of 'resilience' and 'recovery' are missing, together with an understanding of the links and relationship among them, and a clear distinction between response and recovery phases is still lacking, while communities in these two phases have different needs and goals. Furthermore, planning and investments for recovery are concentrated mainly on getting the system back to its pre-disaster state. There are not enough plans and strategies that view recovery from disasters as an opportunity to improve the urban system's resilience. Moreover, the main emphasis in recovery planning is still on the outcome, without considering recovery as a dynamic and non-linear process, characterised by different paces and parallel activities. This misperception led the scientific community to suggest an ordered linear recovery roadmap for all communities, that is not able to successfully reflect the real-world dynamics.

The outcomes of this critical literature can set the basis to outline the key research directions in the field of disaster recovery. As a key direction, the pre-disaster time domain should be considered as the beginning point of the recovery process, using the time before the occurrence of a disaster to plan, but also to take actions to get the built environment prepared for a good, advantageous, and quick recovery. Furthermore, future studies should model the recovery process in a dynamic way rather than with a series of sequential actions. In such a way decision-makers and planners will be able to implement early recovery activities and developmental reconstructions simultaneously to maximise the functionality of urban systems in the shortest time possible.

Recovery planning should be addressed by developing holistic tools that consider the relationship between the different DRM phases and the impact of the activities in each phase one on another, to better optimise the investments with the goal of increasing urban system resilience. Future recovery planning approaches should promote a functional recovery, where physical reconstruction and socio-economic recovery are jointly achieved. To ensure such an ambitious result, one of the focal points of future recovery research should develop strategies for enhancing and facilitating participatory recovery planning and actions, to ensure that stakeholders' needs, requirements, viewpoints, and preferences are successfully included. The future recovery planning models and tools would be general and flexible enough to fit different urban systems with varying socio-economic characteristics, stakeholder preferences, and exposure to multiple hazards.

Moreover, disaster recovery research should permanently shift from a single to a multi-risk perspective, providing comprehensive tools for recovery planning able to capture asynergies, cumulative damages, and multi-risk recovery dynamics. The identified research direction will ultimately enable stakeholders in making decisions and optimising their investments in the pre-disaster phase to improve the urban system's recoverability and overall urban resilience.

7 Author contribution

S. M.: Conceptualization, Methodology, Formal analysis, Visualization, Writing - Original Draft.
S.D.A.: Conceptualization, Methodology, Writing - Original Draft.
S.C.: Conceptualization, Supervision, Writing - Review & Editing.
G.B.: Conceptualization, Supervision, Writing - Review & Editing.
F.P.: Conceptualization, Supervision, Writing - Review & Editing.
All authors have read and agreed to the published version of the manuscript.

8 Competing interests

The authors declare that they have no conflict of interest.

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