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ORIGINAL ARTICLE OPEN ACCESS

Fuzzy Cognitive Mapping to Uncover Vital Urban Functions and Their Interdependencies for Disaster Recovery

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ABSTRACT

Engaging stakeholders in disaster recovery planning helps identify recovery needs accurately and integrates diverse perspectives into planning procedures. This study presents a quali–quantitative participatory method for identifying the urban functions that must be preserved to initiate the recovery process and ensure the rapid restoration of the entire urban system. The method involves evaluating the relative importance of different functions and analyzing their interdependencies through participatory fuzzy cognitive mapping (FCM) with local stakeholders. The inclusion of diverse stakeholders facilitates precise need assessment, fosters dynamic information exchange and promotes innovative, user-centred, bottom–up interventions that better reflect the realities of the affected communities. The approach was tested in a case study conducted in Sanremo, Italy, as part of broader research aimed at developing a decision support system to expedite recovery processes and enhance urban resilience. The participatory FCM session in Sanremo identified essential functions beyond emergency services, including supermarkets, educational services and pharmacies, centred around the temporary shelter function, which emerged as pivotal during the recovery process. A critical analysis of the FCM-based approach highlights its benefits and offers insights for further strengthening participatory planning in disaster recovery.

1 | Introduction

Involving stakeholders in disaster recovery planning helps ensure that recovery priorities are accurately identified, promotes meaningful dialogue among participants and brings together diverse viewpoints that can strengthen the overall planning process (Chandrasekhar et al. 2014). Understanding the needs and capacities of the community integrates various viewpoints into recovery plans, promoting the development of resilience in

disaster-affected communities (Chandrasekhar 2012; Iuchi et al. 2015; Bolin and Stanford 1998; Gaillard and Mercer 2013; Horney et al. 2016). Communities enthusiastically participate in recovery activities when the recovery process is tailored to address their needs (Iuchi 2014; Sovacool 2017). Moreover, identifying community capacity is essential to deliver solutions to challenges that are pertinent and optimally addressed at the community level (Bolin and Stanford 1998; Gaillard and Mercer 2013; Horney et al. 2016).

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In the context of disaster recovery planning within urban areas, a notable challenge is the heterogeneity of engaged stakeholder groups. These stakeholders exhibit diversity in capabilities, deficiencies and expectations. Failure to include diverse perspectives from various groups when setting recovery goals can lead to detrimental outcomes for certain groups, worsening community inequality (Mohammadi et al. 2023; Tuhkanen 2023). However, involving diverse stakeholders in an urban context can be highly time-consuming (Maginn 2007), posing challenges in the context of the complex and urgent nature of disaster recovery activities (Olshansky et al. 2012, 173). To address this challenge, it is preferable to engage stakeholders in pre-disaster planning. This helps establish a robust social organization, which in turn supports the effective implementation of post-disaster recovery efforts (Berke et al. 2014; Delilah Roque et al. 2020; Hamideh 2020).

Planning for the recovery of a future disaster requires identifying key structures within the urban system that will play a vital role in the recovery process. Strengthening critical structures and infrastructure can significantly enhance community resilience (Sivakumar et al. 2024). This proactive strategy aims to preserve and leverage these physical elements within the urban system, which are essential during recovery, ensuring a smoother and more effective transition.

However, a key challenge lies in identifying and prioritizing these essential physical elements and buildings, particularly when faced with resource constraints and the need for decision-makers to make strategic investment choices (Cara et al. 2018; Lin and Jia 2012).

Within the context of seismic risk, the Italian Civil Protection Department (ICPD) has established specific Limit Conditions (LCs) for urban settlements (Dolce et al. 2019), aiming to define target objectives for mitigation plans throughout various phases of the disaster risk management cycle, including pre-, post- and during earthquake disaster scenarios. Among these LCs, the Emergency Limit Condition (ELC) has been thoroughly investigated, with the ICPD offering manuals and operational guidelines for its application in analyzing urban systems and their physical elements and guiding practical responses to emergencies (Bramerini and Castenetto 2014).

While ELC focuses on the immediate response phase following a seismic event, other LCs play crucial roles in different stages of disaster risk management, such as recovery (Bramerini et al. 2013). For instance, the primary aim of 'Limit Condition for Safeguarding the Existence of the Settlement' (SLC) is to safeguard essential urban structures critical for initiating the recovery process and ensuring the rapid restoration of all urban system functions (Cattari et al. 2024). These essential structures, in connection with each other, establish a core system vital for initiating post-disaster recovery. This core system should be closely connected with the ELC components and ensure the response and emergency services provision alongside maintaining social and economic urban functionality, facilitating a rapid return to pre-disaster conditions (Cattari et al. 2024). However, unlike the ELC, the SLC has not been as extensively investigated, and no specific guidelines currently exist for identifying the parts of the urban system that play a crucial role in recovery. Addressing this gap is essential to establishing a

structured framework for SLC application in urban disaster risk management. The LCs were introduced by ICPD specifically for seismic risk management; however, some of their general concepts can be easily adapted to manage disasters caused by other natural phenomena. In multi-hazard risk conditions, the recovery dynamics and residual damage are essential aspects to be considered in recovery planning (De Angeli et al. 2022). Considering the possibility of consecutive disasters occurring during the recovery phase, neglecting this aspect could heighten vulnerability and diminish the community's resilience to other types of hazards (De Ruiter et al. 2020). Without structures in place to protect against additional risks that may emerge during the recovery period, the population's ability to cope effectively could be compromised.

The main research goal of this study is to develop a qualitative participatory method for identifying the urban functions that must be preserved to satisfy the SLC requirements, that is, the vital functions needed to initiate the recovery process and ensure the rapid, effective, and sustained restoration of the entire urban system. This identification is achieved by (a) evaluating the relative importance of different functions, (b) analyzing their interdependencies and (c) examining their relationships with functions that ensure the ELC. By using participatory methods, the presented approach aims to successfully integrate heterogeneous stakeholder engagement and perspectives into the pre-disaster recovery planning processes.

Compared to the emergency phase, recovery is an extended process (Dunford and Li 2011). It requires addressing a wide range of requirements, encompassing both tangible and intangible factors, which are essential for initiating and sustaining this prolonged process (Alexander 2013; Mohammadi et al. 2023). To comprehensively and systematically conceptualize these recovery requirements and elucidate their relations with urban system components, the concept of 'resources' is introduced in this study. This unifying concept encompasses the critical tangible and intangible elements required for recovery. It emerged from a participatory modelling initiative conducted through a focus group. This approach was specifically undertaken to clarify the objective of the research, ensuring that the relationships between recovery needs and urban system components are explicitly understood and effectively addressed.

A focus group discussion held as part of the EU-funded CRISPRO project in Savona, Italy, brought together disaster risk management experts from municipalities, academia, practitioners and first responders across Europe (CRISPRO 2022). Participants explored urban recovery needs, highlighting six key resources as essential for urban recovery: governmental and public security, human and social, economic, construction, environmental and lifeline infrastructure. These findings underscore the need for a structured, resource-centred framework for urban recovery planning. Details of the focus group participants and their insights are provided in Annex S1A.

Subsequently, a literature review was conducted to refine the framework developed through the focus group discussions, aiming to assess the relevance of the identified resources and minimize potential biases. The review focused on 6 key resource

categories and yielded over 130 papers, with 64 deemed relevant to post-disaster recovery. Lifeline infrastructure, though critical, was excluded from the current study's scope, except for the transportation network, which was considered a distinct resource due to its pivotal role in:

1. Shaping urban layouts and spatial interdependencies.
2. Identifying the core system essential for recovery (e.g., the SLC), where determining the minimum road network is crucial to maintaining physical interdependencies among urban assets and preventing significant serviceability issues.
3. Enabling reconstruction efforts by maintaining access to disaster-affected areas.

The literature review's findings, along with the focus group insights, contributed to defining the research objectives and the participatory planning framework. A detailed explanation of the six resource categories and their contributions to recovery is provided in Annex S1B. These resources encompass comprehensive concepts that include both tangible and intangible elements essential for recovery. However, they do not directly correspond to the physical components of the urban system.

To bridge the gap between these resources and physical urban elements, the concept of 'functions', defined as collections of physical assets that, together, provide a distinct set of services to urban inhabitants, is introduced. A total of 44 urban functions were identified and categorized into 6 sets corresponding to the key resources (please refer to Section 2).

It is important to note that although a function may be categorized under a particular resource, this does not imply exclusivity to that resource. Functions can also play analogous roles in relation to other resources. The classification is structured based on the predominant role of each function within the urban system. Urban functions play a pivotal role in enabling the population to access and regenerate these resources, ensuring that recovery processes remain renewable and sustainable (Agudelo-Vera et al. 2012). For example, economic resources require functions that facilitate individuals' reintegration into pre-disaster economic activities, thereby supporting the restoration of economic, social and other community resources (Asgary et al. 2012; Rouhanizadeh et al. 2020). Functions also enhance safety and security by establishing necessary links between raw resources, enabling essential services for the population (Candia et al. 2019). Furthermore, they act as catalysts for the interconnectedness of resources, ensuring their integration into recovery efforts (Zhao et al. 2024). As components of the urban system, functions are inherently interdependent. For example, in a coastal tourist destination, hotels rely on tourists, who, in turn, depend on beach access and operational safety services like police and fire stations (Carlisle et al. 2016).

This study aims to develop a quali-quantitative participatory method to identify key urban functions for disaster recovery planning. While the primary research goal is on establishing a structured, stakeholder-informed framework to guide the identification of these vital urban functions, the proposed approach will ultimately ensure that, by preserving the most

critical functions and their interdependencies as a core system, urban areas can rapidly and effectively initiate and sustain recovery efforts after a disaster, while also strengthening their preparedness for multi-hazard risks and consecutive events.

This paper is structured as follows: Section 2 outlines the methodology employed in the study. Section 3 introduces the case study of Sanremo, a city in northwest Italy, along with the stakeholder mapping process. The results are detailed in Section 4, followed by a discussion of the main findings in Section 5. Finally, Section 6 presents the key conclusions and highlights directions for future research.

2 | Methods

A participatory approach using the fuzzy cognitive mapping (FCM) method (Kosko 1986; U. Özesmi and S. Özesmi 2004) was employed for identifying the vital urban functions that must be preserved to initiate the recovery process and ensure the rapid, effective and sustained restoration of the entire urban system. FCM combines fuzzy logic with cognitive mapping, making it particularly effective for examining complex systems like urban systems, especially when dealing with limited or uncertain data (Mehryar et al. 2019; Papageorgiou et al. 2012; Reckien 2014). This method serves as a participatory semi-quantitative modelling tool, enabling the structuring and representation of participants' perceptions and knowledge visually and communicatively (Jetter and Kok 2014; U. Özesmi and S. Özesmi 2004). This approach allows for an in-depth understanding of how stakeholders conceptualize the key components and processes of a system, such as urban recovery, along with the interdependencies among its elements (Gray et al. 2019). FCM is particularly well-suited to capturing and synthesizing systemic perspectives, regardless of participants' varying levels of understanding of urban complexity; this makes it particularly effective whenever highly heterogeneous stakeholders with diverse backgrounds are involved (Christen et al. 2015; Knox et al. 2023).

In participatory FCM, stakeholders with an understanding of the dynamics of a system are invited to identify and articulate the most crucial variables and components within the system. They are asked to demonstrate the causal relationships among these variables and assign weights to the connections, indicating the extent to which a change in one variable influences another (Mehryar and Surminski 2022; Singh and Chudasama 2017). Through this process, participants quantify connections between variables and provide feedback on the relationships, shedding light on the interdependencies among urban functions. These interdependencies are vital for identifying critical system components essential for recovery, and FCM has proved to be the most appropriate method for extracting these relationships (Ding and Grundmann 2025).

FCM models can be prone to excessive generality for analysis (Mourhir et al. 2016). In the FCM approach presented in this paper, to avoid this problem and to facilitate the configuration of the participatory planning process within a defined framework, a list of the functions that should be considered as the variables of the urban system was provided to the participants.

To this end, a framework comprising 6 key resources and 44 associated urban system functions was introduced to them, as illustrated in Figure 1. This framework was built on the concepts of ‘resources’ and ‘functions’ introduced in Section 1 and served as the foundational structure for guiding the participatory activities. Stakeholders were asked to express their perspectives within this structure, facilitating more focused and coherent input.

FCM leverages individual perspectives for data collection and offers a perspective on the behaviour of the entire system by aggregating their knowledge (Mehryar and Surminski 2022). In the research presented in this paper, stakeholders participated in a FCM to identify important functions and demonstrate interdependencies amongst them, offering a macro-level view of the urban system's behaviour.

2.1 | Implementation

In the initial phase of the FCM session, participants were introduced to the concept and definition of disaster recovery. Short presentations on natural hazard events, past disaster recovery experiences and potential natural risks in the territory under consideration were delivered. These presentations aimed

to familiarize participants with various dimensions of disaster recovery planning, fostering a holistic and systems-thinking perspective before engaging in the FCM session.

Following this introduction, the framework shown in Figure 1 was presented to the participants. Each participant was provided with a list of the resources and related functions. To ensure comprehensiveness, stakeholders were invited to suggest additional resources and functions that might have been overlooked.

The FCM process involved the participants completing the following six sequential tasks:

- (i) Add any additional resources or functions that may have been overlooked in the provided list.
- (ii) Pick from a minimum of 3 to a maximum of 5 functions from the list, representing the most important functions to be preserved for the community to ensure the recovery process gets started and continues in the city after a disaster, allowing the urban area to provide the recovery resources through the selected functions. Write each selected function on sticky notes of different colours, with each colour corresponding to the related resource category. For instance, as shown in Figure 2, beaches are represented by green sticky notes because

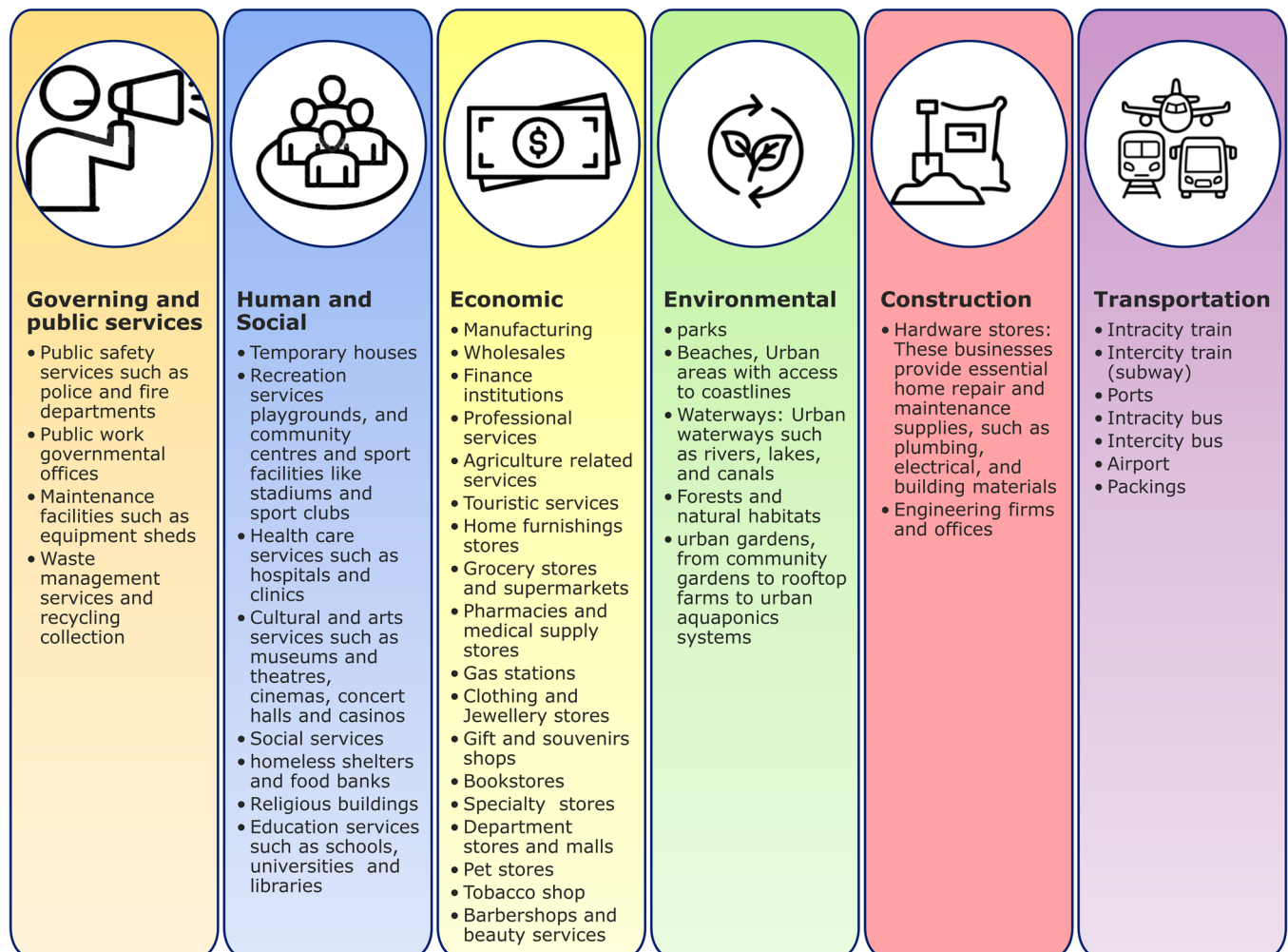


FIGURE 1 | List of functions in the urban system categorized into six different classes associated with their related resources. *Source:* Authors.

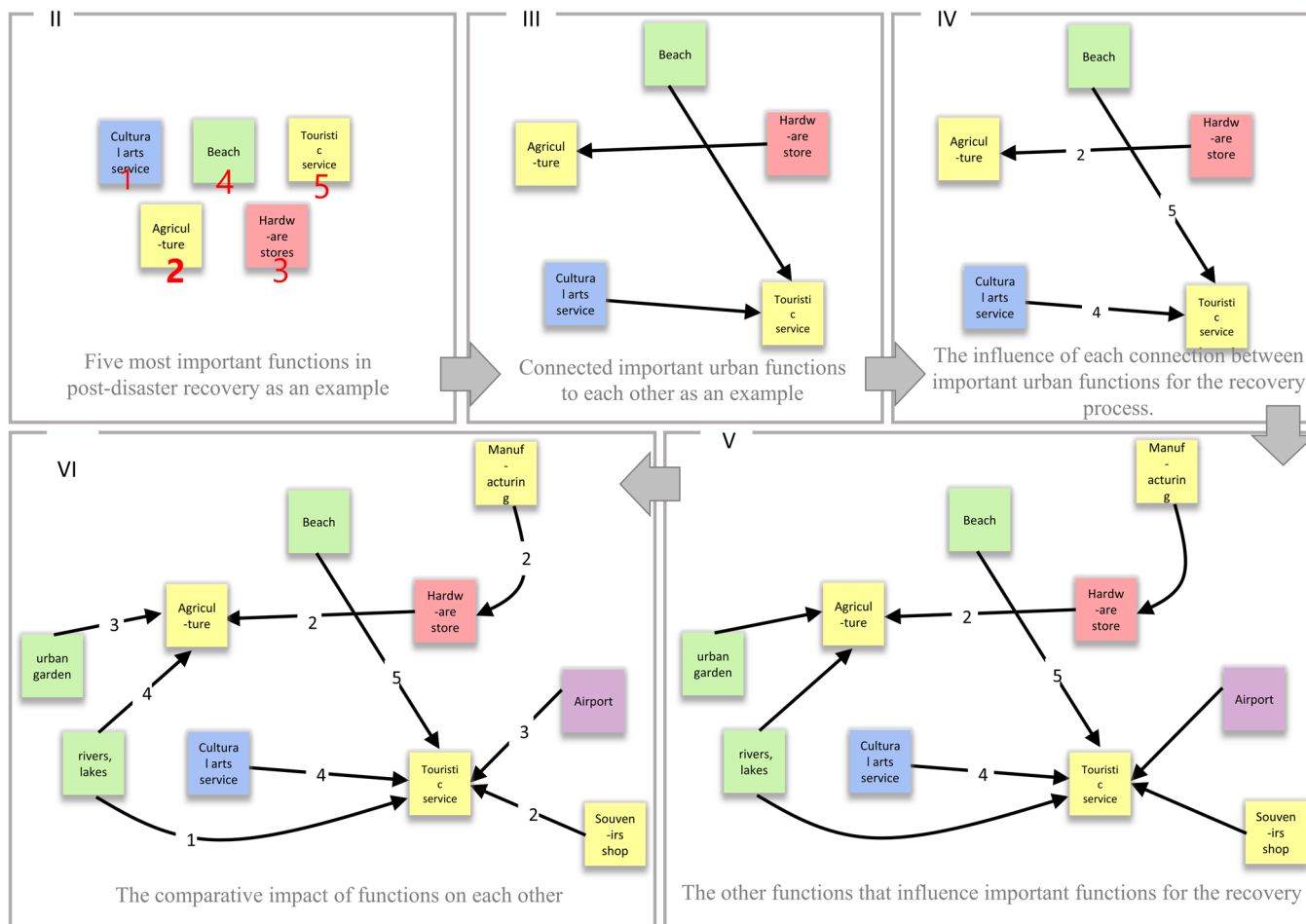


FIGURE 2 | FCM implementation steps. The Roman numerals in each part of the figure correspond to the steps explained in the text. *Source:* Authors.

they belong to environmental resources. Once identified, rank the selected functions by assigning them a score from 1 to 5, where 5 indicates the most significant function and 1 the least significant among your selected priorities.

- (iii) Identify which of the selected functions impact or support the functionality of each other and demonstrate connections accordingly as shown in Figure 2.
- (iv) Assess how much each function impacts or supports the others. Assign a value between 1 and 5, indicating the lowest to highest impact or support to each connection. Connections could receive similar values.
- (v) Identify any other functions that impact or support the functionality of the selected functions. Add those functions by connecting them to the impacted or supported functions. Functions can be either selected from the functions list cards or created as a new card.
- (vi) Assign a value between 1 and 5 to each connection (indicating the lowest to the highest impact or support) to represent the influence of functions on each other.

It was explained to the participants that the classification of functions into different resources was primarily for simplification and to facilitate recognition. In other words, stakeholders were

not required to select functions from all resource categories; instead, they were encouraged to choose those they deemed essential for the recovery of the settlement after a disaster.

Each participant created their individual map and explained their interpretation of selected functions to the facilitator. These explanations were incorporated into the maps if they differed from the reference definitions. This approach ensured that participants' perceptions of pre-defined functions were well-understood and accurately reflected in the aggregated FCM. The FCM session lasted between 45 and 60 min. While the session was conducted in a collective setting, it was not a traditional focus group, as each participant developed their map independently.

The main advantage of conducting FCM in a group session is fostering interaction among participants from diverse backgrounds, encouraging the integration of varied perspectives in cognitive maps (Johnstone 2017). Focus groups require significantly more logistical effort than individual interviews. When considering participant efficiency, independent interviews are more productive in terms of data collection (Guest et al. 2017). Despite these challenges, a group setting was opted for to leverage the benefits of participant interaction while ensuring each individual created their map with facilitator assistance, aiming to balance collective insights with robust individual data generation.

2.2 | FCM Analysis

The visual maps produced by each stakeholder were individually translated into square adjacency matrices, wherein the functions/nodes were listed along both the vertical and horizontal axes within a spreadsheet. The assigned values to connections were normalized within the range of 0–1 based on the minimum and maximum scores assigned across all FCMs, typically from 0 (indicating no connection) to 5. These normalized values were then encoded into the corresponding cells of the adjacency matrices. Next, the individual homogenized maps were aggregated into a unified map, employing a straightforward matrix addition process. Then the resulting values were once again normalized between 0 and 1 based on the full range and total sum of assigned scores. This iterative normalization method accounts for both how often a connection is identified and the range of scores it receives from participants. Unlike conventional approaches that rely on simple averages, which can obscure important distinctions (Papageorgiou et al. 2020), this method preserves information about both the frequency and variation in judgments. For example, two different interdependencies might have received the same average score, but one could have been evaluated by three participants and the other by six. Averaging alone would have treated them equally, ignoring the broader consensus implied by the latter. By normalizing based on the full range and total of assigned scores, our approach more accurately reflects the collective assessment and relative importance of each connection. In a context involving heterogeneous stakeholders, neglecting this aspect might have failed to adequately represent the consensus or variability inherent in their perspectives.

The aggregated FCM was then analyzed using ‘FCMapper’ (<http://www.fcappers.net/>), a spreadsheet-based analytical tool facilitating structural analysis of FCMs, and was visualized using ‘Visone’ (<http://visone.info/>), a network-analysis software (Mehryar and Surminski 2022).

Beyond individual function analysis and their interdependencies, the functions were grouped into ‘6 resources’ and ‘ELC-SLV’ categories (as explained in Section 3). Subsequently, the causal relationships among distinct function groups and the importance of different groups were analyzed.

In terms of the analytical approach, first, function rankings obtained during the initial phase of the FCM session were analyzed using voting methods (Pacuit 2019). Then, the structural characteristics of the integrated FCM were explored through graph and network analysis methodologies, addressing indegree, outdegree and centrality degree metrics (Yoon and Jetter 2016). The results of the voting method analysis highlighted the most important functions for the initiation and continuation of the recovery process. The graphs and network analysis revealed the functions with the highest impact and those requiring substantial support from other functions.

The voting mechanisms that are used to measure the importance of the functions include the plurality score, the average score and the Borda score (Pacuit 2019):

- **Plurality score:** In plurality voting, the winner is the option that has the highest number of votes, and the other options

are ranked based on the number of votes they receive. In this study, the plurality score was computed based on the frequency with which each function was chosen as one of the most important functions across individual maps in stage (ii) of the FCM. The plurality score highlighted the functions that stakeholders from diverse backgrounds most frequently recognized as important. This prioritizes functions that are commonly agreed upon, which may represent core aspects of the urban system.

- **Average score:** In the context of average scoring, the winner is the option with the highest average score. This score is calculated by summing the scores (ranging from 1 to 5) a function receives when selected as one of the most important functions in stage (ii) of the FCM and dividing that sum by the frequency of its election (i.e., the plurality score). Given the diverse backgrounds of stakeholders, one participant might have viewed a function as important based on their specific perspective, assigning it a high value. However, this perception might not have found support from others with different backgrounds (Grimble and Wellard 1997). Since participants were not fully representative of the population, this did not necessarily diminish the importance of that specific function (Ferretti 2016). Thus, the average score was chosen as a reflective measure of a function’s importance, capturing aspects that might have not been universally selected by many participants but were still significant to certain perspectives.
- **Borda score:** In the Borda voting method, voters provide a ranking for each option. The Borda count then determines the winner by assigning points based on the ranking. Specifically, in a scenario with n options, the option ranked first receives $n - 1$ points, the second-ranked option receives $n - 2$ points and so forth, with the second-to-last option receiving 1 point and the last option receiving 0 points (Pacuit 2019). The Borda score for option A , denoted as $BS(A)$, is calculated by aggregating scores from all voting cards, utilizing the following formula (where $\#U$ represents the number of elements in set U and i is a voter):

$$BS(A) = (N - 1) \times \#\{i | i \text{ ranks } A \text{ first}\} + (N - 2) \times \#\{i | i \text{ ranks } A \text{ second}\} + \dots + 1 \times \#\{i | i \text{ ranks } A \text{ second last}\} + 0 \times \#\{i | i \text{ ranks } A \text{ last}\}.$$

Therefore, the Borda count elects broadly acceptable options, rather than those preferred by a majority (Mehryar and Surminski 2022).

Together, these three voting methods explore various facets of stakeholder priorities, enabling a holistic identification of important functions. They ensure the results reflect not only shared priorities but also significant minority perspectives, essential in a complex system like urban recovery planning.

The network analysis aims to uncover the interdependencies among various system components (White et al. 2021). By examining the connections between variables and analyzing feedback on their relationships, it is possible to understand the system’s dynamics from the participants’ perspectives. This approach not only identifies impactful functions but also

highlights those that may differ from the most frequently voted functions in the initial phase of analysis (Mehryar and Surminski 2022). Additionally, some important functions may require significant support to remain operational. The network analysis identified these functions and their supporting elements, enabling a better understanding of the interconnections necessary for their sustained functionality. The analysis was conducted by evaluating the indegree, outdegree and centrality degree metrics. 'Indegree' refers to the cumulative weights of incoming links to a node, while 'outdegree' represents the cumulative weights of outgoing links from the node (Yoon and Jetter 2016). Indegree and outdegree reveal how much a node is impacted or supported by others and how much it impacts or supports others, respectively (Yoon and Jetter 2016).

The 'centrality' is the sum of indegree and outdegree, representing a measure of the relative criticality of the nodes in the FCM analysis (Yoon and Jetter 2016). The greater the centrality, the greater the potential for that node to affect change in the whole map/system (Yoon and Jetter 2016). Therefore, centrality $C(V)$ is:

$$C(V) = \Sigma(id(V) + od(V))$$

where $id(V)$ and $od(V)$ are the indegree and outdegree of node V .

These measures highlight not only which functions are pivotal but also their role in system-wide interdependencies.

Finally, a group analysis of the aggregated FCM was conducted to uncover insights into the causal relationships among distinct sub-groups of functions, specifically the six resources and ELC-SLC categories outlined in Section 3. To consolidate links among nodes within the same category, the weights of the links were summed up. As a result, these merged maps illustrate the collective impact of nodes within the same resource or LC category. For example, the merged resource map highlights the cumulative impact of economic resources on social, environmental or construction resources.

3 | Case Study

3.1 | Characterization of the Sanremo Urban Area

Sanremo is a town on the Mediterranean coast of Liguria, in north-western Italy. According to the latest statistics provided by the Italian National Institute of Statistics (Istat 2021), the total population is ~52,918 inhabitants, with a slightly higher number of females (27,648) than males (25,270). According to the age pyramid (Istat), the largest age groups are observed in the 50–54 and 55–59 years categories, showcasing a significant portion of the population in the middle-aged and pre-retirement stages. In total, 73% of the families are 1- or 2-member, and more than 70% of dwellings are occupied by the owners.

The city hosts numerous sports competitions and cultural events, such as the Milan–Sanremo cycling classic and the Sanremo Music Festival. The festival brings 41 thousand people

to Sanremo and the surrounding areas every year, including guests, organizers, staff and tourists. In practical terms, the impact of these presences falls mainly on accommodation (8.8 million euros), catering (2 million euros), shopping (2 million euros including expenses at the Casino and event ticketing) and transport (0.6 million euros) (Forbes 2023).

The Sanremo's Mediterranean climate and attractive seacoast setting on the Italian Riviera make it a popular tourist destination. In addition to its prominence in tourism, the city holds a notable position in agricultural activity. Sanremo has earned the moniker 'City of Flowers', underscoring the economic importance of floral and plant-related industries. Remarkably, within a cohort of 97 companies boasting a turnover exceeding 1 million euros, a noteworthy 20% engage in the production of flowers and plants.

Sanremo is vulnerable to a range of significant natural hazards, including seismic events, urban, riverine, coastal flooding and landslides (Cattari et al. 2024; Ferrando et al. 2021; Guzzetti et al. 2004).

Sanremo and its hinterland sit at the hinge between the Mediterranean coast and the first Alpine ridges, and it is exposed to multiple hazards that recur every year in different forms. Hydrogeological events (flash floods and associated landslides) are the most recurrent. One of the most destructive floods occurred in 1998, when 83.8 mm of rainfall was recorded in one hour and 119.2 mm in three hours and resulted in the loss of a life (Guzzetti et al. 2004). Many communication routes were interrupted, and the Sanremo was isolated due to the interruption of the motorway and the railway by landslides. Wildfires are seasonally frequent as well; the SIRIO optical–thermal system typically issues 15–20 high-risk alerts each summer for the maquis-covered slopes immediately north of the city, where steep topography funnels sea-land winds and accelerates fire spread (Grasso et al. 2018; Losso et al. 2012). By contrast, seismic shaking is rarer but potentially catastrophic: the 1887 Mw≈6.5 earthquake that destroyed the Bussana region in Sanremo remains the reference scenario (Degli Abbatini et al. 2024).

Exposure is strongly differentiated within the municipality. The historic centre, the seafront tourist zone and the arterial Via Aurelia concentrate hotels, hospitals and lifelines within a few metres of sea level, leaving them vulnerable to storm surges and the flash floods of the San Romolo and Foce torrents. Conversely, peri-urban hamlets and the hill-slope greenhouse belt are more exposed to landslides and wildfires but less to flooding.

This diverse exposure to multiple hazards makes Sanremo an ideal case study for investigating disaster resilience and the critical importance of investing in effective recovery strategies.

3.2 | Stakeholder Engagement

A diverse group of 50 stakeholders, representing various sectors and backgrounds related to 6 resource types, as outlined in Section 3.1, were invited to partake in the FCM session. Of the invitees, 22 stakeholders provided their FCM. The average age of the participants was 53 years, and they represented a range of

professions, including geologists, teachers, housewives, workers from the tourism sector, farmers, police officers, engineers, municipal workers, employees from insurance companies, contractors and civil protection. For a detailed list of participants, including their occupations, ages and genders, please refer to Annex SIC.

Invitations were extended to stakeholders of diverse genders, with participants self-declaring their gender for inclusion in the analysis. As a result, the table in Annex SIC reflects participant information by gender, based on their self-declarations.

Stakeholders were carefully selected based on their significance and roles within specific resources. For instance, in the domain of economic resources, stakeholders were chosen with a focus on sectors crucial to the city's economy, such as tourism and agriculture. The significance of these sectors was determined through the analysis of quantitative data obtained from open-source databases such as the Istat.

4 | Results

This section presents the main results of the FCM, organized around the key steps necessary to identify the vital urban functions that must be preserved to satisfy the SLC requirements: (a) evaluating the relative importance of various functions, (b) analyzing their interdependencies and (c) examining their relationships with functions that ensure the ELC. The section begins with the prioritization of functions based on participant input collected through different voting methods. This is followed by an exploration of the network of interdependencies among functions and resources using FCM-derived metrics such as centrality and outdegree, with particular attention to their connections to ELC-supporting functions. Finally, as an additional exploratory analysis, the adaptive organization of local recovery systems is investigated by systematically removing ELC functions, aiming to reveal alternative structures and priorities within decentralized contexts.

The vital urban functions that must be preserved to initiate the recovery process and ensure the rapid, effective and sustained restoration of the entire urban system in post-disaster time for the Sanremo municipality were identified as a result of the FCM and its analysis according to points a, b and c. The vital urban functions include: healthcare, public safety, public works governmental offices, grocery stores, temporary houses, education services, pharmacies, engineering firms and offices, hardware stores, urban busses, waterways, social services, touristic services, recreation services, cultural and art services, maintenance facilities, homeless shelters, waste management and parking. The vital functions identified for sustaining recovery encompass a range of services and provisions that extend beyond those defined within the ELC framework.

4.1 | Relative Importance of Urban Functions

At the outset of the FCM sessions, many participants chose not to introduce new functions or resources to the existing list. Although some suggested including lifeline infrastructure, it

was collectively decided to exclude them due to the research's primary focus on functions rather than lifelines.

To identify the most critical urban functions for disaster recovery, participants were asked to select the top 5 functions. A total of 24 out of 45 functions were selected at least once, spanning all 6 resource categories. The plurality score, indicating the frequency of selection by participants, ranged from 1 to 18. Figure 3 presents a detailed summary of the frequency with which specific functions were identified as among the top 5 most important for the recovery process (plurality score) and other scores that are assigned to them. The figure focuses exclusively on functions selected at least once as a top-5 priority. Functions added to the maps in response to questions (iii) to (iv) as supportive functions but not selected in the top 5 are excluded from the figure to reduce visual clutter and maintain clarity in the presentation. It should be noted that healthcare services, public safety services and public works governmental offices as three functions with high scores, are essential functions that must remain operational during emergencies (Bramerini and Castenetto 2014). These are classified as ELC functions.

Based on the plurality score, healthcare services, public safety services and grocery stores rank as the top 3 most frequently chosen functions among the top 5. Temporary housing, public governmental offices and urban buses follow, with each receiving 8 times selections. In total, 12 functions are selected only by 1 or 2 participants, while 21 functions remain unselected. At the resource level, the frequency of selections varies, with human and social resources receiving the highest count at 36, and environmental resources receiving the lowest at 6, as shown in Figure 3.

The Borda score almost mirrors the plurality score results. However, in cases where multiple functions receive the same frequency of selection, they are ranked equally regarding the plurality score. This suggests that differences in Borda scores primarily stem from the fact that Borda assigns more weight to functions ranked higher, more consistently, rather than just their frequency of being selected in the top 5. As a result, functions that are ranked higher across participants tend to receive higher Borda scores, while those selected less frequently, or with less consistency, tend to score lower overall.

Using the average score as a measure to identify the most important functions for recovery, the rankings diverge significantly from those based on the Borda and plurality scores. Recreation services, maintenance facilities, homeless shelters, temporary housing and public governmental offices emerge as the top 5 functions, reflecting distinct priorities in this approach.

At the resource level, as shown in Figure 3, governing and public resources, along with human and social resources, share the highest average scores. However, based on the Borda score, human and social resources stand out as the most critical for recovery, with a significant margin according to participant opinions.

4.2 | Interdependencies Among Urban Functions

To understand interdependencies among functions and identify which functions play a supportive or structuring role in the

| Resources | | Number of repeat | Average of the scores | Borda score | Out-degree | In-degree | Centrality |
|-----------------------------------|---|------------------|-----------------------|-------------|------------|-----------|------------|
| Governing and public service (GP) | | 24 | 0,73 | 1048 | 8,31 | 4,4 | 12,71 |
| Human and social (HS) | | 36 | 0,72 | 1570 | 6,26 | 12,46 | 18,71 |
| Economic (EC) | | 21 | 0,52 | 895 | 4,17 | 4,6 | 8,77 |
| Environmental (EN) | | 6 | 0,27 | 248 | 0,63 | 0,89 | 1,51 |
| Construction (CR) | | 11 | 0,45 | 465 | 2,49 | 2,14 | 4,63 |
| Transportation (TP) | | 11 | 0,4 | 462 | 4,51 | 1,89 | 6,4 |
| Resource | Functions | Number of repeat | Average of the scores | Borda score | Out-degree | In-degree | Centrality |
| HS | Health care services | 18 | 0,72 | 785 | 1,91 | 5,09 | 7 |
| GP | Public safety services | 14 | 0,73 | 611 | 3,69 | 2,4 | 6,09 |
| EC | Grocery stores and supermarkets | 13 | 0,52 | 554 | 1,94 | 2,06 | 4 |
| HS | Temporary houses | 8 | 0,8 | 352 | 2,03 | 3,46 | 5,49 |
| GP | Public works governmental offices | 8 | 0,775 | 351 | 3,6 | 1,8 | 5,4 |
| TP | Urban buses | 8 | 0,45 | 338 | 2,49 | 0,51 | 3 |
| CR | Engineering firms and offices | 6 | 0,43 | 253 | 0,91 | 0,83 | 1,74 |
| EC | Pharmacies and medical supply stores | 4 | 0,5 | 170 | 1 | 0,89 | 1,89 |
| CR | Hardware stores | 4 | 0,5 | 170 | 1,57 | 1,31 | 2,89 |
| EN | Waterways: Urban waterways | 4 | 0,3 | 166 | 0,2 | 0,2 | 0,4 |
| HS | Social Services | 3 | 0,67 | 130 | 0,46 | 0,94 | 1,4 |
| HS | Education services | 3 | 0,53 | 128 | 1,09 | 1,11 | 2,2 |
| EC | Touristic services | 2 | 0,7 | 87 | 0,26 | 1,03 | 1,29 |
| HS | Cultural and arts services | 2 | 0,6 | 86 | 0,29 | 1,11 | 1,4 |
| EC | Department stores and malls | 2 | 0,4 | 84 | 0 | 0,34 | 0,34 |
| TP | Parkings | 2 | 0,3 | 83 | 1,77 | 0,74 | 2,51 |
| HS | Recreational services | 1 | 1 | 45 | 0,29 | 0,2 | 0,49 |
| GP | Maintenance facilities such as equipment sheds | 1 | 0,8 | 44 | 0,34 | 0,14 | 0,49 |
| HS | Homeless shelters and food banks | 1 | 0,8 | 44 | 0,09 | 0,66 | 0,74 |
| GP | Waste management services and recycling collection | 1 | 0,4 | 42 | 0,69 | 0,06 | 0,74 |
| CR | Laboratories for geotechnical and geological analyses | 1 | 0,40 | 42 | 0 | 0 | 0 |
| EN | Parks | 1 | 0,2 | 41 | 0 | 0,11 | 0,11 |
| EN | Beaches, Urban areas with access to coastlines | 1 | 0,2 | 41 | 0,09 | 0,17 | 0,26 |
| TP | Ports | 1 | 0,2 | 41 | 0,26 | 0,57 | 0,83 |

FIGURE 3 | Selected functions, resources and their corresponding scores and indegree in the integrated FCM. *Source:* Authors.

recovery, the following FCM-based network metrics have been examined: outdegree (impact on other functions), indegree (reliance on other functions) and overall centrality (influence within the system).

Public safety services, public work governmental offices, urban buses, temporary houses and grocery stores were identified as the most impactful or supportive functions, examining functions with the highest outdegree. However, considering centrality, healthcare services claim the top spot primarily due to their high indegree. Public work governmental offices exert the strongest impact on healthcare services, as indicated by the highest edge scores directed towards healthcare in the FCM map. Following closely, public safety services also significantly impact and directly support healthcare functions.

Figure 4 illustrates the interdependencies among functions, with the circle size denoting the centrality degree. The darkness of the interconnected lines signifies the strength of the interdependencies or, in other words, higher degrees of the linkages. Figure 5 illustrates the interdependencies among various resources. Self-connected edges indicate interdependencies within the same resource, called intradependencies. Besides the self-connections for governing and public resources and human and social resources,

two major interdependencies are evident: one between human and social resources and governing and public services resources, and another between human and social resources and economic resources. The size of the circles in the figure shows the outdegree of each resource, with environmental resources having the lowest outdegree, indicating their comparatively smaller impact.

4.3 | Relationships With ELC Functions

After segregating the ELC functions and consolidating them into a single subsystem, as depicted in Figure 6, the interdependencies among the other functions and the ELC subsystem can be more easily observed. Functions strongly connected to the ELC include temporary houses, urban buses and grocery stores.

The presence of an ELC zone and its associated functions within the urban system is assumed based on the ICPD framework (Dolce et al. 2019). The ELC serves as a centralized hub that hosts a range of services and assets essential for supporting city-wide emergency response operations. These functions are intended to be accessible to multiple neighbourhoods or sub-communities across the city, ensuring broad coverage and support during times of response and recovery.

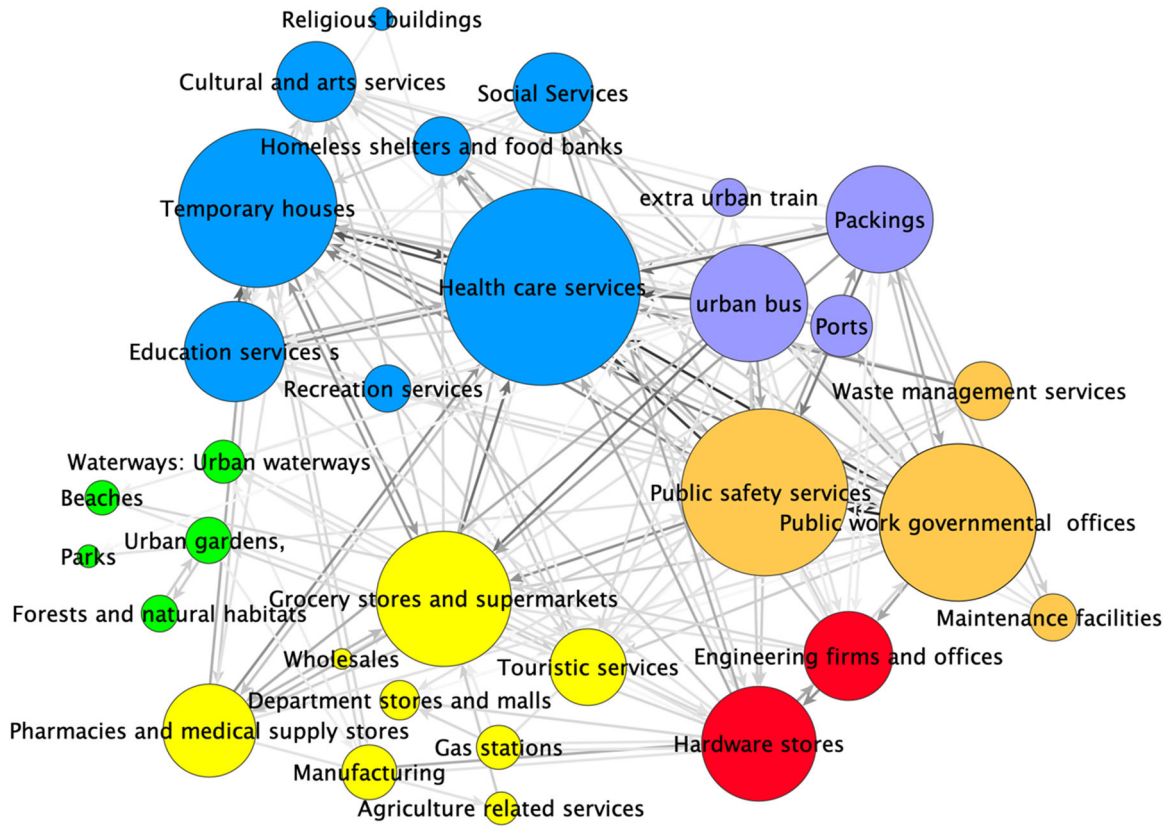


FIGURE 4 | Integrated FCM demonstrating the interdependencies among functions, with the circle size denoting the centrality degree of the functions. *Source:* Authors.

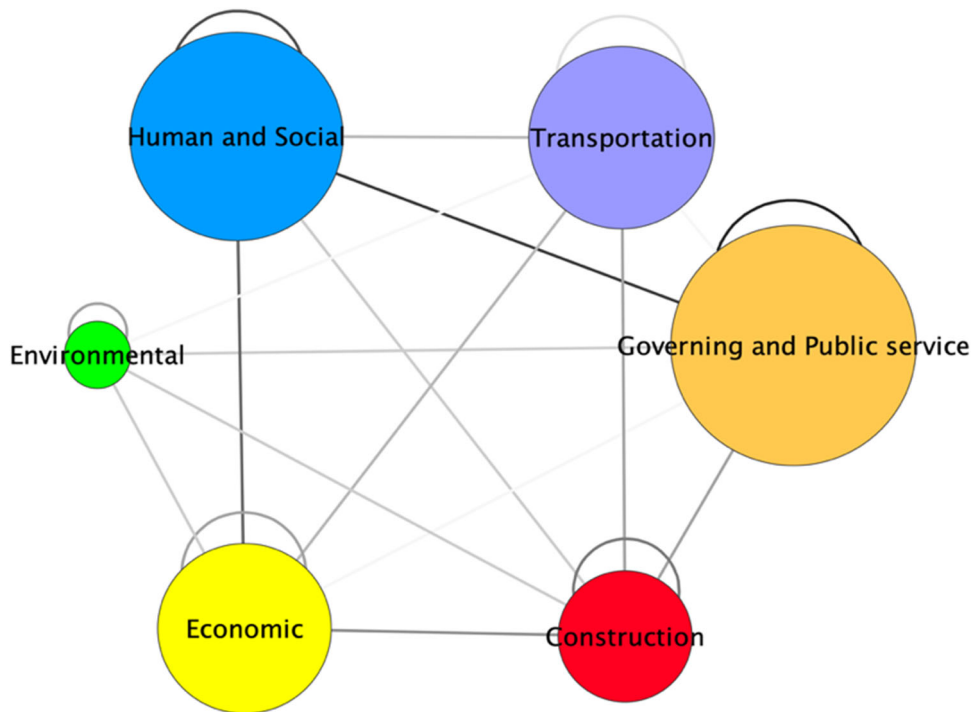


FIGURE 5 | Integrated FCM at the resource level demonstrates the interdependencies and intradependencies amongst resources, with the circle size denoting the outdegree of the resources. *Source:* Authors.

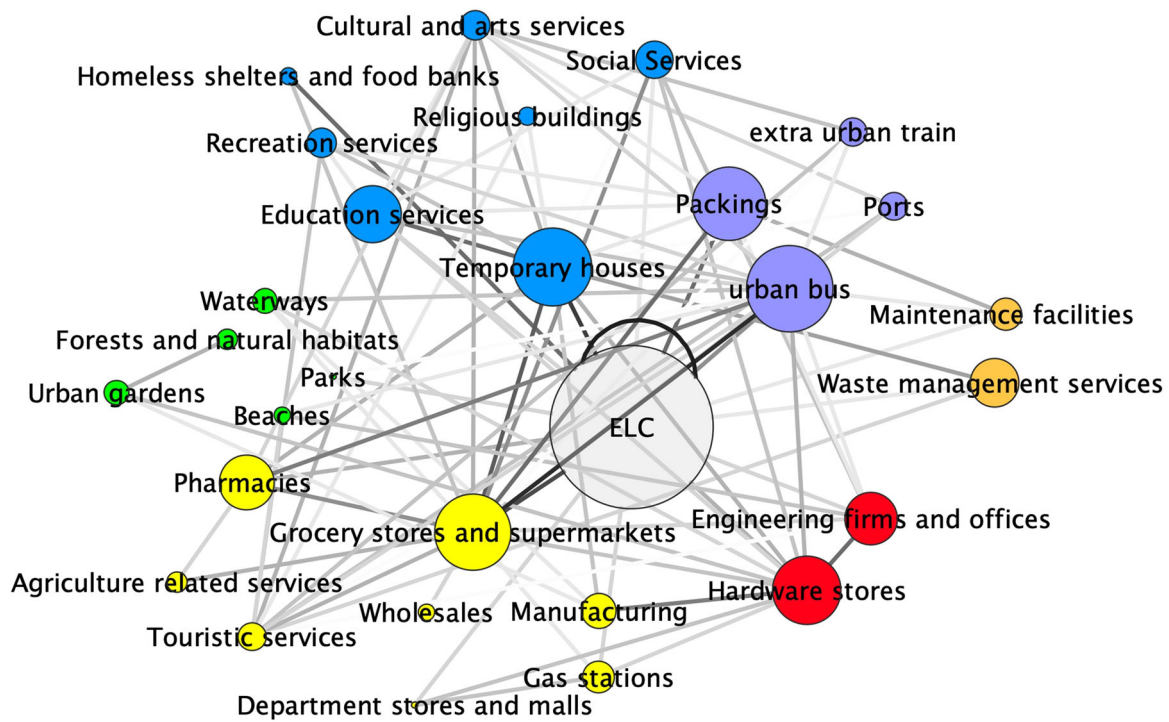


FIGURE 6 | Interdependencies amongst the ELC subsystem and the other functions and intradependencies amongst the ELC functions. In this figure, the size of the circles illustrates the outdegree of the functions and ELC subsystem. *Source:* Authors.

However, while local communities depend on the ELC for essential services, such as healthcare, municipality, police and fire station, they may not possess all these functions within their immediate vicinity. Rather than replicating the full range of ELC capabilities at a smaller scale, these communities are expected to organize themselves around alternative key functions or elements that are central to their own localized recovery strategies and build around the most relevant and accessible resources within their context, while still maintaining linkages to the city-level support provided by the ELC.

4.4 | Local System Organization Without ELC

To investigate these organizing principles, ELC functions were removed systematically from the FCM integrated map. This approach aims to identify the foundational components or functions around which these emerging sub-communities are structured, shedding light on how recovery and urban systems evolve at a localized level in the absence of ELC. Upon removal of the ELC functions and reintegration of the maps, the resulting map is depicted in Figure 7. Notably, temporary houses emerge as the central function with the highest centrality degree, with numerous connections to other functions.

Hardware stores and engineering firms were selected 4 and 6 times, respectively, as important functions, ranking 7th and 8th in the Borda score, which reflects their significance. Comparing the results of various voting methods highlights some differences. For instance, urban waterways, selected 4 times and ranked 10th by Borda score, exhibit one of the lowest average scores, falling below social, education and touristic services. Similarly, touristic services, although selected twice as important, achieve average scores almost equal to those of ELC services.

The comparison of the results from the voting methods with network analysis metrics (indegree, outdegree and centrality) further reveals notable discrepancies. Healthcare and grocery stores, despite being chosen 18 and 13 times as essential functions, rank lower in outdegree than urban bus services, which are not among the top 5 by Borda or average score. Additionally, parking, with a plurality score of just 2, ranks 7th in outdegree, demonstrating significant network connectivity and impact that is not reflected in the voting-based rankings.

5 | Discussion

The main goal of this study is to develop a method for identifying the urban functions that must be preserved to satisfy the SLC requirements, those vital for initiating recovery and ensuring rapid restoration of the urban system. This goal responds to a key challenge in disaster recovery research: how to prioritize and integrate the diverse and interdependent urban functions that support both immediate and long-term recovery (Cattari et al. 2024; Contreras et al. 2017; Giuffrè et al. 2025). The identification process involves (a) evaluating the relative importance of different functions, (b) analysing their interdependencies and (c) examining their relationships with functions that ensure the ELC. This section presents a critical discussion of the results presented in Section 4, focusing on these three aspects, and highlights the key functions identified as essential for meeting the SLC requirements in the Sanremo municipality.

The FCM resulted in the selection of 24 out of the 45 initially identified functions, indicating that participants perceive recovery as a comprehensive process that demands contributions from a wide range of domains, echoing the complexity

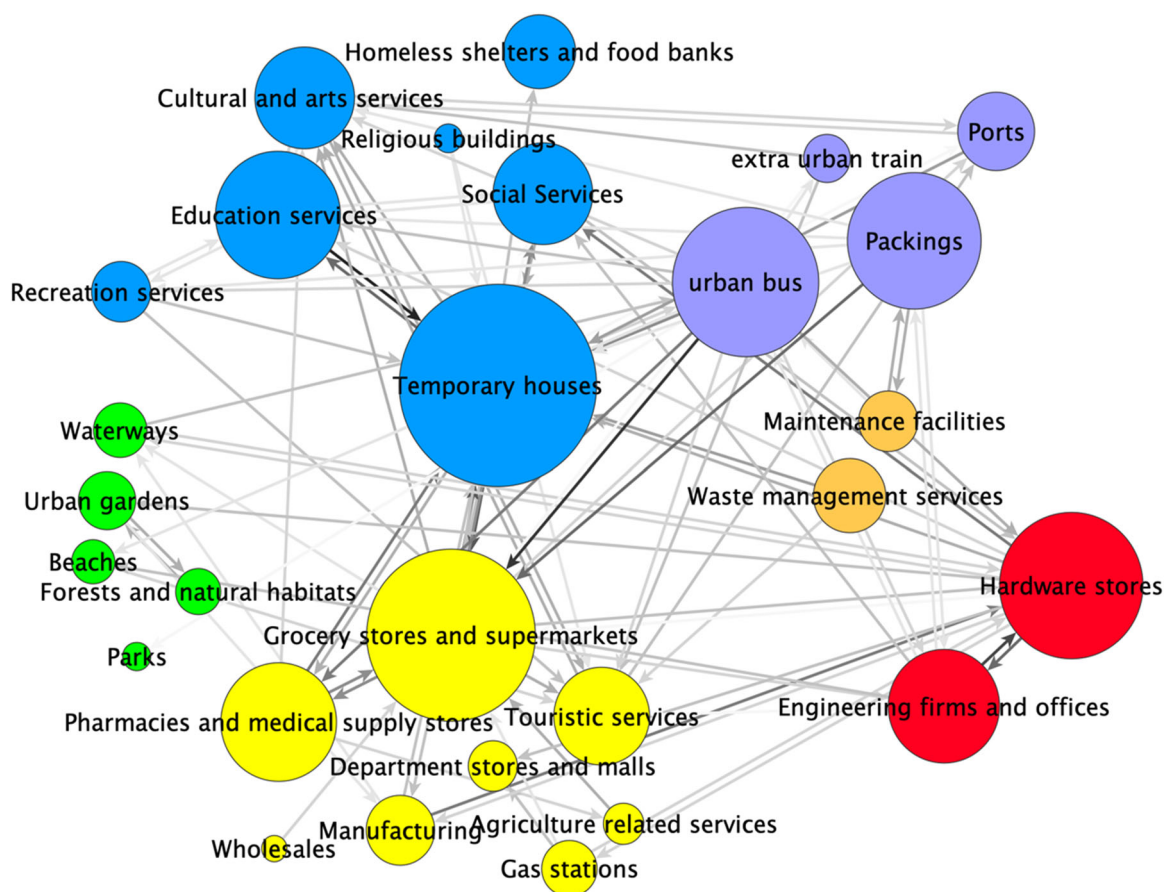


FIGURE 7 | Integrated FCM excluding ELC functions demonstrating the interdependencies among functions, with the circle size denoting the centrality degree of the functions. *Source:* Authors.

noted in previous studies (Contreras et al. 2017; Mohammadi et al. 2023; Tuhkanen 2023). This diversity underscores the multifaceted nature of recovery planning, where different stakeholders recognize the importance of a broad range of services and functions to address the complex challenges posed by post-disaster contexts (Hamideh 2020). The wide range of functions chosen could pose challenges for prioritization, especially in resource-limited scenarios where decision-makers must focus on the highest-priority functions (Ghannad et al. 2021). However, the voting methods provide a mechanism for narrowing down options by emphasizing the functions that resonate most strongly across the participant group.

When analyzing various voting methods to determine the most important functions for facilitating a fast and efficient recovery process, it could be observed that the results from the Borda score and plurality score are not significantly different. This suggests that relying on just one of these two methods may suffice for understanding the broadly chosen functions as important functions.

The high plurality and Borda scores attributed to grocery stores, temporary housing and urban bus services highlight their perceived importance among participants. These findings highlight the importance of everyday, frequently used services in the recovery process, such as groceries and temporary housing, alongside emergency services provided by the ELC functions. This suggests that effective long-term recovery planning should

not focus solely on preserving emergency response functions, but also consider services that support the population's daily needs, as they play a critical role in restoring normalcy and ensuring the continuity of community livelihood and recovery process (Contreras et al. 2017).

Furthermore, the analysis of resource-based Borda scores reveals the paramount importance of human and social resources in long-term recovery efforts. These resources received the highest scores by a significant margin, reflecting the critical role they play in recovery and sustaining communities over time. Recognizing and leveraging these resources is essential for fostering resilience and ensuring a comprehensive recovery strategy (Delilah Roque et al. 2020; Hassan and Mahmoud 2021).

While Borda and plurality scores generally yield similar rankings of important functions, the average score analysis offers a complementary perspective. By emphasizing the intensity of prioritization, the average score brings additional functions into focus, providing nuanced insights that may otherwise be overlooked. Touristic services, for instance, achieve prominence in the average score, standing out compared to their rankings in the plurality and Borda score methods. A similar trend emerges with cultural and art services, as well as recreation services, which also achieve high average scores. These functions are vital in the context of Sanremo, where festivals and events serve as major attractions and contribute to the city's cultural and economic vibrancy (Cattari et al. 2024; Cheng and Zhang 2020;

Degli Abbati et al. 2024). It is important to acknowledge that only one participant has a background in touristic activities, leading to these functions being selected less but assigned high importance. This analysis underscores the utility of incorporating average score measures. While measures like Borda and plurality scores identify widely agreed-upon functions, average score analysis reveals less commonly selected but highly valued services, ensuring a more comprehensive and balanced approach to decision-making.

The limited representation from the tourism sector constrains the ability to fully capture the sector's important functions, even though voting measures like average scores highlight its importance. This is one of the consequences of conducting FCM in a focus group manner. Conducting FCM in a focus group setting offers the advantage of fostering communication among participants with varied perspectives, enriching the cognitive mapping process. However, coordinating such sessions can be challenging, and the final composition of stakeholders often fails to fully represent the city's economic or social characteristics.

Additionally, the group of Sanremo stakeholders exhibited a gender imbalance, with a predominance of male participants. Although stakeholders of all genders were invited, not everyone accepted, and some left before the FCM phase began. This imbalance risks overlooking essential perspectives and may lead to biased results, particularly in identifying functions important to underrepresented gender groups.

An essential consideration in the FCM process is ensuring that the presentations and examples provided beforehand remain neutral, avoiding any influence that might steer stakeholders in a particular direction (Mehryar and Surminski 2022). In this case study, a lack of neutrality appears to influence outcomes, as seen in the selection of urban waterways as a key function. Despite Sanremo's limited reliance on significant urban waterways, this function receives high Borda and plurality scores. However, it also ranks among the lowest in average scores and lacks connections to other identified functions. This inconsistency likely stems from the brief presentations provided at the beginning of the FCM session that include examples of past multi-hazard scenarios, such as flooding following earthquakes (see Section 2.1). These examples, while intended to be illustrative, seem to direct participants' focus towards functions less relevant to Sanremo's specific context.

Another disadvantage of doing FCM in a focus group manner is that the possibility of a more dominant stakeholder group emerging during the FCM process is high. This dominance potentially skews collective perceptions of function importance (Tuhkanen 2023). For instance, hardware stores and engineering firms have high Borda and plurality scores despite their lower average scores. This can be attributed to the civil engineering background of seven participants, who prioritized physical reconstruction over socioeconomic recovery.

The findings highlight that the most impactful and supportive functions are not always those most frequently identified as important by participants. For instance, urban bus services and parking emerge as highly impactful functions with significant outdegree values in the analysis. These functions are primarily

recognized by participants as supportive rather than as initially important functions for recovery efforts. This underscores the difficulty of identifying such influential roles without adopting a systemic perspective, as offered by methodologies like FCM, which reveal the interconnectedness and broader influence of these functions on recovery processes.

At the resource level, the high outdegree of governing and public services, despite comprising only four functions, indicates that most functions within this category act as crucial supportive elements in the system. These functions often act as supporters, facilitating coordination and ensuring safety, which allows other functions to operate effectively and efficiently during the recovery process, where cross-sectoral support is crucial (Haraguchi 2020).

The importance of the healthcare system as one of ELC's functions is demonstrated and affirmed by every measure discussed in the current research, especially indegree and centrality. Given Italy's national healthcare structure, where the central government sets guidelines and standards while regions manage resources and provide healthcare services, the role of governmental offices as supporters of healthcare functions is understandable (Tikkanen et al. 2020), a dynamic reflected in the FCM analysis. Furthermore, the security of healthcare functions relies on public service functions (Goel 2013; Redwood-Campbell et al. 2014), which are also highlighted in the results. Within the realm of governmental resources, waste management also plays a critical role in supporting healthcare functions.

The healthcare function is a primary reason why the indegree of the ELC is notably high, equalling 9.2, with only 3.6 stemming from within ELC functions. Conversely, while the outdegree of the ELC also equals 9.2, most of it comes from two other functions, namely, public safety and public works government. This suggests that the ELC is both impactful on the system and reliant on external support. Therefore, ensuring the operation of the ELC depends on other system functions not included within the ELC. This underscores the inefficiency and ineffectiveness of solely focusing on preserving the ELC without considering its supporting components. For instance, healthcare services not only rely on support from pharmacies (Mossialos et al. 2015), waste management (Thakur and Ramesh 2015) and transportation (Syed et al. 2013), but also seemingly unrelated functions such as education play a significant role in supporting healthcare services. Conversely, healthcare functions also strongly support education functions. This interrelation, as noted by participants, is also highlighted in previous research (see, e.g., Hassan and Mahmoud 2021).

As illustrated in Section 4, excluding ELC to identify the foundational functions around which neighbourhoods and sub-systems are structured, temporary housing exhibits the highest centrality degree, signifying its central role within these sub-systems. This finding highlights that in the long-term recovery phase, after immediate emergency needs are met, temporary housing serves as the linchpin for maintaining the affected population within the disaster area and facilitating their engagement in the recovery process, thereby averting displacement (Contreras et al. 2013; Mohammadi et al. 2024). To support this, other functions must be strategically positioned to

deliver essential services to the population reliant on housing assets (Di Bucci et al. 2023; Félix et al. 2013; Hosseini et al. 2016; Johnson 2007). Neglecting to do so risks triggering population migration, mirroring real-life experiences observed in disaster scenarios where displaced individuals relocated to areas lacking essential services, hampering their effective participation in the recovery process (Contreras et al. 2014, 2017).

6 | Conclusion

This study evaluates the relative importance of different urban functions to ensure a fast and efficient recovery process after disasters. A participatory planning approach that incorporates the diverse knowledge of stakeholders in pre-disaster recovery planning has been adopted. The methodology engages two stakeholder groups at different stages, from development to implementation. FCM, as a tool to provide a systemic perspective on urban functions, their roles and interdependencies, is utilized. This approach allows us to identify critical and impactful functions based on stakeholders' cognitive maps and their understanding of urban systems. In light of what emerged from the application of the methodology, combining different voting methods and network analysis emerges as the most recommended procedure to adopt. Some, like the Borda and plurality scores, produced similar results, while others offered more nuanced insights into the functions' roles within the system.

This study underscores the importance of a systemic, participatory approach in identifying vital urban functions for post-disaster recovery. The findings reveal that impactful yet often overlooked functions, such as urban bus services, parking and pharmacies in the case of Sanremo city, are not easily recognized without network-based analysis as vital urban functions. The FCM methodology brings to light their indirect but essential roles, particularly in supporting core systems like healthcare. The results clearly indicate that a sustained recovery depends not only on functions within the ELC category but also on those classified under the SLC. Expanding the recovery framework beyond ELC to include SLC functions is therefore crucial. Moreover, the analysis shows that in the absence of ELC functions, recovery dynamics reorganize around alternative foundational elements, with temporary housing emerging as a central local hub. These insights demonstrate that long-term recovery planning must extend beyond emergency services to include essential daily functions that sustain community well-being and enable a return to normalcy.

In the context of participatory recovery planning, combining individual interviews with focus group sessions is recommended to balance the benefits of individual input from the composition of the stakeholders, more compatible with the urban area characteristics, and collaborative knowledge exchange. Additionally, presentations introducing the approach and research goals should remain neutral to ensure that stakeholders' contributions are not influenced by external biases.

Overall, FCM proves to be a valuable and practical method for identifying key urban functions and their interdependencies. The results of the current research can be used to highlight the significance of various functions within the urban system and to

analyze the urban system on a macro scale. In the next steps, the identified key functions can be examined in more detail by focusing on the specific physical assets that support them. This will allow for the determination of each asset's relative importance within the broader urban system.

Author Contributions

Soheil Mohammadi: conceptualization, data curation, formal analysis, investigation, methodology, software, visualization, writing – original draft, writing – review and editing. **Silvia De Angeli:** conceptualization, supervision, validation, writing – review and editing. **Fabrizio Bruno:** data curation, investigation, writing – review and editing. **Ilenia Spadaro:** investigation, methodology. **Giorgio Boni:** conceptualization, supervision, writing – review and editing. **Serena Cattari:** conceptualization, supervision, writing – review and editing. **Francesca Pirlone:** conceptualization, methodology, supervision, validation.

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Data Availability Statement

The authors confirm that the aggregated data supporting the findings of this study are available in the main body of the article and its [Annexes](#). The individual Fuzzy Cognitive Maps collected during the workshop are available upon request from the corresponding author.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.
Supplementary-MaterialReview.