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Josiana EL HAGE

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Defended on June 24th, 2024, in front of the jury composed of

Isam SHAHROUR	Professor, University of Lille, France	Director
Fadi HAGE CHEHADE	Professor, Lebanese University, Lebanon	Director
Fadi GEARA	Professor, Saint Joseph University, Lebanon	Reviewer
Edith KUSSENER	Director, ISBA TP CCIAMP	Reviewer
Faten ABI FARRAJ	Doctor, Advanced Construction Technology Services	Examiner
Zoubeir LAFHAJ	Professor, Ecole centrale de Lille	Examiner

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Josiana EL HAGE

Reconstruction intelligente après les catastrophes naturelles ou d'origine humaine : Retour d'expérience, méthodologie et application à la catastrophe du port de Beyrouth

Soutenue le 24 Juin 2024, devant le jury composé de

Isam SHAHROUR	Professeur, Université de Lille, France	Directeur
Fadi HAGE CHEHADE	Professeur, Université Libanaise, Liban	Directeur
Fadi GEARA	Professeur, Université Saint Joseph, Liban	Rapporteur
Edith KUSSENER	Directrice, ISBA TP CCIAMP	Rapporteur
Faten ABI FARRAJ	Docteur, Advanced Construction Technology Services	Examinatrice
Zoubeir LAFHAJ	Professeur, Ecole centrale de Lille	Examinateur

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Abstract

The objective of this study is to develop a smart framework for post-disaster reconstruction of buildings, with a focus on the Beirut explosion as a case study, due to its complex geopolitical context, extensive damage, and socio-economic crises. The study delves into various dimensions encompassing physical, economic, and social to prioritize marginalized community groups in the recovery efforts and advocate for the "Build-Back-Better approach", according to the recommendations of "Sendai Framework For Disaster Risk Reduction".

To attain these objectives, the thesis starts with a literature review (Chapter 1) to identify research gaps and existing post-disaster reconstruction frameworks. Drawing from this review, a research methodology is formulated to address these gaps with emphasis on Beirut city in Lebanon (Chapter 2). It includes the local context study, the data analysis methods, and an understanding of the challenges facing the post-disaster reconstruction with a focus on Beirut. A comprehensive framework for assessing post-disaster buildings in Beirut following the explosion is developed (Chapter 3), comprising 12 indicators spanning physical attributes of the building and socio-economic profile of its residents. This framework facilitates the calculation of a Priority Index for a large set of damaged buildings in Beirut (Chapter 4). The assessment assists decision-makers and stakeholders involved in the reconstruction process to manage and monitor building renovation projects while encouraging the affected community engagement. It prioritizes the most vulnerable individuals, thereby fostering a people-centric approach to recovery, underpinned by the principles of "building-back-better" and inclusivity.

The data-based framework and results presented in this thesis form a step forward in the post-disaster reconstruction field. However, this research shows some limitations including the data collection via crowdsourcing and the lack of people participation, the dynamics and the complexity of the post-disaster context, and the focus on the building sector only. Future research could focus on (i) considering all the sectors affected by the disaster, (ii) investigating the social acceptance for participating in the data collection process, (iii) and diversifying the data collection sources.

Keywords: Beirut explosion, Assessment, Buildings, Smart Reconstruction, Resilience, social, economic, Priority Index.

Résumé

L'objectif de cette étude est de développer un cadre intelligent pour la reconstruction post-catastrophe des bâtiments, en se concentrant sur l'explosion de Beyrouth comme étude de cas, en raison de son contexte géopolitique complexe, de l'étendue de ses dommages et des crises socio-économiques qui ont frappé le pays pendant ces dernières années. L'étude explore diverses dimensions comprenant l'état structurel des bâtiments et le profil socio-économique de ses occupants. L'objectif est de prioriser les groupes communautaires marginalisés dans les projets de reconstruction et plaider en faveur de l'approche "Build-Back-Better", selon les recommandations de "Sendai Framework For Disaster Risk Reduction".

Pour atteindre ces objectifs, la thèse commence par l'état de l'art du sujet (Chapitre 1) pour identifier les lacunes de recherche et les cadres de reconstruction post-catastrophe existants. S'appuyant sur cette revue, une méthodologie de recherche est formulée pour combler ces lacunes en mettant l'accent sur la ville de Beyrouth au Liban (Chapitre 2). Elle comprend l'étude du contexte local, les méthodes d'analyse des données et une compréhension des défis de la reconstruction post-catastrophe, plus particulièrement à Beyrouth. Un cadre complet pour évaluer les bâtiments post-catastrophe à Beyrouth suite à l'explosion est développé (Chapitre 3), comprenant 12 indicateurs couvrant les attributs physiques du bâtiment et le profil socio-économique de ses occupants. Ce cadre facilite le calcul d'un indice de priorité pour un grand ensemble de bâtiments endommagés à Beyrouth (Chapitre 4). L'évaluation aide les décideurs et les parties prenantes impliquées dans le processus de reconstruction à gérer et à surveiller les projets de rénovation des bâtiments tout en encourageant l'engagement de la communauté affectée. Elle donne la priorité aux individus les plus vulnérables, favorisant ainsi une approche centrée sur les personnes pour le rétablissement, soutenue par les principes de "Build-Back-Better" et d'inclusivité.

Le cadre basé sur les données et les résultats présentés dans cette thèse constituent une avancée dans le domaine de la reconstruction post-catastrophe. Cependant, cette recherche montre certaines limitations, notamment la collecte de données via la méthode de crowdsourcing et le manque de participation des personnes, la dynamique et la complexité du contexte post-catastrophe, ainsi que la concentration uniquement sur le secteur du bâtiment. Les futures recherches pourraient se concentrer sur (i) la prise en compte de tous les secteurs affectés par la catastrophe, (ii) l'étude de l'acceptation sociale pour participer au processus de collecte de données, (iii) et la diversification des sources de données.

Mots-clés : Explosion de Beyrouth, Évaluation, Bâtiments, Reconstruction Intelligente, Résilience, social, économique, Indice de Priorité.

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General Introduction

Aim and significance of the research

Disasters pose a significant threat to humanity, impacting hundreds of millions of people annually, with a concerning upward trend. Contributing factors such as climate change, rapid urbanization, and population growth exacerbate the effects of both natural and man-made disasters. Disaster cycle constitutes of four phases: mitigation and preparedness in the pre-disaster phase, response and recovery/reconstruction in the post-disaster phase. Post-disaster reconstruction, a long-term process, aims to fully restore affected cities and communities, striving to return to normalcy. (UNISDR, 2015) defined disaster recovery as “decisions and actions aimed at restoring or improving livelihoods, 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, including “build-back-better” to avoid or reduce future disaster risk”. Current research forecasts an uptick in the frequency and severity of disasters, underlining the necessity for proactive measures to enhance community resilience, such as the emerging of concepts of “building-back-better”, “disaster risk reduction”, “building community resilience”.

Traditional post-disaster reconstruction frameworks often fail to achieve the affected community expectations in rebuilding their livelihoods after a disaster, particularly in developing countries. According to (Yi & Yang, 2014) research efforts lack in developing countries in Asia, South America, and Africa in comparison to the developed world. It focuses usually on building physical structure while neglecting the socio-economic conditions of the affected communities. Additionally, post-disaster reconstruction is challenged by many obstacles that can result in its failure, such as lack of community participation, relocation issues, fraudulent use and waste of project funds, and ignoring local needs and culture (Sadiqi Wardak et al., 2012). Failures of traditional reconstruction also include inadequate management of the projects, poor governance system and policy, lack of data and technical expertise (Ade Bilau & Witt, 2016).

In order to avoid the failure of post-disaster reconstruction process, and improve the disaster resilience, countries, international and national organizations are starting to implement post-disaster reconstruction frameworks that aim to monitor this process so that it achieves its desired outcomes. For instance, the “Hyogo Framework for Action 2005-2015” promoted a strategic and systematic approach to reduce vulnerabilities and risks to hazards, and build the resilience of nations and communities to disasters. The strategic goals were to integrate the disaster risk reduction into sustainable development policies and planning, to develop and strengthen institutions, mechanisms and capacities to build resilience to hazards, and to incorporate the risk reduction approaches into the implementation of emergency preparedness, response and recovery programs (UNISDR, 2005). Ten years later, came the “Sendai Framework for Disaster Risk Reduction 2015-2030” (SFDRR) with nearly the same goals: “Prevent new and reduce existing disaster risk through the implementation of integrated and inclusive economic, structural, legal, social, health, cultural, educational, environmental, technological, political and institutional measures that prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness for response and recovery, and thus strengthen resilience” (Nations Office for Disaster Risk Reduction, 2015). The SFDRR set many specific targets, and four priorities: i) Understanding disaster risk; ii) Strengthening disaster risk governance to manage disaster risk; iii) Investing in disaster risk reduction for resilience; iv) Enhancing disaster preparedness for effective response, and to “Build Back Better” in recovery, rehabilitation and reconstruction. It also defined many guiding principles to assist communities and authorities in developing their frameworks.

In parallel, countries have developed their own national disaster risk reduction or post-disaster reconstruction frameworks such as the United States with their National Disaster Recovery Framework (FEMA, 2016), Japan with their Disaster Management plan (Cabinet Office Government of Japan, 2021), Turkey with their 2013-2017 Strategic Plan (AFAD, 2012), etc. Despite the formulated policies and strategies, the on-ground reality paints a starkly different picture. The number of victims and affected individuals continues to rise, accompanied by escalating losses and increasingly severe disasters. Despite efforts to mitigate these events, disasters persist in growing in frequency and intensity, challenging the efficacy of existing approaches (IFRC, 2023). In light of the disproportionate impact of disasters on developing countries, particularly those with complex geopolitical contexts, such as Lebanon in recent years, there is a pressing need for a tailored approach to post-disaster reconstruction. This research endeavors to develop a smart reconstruction framework that accounts for the unique challenges of each context, even the most complex ones.

Smart post-disaster reconstruction can offer an opportunity for contexts to achieve the recovery ultimate goals and even improve the pre-disaster vulnerable conditions (Bănică et al., 2020; Davidsson, 2020; Di Ludovico et al., 2020; Mochizuki & Chang, 2017). The emergence of this concept within disaster management frameworks, as well as national and international policies for disaster resilience, is notable. However, literature review is scarce in research or case studies of integrating this concept into post-disaster frameworks as a whole; instead, it is typically applied to specific dimensions of the process, such as assessing physical infrastructures or environmental impacts. Nevertheless, existing cases where smart technologies or concepts have been utilized in various aspects of post-disaster reconstruction demonstrate promising potential for enhancing the entire process, particularly in developing nations. For instance, (Saeed et al., 2021) investigated the potential of implementing BIM for the post-conflict reconstruction of Mosul city , and showed its effectiveness in reducing time and errors. (Riccardi, 2016) has shown the effectiveness of Ushahidi platform use for crowdsourcing after the Haitian earthquake, as a tool to provide situational awareness for victims and disaster managers, to recruit resources such as volunteers, donations, imagery analysts, etc., and to help control the chaos that occurs during recovery operations.

The proposed methodology aims to establish a comprehensive and reliable assessment system that evaluates the vulnerability of damaged buildings using identified indicators. The ultimate goal is to create a tool that assists decision-makers, particularly in contexts where governance systems may be deficient, in effectively monitoring and prioritizing reconstruction projects. In Lebanon's case, the focus will be on rebuilding damaged buildings while considering not only their physical characteristics but also the socio-economic profiles of their residents. This approach seeks to target the most vulnerable groups of the community, recognizing that enhancing their resilience is paramount to achieving sustainable and smart reconstruction and “building-back-better”. By addressing both physical and socio-economic dimensions, the framework aims to foster community resilience and facilitate the recovery process in a manner that is responsive to Lebanon's complex geopolitical landscape.

This study holds significant importance as it contributes to the development of a smart post-disaster reconstruction framework applicable to various contexts, especially those struggling with complex crises. By integrating socio-economic dimension alongside physical assessments of structures, the framework addresses multifaceted challenges. Moreover, it provides a decision-making tool for contexts lacking robust governance systems, thereby enhancing reconstruction efforts. Central to the framework is community involvement, fostering participation in data collection and ensuring a human-centered approach to reconstruction. Emphasizing the restoration of community livelihoods, the framework aligns with the principles of SFDRR, smart post-disaster reconstruction, and “build-back-better." It also improves coordination among stakeholders, including public authorities, organizations, and affected communities. By promoting transparency, effectiveness, and community participation, the framework aims to establish a humanitarian approach to post-disaster reconstruction, ultimately facilitating more resilient and sustainable recovery processes across diverse contexts. Finally, the study disseminates best practices and innovative technologies for assessing post-disaster situations and monitoring long-term reconstruction efforts.

Thesis Outline

The thesis is presented in four chapters:

- Chapter 1. This chapter provides a comprehensive literature review on disasters and their impacts on cities and societies, the post-disaster reconstruction concepts, frameworks and good practices, the main components of post-disaster reconstruction, and the role of technologies in the process. In addition, the research gaps and the contribution of the thesis are discussed.
- Chapter 2. This chapter explains the research methodology, including data analysis tools, strategies, and methods. It also identifies the barriers and challenges facing post-disaster reconstruction with a focus on Beirut case.
- Chapter 3. This chapter presents the structure and development of the smart post-disaster reconstruction framework following the port explosion in Beirut. It describes the categories and indicators selected for the buildings assessment and priority evaluation, as well as the role of the experts in determining the weights and importance of these indicators.
- Chapter 4. This chapter discusses the results of the Physical Priority Index and Socio-Economic Priority Index of Beirut buildings, for conducting a smart post-disaster reconstruction that takes into account the socio-economic profile of the affected community. It also identifies the limitations of the tool.

1 State of the art

1.1 Introduction

Disasters are large-scale events that cause significant disruption, damage, and distress, affecting communities, ecosystems, and individuals, resulting in loss of life, destruction of property, and widespread social, economic, and environmental consequences. Disasters can be broadly categorized into two main types: natural disasters and man-made disasters. They constitute a major threat to humankind because they disrupt the development; and their impacts touch nearly every sector: urban, social, economic, physical, cultural, transportation, etc… Contemporary research is increasingly focused on studying disasters due to the escalating severity and frequency of their threats. Factors such as climate change, rapid urbanization, population growth, and environmental degradation play a significant role in aggravating the situation. For instance, in the past ten years, 83% of all disasters triggered by natural hazards were caused by extreme weather- and climate-related events, such as floods, storms and heatwaves, and the number of climate- and weather-related disasters has been increasing since the 1960s, and has risen almost 35% since the 1990s (IFRC & RCS, 2020).

Disasters have impacted and reshaped the everyday lives of tens of millions of people in the world. Some of the most recent devastating disasters (e.g., 9–11, the Indian Ocean Tsunami, Hurricane Katrina, and the meltdown of the Fukushima Dai-Ichi nuclear plant, among others) caused long-term negative consequences, particularly for the most vulnerable populations throughout the world. The fact that the vulnerability increases the negative impacts of disasters on communities proves that disasters are socially constructed events that result from the intersection of hazard events combined with societal responses or lack of it. For over 50 years, disaster researchers throughout the globe have studied the social, economic, organizational, and political factors that give rise to devastating disasters, as well as the impacts, outcomes, and consequences of such events.

Disasters are followed by the post-disaster reconstruction period which englobes the recovery projects in every sector. It is a long-term process that aims to help the affected community return to the normalcy before the disaster and restore their livelihoods. It requires coordinated emergency response efforts to address immediate needs, followed by long-term recovery and reconstruction. Effective disaster management involves mitigation, preparedness, response, and recovery phases. Post-disaster reconstruction can offer an opportunity to improve the pre-disaster conditions or status-quo, and the community resilience to face future disasters. However, post-disaster reconstruction is a multifaceted and intricate process marked by a myriad of challenges and complexities. Beyond the immediate physical devastation, the complexities arise from navigating socio-economic, environmental, and cultural dimensions. Rebuilding after a disaster necessitates intricate planning, resource mobilization, and the coordination of various stakeholders. Balancing the urgency of reconstruction with the need for comprehensive, sustainable solutions adds an additional layer of complexity. Social dynamics, community engagement, and cultural considerations play pivotal roles in shaping reconstruction efforts, requiring a nuanced understanding of local contexts. Furthermore, the allocation of resources, policy formulation, and the incorporation of innovative technologies demand strategic decision-making.

This chapter addresses the disasters and their impacts on the different sectors: economic, social, human, and other dimensions. It highlights the importance of the subject particularly and disaster research in general, by showing the severe negative impacts and costs of disasters on humankind and planet Earth. The second section presents the post-disaster reconstruction process, starting with the definitions and detailing its principal components. The third section focuses on the role of smart technologies improving the post-disaster reconstruction steps and phases. The chapter ends with highlighting the research gaps and how this work addresses them.

1.2 Disasters, a threat to humankind

Disasters are extreme events that can be caused by natural or man-made hazards, which can have a significant impact on the affected community. These events can disrupt the community's development, livelihood, and functions, requiring external or internal assistance from various organizations.

Natural disasters are caused by natural processes and forces of the Earth. They include events such as earthquakes, volcanic eruptions, floods, hurricanes, tornadoes, tsunamis, landslides, droughts, and wildfires. These phenomena are often beyond human control and may occur due to geological, meteorological, or climatic factors. Natural disasters can have severe and immediate impacts on affected areas, leading to the displacement of populations, destruction of infrastructure, and loss of life.

Man-made disasters result from human actions, negligence, or technological failures. This category includes industrial accidents, chemical spills, nuclear incidents, transportation accidents, structural failures, acts of terrorism and armed conflicts. Human error, inadequate safety measures, and lack of proper planning can contribute to the occurrence and severity of these disasters. Unlike some natural disasters, many man-made disasters are preventable through improved regulations, safety protocols, and responsible decision-making.

Through the last decades, disasters, particularly natural disasters have increased in frequency and severity. For instance, the International Federation of Red Cross investigated the climate- and weather-related disasters through the last 70 years and found that the trend suggests that certain types of disasters are indeed becoming more frequent and severe. Figure 1-1 illustrates the number of climate- and weather-related disasters per year between 1960 and 2019. While the number was around 50 between 1960 and 1975, it started to alarmingly increase after 1980, emphasizing the urgency to take proactive measures and develop strategies for enhancing community resilience and minimizing devastating consequences (IFRC & RCS, 2020).

This dramatic increase results in profoundly destructive consequences to human lives, health, and infrastructure. The severity of these impacts is primarily determined by the scale, frequency, and duration of the disaster, as well as the vulnerability of the affected community. There are also the multiple overlapping events or crises that cause even greater harm. They place increased pressure on public services, including health systems. For instance, the impacts from COVID aggravated – or were aggravated by – a host of other hazards, such as hurricanes, droughts, other health threats, and conflicts. These hazards were often overshadowed by the pandemic but 2020’s Storm Alex caused extreme flooding in the Mediterranean region and a locust infestation devastated crops in east Africa, the Arabian Peninsula and Indian subcontinent, or Hurricane Ida, which made landfall in Louisiana, causing damage second only to 2005’s Hurricane Katrina (IFRC, 2023). The number of overlapping disasters has increased through the years as shown in Figure 1-2, as disasters can trigger each other. Measures should be immediately taken worldwide to avoid reaching a no-return point.

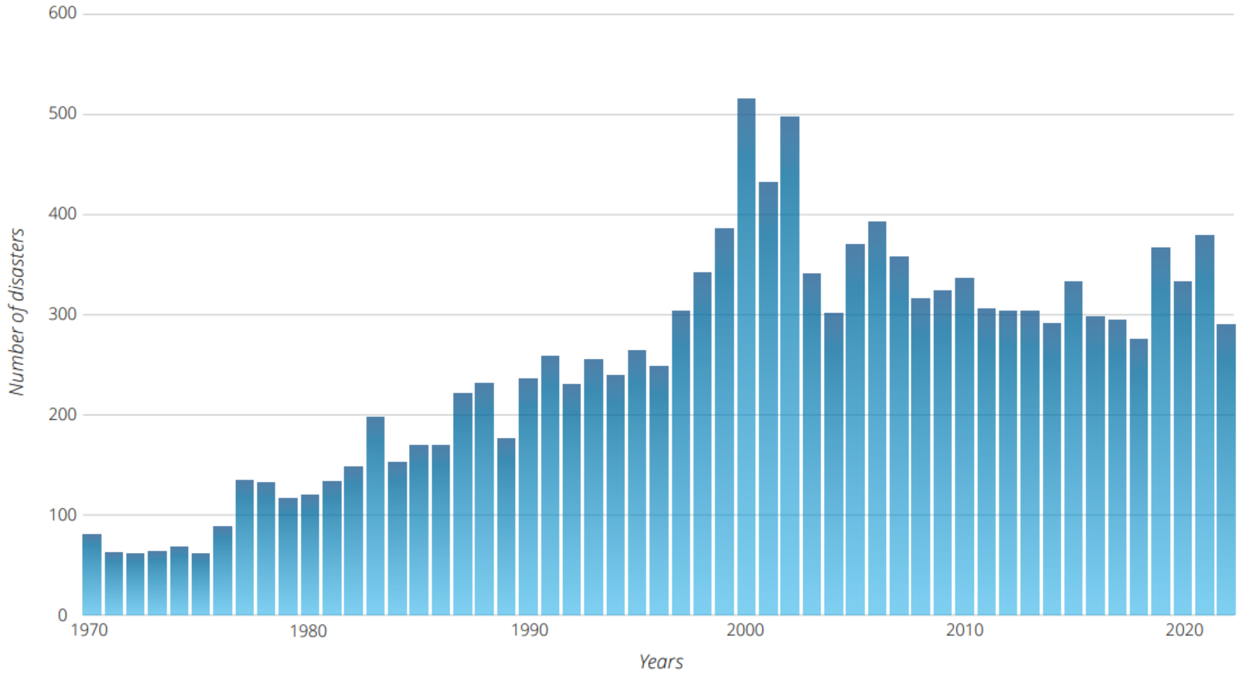


Figure 1-1. Number of disasters triggered by natural hazards recorded globally per year, 1970–2021. Source: IFRC, World disasters Report, 2022.

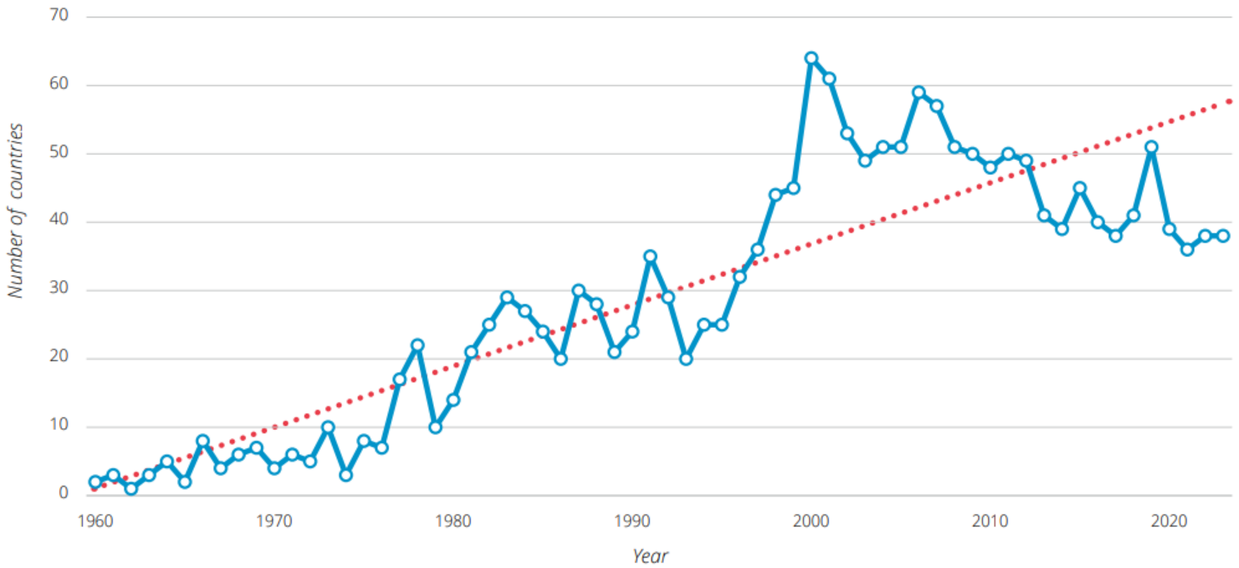


Figure 1-2. Number of countries experiencing two or more overlapping disasters at least once in a year, 1970–2021. Source: IFRC, World disasters Report, 2022.

As mentioned earlier, disasters have negative consequences on all levels and dimensions. The most important direct impacts are discussed below.

1. <u>Deaths and people affected:</u> In the 20 years between 2000 and 2019, EM-DAT recorded 7,348 disasters events, which claimed a total of approximately 1.2 million lives and affected more than 4.03 billion people, according to the "The Human Cost of Disasters 2000-2019" report. (Pettersson & Öberg, 2020) gives the total number of fatalities caused by conflict in 1989-2019, which is approximately 2,550,000 deaths. The Covid-19 pandemic alone took the lives of nearly 6,600,000 persons between 2020-2022, and affected all humankind, according to

the IFRC World Disasters Report 2022 (IFRC, 2023), while the next most deadly event was the Indian Ocean Tsunami in 2004 which took the lives of 284,500 persons.

2. Economic losses: EM-DAT estimated total losses of US$ 2.97 trillion from recorded natural and technological disasters between 2000 and 2019. This value seems to be underestimated, given the under-reporting of losses worldwide. EM-DAT data show that storms cost more than any other disaster type in terms of recorded economic damage (1.39 trillion US$), followed by floods (651 billion US$) (CRED & UNDRR, 2020). And according to the "World disasters Report" by IFRC published in 2020, it is estimated that the total cost of disaster losses in 2019 was 150 billion US dollars, 39.5 billion US dollars attributed to climatological disasters (IFRC & RCS, 2020). The Covid-19 pandemic caused the economic activity to contract in 90% of countries, and the world economy to shrink by about 3% (World Bank, 2022). The economic impacts were most severe in emerging economies and among disadvantaged populations. As a result, inequality increased both within and between countries (World Bank, 2022).

   Large economic losses can also be caused by armed conflicts, similarly to natural disasters, except for the fact that they last for a longer period than other disasters, which can make them more dangerous. For example, a damage assessment conducted in Syria by the World Bank Group estimates that the total losses in only three Syrian large cities, Aleppo, Idlib and Hama, was up to $7.8 ~ $9.4 billion by February 2017, with Aleppo taking the highest loss (World Bank Group, 2017).
3. Social Impacts: (Paul, 2011) stated that disasters disrupt human lives, their displacement from their homeland, and their separation from family and friends. The destruction of educational structures deprives children of education, for example, in Syria, more than two million children had no access to education by August 2019, and at least 1 million more were at risk of losing it (The International Institute for Strategic Studies (IISS), 2020). The destruction of businesses results in the loss of many employments. All these consequences can lead to mental and physical disorders. According to (Jayawardana et al., 2019), armed conflicts negatively affect social bonding and bridging, community trust and communication, and relationship with governmental institutions.
4. Demographic impacts: (Paul, 2011) referred to the outward temporary or permanent migration flows triggered by disasters for many reasons, such as lack of access to employment, material assistance, safety and security, non-availability of natural resources, poverty, etc. A study by (Drabo & Mously Mbaye, 2015) showed that there is a relationship between natural disasters related to climate change and migration. Technological disasters can also cause the evacuation and relocation of affected people, especially when there is a nuclear or toxic contamination of the disaster area, as happened in Fukushima nuclear accident, where some evacuees relocated to other places and never returned (Murao, 2020). Armed conflicts and political instability are also principal causes of population migration. For instance, the Syrian conflict has forced more than half the country's population, 11.1 million persons, to flee their homes (AlArabiya News, 2021). According to the International Migration Organization, there were 28 million new internal displacements across 148 countries and territories by the end of 2018. Disasters triggered 61% (17.2 million) of these new displacements, and 39% (10.8 million) were caused by conflict and violence.
5. Health impacts: Besides the direct human life losses and injuries, (Paul, 2011) pointed out to the indirect health impacts of disasters that include the potential for an increase in communicable, waterborne, and other diseases such as hepatitis and malaria, pneumonia, eye infections, and skin diseases. These diseases can emerge because of damaged water systems, lack of hygiene and food, lack of medical attention and equipment, or destruction of medical

facilities, and damage to transportation infrastructures. (Goldmann & Galea, 2014) mentioned post-traumatic stress disorder (PTSD), and other mental health problems, in the aftermath of disasters.

6. Property Damage and Infrastructures Destruction: Physical infrastructure, homes, and essential facilities may be damaged or destroyed, leading to economic losses and the displacement of populations. In 2004, nearly 500,000 people lost their homes in Sri Lanka as a result of the Indian Ocean Tsunami. The February 6th earthquake of Turkey and Syria caused the damage or collapse of over 150,000 buildings (Ibrahim et al., 2024). Critical infrastructure, such as transportation networks, communication systems, and utilities, can also be severely affected, hindering emergency response and recovery efforts.

This paragraph highlights the devastating impacts of natural and man-made disasters on various dimensions of livelihoods. This underscores the urgent need and importance of addressing the subject matter, especially in light of these disasters' escalating frequency and severity. Since the majority of disasters cannot be avoided, post-disaster reconstruction process is the only opportunity to restore the damaged livelihoods and improve the pre-disaster conditions to prevent or reduce the impacts of future disasters.

1.3 Post-disaster reconstruction

1.3.1 Definitions

Post-disaster reconstruction refers to the comprehensive efforts undertaken after a disaster to restore and rebuild affected communities, infrastructure, and livelihoods. It involves many activities, including physical rehabilitation, economic recovery, social reintegration, and institutional strengthening. In the 2009 UNISDR Terminology, disaster recovery was defined as “The restoration, and improvement of facilities, livelihoods and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors” (UNISDR, 2009). In the 2015 updated version, (UNISDR, 2015) defined disaster recovery as “decisions and actions aimed at restoring or improving livelihoods, 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, including “build-back-better” to avoid or reduce future disaster risk.” They defined reconstruction as “The medium and longer-term repair and sustainable restoration of critical infrastructures, services, housing, facilities and livelihoods required for the full functioning of a community or a society affected by a disaster”. The disaster recovery in these definitions takes a more global view by including all the aspects such as social, economic, environmental, physical, and others. The definition of reconstruction is limited to the physical component of global recovery. Similarly, (Smith & Wenger, 2007) defined the disaster recovery process as restoring, rebuilding, and reshaping the physical, social, economic, and natural environment through pre-disaster mitigation and post-disaster actions. (Schwab et al., 2014) defined post-disaster recovery as restoring housing, transportation, and public services; restarting economic activity; and fostering long-term community redevelopment and improvements. (Moatty et al., 2017) included the housing and infrastructure rebuilding or permanent replacement in the post-disaster reconstruction period, the complete restoration of all services, and the revitalization of the economy.

These definitions highlight both short-term and long-term recovery efforts. The short-term focus is on restoring the community to its pre-disaster state, while the long-term focus is on enhancing resilience, reducing vulnerabilities, and increasing the ability to handle future disasters over a span of several years (Hwang et al., 2015; Rouhanizadeh et al., 2020). Achieving both short-term and long-term recovery signifies a successful recovery process (Rouhanizadeh et al., 2020). Hence, the post-disaster cycle comprises two significant phases: the response and recovery phases (Hidayat & Egbu, 2010). The response phase, encompassing the short-term, involves taking actions to preserve lives, minimize property damage, and expedite the recovery process with maximum efficiency. On the other hand, the recovery phase extends to the long term and focuses on reversing the detrimental impacts of disasters and reinstating community life. Conventionally, post-disaster recovery has been regarded as a progression of activities and processes led by governmental and non-governmental entities, aiming to swiftly restore the pre-disaster normalcy of the affected community (Su & Le Dé, 2020).

1.3.2 Build-Back-Better for Post-Disaster Reconstruction

The increasing frequency and severity of the disasters on one hand, and the aggravating vulnerability of communities on the other hand, resulted in the emergence of concepts such Build-Back-Better (BBB), disaster risk reduction, building community resilience against disasters to reduce the disaster impacts on human livelihoods and societies (Dube, 2020). Researchers and authorities realized the importance and the complexity of the subject, therefore, many frameworks and procedures has emerged in the last decades to try to find the best post-disaster reconstruction scenario. For instance, many scholars have focused on the necessity to transform disaster recovery into an opportunity to build back better than the pre-disaster conditions, to improve the livelihoods of the affected communities, reduce their vulnerabilities, and increase their resilience to face future possible disasters and reduce losses and impacts (Bănică et al., 2020; Davidsson, 2020; Di Ludovico et al., 2020; Mochizuki & Chang, 2017). The Sendai Framework for Disaster Risk Reduction emphasized enhancing disaster preparedness for effective response and Build-Back-Better in recovery, rehabilitation, and reconstruction (Mannakkara et al., 2018; Nations Office for Disaster Risk Reduction, 2015). (Mannakkara & Wilkinson, 2014) represented the BBB concept in a comprehensive framework with three components (Figure 1-3):

- risk reduction, improving the structural designs and land-use planning to avoid huge losses when facing future disasters.
- community recovery, social and economic recovery to reduce existing vulnerabilities and improve development
- implementation of laws and regulations for post-disaster reconstruction and building-back-better and the management and coordination of the stakeholders' actions.

(Zhou et al., 2022) also proposed a post-disaster build-back better framework for sustainable recovery assessment (Figure 1-4), based on three components:

- the element comprising physical, financial, natural, social, and human capital;
- the structure, including community social capital, leadership, and social governance;
- the function includes disaster preparedness, response, immediate recovery, and disaster learning, the four phases of the disaster management cycle.

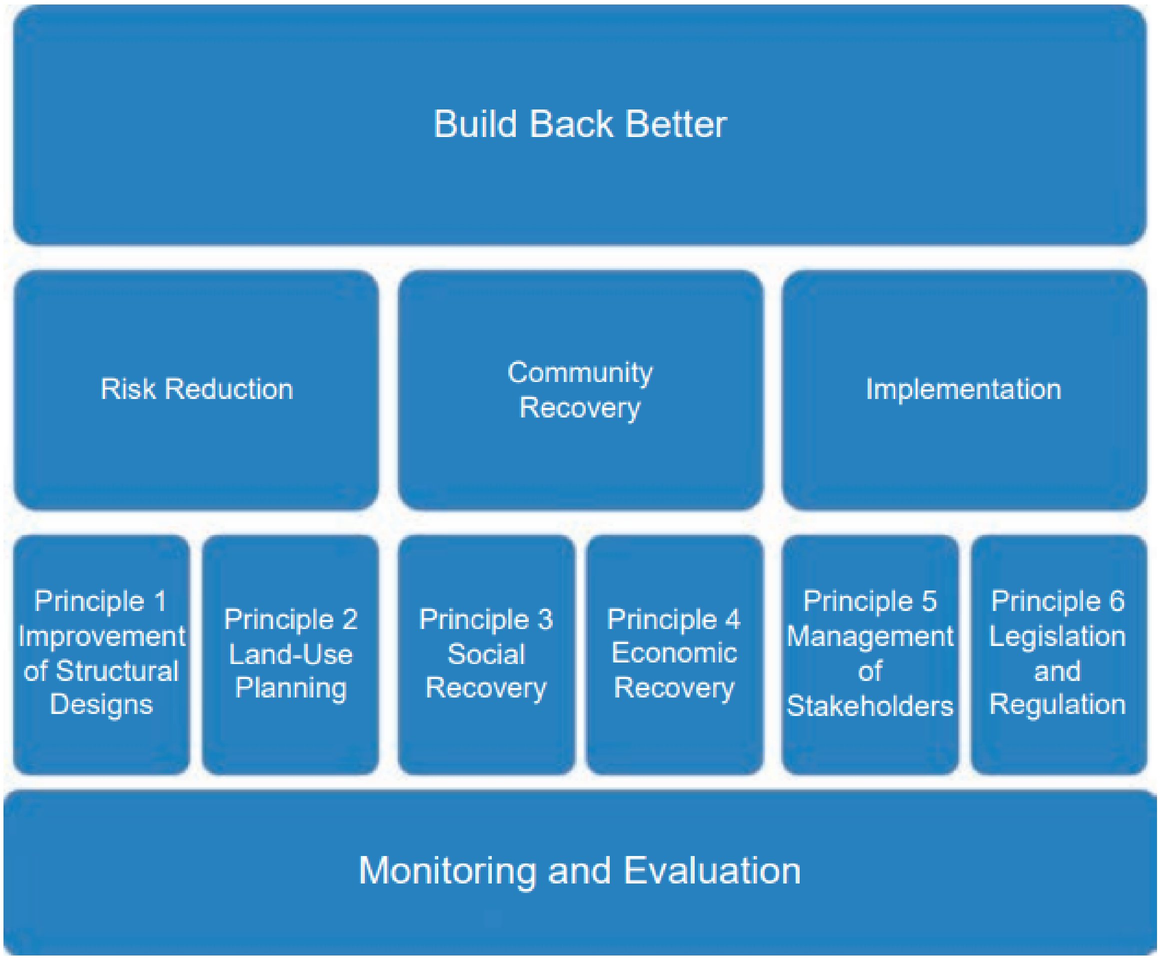


Figure 1-3. Build-Back-Better Framework by Mannakkara & Wilkinson,

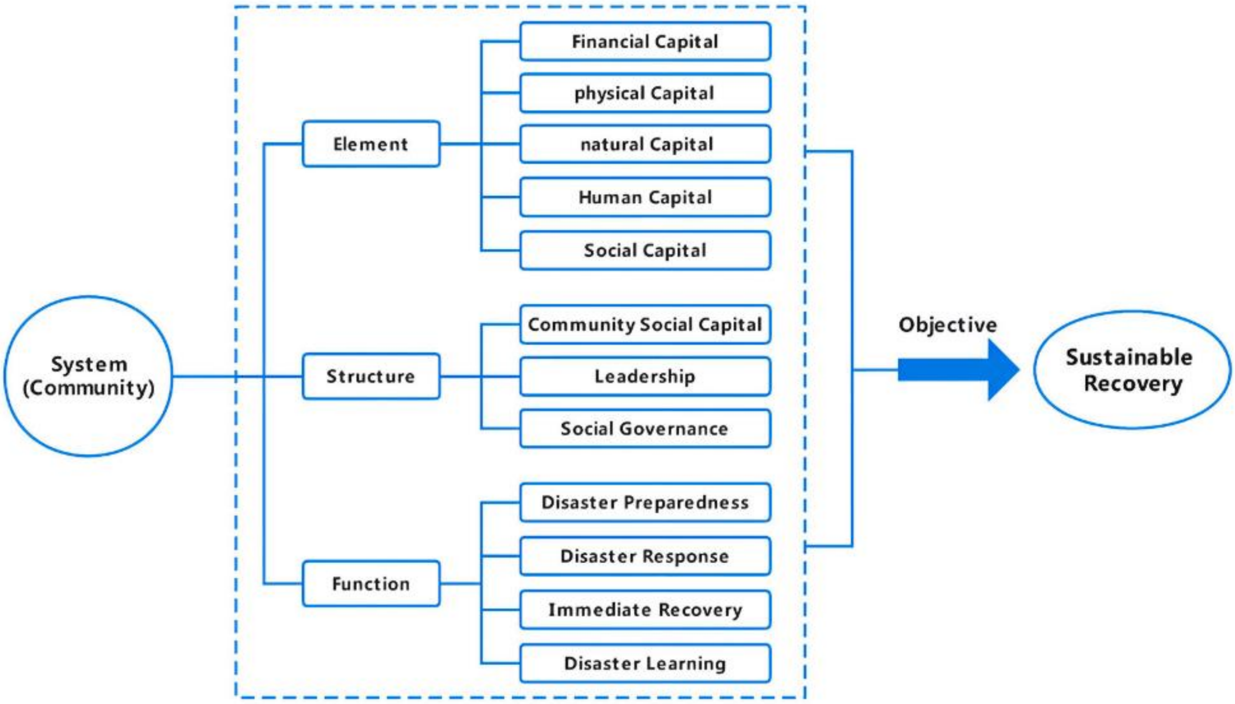


Figure 1-4. Post-disaster build-back better framework for sustainable recovery assessment by Zhou et al., 2022

(Zhao et al., 2023) combined the "Build Back Better" to scenic spot restoration and efficient implementation, to ensure Jiuzhaigou Lake landscape's restoration and sustainable development in the aftermath of the earthquake. The framework constituted of three sectors, each one comprising many sub-sectors (Figure 1-5). The first encompasses the diagnosis, which means the assessment; the second is the BBB guidelines including risk reduction, scenic restoration and efficient implementation; the third is a list of resilience measures such as building isolation, public participation, travel insurance, etc…

(Chester et al., 2021) established a framework for improving the resilience of critical infrastructures across different scales and periods of reconstruction. It aims to include many stakeholders such as agencies and regulators, insurers, and the population to cover climate uncertainties and unforeseen hazards and for knowledge cogeneration. This framework incorporates failure costs into the infrastructure design process. (Tao et al., 2021) established a continuous-time Markov decision making framework, based on lifecycle cost and focused on bridges in the face of earthquakes.

The BBB concept and resilience are emerging concepts, and literature is scarce in frameworks for post-disaster recovery and post-disaster reconstruction (housing, critical infrastructures, …) (Der Sarkissian et al., 2023). Additionally, post-disaster recovery is a complex, complicated, multi-faceted, and dynamic process, according to many authors (Bilau et al., 2015; Chang et al., 2010; Rouhanizadeh et al., 2020; Tambe et al., 2018). It is related to political, social, economic, urban, technological, and many other factors, making it a complex system with many interdependencies and interactions.

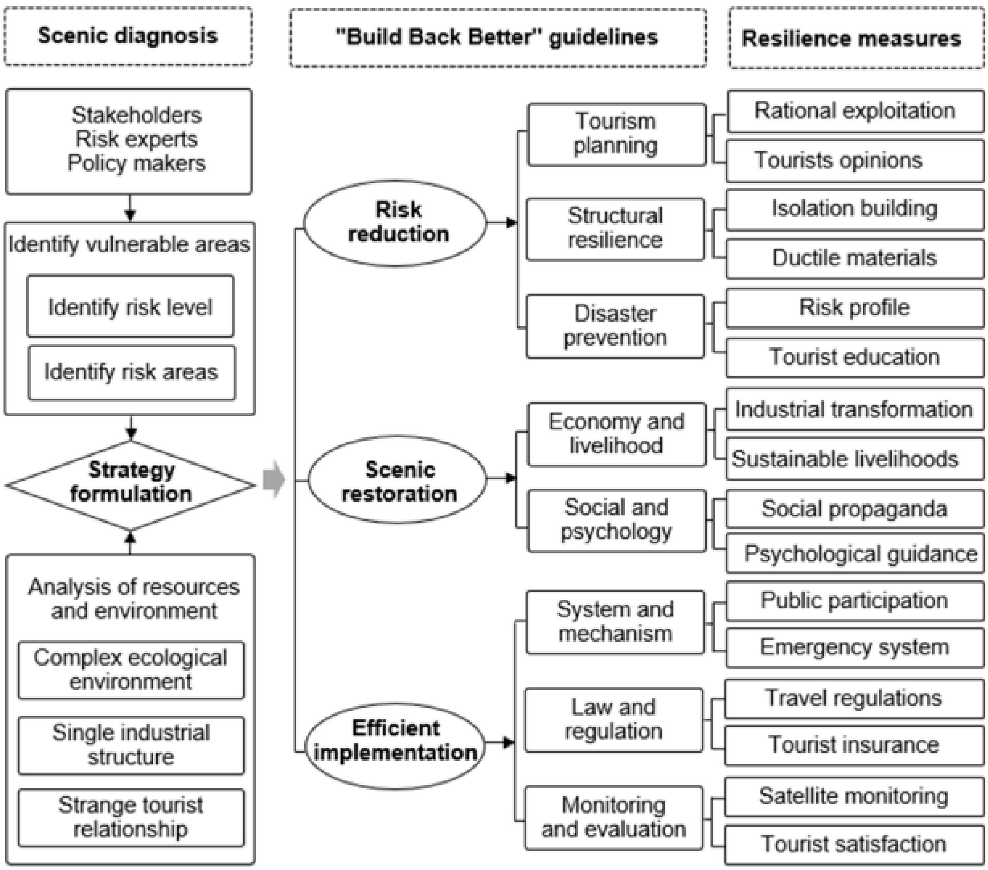


Figure 1-5. Build Back Better" framework to scenic spot restoration by Zhao et al., 2023.

The presented frameworks share many common dimensions and principles, such as socio-economic livelihood, governance and law regulation, technical and physical design improvement of housing and infrastructures, management and stakeholders' roles, disaster preparedness and awareness, community resilience. Since disasters affect livelihoods on many levels, therefore, post-disaster reconstruction should target all these dimensions to be successful. This results in the complexity of the process and the difficulty to find a unique methodology or framework that could be implemented in any post-disaster context.

1.3.3 Components of the post-disaster reconstruction

This section provides an overview of the main post-disaster reconstruction components. This analysis will allow us to understand the core principles of a post-disaster reconstruction framework, prior to any post-disaster reconstruction process. The second priority of the SFDRR (after understanding the risk) is to strengthen the disaster risk governance to manage the disaster risk. Previously, the Hyogo Framework for Action 2005-2015 identified the governance and knowledge management as of the main gaps and challenges of post-disaster reconstruction framework. Many scholars have also related the lack of proper decision-making and management to the failure of post-disaster recovery (Rouhanizadeh et al., 2020). Understanding these principles can help in addressing the gaps in the current existing frameworks and procedures.

Governance

Governance is the first axis of post-disaster reconstruction. The notion of governance is complex, but it now incorporates collective systems and good government (Eufemia et al., 2021). Governance is the application of rules and processes through which authority and control are exercised in society, political decisions are made, the rules for the scope of action of state and society are structured, and resources for economic and social development are administered. According to (Addink, 2019), governance is described as a basic measure of a society’s stability and performance and the functioning of its political and social systems, and it involves the rules, processes, and behaviors whereby interests are articulated, resources are managed, and power is exercised in society. The World Bank (2007) defines governance as selecting those capable of making authoritative political decisions, the government's capacity to manage its resources and implement sound policies effectively, and the respect citizens and governments have for the institutions governing their interactions. Governance has become a concept that surpasses governments in different sectors.

In post-disaster reconstruction, good governance is key for achieving a successful recovery. (Francis et al., 2018) argued that recovery efforts should be supported and facilitated with proper rules and regulations for using governance. (Tierney, 2012) introduced the term “disaster governance” in 2012 and defined it as “a polycentric and multi-scale network constituted of an interrelated set of norms, organizational and institutional actors, and practices … that are designed to reduce the impacts and losses associated with disasters arising from natural and technological agents and from intentional acts of terrorism”. The UN Office of Disaster Risk Reduction also defines disaster risk governance as “the system of institutions, mechanisms, policy and legal frameworks and other arrangements to guide, coordinate and oversee disaster risk reduction and related areas of policy” (UNISDR, 2015). Disaster governance was introduced in the Hyogo Framework for Action (2005-2015) and the Sendai Framework for Disaster Risk Reduction (SFDRR). SFDRR focuses on governance as a central theme in disaster risk management in Priority 2 (Nations Office for Disaster Risk Reduction, 2015). Many scholars pointed out to the importance of governance in disaster risk management and reduction, as well as reducing vulnerabilities among societies and enhancing their resilience (Albris et al., 2020; Munene et al., 2018). Disaster governance has evolved as a concept and practice with a more understanding for participatory approaches, where governments still play a critical role in disaster management (Paolo et al., 2021). Governance building is also important in post-conflict reconstruction (Sakalasuriya et al., 2016; Welch et al., 2015). (Wahba et al., 2022) argued that bringing urban governance closer to communities can empower them to influence decision-making around issues related to post-conflict reconstruction activities.

However, (Tierney, 2012) remarked that global disparities in income, well-being, access to services, political empowerment, gender inequality, corruption, absence of the rule of law, and lack of public participation, along with sociodemographic trends such as rapid growth and urbanization, are governance deficits. For instance, (Oggioni et al., 2019) showed how the temporary housing after the 2009 L'Aquila earthquake was excessively expensive and did not consider many issues, including durability and maintenance, longevity and future uses, availability of public services and urban functions, ecological preservation, safety, corruption, and social fragmentation of pre-existing communities. They argued that this ineffective disaster response was entangled with governance and power issues and social and economic conflicts around built environment and natural resource management. (Cook et al., 2019) found that Delays in responding to disasters, low capacity, and issues with coordination between the different stakeholders were caused by absence of political will and financial resources in the government of Timor-Leste despite the external support, in addition to several hazards such as flooding and landslides, water and food insecurity, and societal tensions. (Mukherji et al., 2021) found that time compression and delays in becoming operational, the risk of facing disputes and conflicts with legislation, and lack of coordination, are the main challenges of creating new good governance structures. (Gjerde & De Sylva, 2018; Paolo et al., 2021) stated that each recovery is unique, and no single governance structure is equally appropriate to all responses, the limitation that leaves significant gaps in understanding of how governance affects recovery domains. (Paolo et al., 2021) argued that disaster governance ideas and practices are not always organized, shared, and extended within the local knowledge, which constitutes a challenge for implementing a participatory and inclusive approach.

As discussed before, good governance is a key factor in conducting a successful post-disaster recovery. But what is good governance, and what are its principles?

(Addink, 2019) identified six principles of good governance: properness, transparency, participation, effectiveness, accountability, and human rights. All the frameworks found in literature review try to achieve one or more of these principles. (Tierney, 2012) recommended that disaster governance approaches should be more inclusive by involving a wider range of actors and considering societal, economic and environmental vulnerabilities. (Djalante & Lassa, 2019) argued that good governance aims to reduce socio-economic vulnerability and urban risks, promote inclusive governance, and integrate climate change and disaster risk reduction in policies and strategies. Scholars proposed many frameworks and approaches for governance and disaster governance that aim to reduce disaster risks and improve community resilience and preparedness. For instance, (Albris et al., 2020) developed a governance approach based around 6 themes: (1) Sharing Knowledge; (2) Harmonizing Capacities; (3) Institutionalizing Coordination; (4) Engaging Stakeholders; (5) Leveraging Investments; and finally, (6) Developing Communication. (Paolo et al., 2021) offered an expanded framework for assessing and improving the governance of disaster responses in Indonesia and Southeast Asia based on the Social Domains Theory of disaster response, Social Network Analysis, and Institutional Behavior Framework of disaster response. (Shahat et al., 2020) conceptualized a smart disaster governance framework encompassing IoT technologies' capabilities and disaster governance functions, in addition to the foreseen enhancements in disaster coping capacities and an overall rise in disaster resilience (see Figure 1-6). (Mardiah, 2018) proposed a framework for participatory disaster governance (see Figure 1-7) based on the following principles: (1) shared goals/plans/guidelines with a sense of ownership; (2) institutional networks with legitimate arrangements; (3) leadership and its key organizations; (4) the capacity and capability of key organizations; (5) financing and aid disbursement; (6) affirmative policy and strategy; and (7) communication and exchange resources, knowledge, data, and information. (Eufemia et al., 2021) used the community-based governance (CBG) framework to guide the synthesis of collective socio-ecological problems, identify the institutions for dealing with them, and visualize joint solutions. The CBG framework focuses on each respective territory's political, economic, and social contexts. According to the author, it fosters the locals’ right to plan, research, develop, manage, and formulate strategies for sustainable development by shaping scenarios for decentralized, environmental, and local governance. (Djalante et al., 2011) identified and discussed the concept of adaptive governance (AG), which they considered important in building disaster resilience since it encourages participation and collaboration, learning and innovation, and self-organization. (Munene et al., 2018) argued that the underlying principles of disaster risk governance proposed by the Sendai framework are strongly aligned with the characteristics of adaptive governance. Although the AG approach presents many opportunities, they found that its applying confronts many challenges, such as social stratification and inequality, inadequate information about Sendai framework, and lack of community participation and resources.

Management

Disaster management is the second axis of post-disaster reconstruction. It is described as a holistic strategy involving disaster risk reduction, preparedness, response, and recovery activities, via cooperation between stakeholders, such as national and local governments, public authorities, and private sectors (Aitsi-Selmi et al., 2015). (Khan et al., 2020) defined it as “a conjunction of many interrelated procedures aimed at offering effective means of understanding, analyzing, monitoring, and predicting disaster events”. The disaster management cycle comprises four stages: mitigation, preparedness, response, and recovery (Paul, 2011; Saleh et al., 2020). The four phases are interrelated, so if appropriate actions and measures are taken in each stage, the overall cycle will lead to better resilience against any type of disaster (Figure 1-8). It is important to note that each post-disaster recovery case is unique, related to the context of the affected community, to the type and extent of the disaster, and the level of commitment of the actors to the planning. In the aftermath of a disaster, recovery strategies and reconstruction policies implemented by the decision-makers must be performed.

Mitigation refers to policies and activities that attempt to reduce and/or eliminate vulnerabilities to damage from future disasters, while preparedness refers to the degree of alertness and readiness of an individual, a household, or a community against a possible disaster (Paul, 2011). Mitigation measures vary according to the disaster type, but we can cite, among them, land use regulations, building codes and standards, public training, and awareness. Whereas preparedness measures can be taken immediately before the disaster strike to avoid casualties such as warning, evacuation, and community and operational training. The response phase comes directly after the disaster, and it refers to the actions taken during and after a disaster to save lives, minimize property damage, and enhance the effectiveness of recovery in the shortest possible time. Response activities include search and rescue operations for survivors, emergency medical care for the injured, provision of temporary shelter, water, sanitation and food, cleaning debris, etc… The recovery phase begins during and/or after the response phase, and its primary purpose is to reverse the damaging effects of the disaster and restore the affected community’s lives. This phase is a long-term process and can extend to many years according to the disaster severity and damage scale. It includes the reconstruction of the residential and commercial buildings and the infrastructures, the restoration of the economic sector, and the affected community’s livelihoods (Paul, 2011).

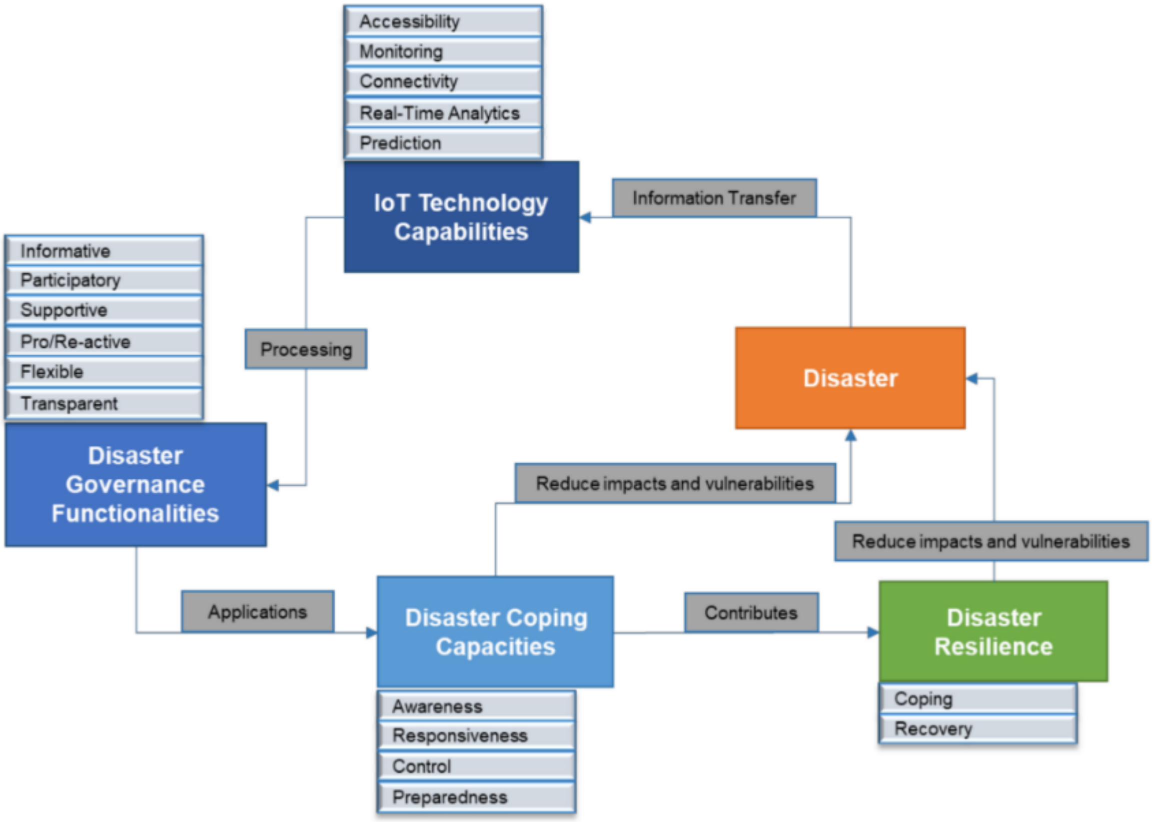


Figure 1-6. Smart disaster governance framework proposed by (Shaht et al.,2020).

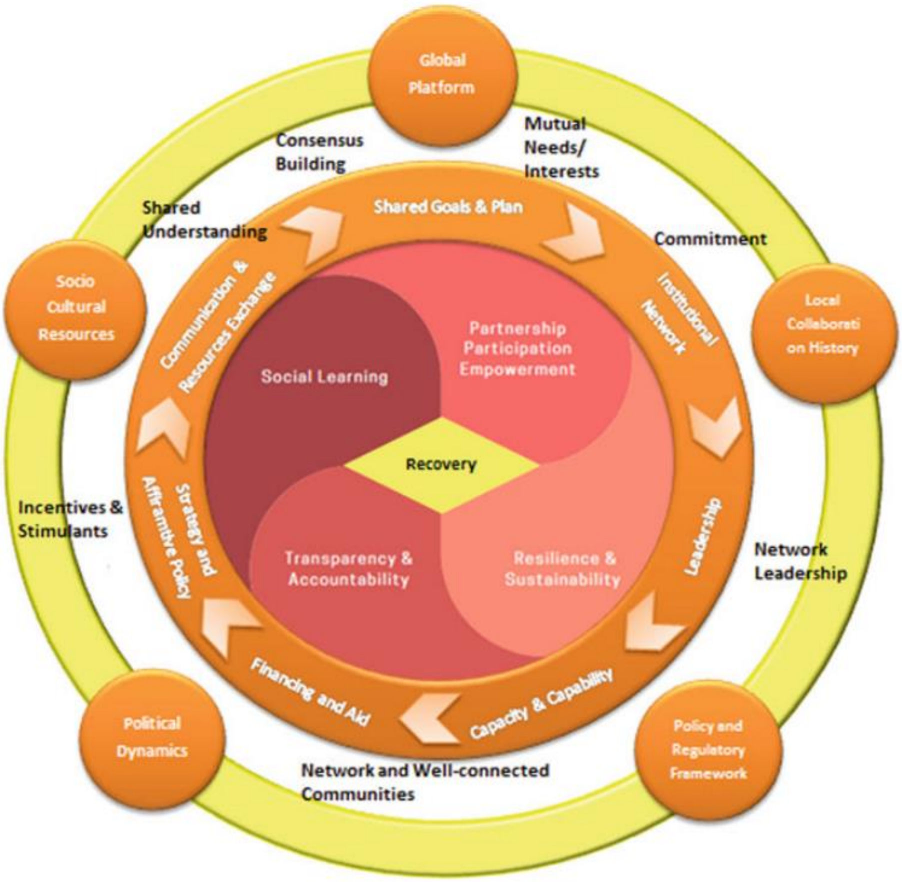


Figure 1-7. Participatory disaster governance framework proposed by (Mardiah, 2018)

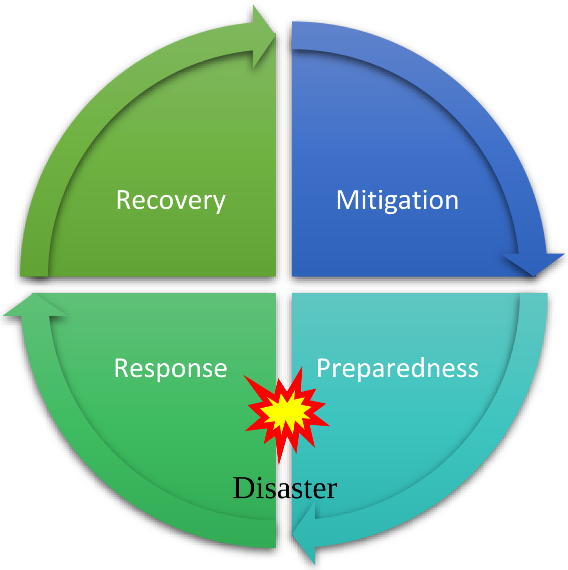


Figure 1-8. Disaster Management phases (Source: Author).

The post-disaster reconstruction lies in the recovery phase since it is a long-term process. Different post-disaster reconstruction approaches were proposed. The two major approaches for managing post-disaster reconstruction are the "top-down" and the "bottom-up" (Yi et al., 2020). The "top-down" approach emphasizes that the central government makes and enforces a policy. In contrast, in the bottom-up approach, ground-level participants (local households, the private sector, local government, and many other bottom-level actors) play an important role (Yi et al., 2020). Top-down approaches to disaster risk management (DRM) have traditionally dominated the management of post-disaster scenarios (Alexander, 2008; Blöschl et al., 2013; Islam et al., 2020). Governments with technical expertise and a centralized and hierarchical management model used these approaches. However, in the last decades, bottom-up approaches have witnessed a development in terms of disaster management, resulting from emerging problems such as increasing population density in urban zones, migration, economic inequalities, increasing frequency and seriousness of disasters, and acceleration of climate change. For instance, many experts argued that community participation in disaster management programs and activities has become important, facilitates the inclusion of the most vulnerable, reduces inequalities, and makes the recovery more effective (Hamideh, 2020; Islam et al., 2020; Robinson & Berkes, 2011; Yi et al., 2020). The Sendai Framework for Disaster Risk Reduction 2015-2030 also promotes a people-centered approach that is community-informed and committed to Build-Back-Better, to rehabilitation and reconstruction (Nations Office for Disaster Risk Reduction, 2015).

The different stakeholders involved in the process must be clearly distinguished. (Ningtyas et al., 2020) found that the key role stakeholders in disaster management are: Non- Governmental Organizations, Research Institutions, national and/or Central Governments, Regional Government, Foreign Government (or external actors), UN and International Organizations, and the general public. (Lu et al., 2018) argued that to conduct an effective community post-disaster reconstruction process, a wide range of stakeholders should assist: central governments, local governments, non-governmental organizations, community-based organizations, international organizations, residents, experts, and academics… (AL-Fazari & Kasim, 2019) identified the government, NGOs, donors, the private sector, media, academia, regional cooperation, community/citizen, as the key stakeholders in disaster mitigation. Scholars highlighted the importance of engaging the stakeholders and institutionalizing their coordination (Albris et al., 2020; Fisher et al., 2020; Putra et al., 2017).

Scholars proposed some frameworks for managing post-disaster reconstruction. For instance, (Bilau et al., 2015) proposed a framework for managing post-disaster housing reconstruction composed of three phases: (i) enabling phase that includes the legislation and institutional structures, resources allocation and strategy development, (ii) reconstruction planning, and (iii) the reconstruction implementation phase (Figure 1-9). (Assem et al., 2020) proposed a framework and a web-based platform for the smart management of post-conflict cities.

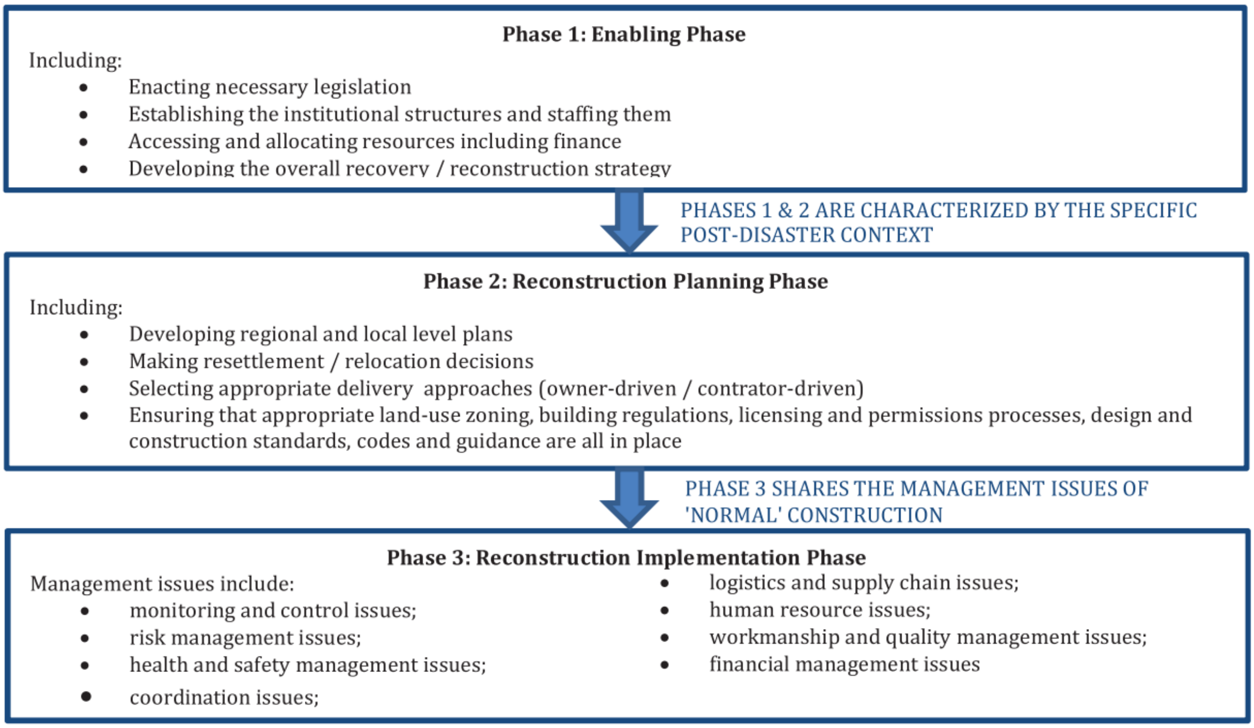


Figure 1-9. Framework for managing post-disaster housing reconstruction by Bilau et al., 2015.

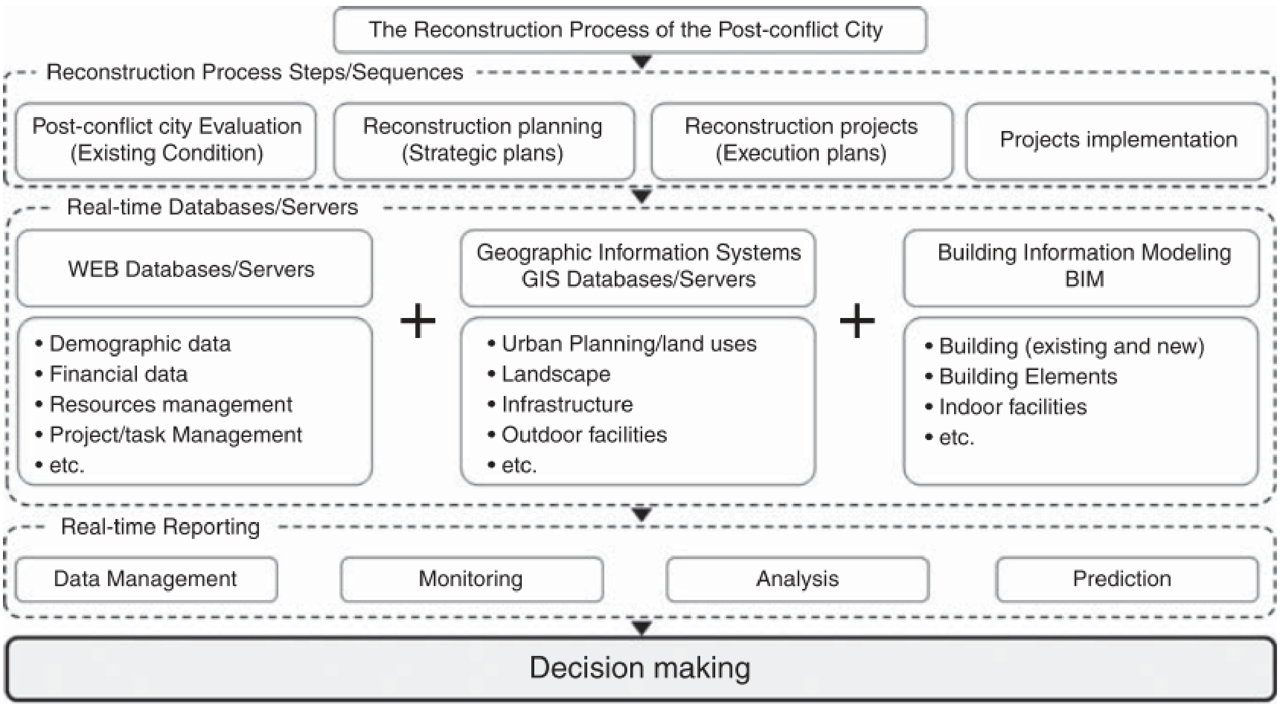


Figure 1-10. Framework and a web-based platform for a smart management of post-conflict cities by Assem et al., 2020

Their approach empowers different stakeholders involved in managing the post-conflict reconstruction process. It integrates BIM and GIS technology with a web-based application allowing real-time analysis, reporting, and decision-making (Figure 1-10).

<u>*Planning*</u>

The Post-disaster reconstruction is a long-term project that should follow strategic planning to achieve the desired outcomes.

According to (Xu & Shao, 2020), planning is “a multidisciplinary field, whose practitioners and researchers constantly draw on knowledge from across social, natural and engineering sciences to inform their work”. Post-disaster reconstruction is one of these fields, that need urgently strategic planning to achieve desired outcomes and improve the resilience and the livelihoods of the affected communities. This phase comes after conducting all the necessary and required assessments in a post-disaster or post-conflict context, and there exists many approaches in the literature review and the real case studies. The planning strategy varies from a context to another, according to the available financial, technological and human resources and capacities of the community, and according to the results of the assessments analysis. The next paragraphs will explore some of damage assessment phases and the planning approaches found in the literature review.

The existing post-disaster reconstruction planning procedures in the literature review begin with the damage assessment phase (Bilau et al., 2018; Li et al., 2019). The literature review is very rich in methods and case studies of post-disaster and post-conflict assessments that target different sectors and aspects of the reconstruction process. For instance, (Parodi et al., 2021) realized a multi-dimensional damage assessment that integrates the disaster-related environmental impacts with economic and social losses and used it to assess the damages in the aftermath of the floods in Peru linked to El Niño. (Ghosh et al., 2011) detailed how the crowdsourcing technique was used for rapid damage assessment after the 2010 Haiti earthquake of the buildings. International organizations also conduct post-disaster damage assessments, such as the rapid socio-economic impact assessment of the crisis in Lebanon (United Nations, 2020), which includes an assessment of the health sector, basic services, macro- and micro-economic response, and social cohesion and resilience. (World Bank Group, 2017) also conducted a damage assessment of the war in Syria in three cities, including housing, health, transport, energy, education, water supply and sanitation, urban institutions and service provision. (Kumar et al., 2020) proposed a methodology for assessing disaster-affected cultural sites using deep learning techniques. The assessment is used in short-term rescue operations and damage assessments, it can also be useful to track the recovery process and the reconstruction projects to check if they are achieving the desired outcomes. (Zhou et al., 2022) created a sustainable recovery framework that considers citizens' needs. It was based on systems theory to evaluate the sustainable recovery level of families and communities from three dimensions Element, Structure, and Function, that include the assessment of livelihood capital, social capital, social governance, disaster preparedness, mitigation and learning of the affected community. (Bressers et al., 2016) created a tool for governance assessment that aims to view implementation processes as multi-actor interaction processes that are ultimately driven by all actors involved. (Rouhanizadeh et al., 2020) argued that a comprehensive analysis and understanding of the barriers that can face post-disaster reconstruction is very crucial because it can lead to the development of policies that help prevent delays and address these barriers in the recovery process and consequently achieves the desired outcomes. The literature review is scarce in presenting a comprehensive analysis of the barriers found in post-conflict contexts. Therefore, the next chapter is going to fill this gap.

(Bilau et al., 2018) proposed a framework, shown in Figure 1-11, for managing post-disaster housing reconstruction in developing countries, based on a comprehensive identification of the barriers facing the management of reconstruction and the measures to address them. The framework highlights the importance of situation awareness, damage assessment, risk and needs assessment to design reconstruction projects that are able to fill these needs. The assessment phase is followed by the implementation, monitoring and evaluation of the projects that includes the procurement of funding and resources, coordination, monitoring and evaluation, in addition to establishing and improving the legal framework and engaging the involved actors and stakeholders.

(Li et al., 2019) discussed the reconstruction planning and results of the Wenchuan post-earthquake in Dujiangyan city housing reconstruction, China, illustrated in Figure 1-12. They found that the followed strategy led to meet the different needs of the victims and accelerate the economic recovery. The success was attributed to the diversification of the Dujiangyan housing reconstruction development model, the participation of multiple entities such as the market and social institutions and solving property rights problems in rural areas.

(Mannakkara et al., 2018) proposed a post-disaster reconstruction planning with a sequence of activities, illustrated in Figure 1-13. The emergency phase encompasses the establishment of the authorities that will be responsible of the decision-making in the reconstruction process, data collection and assessments, and cleaning of debris. It can also include the revision of the building codes and standards, assisting the affected community financially and psychologically, and arrange funding sources. After this phase, the reconstruction can start with the involvement of local community and their coordination with the government and the other stakeholders.

1.3.4 Summary

The state-of-the-art lacks a well-defined approach that links governance and management systems of post-disaster reconstruction without confusing the stakeholders and their roles in each system. Therefore, there is a need for establishing a comprehensive framework that identifies the different stakeholders from the governing body and the management teams and defines their roles respectively within the post-disaster reconstruction process.

Additionally, there are a lot of damage assessments in the literature as well as indicators and indices for measuring damage, vulnerability, or resilience. In pre-disaster mitigation, it is important to assess the capacity of a community to face future disasters and their assets and resources, as well as to measure the disaster risks. In the short-term disaster response, assessments are vital for rescue and life-saving operations. In the medium and long-term recovery, they are useful to manage and conduct a successful reconstruction process, for achieving the desired outcomes and improving the livelihoods and resilience of the affected community on all levels.

The techniques and methods used to accomplish the post-disaster phases vary from a country to another. The scale of the disaster and the damage can also play a role in choosing the methods. Smart technologies and digital tools offer new opportunities in improving the assessment, coordination, design methods, and all the phases of reconstruction planning. The next paragraph will explore the different technologies used in post-disaster reconstruction phases and will highlight their role.

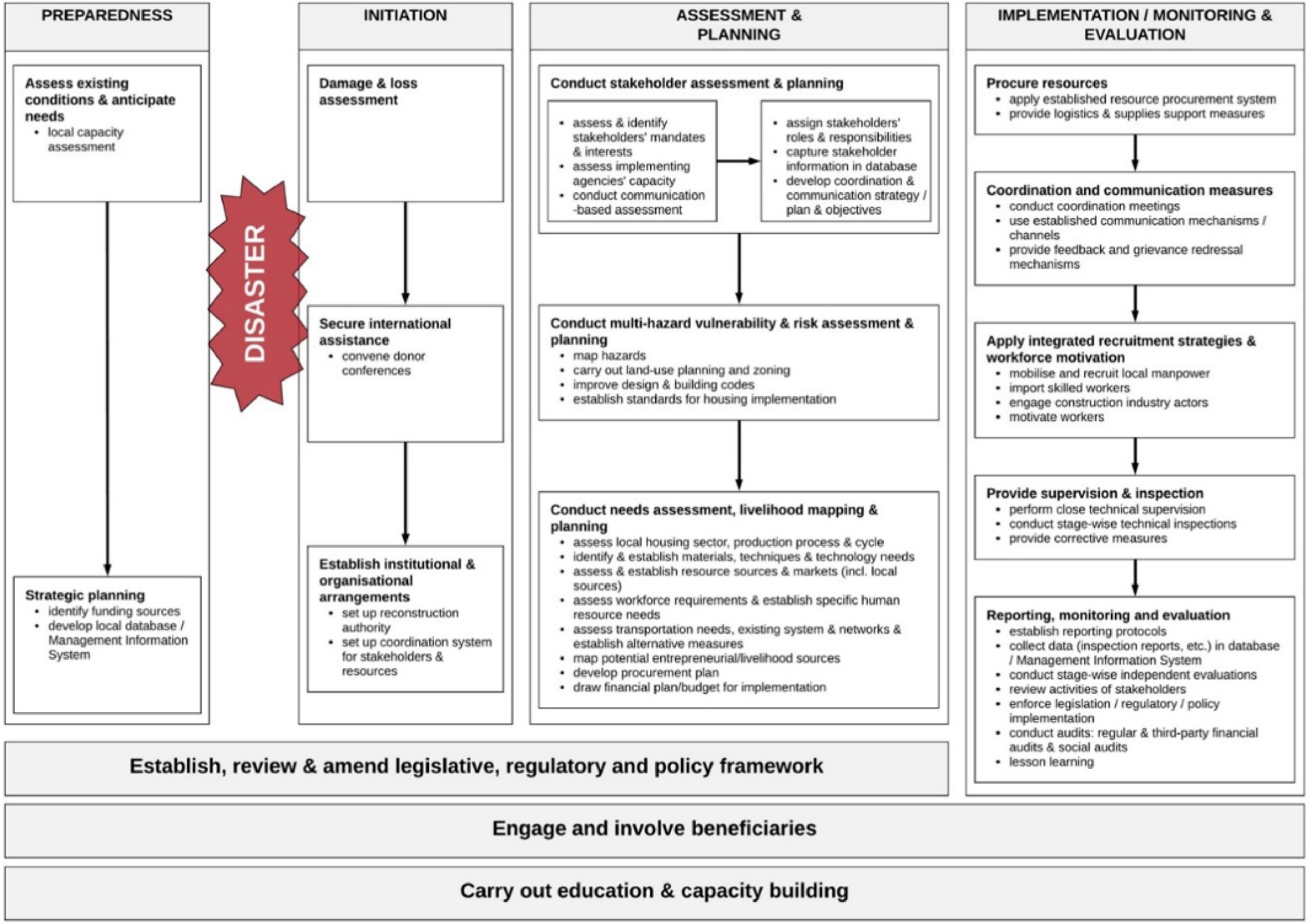


Figure 1-11. Framework for post-disaster housing reconstruction management by (Bilau et al., 2018).

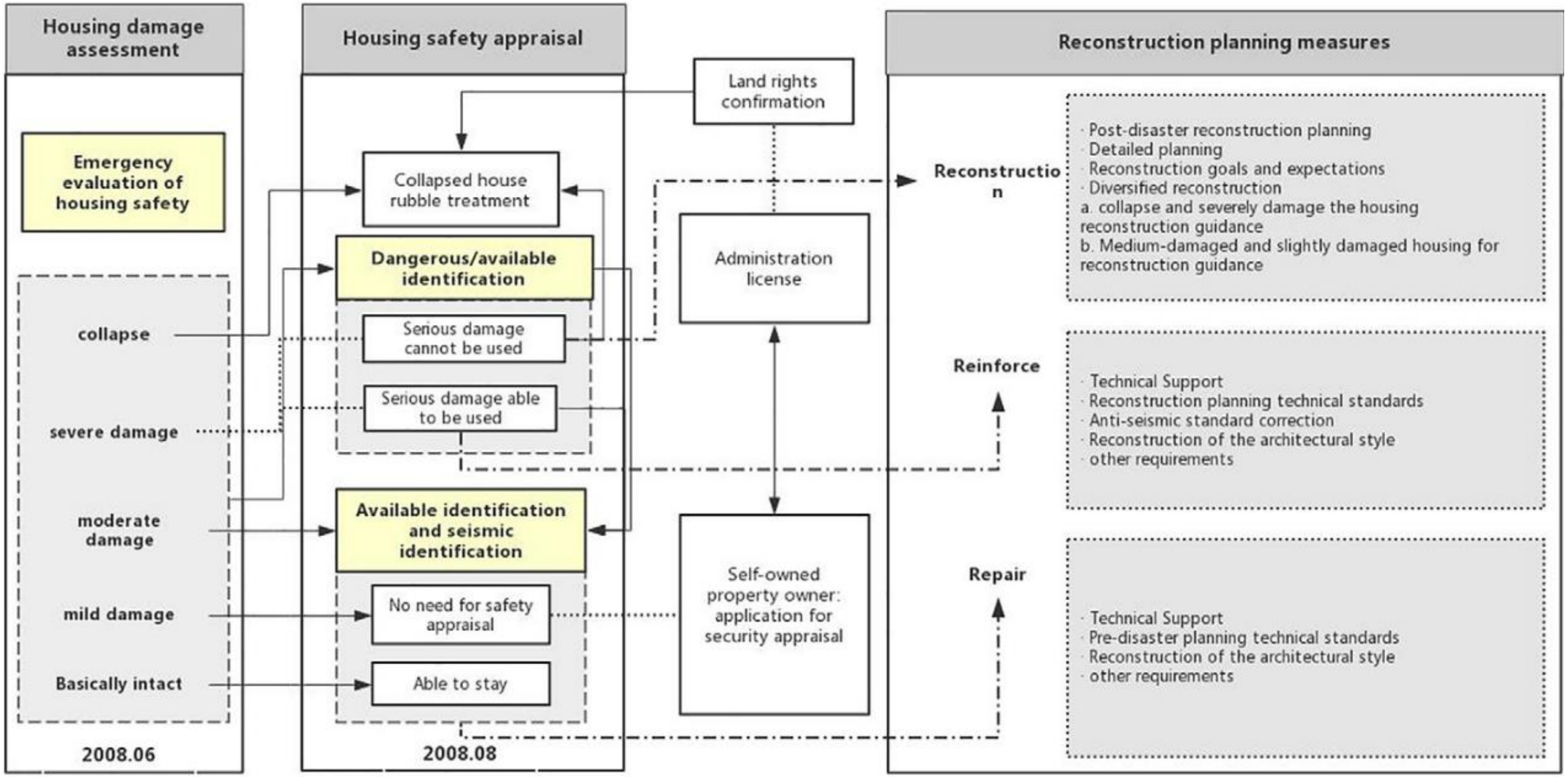


Figure 1-12. Reconstruction planning framework of the Wenchuan post-earthquake in Dujiangyan city housing reconstruction by Li et al., 2019.

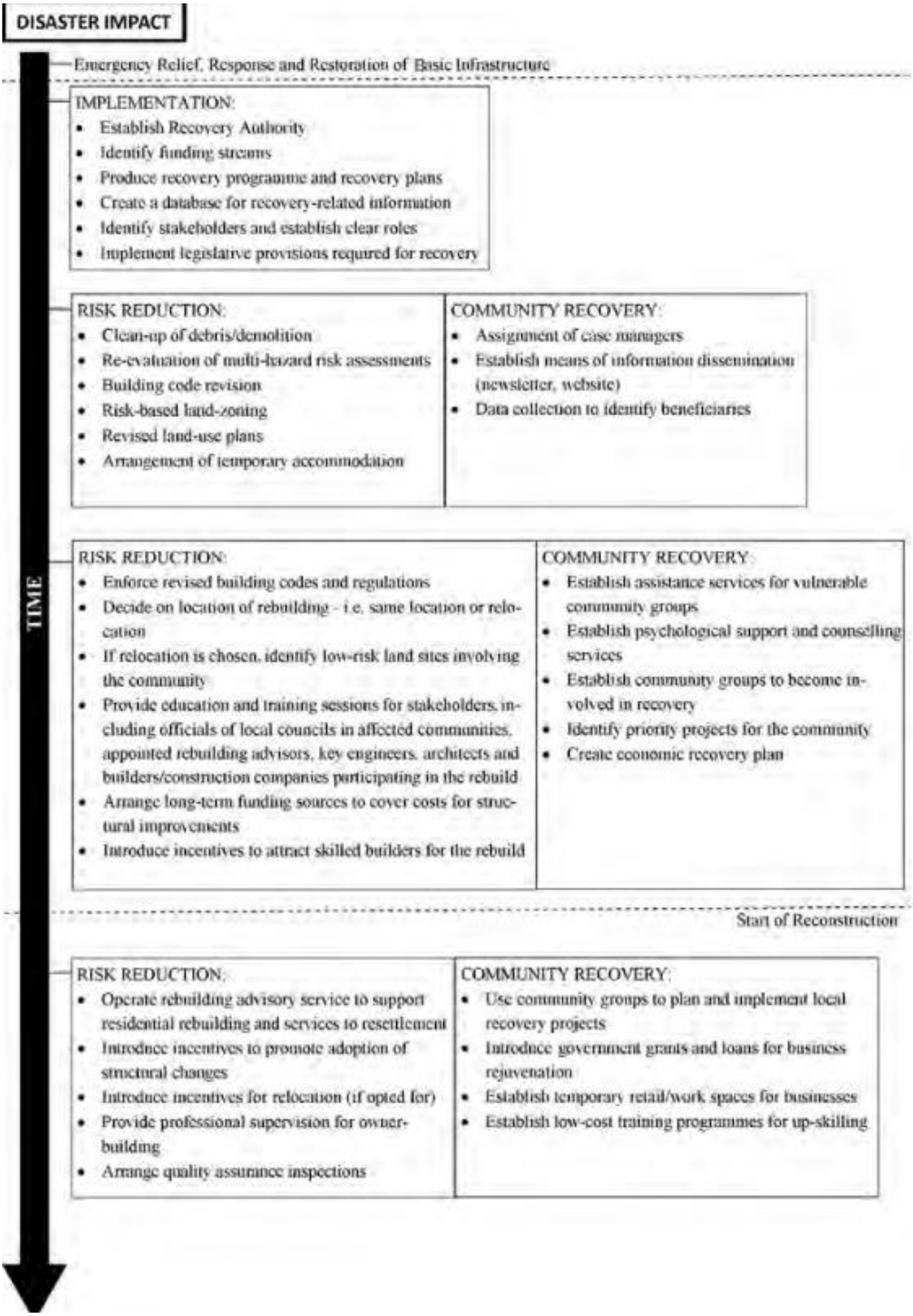


Figure 1-13. Post-disaster reconstruction planning proposed by Mannakkara et al., 2018

1.4 Role of smart technologies in post-disaster reconstruction

The post-disaster context offers the opportunity of improving urban planning and resilience by building back better, greener, stronger, and more sustainable (Bănică et al., 2020; Davidsson, 2020; Di Ludovico et al., 2020; Mochizuki & Chang, 2017). The Sendai Framework for Disaster Risk Reduction recommended using smart technologies to address the challenges of risk reduction. It also focused on technology transfer between developed and developing nations and partners and capacity building via international commitments. (Pereira et al., 2018) argued that the intelligent use of ICT improves decision-making and collaboration among stakeholders, including government and citizens. (Assem et al., 2020) highlighted the importance of integrating GIS, BIM, and other digital tools in the management of post-conflict reconstruction. These contexts present complex and chaotic conditions that can take many years to improve and need continuous monitoring and real-time data acquisition and archival of reconstruction efforts. The use of digital tools helps to complete a smart assessment of existing conditions, strategic planning and management of efficient reconstruction, and effective communication among all involved stakeholders according to the authors. (Liu et al., 2019) introduced an integrated disaster reduction intelligent service prototype system to provide technical support for China's comprehensive disaster reduction decision analysis from the perspective of surveying, mapping, and geoinformation. Digital technologies and IoT tools can be introduced in any phase of post-disaster reconstruction planning. For instance, (Shahat et al., 2020) integrated IoT technology into the smart disaster governance, which can reduce impacts and vulnerabilities and improve community disaster resilience and coping mechanisms. (Falco et al., 2018) proposed smart mobility models to improve the public transportation system of L'Aquila by leveraging digital technologies, open data, and open source software. A digitization and geo-referencing procedure, software architecture, and web and mobile apps were used to improve the information flow available to citizens and increase the transportation system's user-friendliness. (Sony et al., 2019) presented a comprehensive literature review of next-generation smart sensing technology developed in recent years for structural health monitoring, including smartphones, UAVs, cameras, and robotic sensors used in acquiring and analyzing the vibration data for structural condition monitoring and maintenance. These techniques could be used in detailed and accurate damage assessments after disasters to help in rconstruction. (Cimellaro et al., 2014) developed a mobile application that can be run by residents on smartphones, for conducting a rapid initial damage assessment of the affected area, which is going to be very useful when resources and the number of experts are limited. It showed its efficiency in statistical terms when comparing it with the standard procedure. (Sarker et al., 2020; Yu et al., 2018) reviewed the role of Big Data in natural disaster management by conducting a comprehensive literature review of the major Big Data sources. They found their emerging achievements in different disaster management phases, from mitigation efforts to assistance in relief and rescue operations, and contribution to the recovery and reconstruction processes. (Ragini et al., 2018) proposed sentiment analysis to disaster response. It consists of collecting disaster data from social networks and categorizing them according to the needs of the affected people through a machine learning algorithm.

According to the authors, the analysis helps the emergency responders and rescue personnel to develop better strategies for effective information management in the rapidly changing and chaotic post-disaster environment. Some scholars also proposed integrating digital tools and smart technologies in post-conflict contexts.

For instance, (Saeed et al., 2021) investigated and discussed the potential of adopting BIM in post-conflict planning and assessing possible housing solutions for the reconstruction of Mosul City. They found that BIM can conduct a comprehensive life-cycle of the proposed design with a better understanding of the strengths and weaknesses. Additionally, it can reduce time and errors and provide more accurate, reliable, and functional procedures. (Ding et al., 2019) also found that BIM implementation may improve the quality of the entire process in renovation projects. (Assem et al., 2020) developed a platform for the smart management of post-conflict cities that focuses on evaluation, strategic planning, reconstruction projects, and implementation by creating a web-based platform that integrates BIM, GIS, and other innovative tools. However, (Wang et al., 2016) remarked that an established building information model achieves value only if the data sources are accurate. Therefore, the accuracy of the digital model will be affected by the inconsistency between the original design drawings and the actual buildings or the inability to obtain building information quickly. (Ding et al., 2019) suggested using Reverse Engineering in these cases to collect building information and overcome the inaccuracies and issues mentioned above. There exist many digital data acquisition systems in the literature review for buildings data collection, able to recreate the 3D design model cited by (Ding et al., 2019), such as the combination of BIM and Virtual Reality (VR), which is a computer technology that ensures that the field staff in a renovation project will better understand what the designers mean.

(Wallentén & Mjörnell, 2021) identified a lack of practical methods for sustainable renovation and a need for a framework and supportive tools to sustainably guide and manage the renovation process. The reconstruction process is challenged by many barriers, and the lack of technical support and human expertise is an obstacle for the success of the recovery (Rouhanizadeh et al., 2020). The challenge lies in finding the most appropriate digital tools and technologies for the specified context, particularly where the financial resources and funding are scarce.

1.5 Research gaps

Scientific gaps identified in the post-disaster reconstruction research include the lack of a comprehensive framework for a smart post-disaster reconstruction that identifies the roles of the different stakeholders in recovery projects and uses the latest technical and social innovation.

Additionally, there is a consideration deficit of geopolitical issues, such as armed conflicts, political crises, or other problems like corruption. The smart post-disaster reconstruction concept could address this gap. Moreover, existing frameworks confuse the governance and the management bodies.

On other axis, some studies identify the barriers facing reconstruction in post-disaster contexts (Rouhanizadeh et al., 2020; Rouhanizadeh & Kermanshachi, 2020). However, no study has considered the barriers and challenges in post-conflict or geopolitical crises. These barriers need to be addressed in the post-disaster reconstruction strategy and planning. Otherwise, if the specificities of the context were not integrated, the process would not lead to a satisfying and successful recovery.

And regarding the community involvement, although there are many studies that discuss the bottom-up approaches and their benefits, as well as try to involve the community in the reconstruction process, however, neither of them adopted a participatory approach that considers the community as an active stakeholder.

For Beirut case, some scholars studied the explosion event itself, however, the literature review lacks studies about the socio-economic impact of the disaster on the city. There were no national or local frameworks to monitor the post-disaster reconstruction, the affected community was left on its own during the process.

These research gaps constitute the core of this research with emphasis on the following question: "In a post-disaster (natural or human-made) and complex geopolitical context, how can we conduct a community-based sustainable and smart recovery and assist the decision-making process, using the digital technologies and available tools?".

To deal with this question, this research aims at establishing a framework for smart post-disaster reconstruction that takes into consideration the disaster context with its specific features and conditions. The framework should integrate smart technologies, sustainability principles, and improve the resilience of the affected communities to restore their livelihoods after the disaster and face possible future disasters. The framework also aims to assist decision-makers in managing post-disaster reconstruction projects, in order to "Build-Back-Better" and help the most vulnerable community members "Leave-no-one-behind".

Accordingly, this research will address the research gap by:

1) Establishing a general framework for smart post-disaster reconstruction that distinguishes post-disaster governance and management concepts, and details each one.
2) Studying the local context specificities and identifying the barriers that could face the recovery process, particularly in complex geopolitical contexts.
3) Integrating smart city principles, sustainability, and resilience into the framework to improve the pre-disaster disaster conditions, so the affected community can face future disasters.
4) Including the local community in the reconstruction process using the crowdsourcing as the main data source.
5) Assisting decision-makers in planning post-disaster recovery by providing them a data-based assessment and informed reporting.
6) Apply the proposed approach to a damaged area in Beirut after the port explosion.

1.6 Conclusion

This literature review identified the threat of disasters on humankind and their devastating impacts on all levels and dimensions. It highlighted the importance of post-disaster reconstruction process as the way to restore the livelihoods of affected communities, and as an opportunity to build back better. The literature review focused also on the complexity of the process as a mutli-sector process, that encompasses physical, social, economic, environmental, political, legal, and many other fields. It detailed the main components of post-disaster reconstruction process governance, management and planning. It distinguished between governance and management of post-disaster reconstruction, and highlighted the importance of community participation to achieve a sustainable and smart recovery. It presented some existing frameworks proposed by international organizations and scholars. It also explored the role of digitization in improving the post-disaster recovery process and rebuilding communities sustainably and resiliently after a disaster. The goal requires the development of a smart post-disaster reconstruction framework that addresses the gaps identified, and assists decision-makers in managing and monitoring the reconstruction projects, focusing on complex geopolitical contexts.

This next chapter will present the research methodology and explore the barriers and challenges that face post-disaster reconstruction, particularly in complex geopolitical contexts. A detailed study of the Beirut explosion disaster is also presented.

2 Research Methodology

2.1 Introduction

The previous chapter presented the literature review of post-disaster reconstruction process. This chapter outlines the research methodology to develop a smart post-disaster reconstruction framework, focused on complex geopolitical contexts. This objective forms the core contribution of this thesis, with a focus on creating a comprehensive post-disaster assessment framework for buildings post-disaster reconstruction.

The first section details the architecture of the research methodology, which serves as a blueprint for achieving our objective. The second section outlines a literature review on the challenges and barriers that may arise during post-disaster reconstruction, specifically focusing on complex geopolitical contexts and developing countries. The third section describes Beirut context, highlighting the challenges and barriers facing the post-explosion reconstruction.

2.2 Research Methodology

Based on the fact that every post-disaster is unique and is a complex system dependent on many factors, a general research methodology is proposed. It encompasses four main phases, as depicted in Figure 2-1. The initial phase comprehensively studies the local context, considering its characteristics and specificities, as well as situational awareness of the city urban systems. The second phase concerns data flow, including data collection, analysis, and exploitation. The final phase proposes the development of a framework that assists decision-makers involved in the reconstruction process. This tool facilitates informed prioritization of reconstruction projects based on comprehensive analysis and assessment conducted in the earlier phases.

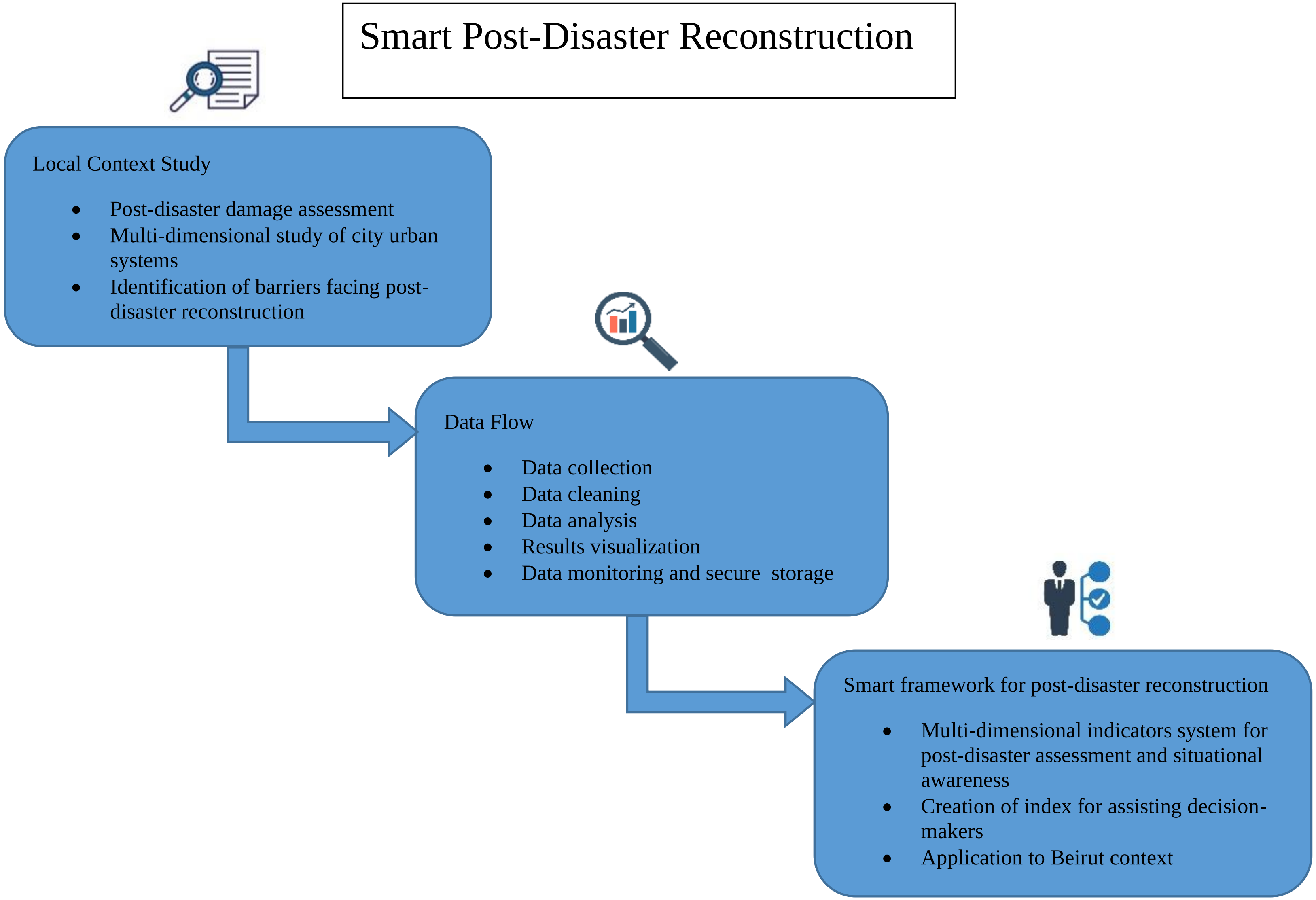


Figure 2-1. Research Methodology.

2.2.1 Local context study

Each post-disaster context is inherently distinct and influenced by a multitude of factors. Cities and countries are intricate systems comprising numerous interconnected and interdependent subsystems. Consequently, the entire system is subject to the influence of political, social, economic, historical, geographical, and other factors. Disasters further amplify the situation's complexity as they disrupt various subsystems, including transportation, communication, energy production, and transmission. Without an effective disaster management program implemented by local governments or authorities, the situation can quickly descend into chaos and become uncontrollable. Such circumstances may give rise to conflicts or other crises, exacerbating the overall challenges faced in the post-disaster environment.

Consequently, conducting a thorough study of the disaster context from all angles becomes a crucial task, that constitutes the foundation for selecting appropriate methods and allocating the necessary resources for recovery. It encompasses a detailed description of the disaster and its impacts on various sectors. During this phase, it is crucial to identify the barriers and obstacles specific to the context, as they pose significant challenges and impede the post-disaster reconstruction efforts.

In 2008, the European Union (EU), the World Bank, and the United Nations Development Group (UNDG) introduced the Post-Disaster Needs Assessment (PDNA) as a means to provide enhanced support to affected populations and governments in their recovery and reconstruction endeavors (European Commission et al., 2013). The importance of conducting PDNA was widely discussed in the literature. (Mejri et al., 2017; Perwaiz & Sinha, 2018) highlighted that PDNA plays a crucial role in identifying the needs of the affected communities. It also provides a mechanism for monitoring the recovery process and emphasizes the significance of spatial analysis in analyzing the collected data. Spatial analysis becomes particularly valuable when dealing with large-scale affected areas, allowing for a comprehensive investigation and the identification of trends and issues that may not be apparent at a smaller scale. (Hinzpeter & Sandholz, 2018) emphasized the importance of PDNA in assisting and supporting local governments, particularly when their coping capacities are overwhelmed by the impacts of the disaster. They also argue that PDNA can aid in allocating technical and financial resources during donor conferences. (Jeggle & Boggero, 2018) defined PDNA as an integrated framework that assesses the effects and impacts of disasters across all sectors, thereby supporting governments in identifying their recovery interests and needs. They emphasized that PDNA is comprehensive, multi-sectoral, and based on well-established analytical methods encompassing recovery's economic, productive, commercial, social, and human development aspects. The PDNA guidelines document provided by the (European Commission et al., 2013) identified the main sectors and sub-sectors the PDNA assessment should cover. The typical sectors that are assessed in the PDNA are:

- Social: education, health, housing, …
- Infrastructure: water and sanitation, energy and electricity, transport and communication, …
- Productive: Agriculture, Tourism, Commerce, …
- Macro-Economy: GDP, Balance of trade, …
- Human-Social Development: HDI, Poverty, …
- Finance: Banks, Financial Institutions, ….
- Cross-Cutting Sectors: Governance, DRR, gender, …

The United Nations Economic Commission for Latin America and the Caribbean (UN-ECLAC) developed the Disaster Damage and Loss Assessment (DaLA) to determine the scope of post-disaster programs. The (GFDRR & World Bank, 2010) adopted this methodology, and argued that DaLA could effectively assist in determining post-disaster needs, including economic recovery planning and reconstruction program design. The DaLA methodology employs a sector-by-sector analysis and a subsequent "bottom-up" approach to estimate the overall effects of the disaster and its impact on society and the economy. It covers sectors like those addressed in PDNA, such as infrastructure, social, economic, and cross-cutting sectors. A practical example of utilizing the DaLA method can be seen in the work of the (World Bank, 2017), when assisting the government of Sierra Leone in estimating the effects and impacts of the landslide and floods that occurred on August 14th in the Western Area. By employing the DaLA method, they could formulate a strategic recovery plan, mobilize resources effectively, and prioritize and allocate resources to address the needs of the most severely affected areas. Governments have also developed tools for post-disaster damage assessment to manage emergency and recovery phases. For example, the US government employed active crowdsourcing through an online reporting form to gather information on storm damage and flooding, focusing on building damage and flood levels (Harrison & Johnson, 2016).

Many scholars have also established frameworks and proposed methods for conducting post-disaster assessments. These frameworks aim to provide a structured approach to comprehensively evaluate the impacts and damages caused by disasters. Within these frameworks, different indices have been proposed. Some researchers have focused on specific aspects, such as buildings' and infrastructure's physical or structural condition. Others have considered broader issues, including social and economic patterns and aspects of management and governance. By combining multiple assessment dimensions, such as physical, socio-economic, and governance factors, these frameworks allow for a more holistic understanding of the post-disaster situation. They enable a comprehensive analysis beyond isolated perspectives, considering the interconnected nature of various issues and their influence on the recovery process.

However, to develop an assessment framework, we have to identify first the types of data we need. (Mejri et al., 2017) identified the data required for post-disaster assessment, ranging from pre-disaster mitigation to post-disaster recovery and reconstruction. It includes diverse data sources such as cadastral maps, statistical data, information on damaged buildings and assets, lifelines, insurance data, and community resources. Their framework, illustrated in Figure 2-2, provides a comprehensive overview of the data needed for post-disaster assessment.

In the multi-dimensional damage assessment (MDDA) approach proposed by (Parodi et al., 2021), the total damage is calculated by considering social, economic, and environmental factors (as shown in Figure 2-3). Social damage encompasses physical and mental harm to the community, economic damage includes the value of lost assets, and environmental damage refers to losses in ecosystems and biodiversity. (Yilmaz et al., 2013) conducted background research to present a theoretical and practical approach for damage assessment surveys in rural contexts, adopting a human-based approach. They developed a list of indicators categorized into five groups: general information, physical evaluation of buildings, social and economic evaluation of residents, and overall evaluation, including trust in the state and level of expectations. (Liu et al., 2019) developed an index system for disaster damage assessment based on four categories: disaster properties, social impact, economic influence, and the natural environment. The system includes sub-indicators such as the number of affected individuals, the need for resettlement, direct and indirect losses, and the unemployment rate among the affected population. (Khajwal & Noshadravan, 2021) designed a survey questionnaire for building damage assessment focusing on public participation, aiming to quantify and reduce uncertainty in the assessment outcomes (Figure 2-4). Their survey specifically addresses physical indicators of buildings, including the condition of walls, roofs, cladding, windows, and doors. (World Bank Group, 2017) conducted a damage assessment during the Syrian armed conflict, analyzing damages and losses in sectors such as housing, health, transport, energy, education, water, and urban institutions and service provision. (Basu et al., 2016) proposed a rapid needs assessment approach based on interactive crowdsourcing, covering aspects such as affected area profiles, health and medical infrastructure, food aid and nutrition, and water and sanitation. (Ghosh et al., 2011) discussed the GEO-CAN methodology that emerged from the theory of crowdsourcing and remote sensing-based damage interpretation and represented a new paradigm in post-disaster damage assessment. They argued that the adoption of the GEOCAN by the Haitian government provided valuable lessons on multi-agency collaboration, rapid and implementable damage assessment protocols under extreme situations for the disaster management profession, developmental organizations, and society. (Ogunjinmi et al., 2022) used pre-trained convolutional neural network (CNN) models and transfer learning (TL) to automatically classify structural damage resulting from earthquakes.

We noticed from the literature review that there is a gap in identifying the barriers and challenges facing post-disaster reconstruction in a specific context, before proposing the corresponding framework. This lack can result in the failure of the program, because the post-disaster recovery is already a challenging and complex procedure, and by ignoring the barriers, risks of not achieving the desired outcomes increase, since these obstacles were not addressed. There are some papers that discuss the barriers facing post-conflict reconstruction such as (Rouhanizadeh et al., 2020) and (Jones et al., 2014), however, they do not constitute a step or a phase in an integrated post-disaster reconstruction general or specified framework. Therefore, this phase will include the identification of the barriers found in post-disaster contexts in general, and then focus on Beirut case.

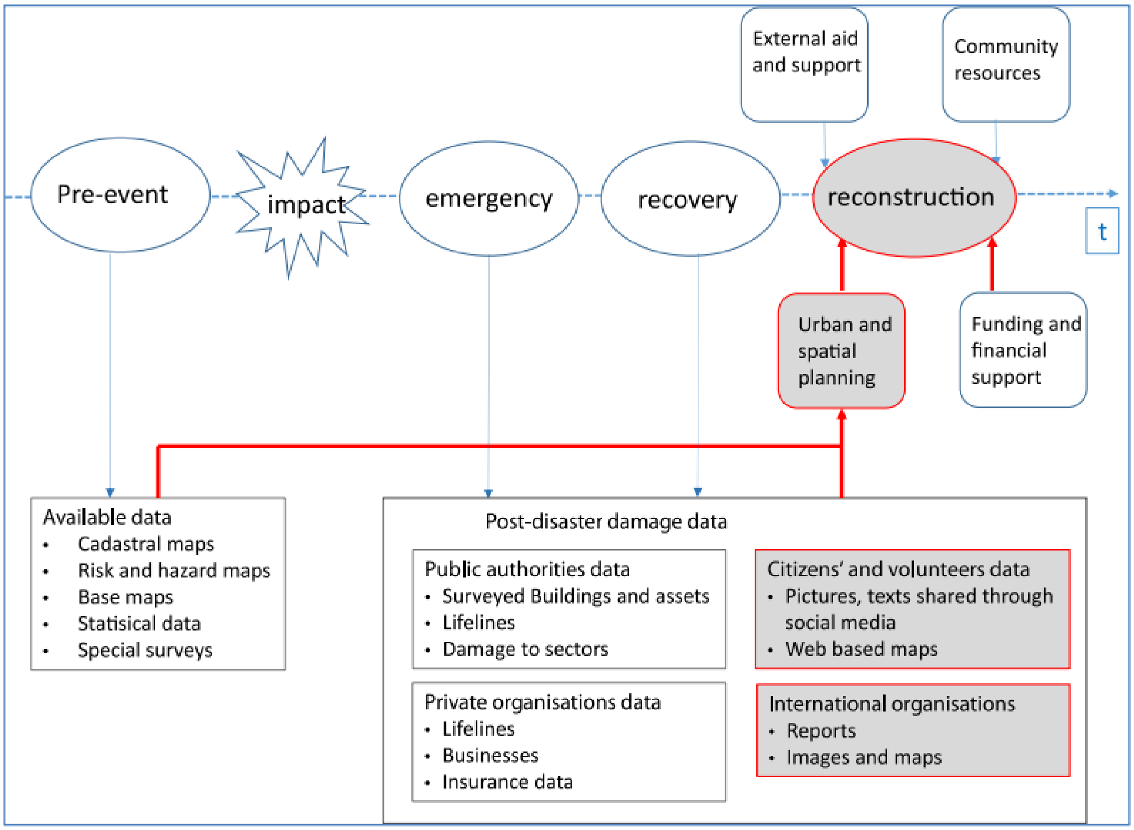


Figure 2-2. Framework for post-disaster needs assessment data types by Mejri et al., 2017.

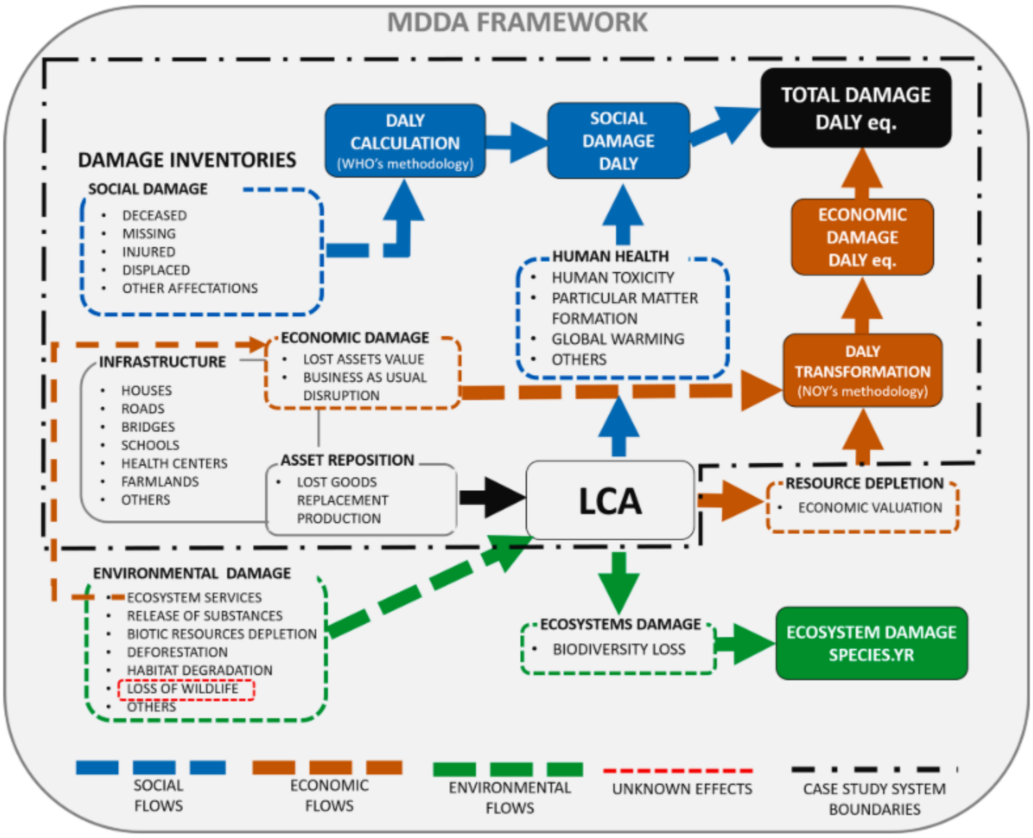
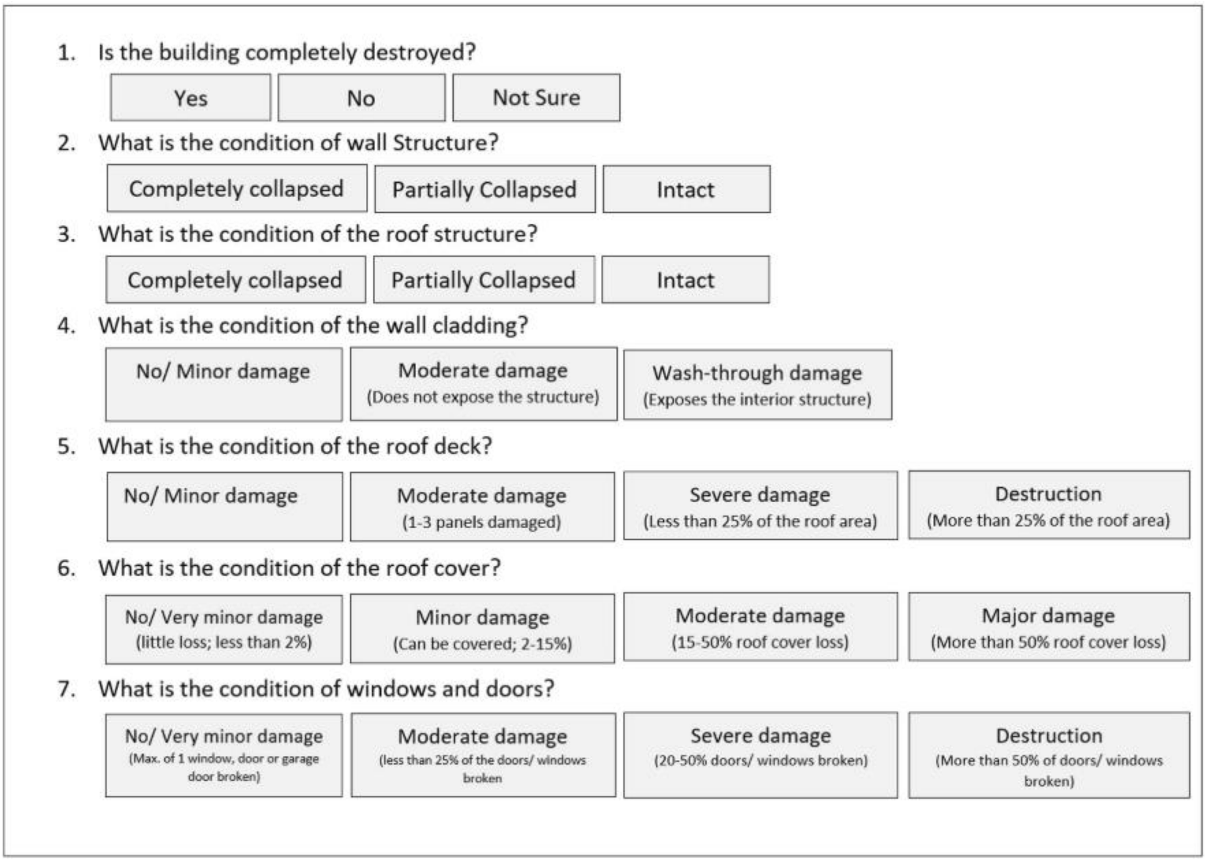


Figure 2-3. Multi-dimensional damage assessment framework by Parodi et al., 2021.


1. Is the building completely destroyed?

Yes	No	Not Sure

2. What is the condition of wall Structure?

Completely collapsed	Partially Collapsed	Intact

3. What is the condition of the roof structure?

Completely collapsed	Partially Collapsed	Intact

4. What is the condition of the wall cladding?

No/ Minor damage	Moderate damage (Does not expose the structure)	Wash-through damage (Exposes the interior structure)

5. What is the condition of the roof deck?

No/ Minor damage	Moderate damage (1-3 panels damaged)	Severe damage (Less than 25% of the roof area)	Destruction (More than 25% of the roof area)

6. What is the condition of the roof cover?

No/ Very minor damage (little loss; less than 2%)	Minor damage (Can be covered; 2-15%)	Moderate damage (15-50% roof cover loss)	Major damage (More than 50% roof cover loss)

7. What is the condition of windows and doors?

No/ Very minor damage (Max. of 1 window, door or garage door broken)	Moderate damage (less than 25% of the doors/ windows broken	Severe damage (20-50% doors/ windows broken)	Destruction (More than 50% of doors/ windows broken)

Figure 2-4. The survey questionnaire distributed among the participants by Khajwal & Noshadravan, 2021

2.2.2 Data Flow

The following phase after establishing the framework or the methodology for post-disaster damage assessment, is determining the data flow system. Data flow has been discussed by various authors who proposed many architecture frameworks. The main common layers are the following: data collection, data transmission, data processing, control and communication layer, and the transformation of data into services.

(Shahrour & Xie, 2021) proposed a six-layer platform for the smart city concept, as illustrated in Figure 2-5. The first layer concerns the physical components of the city, encompassing the urban environment, services, stakeholders, and socio-economic activities. The second layer, known as the sensing layer, involves the use of Internet of Things (IoT) technologies, including sensors, open data, and crowdsourcing, to gather information and encourage citizen participation. Data transmission, which constitutes the third layer, utilizes both wired and wireless communication infrastructures. Wireless technology is utilized at the local level, while wired technology is employed for longer distances. The fourth layer deals with data processing, involving tasks such as data filtering, storage, fusion, and analysis. These processes transform collected data into valuable services. The fifth layer facilitates interaction with stakeholders and device control, enabling effective communication and management of the smart city system. Finally, the service layer, the last layer, provides a range of services aimed at optimizing and ensuring the safe management of urban infrastructures. These services include tasks such as surveying and controlling the urban environment, improving community services like public transportation and real-time parking availability mapping, detecting water leakages or contamination, optimizing stormwater systems to mitigate flood risks, and early detection of electrical outages. The service layer also provides tools to inform citizens about city news, projects, events, and hazards, fostering their involvement in participatory governance. Additionally, it offers information on socio-economic activities, including sporting, cultural, and artistic events, local social gatherings, job opportunities, new business installations, and support for innovation and economic initiatives. This comprehensive architecture demonstrates the multifaceted nature of smart city platforms, integrating various layers and services to create efficient and sustainable urban environments.

(Chen et al., 2017) proposed a framework for the design and implementation of a geological hazard monitoring and early warning system, based on multi-sourced data. The data flow architecture of the system is illustrated in Figure 2-6. The system consists of five layers: data collection, transmission, data storage, data analysis, and system service.

(Wehbi, 2021) designed a data flow system to construct a platform that monitors, detects, acts, and prevents in the best way indoor hazards, such as fire hazards. The system is composed of five layers: data collection, data processing, data analysis, control layer and smart services. The architecture is illustrated in Figure 2-7.

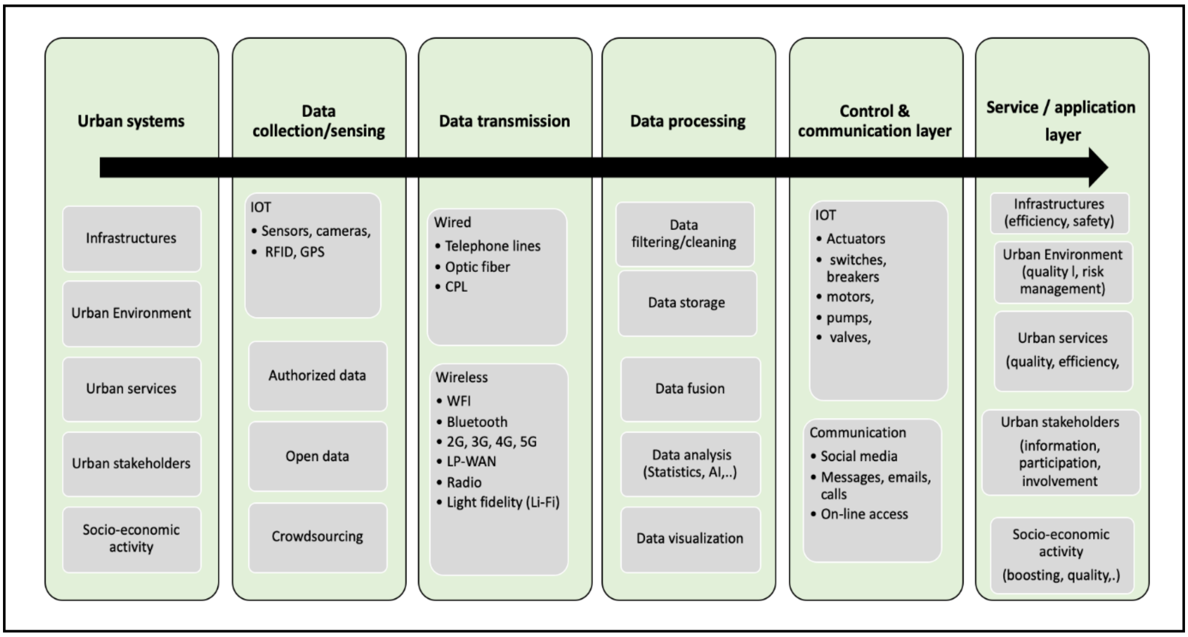


Figure 2-5. A six-layer platform for the smart city (Shahrour & Xie 2021).

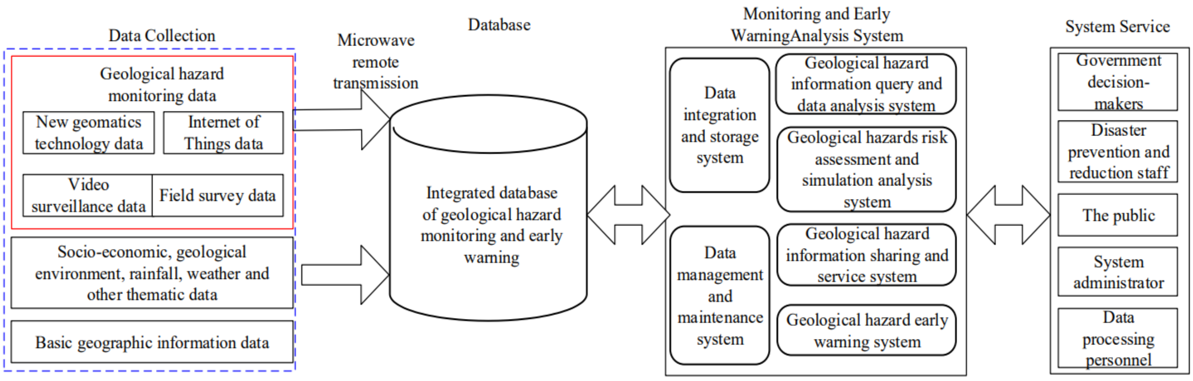


Figure 2-6. A five-layer data flow system for geological hazard monitoring data (Chen et al., 2017)

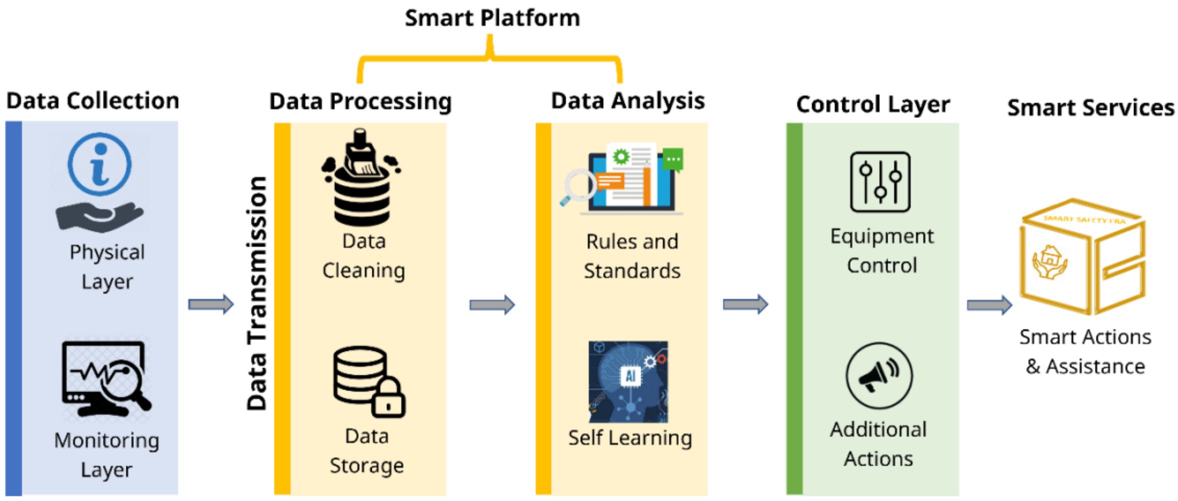


Figure 2-7. Data system architecture for smart platform by Wehbi, 2021.

2.2.3 <u>Smart framework for post-disaster reconstruction</u>

The two phases presented in the previous paragraphs lead us to the phase of the smart post-disaster reconstruction framework development which is the core of this work. Despite numerous frameworks and platforms proposed for post-disaster reconstruction in various countries, and discussed in the first chapter, there is a significant gap in addressing local context situation and strategies, particularly in regions facing geopolitical and/or socio-economic crises.

This phase will be developed in the next chapter and it encompasses the following steps:

- Identification of an indicators' list to measure certain variables and characteristics, required for the conducted assessment
- Development of a multi-dimensional indexing system for damage assessment and situational awareness of a post-disaster context
- Application to the Beirut Harbor disaster

It is important to mention that the framework takes a human-centered and participatory approach, ensuring the involvement of the affected community and adhering to the principle of "Leaving No One Behind." This will impose an additional condition on the framework, to take into consideration the available digital tools that allow the community to participate.

The case of Beirut city is investigated as a specific context, and a framework is developed that considers the city's unique challenges and characteristics. By considering the specificities of the context, the framework aims to enhance the effectiveness and efficiency of post-disaster reconstruction efforts, ultimately fostering a more inclusive and sustainable recovery process.

2.3 Barriers facing post-disaster reconstruction

This section explores the barriers and challenges encountered in post-disaster reconstruction. While research specifically focusing on post-disaster reconstruction barriers is scarce, some scholars have identified common challenges in this area. For instance, (Rouhanizadeh & Kermanshachi, 2019a) conducted a study, ranking 15 socio-economic barriers based on their importance. (Safapour et al., 2021) identified 69 barriers to post-disaster recovery in urban and rural contexts. It categorized them into five categories: management and coordination, resources, social and cultural, physical and territorial, and legal. (Rouhanizadeh et al., 2020) conducted a systematic literature review and found 63 barriers grouped into five categories: financial and economic, social, infrastructure and housing reconstruction, environment, and coordination and resources. (Rouhanizadeh & Kermanshachi, 2020) further delved into the challenges specifically related to transportation infrastructure reconstruction in the aftermath of disasters. Additionally, scholars have discussed barriers to post-conflict reconstruction, highlighting categories such as poor governance and management, socio-economic degradation resulting from conflicts or political instability, resource constraints, and environmental degradation (Boussauw, 2012; Earnest, 2015; Höglund & Orjuela, 2011; Roach & Al-Saidi, 2021; Sakalasuriya et al., 2018; Steinø et al., 2020; Tortorici & Fiorito, 2017).

The following paragraph summarizes the barriers identified in the literature review, particularly emphasizing contexts characterized by complex geopolitical situations like armed conflicts or political instability. These barriers are classified into three categories: governance and management, social and economic, and physical and technical.

Table 2-1 Summary of the barriers for post-disaster reconstruction review.

Governance & Management	Social & economic	Physical & technical
Ineffective coordination and management between the different stakeholders (Rouhanizadeh et al., 2020; Safapour et al., 2021; Steinø et al., 2020)	Lack of economic resources for recovery (Rouhanizadeh & Kermanshachi, 2019a, 2020; Safapour et al., 2021; Roach & Al-Saidi, 2021)	Ignorance of land-use and construction standards in reconstruction process (Rouhanizadeh et al., 2020; Rouhanizadeh & Kermanshachi, 2019a, 2020; Safapour et al., 2021)
Lack of political will and/or capacity in decision-making, management and funding to achieve a successful recovery (Rouhanizadeh et al., 2020; Rouhanizadeh & Kermanshachi, 2019a; Safapour et al., 2021; Sakalasuriya et al., 2018; Steinø et al., 2020)	Low rate of employment (Rouhanizadeh et al., 2020; Rouhanizadeh & Kermanshachi, 2019b; Sakalasuriya et al., 2018)	Damage to buildings and infrastructures (Rouhanizadeh et al., 2020; Rouhanizadeh & Kermanshachi, 2020)
Financial and governmental corruption that instill distrust of community in governmental institutions (Rouhanizadeh & Kermanshachi, 2019a; Safapour et al., 2021; Alpaslan Özerdem, 2016; Earnest, 2015b; Steinø et al., 2020; Zabyelina, 2013)	High level of lost or low household income (Kermanshachi & Rouhanizadeh, 2018; Rouhanizadeh & Kermanshachi, 2019b; Safapour et al., 2021)	Lack of reliable and comprehensive data (Roach & Al-Saidi, 2021)
Political instability or security threats and hostilities (Alpaslan Özerdem, 2016; Roach & Al-Saidi, 2021)	Lack of community participation in the process (Rouhanizadeh et al., 2020; Safapour et al., 2021; Steinø et al., 2020)	Damage to environmental areas and resources (Rouhanizadeh et al., 2020; Tortorici & Fiorito, 2017)
Unfair use and allocation of funding resources (Alpaslan Özerdem, 2016; Rouhanizadeh & Kermanshachi, 2019a)	High population density (Rouhanizadeh et al., 2020; Rouhanizadeh & Kermanshachi, 2019b)	
	Exclusion of local community from recovery process (Gellman, 2010; Sakalasuriya et al., 2018)	
	Disruption of social networks and bonding (Ohiorhenuan, 2011; Rouhanizadeh et al., 2020; Jayawardana et al., 2019)	

	Illegal constructions and illicit economic activities (Boussauw, 2012; Ohiorhenuan, 2011; Rouhanizadeh et al., 2020; Rouhanizadeh & Kermanshachi, 2020)	

2.3.1 Governance and management

Real case studies highlighted governance and management as significant obstacles to recovery. Lack of political will, decision-making capacity, and adequate funding are cited as key factors contributing to the failure of post-disaster and post-conflict reconstruction efforts (Rouhanizadeh et al., 2020; Rouhanizadeh & Kermanshachi, 2019a; Safapour et al., 2021; Sakalasuriya et al., 2018; Steinø et al., 2020). Insufficient political and governmental institutional strength can lead to instability, security threats, and hostilities, impeding effective reconstruction (Alpaslan Özerdem, 2016; Roach & Al-Saidi, 2021). Furthermore, financial and governmental corruption erode community trust in institutions and decision-makers, which hampers their participation in the reconstruction process (Alpaslan Özerdem, 2016; Earnest, 2015; Rouhanizadeh & Kermanshachi, 2019a; Safapour et al., 2021; Steinø et al., 2020; Zabyelina, 2013).

Effective coordination and management of recovery efforts are crucial to avoid stakeholder conflicts and eliminate redundancy. Inadequate coordination and management between different stakeholders can hinder successful post-disaster reconstruction (Rouhanizadeh et al., 2020; Safapour et al., 2021; Steinø et al., 2020). (Alpaslan Özerdem, 2016) reported that resources could be wasted by poor management. Moreover, disasters and complex geopolitical situations exacerbate income disparity and the diversification of livelihoods, making it crucial to ensure the fair use and allocation of funding resources to prevent neglecting the needs of low-income affected individuals (Alpaslan Özerdem, 2016; Rouhanizadeh & Kermanshachi, 2019a).

2.3.2 Social and economic

Disasters have severe impacts on businesses and employment, leading to a loss or reduction in household income (Kermanshachi & Rouhanizadeh, 2018; Rouhanizadeh & Kermanshachi, 2019a, 2019b; Safapour et al., 2021; Sakalasuriya et al., 2018). This financial strain often leaves households unable to afford the costs of renovation or reconstruction, necessitating assistance to proceed with the recovery process. As discussed in the previous chapter, disasters result in significant economic and physical losses, requiring substantial resources to complete the reconstruction. In poorer countries or unprepared states, resources for recovery efforts can be insufficient (Roach & Al-Saidi, 2021; Rouhanizadeh et al., 2020; Rouhanizadeh & Kermanshachi, 2019a; Safapour et al., 2021). Additionally, post-conflict contexts may witness illegal constructions and illicit economic activities, which hinder the re-establishment of a healthy economic development and real estate market (Boussauw, 2012; Earnest, 2015; Ohiorhenuan, 2011).

The involvement of local communities is a crucial factor in the success of post-disaster reconstruction. Excluding local communities from the recovery process can have negative consequences, as highlighted by (Earnest, 2015; Gellman, 2010; Rouhanizadeh et al., 2020; Safapour et al., 2021; Sakalasuriya et al., 2018). Disasters and conflicts can lead to significant population displacement (Earnest, 2015) and the degradation of local human capital (Earnest, 2015; Ohiorhenuan, 2011; Steinø et al., 2020). Moreover, disasters and conflicts disrupt social capital, including the degradation of social networks and bonding, as emphasized by (Jayawardana et al., 2019; Ohiorhenuan, 2011; Rouhanizadeh et al., 2020).

2.3.3 Physical and technical

Disasters and conflicts result in the destruction of buildings and infrastructure, leading to a significant disruption of essential services such as energy, water, and transportation, as well as damage to environmental areas and resources (Earnest, 2015; Rouhanizadeh et al., 2020; Rouhanizadeh & Kermanshachi, 2020) Environmental areas and resources are also damaged (Rouhanizadeh et al., 2020; Tortorici & Fiorito, 2017). The extensive damages incurred pose a significant obstacle to reconstruction efforts, as their repair can be costly, and their unavailability has negative impacts on economic activity. (Rouhanizadeh et al., 2020; Rouhanizadeh & Kermanshachi, 2019a; Safapour et al., 2021) emphasized the importance of applying land-use and construction standards in the reconstruction process. Neglecting these standards can impede the "build-back-better" principle, meaning that if another disaster strikes, the destruction could be as severe or even worse. (Roach & Al-Saidi, 2021) highlighted the lack of reliable and comprehensive data, particularly in post-conflict contexts, as a significant obstacle to effective post-disaster reconstruction. The availability of accurate and up-to-date data is crucial for informed decision-making and efficient resource allocation during the recovery process.

2.4 Beirut Context Description

In this section, we provide an in-depth overview of the Beirut context following the devastating Port explosion disaster. Furthermore, we examine and highlight the various barriers and challenges encountered during the recovery process.

2.4.1 Brief disaster description

Beirut, the capital of Lebanon, has a rich history and cultural heritage. Situated along the Mediterranean Sea coast, it has a total population of 1,291,280 according to data from the Lebanon Crisis Response Plan (UN-Habitat, 2021), The city spans an area of 146 km^2 and exhibits a distinctive urban pattern, architectural expressions, and sociocultural fabric. However, Beirut faces significant socioeconomic disparities, which have been further compounded by the financial collapse, the COVID-19 pandemic, and the devastating explosion. These crises have had adverse effects on economic activity and the livelihoods of individuals. Poverty levels in Lebanon have rapidly escalated, with over 55 percent of the population estimated to be trapped in poverty in 2020 (ESCWA, 2020). The current situation is characterized by a decline in business activities, high unemployment rates, food insecurity, and increased poverty (UN-Habitat, 2021). Additionally, Beirut has grappled with decades of civil unrest, conflict, underinvestment, inadequate data management, uncontrolled urban growth, and governance challenges (UN-Habitat, 2021). According to (Salameh et al., 2016), The Lebanese civil war from 1975 to 1990 had a significant impact on building construction, with poor design provisions and a lack of material quality control. Many buildings in Beirut were initially designed to withstand only gravity loads and lacked consideration for lateral loads. Seismic standards were introduced in the 1990s but were not strictly enforced until 2013. Furthermore, the city is affected by issues such as building vacancies due to factors like affordability, real estate development, and ineffective urban planning policies.

On August 4, 2020, a massive explosion at the Beirut port resulted in the loss of more than 200 lives and over 6,500 injuries. The explosion rendered approximately 300,000 people homeless and impacted around 25,000 buildings, ranging from minor damage to complete collapse. The widespread destruction prompted national and international solidarity, but the coordination and management of the recovery process often proved ineffective. Conflicts arose among property owners, organizations, donors, and public authorities, leading to redundancies and duplications in the renovation efforts. The persistence of damaged buildings, even after almost three years since the explosion, underscores the significance and relevance of this research. This study focuses on four highly affected zones near the explosion's epicenter, encompassing approximately 300 buildings with diverse architectural and structural characteristics. The distance between the epicenter and the study area ranges from 500 m to 900 m (Figure 2-8).

2.4.2 Barriers facing Reconstruction Beirut port

Barriers and challenges vary across different contexts and are influenced by various factors such as social, economic, environmental, political, and historical aspects. Thus, a crucial step in developing a framework for smart post-disaster reconstruction in Beirut City is to identify its specific barriers and challenges. This paragraph outlines the barriers and challenges encountered in the post-explosion reconstruction of Beirut.

- **Governance and management**

Lack of state's institutional capacity and governance

The Beirut city profile report, conducted by (UN-Habitat, 2021) highlights the complex decision-making and governance landscape in Beirut, where no single authority holds overall responsibility. Beirut City consists of 31 municipalities, each operating within its designated administrative boundaries. However, these municipalities lack formal mechanisms to address the broader system in which they exist. This poses significant limitations to achieving unified governance and planning throughout the city, impeding the integration of central city areas and their surrounding suburbs. Consequently, it becomes challenging to provide adequate, reliable, equitable, and cost-efficient infrastructure, services, and access to markets in Beirut. While various issues such as traffic congestion, ineffective public transportation, housing shortages, water and electricity shortages, and insufficient solid waste management are prevalent, the municipalities do not collectively assess or discuss their shared needs and challenges, nor do they coordinate efforts to provide the necessary services and infrastructure. Furthermore, there is a lack of regional planning to effectively integrate urban areas with their surrounding regions.

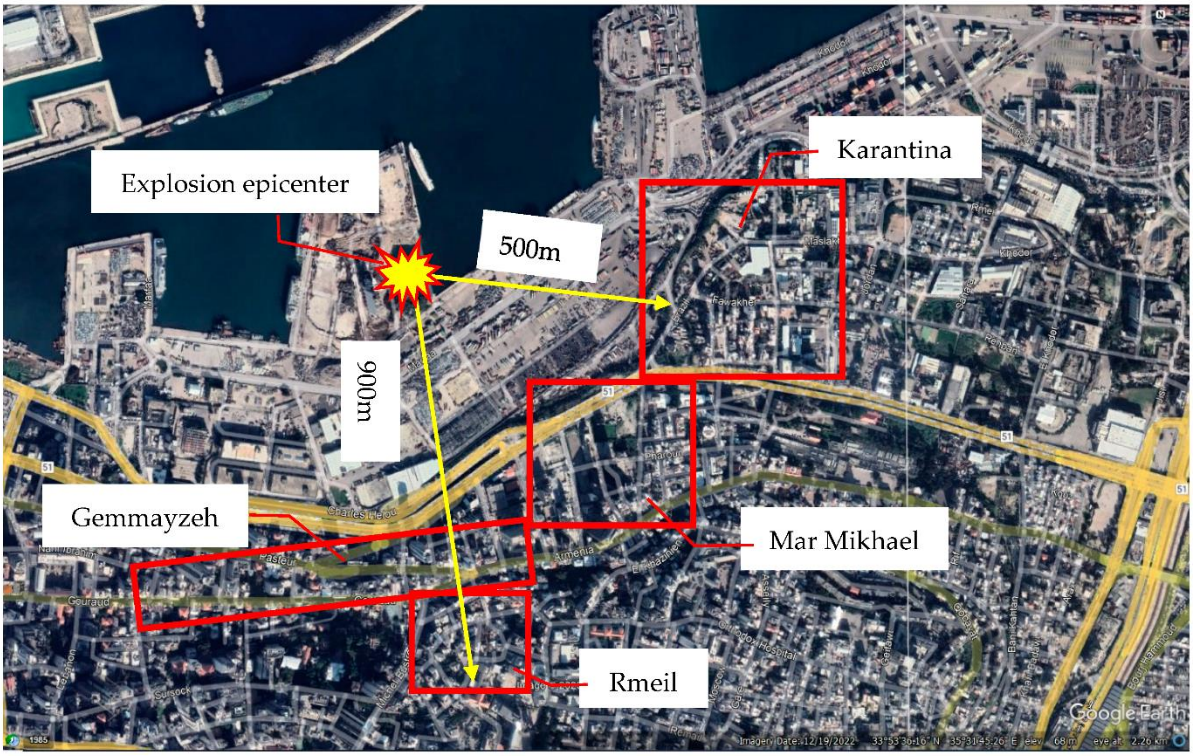


Figure 2-8. Studied zone in the damaged area.

Security threats and hostilities resumption

Lebanon, particularly Beirut, has experienced a series of political instabilities since 2019. The civil uprising that commenced on October 17, 2019, called for a complete overhaul of the political system, an end to sectarianism and corruption, and financial reforms. These demonstrations spread across the country, with Beirut, given its political, historical, and economic significance, serving as the focal point of the protests. The 4th of August port explosion further intensified the unrest, leading to a renewed wave of protests. As a result, two governments resigned within a span of less than a year, with the most recent resignation occurring on August 10, 2020, in the aftermath of the port explosion.

Corruption and lack of transparency among the local authorities

The control of corruption in Lebanon has experienced a decline, as indicated by the Worldwide Governance Indicators spanning from 2010 to 2020. This deterioration has adversely affected various sectors within the country, including the business environment, energy governance, and transportation systems. The presence of corruption has hindered the development and effectiveness of these sectors, impeding their ability to thrive and contribute to the overall growth and well-being of Lebanon (UN-Habitat, 2021).

Land use and land property issues

The absence of defined spatial boundaries that account for the expanding urban fabric presents a significant challenge to achieving unified city-wide governance and planning in Beirut. This limitation hampers the integration of central city areas with the growing suburbs (UN-Habitat, 2021). Furthermore, the utilization of micro-mobility modes such as walking, cycling, or scootering is severely constrained in Beirut. Despite journeys typically being shorter than 5km, several factors impede their viability, including a lack of pedestrian-friendly land use, insufficient sidewalks with random barriers that hinder accessibility, inadequate pedestrian crossings, minimal public and green spaces, and the absence of dedicated bicycle lanes or functioning bike-sharing systems (UN-Habitat, 2021). In her study about Beirut's public spaces, (Mady, 2022) emphasized how the war devastated public spaces and accentuated politico-sectarian divisions, resulting in the mobilization of representational spaces. The securitization of urban spaces further complicated matters, restricting perceived spaces for everyday activities and leading to contestations and exclusions.

Absence of coordination among stakeholders

The response to the blast in Beirut has involved a wide range of stakeholders, including the Lebanese central and decentralized governments, the United Nations, international and national non-governmental organizations, academic institutions, local and international volunteers, foreign governments, and religious groups. However, the involvement of numerous actors poses challenges in terms of coordination, particularly in conducting assessments, identifying needs, and implementing prioritized activities. This challenge is further compounded by the absence of a robust central government and limited capacity at the municipal level. As a result, response efforts have been concentrated in specific areas such as Geitawi, Mar Mikhael, Karantina, and Achrafieh, while other affected areas have received comparatively less attention (UN-Habitat, 2021).

Apart from the coordination and management challenges, a survey conducted by the World Bank on the perspectives of Beirut residents regarding the blast revealed a significant level of distrust among various stakeholders. Specifically, there was a lack of trust between citizens and the government, as well as political and religious organizations. However, the survey indicated that the Lebanese Red Cross and international organizations were viewed as the most trustworthy entities by the residents. This highlights the importance of rebuilding trust and fostering effective communication between stakeholders to ensure a more inclusive and successful post-disaster reconstruction process.

- **Social and economic**

The trauma of affected communities prevents them from coming back to normalcy

In a study focusing on mental health in Lebanon amidst the various crises, (Farran, 2021) raised a concerning alarm about a pervasive sense of despair that has engulfed millions of Lebanese individuals. She further emphasized that given the ongoing circumstances, the mass exodus of people, and the worsening economic situation, local efforts alone will be insufficient to effectively address the situation, promote well-being, and uphold the dignity and rights of the people. This highlights the urgent need for comprehensive and coordinated interventions that involve both local and international actors to provide adequate support and assistance to the affected population.

Weak and disrupted social networks

Lebanon, with its history of civil war and conflicts, faces significant threats to its already fragile social peace. The World Bank identified two key overarching constraints to development in Lebanon: elite capture disguised by confessionalism and conflicts and violence (Le Borgne &

Jacobs, 2016). The sociodemographic divisions that emerged during and after the civil war have contributed to the fragmentation of social ties among Beirut's diverse communities. The post-war reconstruction plan focused primarily on Downtown Beirut (Solidere), neglecting the rest of the city. This led to a two-track urban development pattern, with extensive real estate development in the downtown area and rapid, largely unplanned construction of affordable housing in the wider city area. These dynamics reinforced existing socioeconomic and sectarian divisions, resulting in patterns of segregation (UN-Habitat, 2021).

A survey conducted by the World Bank on the areas most affected by the blast in Beirut revealed socioeconomic divisions, with some areas more vulnerable than others. Therefore, policy and programming efforts must strike a balance between providing support to those who have suffered significant losses from the immediate crisis and addressing the existing deprivation (World Bank Group, European Union, et al., 2020). The UN Office for the Coordination of Humanitarian Affairs has published a map illustrating the socioeconomic vulnerability of operational zones in the central area of Beirut (Figure 2-9). Adding to the existing vulnerabilities and divisions, the current economic and financial crisis has led to a distressing surge in poverty. According to the World Bank, more than half of the population is likely below the national poverty line (World Bank Group, 2021).

The collapse of economic growth

According to the World Bank, the financial and economic crisis in Lebanon is considered one of the most severe episodes globally since the mid-nineteenth century. The country has experienced a significant contraction in real GDP growth, estimated at 20.3 percent in 2020, following a 6.7 percent contraction in 2019 (World Bank Group, 2021). The Lebanese Pound has also suffered a substantial depreciation, losing nearly 1730% of its value by the end of 2021.

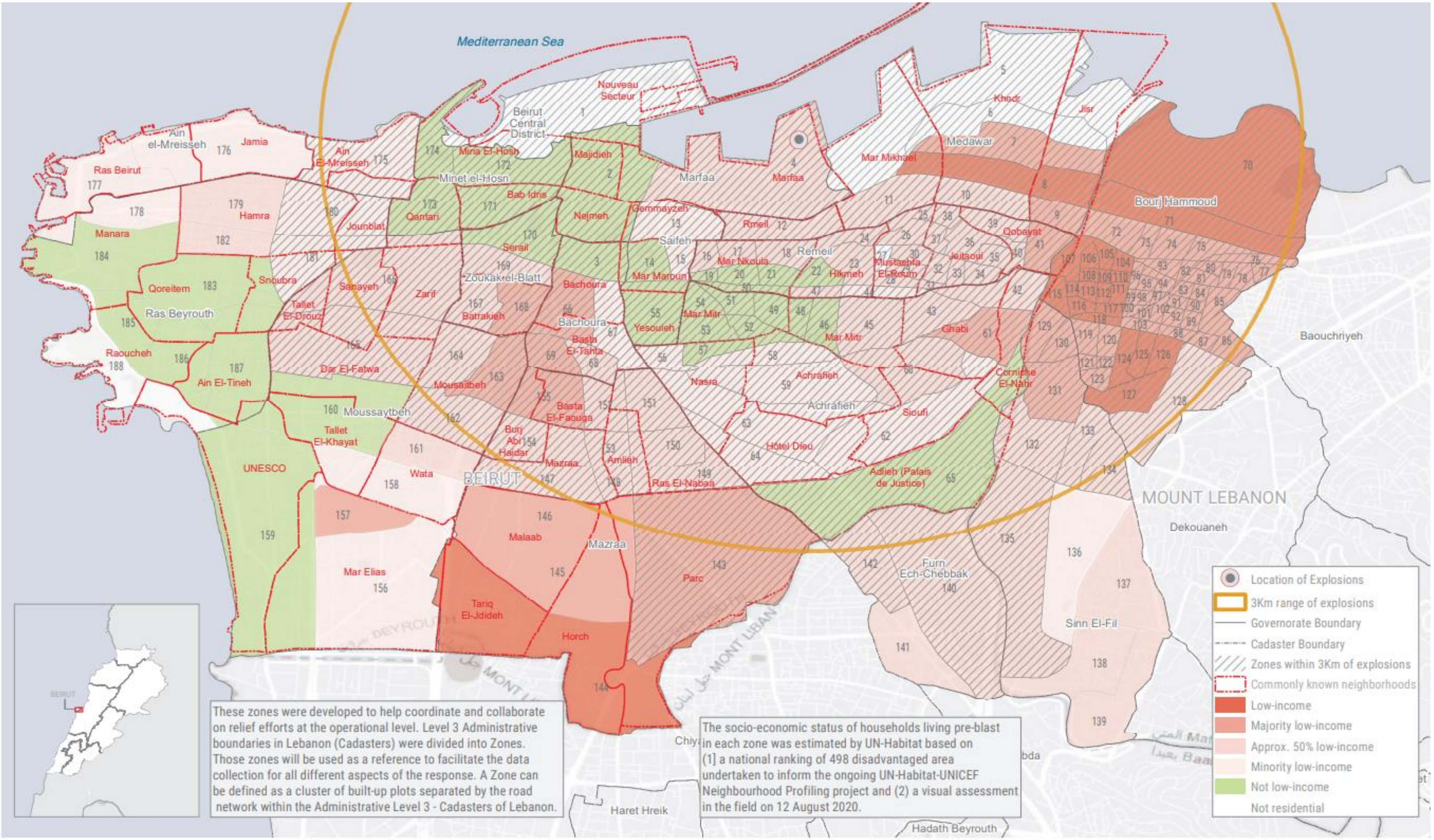


Figure 2-9. Socioeconomic vulnerability categorization of operational zones in Beirut's central area. Source: UNOCHA.

Inflation in Lebanon has had a disproportionate impact on the poor, vulnerable groups, and individuals with fixed incomes. Basic necessities, which constitute a significant portion of the consumption basket, have been the primary drivers of overall inflation. In 2020, inflation reached 145.8 percent, particularly exacerbated by the removal of subsidies (World Bank Group, 2021).

Lebanon's public debt has also reached alarming levels. In 2020, the country had the highest rate of public indebtedness in the MENA region and one of the highest globally (Bertelsmann Stiftung, 2020). These economic challenges further exacerbate the already complex and difficult situation faced by Lebanon, impacting the livelihoods and well-being of its population.

Loss of employment and livelihoods

According to a study conducted by (El Hage Sleiman, Sama Abdel Ahad, Maguy Chalhoub, 2021), the COVID-19 pandemic has had a significant impact on the employment and income levels in Lebanon. More than a third of the residents in the country have lost their jobs, and approximately 60 percent have experienced a decline in their income. In contrast, less than 10 percent of individuals reported an increase in their salaries.

The World Bank report supports these findings, highlighting the rise in unemployment rates in Lebanon. The unemployment rate increased from 28 percent in February (pre-COVID) to nearly 40 percent in November-December 2020 (World Bank Group, 2021). These statistics reflect the severe economic consequences of the pandemic on the labor market in Lebanon, leading to a loss of jobs and reduced incomes for a significant portion of the population.

- **Physical and technical**

Large pollution

The explosion in Beirut significantly damaged the environmental sector, particularly impacting infrastructure. The Solid Waste Recycling and Sorting Facility in Karantina was destroyed, while the Solid Waste Composting Facility in Coral, Bourj Hammoud, suffered partial damage. The healthcare waste storage facilities of three hospitals in Beirut were also affected. The estimated cost of the damages amounted to approximately US$ 20.0 - 25.0 million.

Weak environmental governance further compounded the environmental challenges in Beirut and Lebanon. The country has experienced various shocks caused by climate change, including heatwaves, droughts, storms, and flooding. The city of Beirut is particularly vulnerable to heat island effects, characterized by energy-inefficient buildings, a reduction in green spaces, and high asphalt density. These factors contribute to the intensification of heat within the city (Kaloustian & Diab, 2015).

Furthermore, the deterioration of groundwater in Beirut is a significant concern, with seawater intrusion posing a particular threat. A study conducted by (Saadeh & Wakim, 2017) highlighted the acute nature of this issue, indicating the pressing need for effective management and protection of groundwater resources in the city.

Lack of baseline data

According to the Beirut City profile report for 2021 by UN-Habitat (UN-Habitat, 2021), one of the major challenges in Beirut is the significant lack of accurate, reliable, up-to-date, multi-sectoral, and disaggregated urban data. This data deficiency hampers the ability to design evidence-based policies and plans for the city. The United Nations Country Team (UNCT) also acknowledges this issue, highlighting the limited availability of good-quality data as a barrier constraining effective decision-making and policy formulation in Beirut.

Low-quality design and implementation methods and projects

In Beirut, the protection and valuation of heritage buildings are not guaranteed, and they do not necessarily gain value from their status as heritage monuments (Dar Al. Handassah, 2020). This lack of protection increases the risk of gentrification and the potential for real estate developers to take over neighborhoods. The current regulatory frameworks for the heritage sector in Beirut also lack sufficient guidelines and incentives for preserving the city's heritage (World Bank Group, United Nations, et al., 2020).

The construction standards and codes in Beirut are outdated, with inadequate construction methods, quality, and practices. During the Lebanese civil war, building construction was affected by poor building code design provisions and a lack of material quality control. Most buildings in Beirut were designed to resist gravity loads only, with little consideration for lateral loads. Seismic provisions were introduced in building codes in the 1990s, but enforcement was not strict until 2013 (Salameh et al., 2016).

The housing sector in the severely affected area of Mar Mikhael was already facing challenges before the blast (Gerbal et al., 2016). These challenges included housing unaffordability, the risk of displacement of long-term residents, the impact of high-rise apartment buildings on neighborhoods, the dominance of private actors in public spaces, and the lack of influence by residents over public policies affecting their neighborhoods. After the blast, many businesses, apartments, stores, and restaurants have been depleted or closed. The relocation process has also resulted in residents choosing to leave the city, either temporarily or permanently, which can permanently alter the city's profile (Ibrahim, 2020).

Disruption of public service allocation and infrastructures

According to rapid damage and needs assessment conducted by the World Bank Group (World Bank Group, European Union, et al., 2020), the housing sector in Beirut suffered significant damage estimated at nearly US$ 1.9 - 2.3 billion, affecting approximately 351,000 residents. Among the assessed housing units, 8 percent were destroyed, 15 percent were partially damaged, and 28 percent sustained minimal damage. Commercial and industrial facilities, including businesses, were heavily affected, with around 56 percent experiencing damage.

In the infrastructure sector, which includes energy, water, transport, and municipal services, the preliminary damage assessment was estimated to be between US$ 390 - 475 million, with losses ranging from US$ 710 - 875 million. The energy sector alone incurred damages of approximately US$ 40.0 - 50.0 million, with a net estimated financial loss of US$ 55.0 - 70.0 million. Before the blast, the energy sector faced challenges, such as long blackouts due to the shortage of foreign currency. The water supply and sanitation facilities in Greater Beirut and

Beirut were also impacted, although they continued to function to some extent. This sector's initial estimate of damage is between US$ 40.0 - 45.0 million.

The blast had a severe impact on medical supplies, exacerbating the existing shortage and putting additional strain on healthcare providers. Out of the 16 hospitals in Beirut, Rosaire, Karantina, Wardieh, and Saint George hospitals were forced to close due to severe damage. Geitawi and Rizk hospitals sustained damage but remained operational. The estimated cost of damages to hospital buildings is in the range of US$ 95 - 115 million. Overall losses in the health sector were estimated to be between US$ 200 - 245 million.

2.5 Conclusion

This chapter provides a comprehensive outline of the research methodology employed in devising a smart framework for post-disaster reconstruction. It begins by introducing the overall methodology and subsequently delves into the sequential phases.

The initial phase presents a thorough examination of the local context, including its unique characteristics, and identification of the barriers challenging the reconstruction process. Through a systematic literature review, prevalent barriers and challenges in post-disaster reconstruction are identified and categorized into three main groups: governance and management, social and economic, and physical and technical aspects. The second phase outlines the data flow of the framework, starting from identifying the data needed, the data sources and collection, the data analysis methods, and the results. The last phase is the development of the framework, which constitutes the core of this research.

The last part of the chapter identifies the barriers in Beirut following the port explosion disaster, focusing on the pre-disaster scenario and the exacerbating crises and difficulties within the aforementioned categories post-explosion.

The innovation of this methodology lies in its consideration of the local post-disaster situation across various dimensions such as social, economic, and political factors. Rather than imposing standardized international or external post-disaster reconstruction frameworks, which often overlook local nuances and obstacles, this approach advocates for the development of specific post-disaster reconstruction frameworks tailored to each country or city's unique circumstances. However, this methodology encounter some limitations:

- Complexity: cities are complex systems, composed of many interdependent and interacting sub-systems. Therefore, the multitude of factors influencing post-disaster reconstruction makes it challenging to enumerate comprehensively, as the interconnected nature of urban systems results in a vast array of variables that must be considered. And since time is a crucial attribute in the post-disaster reconstruction, the framework must integrate a limited number of factors to avoid the diversion of the method. The next chapter will develop the methodology to overcome this limitation.
- Dynamics: Urban systems exhibit dynamic characteristics, constantly evolving over time. Hence, factors deemed relevant at one point may lose significance later, while previously overlooked factors could gain prominence following an event or urban transformation. To address this challenge, it is imperative to periodically review and update the framework to accommodate the perpetual changes in the urban environment.

The forthcoming chapter will introduce a comprehensive framework designed for smart post-disaster reconstruction, specifically tailored to address complex geopolitical situations. The framework's is developed to examine various barriers, which serve as the foundation for its establishment. The main objective is to construct the framework in such a manner that its implementation effectively overcomes these identified barriers. While the post-disaster reconstruction englobes all the systems of the urban space, the framework will focus on the buildings reconstruction and renovation sector. The application of this framework to the case of Beirut will be discussed in Chapter 4, providing a practical illustration of its implementation and effectiveness.

3 Smart post-disaster reconstruction framework

3.1 Introduction

This chapter introduces an innovative framework for smart post-disaster reconstruction, adaptable to diverse contexts, even those influenced by complex geopolitical factors. It serves as a valuable tool for decision-makers, helping them in the monitoring and management of reconstruction projects during the critical aftermath of any disaster. The framework is designed to incorporate the unique characteristics of each context, with the goal of fostering an inclusive, participatory, and intelligent recovery process.

The first section of the chapter outlines the core objectives of the framework, which revolve around three main pillars: governance, management, and planning. Governance encompasses the decision-making processes from overarching country or city reconstruction strategies to individual recovery projects across various sectors. Effective governance is paramount for successful recovery efforts, as poor governance can exacerbate already complex situations. Hence, the primary aim of the framework is to enhance decision-making processes. The second objective pertains to the management of reconstruction projects, recognizing it as pivotal for the success of every project. Lastly, the framework seeks to outline the planning process comprehensively, spanning from the emergency phase to full recovery.

The second section of the chapter delves into the framework's application within the realm of building reconstruction, introducing the Physical Priority Index (PPI) and Socio-Economic Priority Index (SEPI). These indices consist of multiple indicators identified through a systematic literature review. Additionally, this section outlines the SWARA tool, utilized for determining the weights of each indicator and subsequently calculating the PPI and SEPI.

In the final section, the chapter applies the framework to the case of Beirut on the reconstruction of buildings following the Port explosion. A questionnaire is addressed to a panel of local experts across various relevant fields, such as civil engineering, architecture, urban planning, humanitarian aid, and disaster management. After determining the weights of the indicators through expert input, the methodology for calculating the PPI and SEPI for each building is presented.

3.2 Objectives of the Smart post-disaster reconstruction framework

As outlined in Chapter I, the smart post-disaster reconstruction framework centers on three core pillars: governance, management, and planning (Figure 3-1). Consequently, the framework aims to enhance decision-making processes, streamline the coordination of reconstruction projects, and optimize planning strategies. Before delving into the specifics of each component, it is crucial to establish connections between them, delineating their boundaries, attributes, and the roles assumed by various stakeholders. The efficacy and success of smart post-disaster reconstruction hinge on the collaboration between governing bodies and management teams.

This paragraph elaborates on the objectives of the framework by incorporating novel concepts for each, aimed at addressing existing gaps in existing frameworks. Before delving into the specifics of each objective, the roadmap of the post-disaster reconstruction process is outlined, with a focus on distinguishing between governance and management structures, as well as identifying relevant stakeholders.

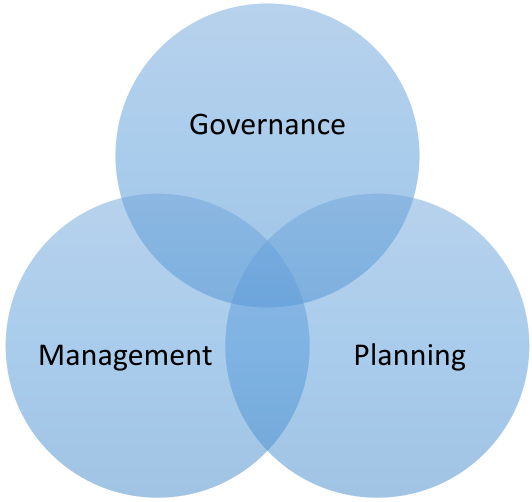


Figure 3-1. The three pillars of post-disaster reconstruction process. Source: Author.

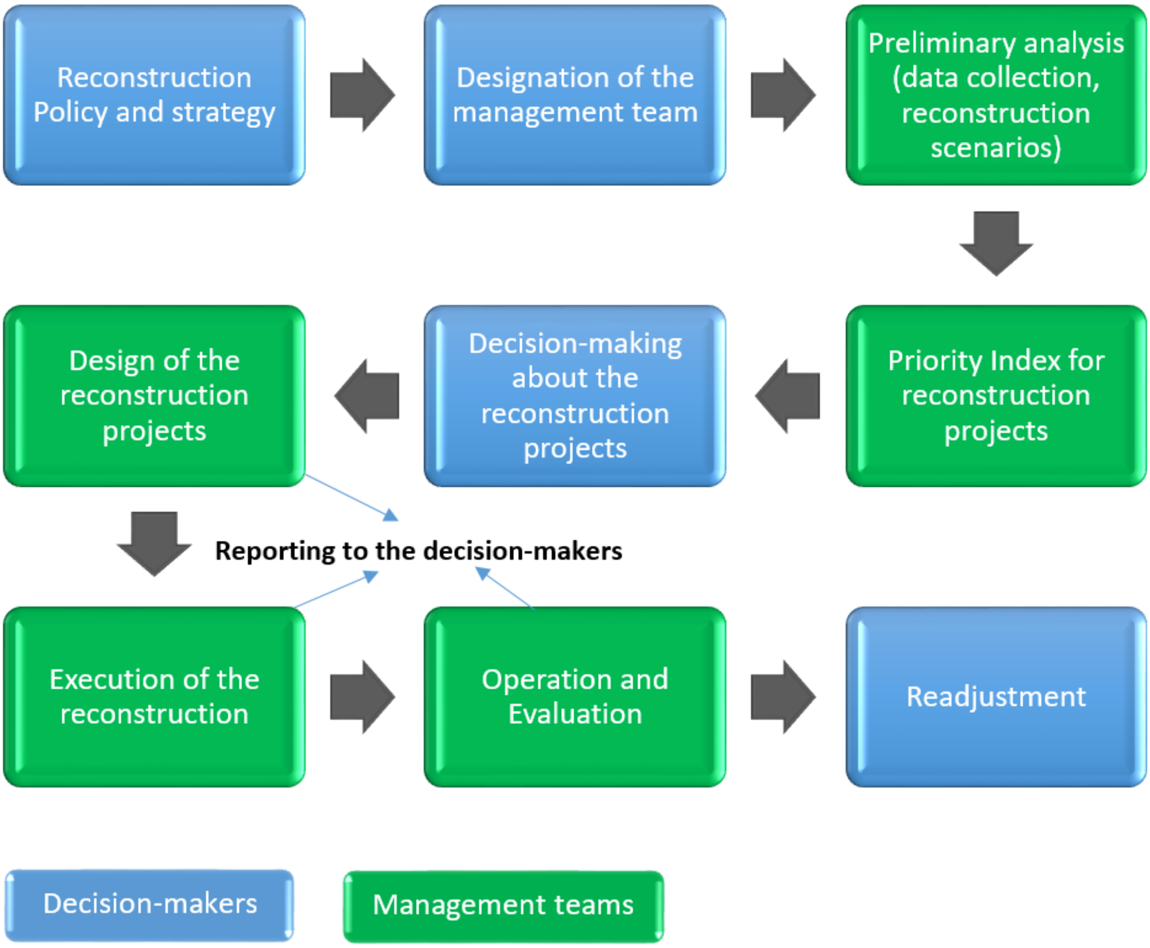


Figure 3-2. Smart post-conflict reconstruction framework. Source: Author.

Figure 3-2 represents all the phases of a post-disaster reconstruction. Governing body and management teams are distinguished by their roles.

- The process starts with the elaboration by the governing body of the reconstruction general policy and strategy.

- Subsequently, the designated management team starts with data collection about the reconstruction area. This data is then subjected to analysis to derive potential reconstruction scenarios. The outcomes of this phase are presented as Priority Indexes, tailored to the specific contextual nuances.
- Using these Priority Indexes as a reference, the governing body monitors and manages the reconstruction projects using the available resources and capabilities.
- The management team carries out the directives of the governing body through the project stages: design, construction, operation, and evaluation.
- At each phase of the project execution, the management team keeps reporting data to the governing body in accordance with predefined performance indicators.
- Based on the project evaluation, the governing body assesses the disparities between the project's accomplishments and objectives, making informed decisions regarding any necessary adjustments or updates to the strategy, resource allocation, and agenda.

With roles and responsibilities clearly defined among stakeholders, this work aims to enhance the decision-making process to ensure that the management and planning of reconstruction projects achieve the desired outcomes of the recovery process effectively and successfully. The subsequent sections will develop the concepts of smart governance and management within the proposed post-disaster reconstruction, as well as the smart planning.

3.2.1 Smart governance

Governance represents the first pillar of post-disaster reconstruction. The first challenge for decision-makers is to mitigate the disorder, build a climate of trust, and transform the hostile environment into a cooperative and inclusive one. The national authority has the legitimacy to coordinate the governing body in collaboration with local authorities and international institutions. When a legitimate national authority is absent, coordinating the governing body can be delegated to a body appointed through consensus among communities and international institutions. It's important to note that identifying a legitimate public authority for post-disaster reconstruction falls beyond the scope of this research. Therefore, we assume the presence of a legitimate governing body with the capacity to make decisions regarding recovery projects.

As discussed in Chapter 1, the governance system should include all the stakeholders involved in the reconstruction process, particularly the affected community, given that the recovery is human-centered at first. Additionally, decision-making should be data-based and transparent to prevent corruption and favoritism. Integrating smart technologies and digital tools enhances decision-making and saves time, which is critical in post-disaster recovery. The strategy should align with community expectations and adhere to criteria related to social and economic issues, as well as environmental preservation.

Smart governance could benefit from recent findings of scholars on the use of smart technology as a support for governance. For instance, (Chatwin & Arku, 2019) proposed two methods for smart public participation in decision-making: (i) civic tech groups that combine governmental information with the community's needs and seek technology-based solutions, and (ii) innovation lab, which uses design thinking methods including immersion, observation, investigations, interviews, prototyping, and experimentations to address the social and economic needs of the population. (Souza & Bueno, 2022) used City Information Modelling (CIM) to support decision-making in urban planning. They showed that using CIM improves decision-making, accessibility to information, interaction among stakeholders, public assessment, and implementation of sustainability. (Parenti et al., 2022) used the blockchain to develop as a mitigator of vulnerabilities to corruption. (Weingärtner et al., 2021) used the blockchain in public procurement to reduce corruption. (Abodei et al., 2019) proposed a collaborative network based on blockchain technology to engage the public in identifying the most critical needs, gain trust and commitment, and share the responsibility of construction project delivery. (Basu et al., 2016) proposed a post-disaster situation awareness and decision support framework during the emergency phase through interactive crowdsourcing.

Smart governance includes a clear identification of the stakeholders involved in PDR decision-making, in addition to their roles and responsibilities:

- The national authority englobes the national government and ministries, along with the security forces such as the national army, police, and the judiciary corpus. They are responsible for applying the law, security, cooperation with international organizations for peacekeeping and financial aid allocation, elaborating a national reconstruction policy and regulations, and adapting buildings and construction codes and standards.
- The next level is the local authorities, such as the municipalities, district councils, and mayors. They are responsible for approving or denying reconstruction and renovation permits, land use and land property management and conflict resolution, and decision-making regarding large public infrastructures.
- International institutions, such as the World Bank and the United Nations, and foreign donors. They can greatly influence the reconstruction process and a political agenda.
- The international and local NGOs play a crucial role in the PDR process when the national and local authorities lack a good governance system and the trust of the external donors, suffer from corruption, and do not possess the required resources for reconstruction. It is important to mention that international or local NGOs can have hidden political and/or external agendas that can influence the PDR process. But we will assume that their role covers assistance for the affected communities in different fields (housing renovation or reconstruction, medical equipment procurement, education fees assistance, psychological and mental health help, marginalized communities' protection and empowerment…).
- The economic actors are also important stakeholders in PDR decision-making. They include construction companies, service providers, and industrials who create and manage a productive economic sector.
- The affected community should also be involved in the decision-making, since reconstruction projects concern mainly this community.

3.2.2 Smart management

The management also plays a determinant role in post-disaster reconstruction because it concerns the efficiency and safety of the reconstruction process throughout the project's life cycle, including planning, design, construction, operation, and evaluation. Each stage of the reconstruction process requires input data and generates new data. Smart management should ensure the safe transmission of data throughout the reconstruction process. This issue is very important because the transition between reconstruction stages could result in an important change in operators and, consequently a high risk of data losses.

Smart management consists of integrating the latest developments in the field of sustainable, resilient, and smart cities. It allows the improvement of the efficiency and the safety of constructions and organizations through the deployment of IT tools for the management and latest developments in smart infrastructures such as smart grid, smart water, smart mobility, smart municipal waste, and smart public lighting.

Scholars have integrated smart technologies into the management of post-disaster reconstruction and construction projects. For instance, (Assem et al., 2020) used GIS, BIM, and web-based platforms for the management of post-conflict cities reconstruction. (Sander & Souza, 2023) conducted a systematic literature review on emergent technologies and skills required for Construction 4.0, from AI-assisted technologies, Advanced manufacture, Smart tools, Digital simulation/Visualization, and Data acquisition/detection. (Gao et al., 2023) developed a model to improve the sustainability of smart cities from a design perspective, by combining concepts of sustainable design with the Internet of Things and ecosystems, using the CIM platform. They analyzed six elements (human, environment, society, economy, and culture) and four dimensions (space, resources, management, and platform) to constitute a sustainable design system for smart cities and construct a system model based on this analysis (See Figure 3-3).

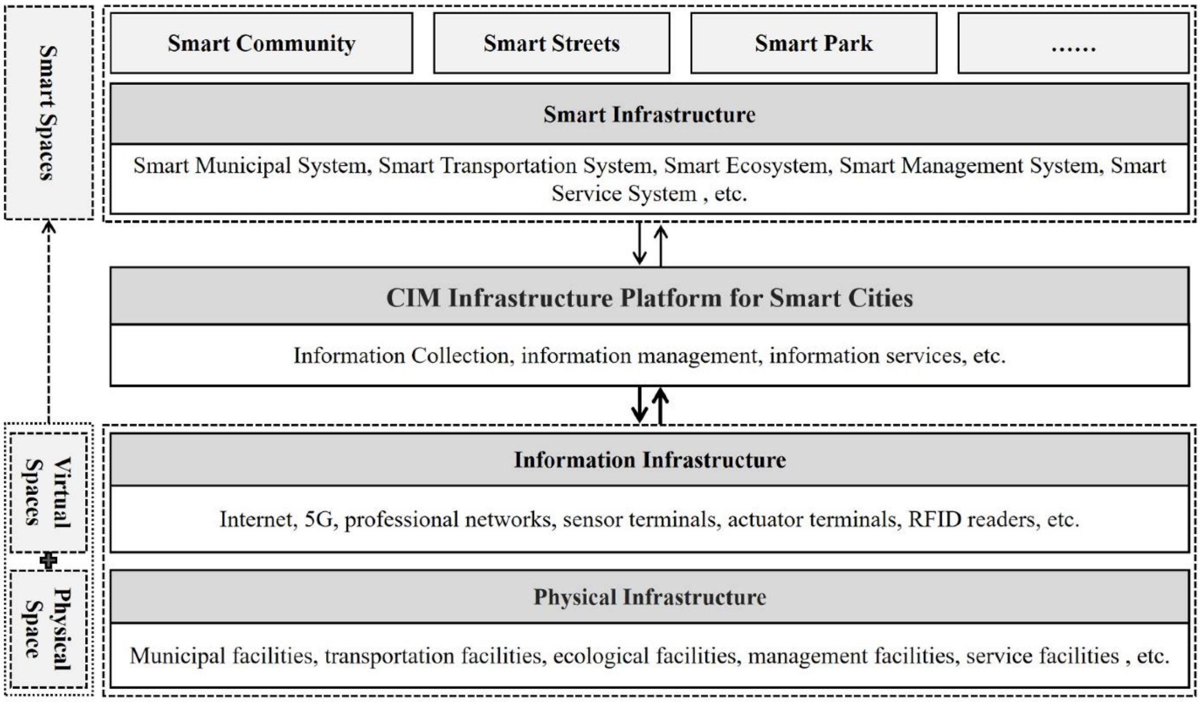


Figure 3-3. Spatial planning model of smart city's sustainability design based on CIM; Source: Gao et al., 2023

Smart management includes stakeholders in charge of executing the reconstruction projects according to the strategy of the governing body. They include:

- The project manager is responsible for delivering the project according to the business objectives.
- The professional teams are responsible for the design of the projects, producing design alternatives, drawings, computation, and specifications while respecting the building codes and standards, in addition to on-site periodic inspection, preparing the budget, schedule, and cost estimate. They can influence the architectural and technical design but should achieve the client's perspectives.

- The contractors are responsible for the performance of all work according to the contract documents prepared by the designer, the preparation of an accurate estimate of the project, a realistic reconstruction project, and the establishment of an effective project control system for cost, schedule, and quality. They can have a high influence on the project along with the client. The main contractor hires the sub-contractors to undertake work areas according to their expertise. The quality of their work impacts the project execution.
- The suppliers provide the required material and equipment for the project execution, the quality and the delivery to the project's site impact the project.

The management of the reconstruction process includes five stages: planning, design, construction, operation, and evaluation. The planning phase is particularly important in the post-disaster reconstruction process because it follows a period of chaos and figures out the features, guidelines, specifications, resources, and agenda of the reconstruction process.

3.2.3 Smart planning

Planning in post-disaster reconstruction includes two phases. The first phase is related to preliminary analysis, which aims to collect and analyze data to establish scenarios for the reconstruction process. The governing body then analyzes these scenarios to select the most appropriate one with an agenda and attributed resources. This scenario constitutes the roadmap for post-disaster reconstruction. The second phase consists of transforming the road map in the planning of the reconstruction project, including guidelines, components, requirements for each component, and the agenda.

The following sections will discuss these two phases in more detail.

- *Preliminary analysis*

Since the output of this phase has a major impact on the totality of the reconstruction process, it should be conducted comprehensively and inclusively. This phase starts by collecting data and information to understand the local context, communities' expectations, legal issues related to the reconstruction area, national and local guidelines, and international institutions and donor recommendations.

The data should be collected during four phases: before the disaster, during the emergency phase, at the start of the recovery phase, and for the future of the reconstruction area.

1) Data before the disaster helps understand the local context and should be considered a starting point in the disaster management framework. It should cover the different components of the reconstruction territory, such as demography, social patterns, economic activity, urban planning, land and construction properties, infrastructures, and services to citizens. Collected data should be integrated into a GIS system to facilitate and secure data processing, sharing, conservation, and analysis operations.
2) Data during the emergency phase concerns damages to communities' infrastructures, and their impact on population displacement, education, health, properties, and emotions. This phase is important because disasters result in social and economic disturbances and large physical damage to buildings and infrastructures that could disturb the reconstruction process.
3) Data at the beginning of the recovery process is required to establish a diagnosis of the context and situation of the reconstruction area and to figure out the amplitude and

priorities of the reconstruction process. It should cover many issues such as social, economic, environmental, infrastructures, and services related to water, energy, housing, transport, telecommunication, education, health, and culture. These data should also be integrated into the reconstruction GIS system.

4) Data related to the future contains two categories of data. The first category is related to the stakeholders' expectations. It is collected through questionnaires, meetings, and analysis of administrative documents, regulations, and treaties. The second category concerns predicting changes in demography, social fabric, economic activity, and climate. It is necessary to integrate future changes in the reconstruction process.

- *Planning*

This phase refers to planning the reconstruction scenario decided by the governing body. It establishes guidelines, requirements, specifications, and agenda for the design of each component of the reconstruction project. It starts with a presentation of the selected scenario to the stakeholders of the reconstruction project, including an overview of the project, its components, resources, and agenda. The presentation should also include options and margins for the reconstruction project. This presentation serves as a basis for a dialogue with the stakeholders for additional precisions about their needs and to explore the best way to integrate them into the project planning. The planning phase also requires additional investigations for the design phase, such as an advanced diagnostic of infrastructures and constructions and a geotechnical and environmental exploration of soils concerned by the reconstruction.

The guidelines should provide sustainability requirements emphasizing materials recycling, use of local materials, protection of heritage constructions and sites, protection of water resources and soils, and eco-construction. They should also provide requirements about friendly urban planning and the use of smart technology to improve the efficiency and safety of infrastructures and services by integrating smart technology, in particular smart mobility, smart grid, smart water, smart municipal waste, smart building, and smart agriculture.

The planning establishes requirements for using smart technology in the operating phase, emphasizing monitoring infrastructures, constructions, mobility, water supply and sanitation, energy supply, renewable energy production, municipal waste collection and treatment, air quality, and socio-economic activities. It should provide specifications about data processing, data analysis, and data sharing with stakeholders for transparency, as well as optimal and safe management of the reconstruction process.

Use of smart technology

The use of smart technology will help in coordinating operations related to data collection, data processing, data analysis, data sharing, and the transformation of data into services. It inquires using digital tools and techniques such as ArcGIS, BIM, LiDAR, smartphones and applications, etc. It also implies making these technologies accessible not only to experts but also to all stakeholders. However, as discussed in the barriers study (Chapter II), digital tools and resources could be limited and expensive in complex geopolitical contexts. This means that choosing the right tools can be a challenging task.

To identify the major data sources and their uses in disaster management, (Sarker et al., 2020; Yu et al., 2018) conducted a systematic literature review on the subject. The findings are summarized in Table 3-1.

Table 3-1. List of data sources and their uses (Source: Sarker et al., 2020; Yu et al., 2018)

Data source	***Uses***
Satellite Imagery	*Land use system, water bodies, damage detection*
Aerial imagery and videos	*Unnamed aerial vehicles Spatial resolution of image Various sensors such as camera, infrared, ultra-violet, radiation, and weather sensors*
Wireless sensor web network	*Increase response time, reduce the latency Effective communication*
Light Detection and Ranging (LiDAR)	*Exact ground condition, Detect structural damages*
Simulation data	*Effective prediction of emergency actions*
Spatial data	*Geographic information system (GIS) Vulnerability assessment and prediction*
Crowdsourcing	*Online platform Real-time data Involves many stakeholders*
Social Media	*Multi-dimensional communication tool Real-time data Supports all phases of disaster management*
Mobile GPS and call record	*Emergency and rescue operations*

Data collection poses several challenges, including privacy and security concerns, issues of accuracy and reliability, and the need for coordination among stakeholders. The proposed method for data systems must address these challenges and strive to overcome them. Data privacy and security should be ensured against cyberattacks or unauthorized alterations, especially that it may contain sensitive information about community members. The accuracy and reliability of the data hinge on the chosen data collection methods, necessitating a robust verification process once methods are selected.

Furthermore, maximizing the utility of the collected data and disseminating it to all involved stakeholders is crucial for enhancing coordination and progress, and preventing conflicts or project recurrences.

3.3 Priority Index

3.3.1 Introduction

Our proposed framework for post-disaster reconstruction focused specifically on the buildings sector, despite the comprehensive nature of such recovery efforts that typically encompass all facets of a city, including infrastructure, transportation, environment, economic activity, and social bonds. The decision to concentrate on the buildings sector was motivated by several key considerations:

- Central Role of Buildings: Buildings are pivotal in shaping human existence, serving as the physical spaces for living, working, learning, and seeking refuge.
- Multifunctional Nature: All human activities in cities, such as home life, economic activities, education, governance, public services, healthcare, and cultural and social interactions, are encompassed within buildings.

- Essential Role of Residential Buildings: Residential buildings are integral to individuals' lives, providing a sense of belonging, comfort, security, and stability. Prioritizing their reconstruction is crucial for restoring the livelihoods of affected individuals.
- Symbolic Significance: In the aftermath of a disaster, the urgent need to reconstruct buildings is emphasized, as they symbolize shelter, resilience, and continuity, as well as restoration of damaged livelihoods.
- Community Stability: Swift reconstruction is vital for restoring normalcy and stability to communities facing upheaval.
- Custodians of Memories: Beyond shelter, buildings house the collective memories, histories, and aspirations of societies, representing tangible expressions of human progress and innovation.
- Identity and Rebuilding Lives: Reconstruction, particularly of buildings, is not merely construction but an essential component of rebuilding lives, fostering a renewed sense of identity, and laying the foundation for a hopeful future.

Given the aforementioned reasons, the post-disaster reconstruction framework is specifically tailored for the buildings reconstruction sector, and a Priority Index is formulated for assessing buildings, aiming to:

- Improve the decision-making process for the post-disaster reconstruction phase.
- Coordinate the activities of the management team.
- Prioritize the most vulnerable communities.
- Establish a rapid situational awareness.
- Involve the affected community and all the stakeholders.
- Integrate a bottom-up approach for post-disaster recovery.

The next paragraphs will detail the development of this Index and its application to the Beirut port disaster.

3.3.2 Scales of indicators

Buildings are typically designed to accommodate numerous individuals who may not necessarily have familial or acquaintance ties. As a result, it is common for buildings to contain multiple units. This arrangement entails shared or common spaces for residents, communal areas for the entire building, and individual unit spaces for residents. Additionally, a single building may have multiple owners, or alternatively, one owner with multiple residents or renters. This implies that the decision-making includes three levels: the overall building level, the shared or common space level, and the personal unit level, as detailed below:

- The overall building level concerns the entire building, such as the exterior facade and demolition and reconstruction of the building. The intervention at this level concerns the owners and residents as well as national and local officials and donors.
- The shared space level includes shared spaces such as elevators and stairs. It also requires the participation and coordination of different stakeholders such as owners and residents. These two levels reveal the necessity of having a building committee for decision-making and managing the reconstruction process.
- The personal unit level concerns mainly the owner and the occupant. The owner is responsible for the renovation process

3.3.3 List of indicators based on experts' opinion

The first list of indicators was proposed to 33 experts in Lebanon. Then it was updated and reduced to 12 indicators, classified into two categories: buildings' physical characteristics and socio-economic indicators. The final list of indicators is presented in Table 3-2.

Table 3-2. List of indicators for the Priority Index PI (Source: Author)

Scales of Indicators	Physical Characteristics	Socio-Economic Profile
Building Scale	Building Type	Occupancy ratio before and after the disaster
	Damage Level	Estimated Rehabilitation Costs
	Cultural Heritage	
Shared Space Scale		Capacity of the owners to afford renovation costs
		Estimated rehabilitation costs
		Funding support
Personal Unit Scale (For N Units)		Estimated rehabilitation costs
		Capacity of households to afford renovation costs
		Presence of temporary shelter
		Funding support

The indicators are classified into two categories:

1) Physical Characteristics Indicators

The physical indicators encompass the architectural and structural features, including:

- The building's purpose and characteristics,
- The level of damage.

These factors help decision-makers identify the most affected and damaged areas, as well as the building profiles, which are necessary for estimating the cost of renovation or reconstruction.

The building type or destination covers different uses such as residential, industrial, commercial, public institution, cultural or social, health, education, or mixed-use.

The damage level has a huge impact on the reconstruction project, from the renovation techniques to the material required, the labor, and the costs (Bahmani & Zhang, 2021; Yilmaz et al., 2013).

The third indicator concerns cultural heritage (Kylili et al., 2016). As mentioned before, Beirut has a rich cultural heritage. Buildings considered cultural heritage are subjected to specific requirements.

The damage level scale ranges from 1 to 4:

- Level 1: no damage
- Level 2: non-structural damage
- Level 3: between 25% and 50% of the building damaged
- Level 4: more than 50% of the building damaged

This assessment could be performed visually, via a crowdsourcing survey form for example, or any other available data source. Images and videos could also be used in the process. Since this data collection method involves citizens in the assessment, the questions was assigned were basic, so that they could be answered by non-experts.

2) Socio-economic indicators

This research focused on the following socioeconomic indicators:

- Buildings' occupancy
- Renovation costs, owners' capacity, and availability of aids
- Existence of temporary shelters

This set of indicators aims to identify the most vulnerable groups that require additional assistance, allowing for an equitable aid allocation.

Recovery efforts and reconstruction projects are designed to restore livelihoods and improve the well-being of affected communities. Therefore, it is important to track the displacement of the affected citizens to coordinate their return or relocation. To consider this issue, the framework uses the occupancy ratio before and after the disaster (Bahmani & Zhang, 2021). Additionally, the renovation cost is an important issue for the post-disaster reconstruction process (Kylili et al., 2016).

At the shared space and personal unit levels, additional indicators are used to measure owners' capacity to afford rehabilitation costs (Bahmani & Zhang, 2021; Kammouh & Cimellaro, 2018; Yilmaz et al., 2013) and funding compensation (Bahmani & Zhang, 2021; Kammouh & Cimellaro, 2018; Yilmaz et al., 2013). The significant socio-economic inequalities in Beirut should be considered by decision-makers. The affected community can receive aid from public authorities, insurance companies, national and international NGOs, or other organisms. However, the recovery process should follow the principle of "Leaving no one behind"; therefore, the aid allocation program must consider funding received by the community. These indicators target the SDG10 "Reduced Inequalities", and along with the other indicators, establish an understanding of the socio-economic issues and vulnerabilities.

For personal units, the availability of temporary shelters must also be considered (Bahmani & Zhang, 2021; Kammouh & Cimellaro, 2018; Yilmaz et al., 2013). Although the strong family ties in Lebanon helped to provide shelter for the displaced citizens after the disaster, a lot of affected people suffered from a lack of temporary shelter.

The capacity to afford the rehabilitation costs is measured using the Likert scale:

- 1: All the costs can be covered
- 2: The majority of the costs covered
- 3: Half covered/Half not covered
- 4: Majority not covered
- 5: Cannot cover any cost

Table 3-3 describes each indicator with the method of calculation and the corresponding unit.

3.3.4 SWARA method for a weighting system

The SWARA method is used for ranking and weighting the indicators. This method was preferred to the AHP method because the AHP requires n(n − 1)/2 pairwise criteria comparisons, which becomes practicality unfeasible to perform such huge consistent pairwise comparisons (Zolfani & Chatterjee, 2019). The SWARA method consists of the following steps:

1- The indicators are sorted in descending order based on their score, which is the sum of the weights attributed to the indicator by each expert.
2- Starting with the second indicator, the relative importance of indicator j with respect to the previous criterion (j-1) for each specific criterion, is a ratio called the comparative importance of average value, s_j as follows:

$$s_j = \frac{s_j - s_{j-1}}{100} \tag{1}$$

3- Determination of the coefficient k_j as follows:

$$k_j = \begin{cases} 1, j = 1 \\ s_j + 1, j > 1 \end{cases} \tag{2}$$

4- Determination of the recalculated weight q_j as follows:

$$q_j = \begin{cases} 1, j = 1 \\ (k_{j-1})/k_j \, , j > 1 \end{cases} \tag{3}$$

5- The relative weights of the evaluation criteria are determined as follows:

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k} \tag{4}$$

w_j indicates the relative weight of the j^{th} indicator, while n shows the number of indicators.

Table 3-3. Description of the indicators for the PPI and SEPI.

Indicator	Description	Units
Physical Characteristics of the Building		
Building Type	Residential, healthcare, education, industrial, commercial, public institution or governmental, cultural or social, or mixed-use	NaN
Damage level	1-Total collapse: more than 50% of the building damaged; 2-Major damage: between 25% and 50% of the building damaged; 3-Minor damage: only non-structural damage; 4-No damage	NaN
Cultural Heritage	Is the building considered a cultural heritage or no?	YES/NO
Socio-Economic Profile of the Residents		
Occupancy ratio before and after the disaster	(Number of occupied units/Number of total units) x 100 calculated before and after the disaster	Percentage
Building's Estimated rehabilitation costs	Estimation of the rehabilitation costs	$
Capacity of owners to afford shared space renovation costs	1-All the costs can be covered; 2-Majority of the costs covered; 3-Half covered/Half not covered; 4-Majority not covered; 5-Cannot cover any cost	NaN
Shared space Estimated rehabilitation costs	Estimation of the shared space rehabilitation costs	$
Compensation from funding for the shared space	Percentage of not funded shared space renovation costs	Percentage
Capacity of households to afford their personal unit renovation costs	1-All the costs can be covered; 2-Majority of the costs covered; 3-Half covered/Half not covered; 4-Majority not covered; 5-Cannot cover any cost	NaN
Personal Unit Estimated rehabilitation costs	Estimation of the unit rehabilitation costs	$
Presence of temporary shelter	Do the households have a temporary shelter that is near their principal house?	YES/NO
Compensation from funding for the personal unit	Percentage of not funded personal unit renovation costs	Percentage

3.3.5 Calculation of the Physical and Socio-Economic Priority Indices

Numerical values were assigned to qualitative indicators for the determination of the Priority Index.

A high score was assigned to critical buildings such as hospitals, residential, and mixed-use buildings, while low scores were assigned for less critical buildings as detailed below.

- Healthcare Center: 5
- Residential and mixed-use Commercial/Residential, Education Center, Public Institution: 4
- Commercial and Industrial: 3
- Cultural and Social: 2
- Not occupied or No data: 1

The cultural heritage status is a YES/NO question, so it needs to be quantified. The state of being a cultural heritage building is more prioritized in reconstruction projects because there is a crucial need to save the cultural aspect of the damaged city and prevent these buildings from demolition and real estate interests. Therefore, the cultural heritage status is given a score of 1, while a score of 0 is assigned to other buildings.

For the temporary shelter, affected residents with no temporary shelter should be prioritized in the reconstruction process. Therefore, a score of 1 was assigned for the absence of a temporary shelter and a score of 0 for others.

The Priority Index is composed of two components: Physical Priority Index (PPI) and Socio-Economic Priority Index (SEPI):

$$PPI = w_{BT} \times BT + w_{DL} \times DL + w_{CH} \times CH, \tag{5}$$

$$\begin{aligned} SEPI = w_{OR} \times OR + w_{BRC} \times BRC + w_{SOC} \times SOC + w_{SRC} \times SRC \\ + w_{SCF} \times SCF + w_{POC} \times POC + w_{PRC} \times PRC \\ + w_{PCF} \times PCF + w_{TS} \times TS, \end{aligned} \tag{6}$$

Abbreviations:

PI	Priority Index
PPI	Physical Priority Index
SEPI	Socio-Economic Priority Index
BT	Building Type
DL	Damage Level
CH	Cultural Heritage Status
OR	Occupancy Ratio
BRC	Building Renovation Costs
SOC	Shared Owners Capacity
SRC	Shared spaced Renovation Costs

SCF	Shared Space Compensation from Funding
POC	Personal Owner Capacity
PRC	Personal Unit Renovation Costs
PCF	Personal Unit Compensation from Funding
TS	Temporary Shelter Availability
w_{BT}	Weight of building type
w_{DL}	Weight of damage level
w_{CH}	Weight of cultural heritage
w_{OR}	Weight of occupancy ratio
w_{BRC}	Weight of building renovation costs
w_{SOC}	Weight of shared owners' capacity
w_{SRC}	Weight of shared space renovation costs
w_{SCF}	Weight of shared space compensation from funding
w_{POC}	Weight of personal owners' capacity
w_{PRC}	Weight of personal unit renovation costs
w_{PCF}	Weight of personal unit compensation from funding
w_{TS}	Weight of temporary shelter availability

It is important to mention that for each building, there can be many personal units. However, the priority index calculated is for the whole building. Therefore, the indicators related to personal units are obtained by calculating the mean of the personal units in the building.

The estimation of each indicator is conducted as follows:

- The survey had two-level questions. One for the entire building and shared/common spaces, and the other for each personal unit in the building. As a result, two tables were created that were related to each other with a one-to-many relationship. The first step consists of merging these tables based on the global ID of the building.
- The second step involves cleaning the data and addressing missing or NaN values.
- The third step consists of handling nominal or categorical data by assigning numerical values to them.
- The fourth step involves calculating the mean of each field within the data corresponding to personal units in the building, for each building.
- The fifth step concerns data normalization, as each field had its scale, unit, and measure. The Min-Max method was used for normalization, which is expressed by the following equation

$$Z_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (7)$$

- The final step consists of multiplying each indicator by its weight and summing the results for each building to obtain the PPI and SEPI, as in equations 5 and 6.

3.4 Application to the Beirut Port Disaster

This section presents the application of the proposed methodology to the post-disaster building damage assessment in Beirut.

Estimating the indicators' weights is based on the opinions of a panel of experts in the building sector, urban planning, disaster management, and reconstruction. Experts' opinions were obtained through a questionnaire composed of two sections. The first focused on the experts' profile, including their field of expertise, experience, and working sector, while the second concerned the indicators' priority based on a 5-level score. High scores indicated high relevance. Table 3-4 summarizes the profiles of the 33 experts. 36% of the experts work in the academic sector, while 36% work in construction and engineering companies. The remaining experts come from organizations (national and international), consulting, and the Lebanese Armed Forces.

Table 3-4. Description of the experts' profiles.

Expert's Field	**Nb of experts**	**Work Sector**	**Nb of experts**	**Years of Experience**	**Nb of experts**
Civil Engineering	20	Academic Field and Research	12	16 to 25	11
Project Management	4	Construction and Engineering Company	12	More than 25	8
Urban Planning	1	NGOs	2	5 to 10	6
Social Sciences	1	International Organizations	2	11 to 15	5
GIS Coordinator	1	Lebanese Armed Forces	1	Less than 5	3
Disaster management	1	UN - Agency	1		
Humanitarian and Emergency Response professional (educational background in engineering)	1	Lebanese Red Cross	1		
Governance and Quality Management Consultant	1	Consultant and training company, Academic, collaboration with International organizations and Lebanese Armed Forces	1		
Architect	2	Consulting	1		
Environment Expert	1				

Table 3-5 summarizes the experts' opinions. It shows that damage level is the most important indicator of the building's physical characteristics (Global score =150). It is followed by the building type and its status of being a cultural heritage or not, which are nearly equal in importance (133 and 132 respectively). In the socio-economic category, the occupancy and the estimated rehabilitation costs are equally important (131). The compensation from funding is the most important at the shared space level (131), followed by the estimated renovation costs (127).

At the personal unit level, the presence of a temporary shelter is the most important with a score of 128, followed by the renovation costs (127). The capacity of the owners is the least critical indicator at the shared space and personal unit levels (124).

Table 3-5. Scores of indicators according to the experts' opinions.

Category	Indicator	Scale					Global Score
		1	2	3	4	5	
Physical Characteristics of the Building	Building Type	0	1	5	19	8	**133**
	Damage Level	0	1	2	8	22	**150**
	Cultural Heritage	1	2	3	17	10	**132**
Socio-Economic Profile of Residents	Occupancy ratio before and after the disaster	0	3	6	13	11	**131**
	Estimated rehabilitation costs of the building	0	2	6	16	9	**131**
	Capacity of owners to afford renovation costs at the shared space level	0	2	10	15	6	**124**
	Estimated rehabilitation costs at the shared space level	0	2	8	16	7	**127**
	Compensation from funding at the shared space level	0	2	7	14	10	**131**
	Capacity of households to afford renovation costs at the personal unit scale	0	1	11	16	5	**124**
	Estimated rehabilitation costs at the personal unit scale	0	2	8	16	7	**127**
	Compensation from funding at the personal unit scale	0	3	6	17	7	**127**
	Presence of temporary shelter at the personal unit scale	1	4	8	5	15	**128**

Table 3-6 summarizes the results of the application of the SWARA method. It shows that the weights of indicators are close. This reveals that the selected indicators are considered by the experts of high importance.

Table 3-6. Weights of indicators following the SWARA method

Attribute	Total Score	sj	kj	qj	Weight
Damage Level	150		1	1	**0.37**
Building Type	133	0.17	1.17	0.8547	**0.32**
Cultural Heritage	132	0.01	1.01	0.8462	**0.31**
Occupancy ratio before and after the disaster	131		1	1	**0.115**
Estimated rehabilitation costs of the building	131	0	1	1	**0.115**
Compensation from funding at the shared space level	131	0	1	1	**0.115**
Presence of temporary shelter at the personal unit scale	128	0.03	1.03	0.971	**0.111**
Estimated rehabilitation costs at the shared space level	127	0.01	1.01	0.961	**0.11**
Estimated rehabilitation costs at the personal unit scale	127	0	1	0.961	**0.11**
Compensation from funding at the personal unit scale	127	0	1	0.961	**0.11**
Capacity of owners to afford renovation costs at the shared space level	124	0.03	1.03	0.933	**0.107**
Capacity of households to afford renovation costs at the personal unit scale	124	0	1	0.933	**0.107**

3.5 Conclusion

This chapter presented a comprehensive smart post-disaster reconstruction framework. The three core objectives of the framework is to integrate smart governance, smart management, and planning concepts, with a detailed description of their functions and role in the post-disaster reconstruction process. It also develops the list of stakeholders and their responsibilities in each process phase. The framework is adapted to complex geopolitical contexts and their challenges and could be adjusted to any other context by conducting a study of its challenges and specificities.

The chapter also proposed a tool to assist decision-makers in assessing buildings for reconstruction projects. The main objective is to prioritize the vulnerable groups of the affected community. In post-disaster situations, and particularly in complex geopolitical contexts, the decision-making process can become a challenging task, as discussed in previous paragraphs. Therefore, the Priority Index, with its two components, Physical Priority Index PPI and Socio-Economic Priority Index SEPI, is a technical tool that aims to assist a data-based, transparent, comprehensive, and innovative decision-making process.

The smart post-disaster reconstruction framework was applied to the Beirut case after the Port explosion. A Priority Index (PPI and SEPI) was designed for the context with the intervention of 33 local experts in civil engineering, disaster management, urban planning, … using the SWARA method for evaluating the weights of each indicator. PPI consisted of 3 indicators describing the physical characteristics of the building after the disaster, and SEPI consisted of 12 indicators describing the socio-economic profile of the building's residents.

The novelties of this framework are:

- It proposes a comprehensive post-disaster reconstruction framework for complex geopolitical contexts where a lot of barriers can hinder recovery efforts.
- It creates a Priority Index for Beirut that considers the context's specificities and challenges, particularly the socio-economic issues.
- It integrates the socio-economic dimensions to endorse a sustainable smart, and resilient post-disaster reconstruction, as well as integrate the principles of Build-Back-Better and leave no one behind.
- Although the application was for Beirut, however, the framework can be manipulated and adapted to any other context since it was designed for this purpose. For other cases, a Priority Index can be created to integrate the specificities of this context with the help of their local experts.

The future work is to apply these indicators to a sample of Beirut buildings and calculate the PPI and the SEPI for each building of the sample. This dataset will help the decision-makers and stakeholders to manage the reconstruction projects while prioritizing the most vulnerable groups in Beirut.

4 Smart Post-Disaster Reconstruction for Beirut Harbor

4.1 Introduction

In this chapter, we apply the smart post-disaster reconstruction framework presented in Chapter III to reconstruct Beirut's buildings after the port explosion. It uses the Physical Priority Index and Socio-Economic Priority Index values for a group of buildings affected by the blast. This tool is designed to assist decision-makers in reconstructing, especially in a context marked by inadequate governance structures, limited financial resources, corruption, and data scarcity. Additionally, the chapter introduces the technical platform developed to operationalize the framework into a practical tool applicable to the port disaster and any potential future risks. The platform grouped the following features:

- The data collection module is accessible to the stakeholders who want to participate, accelerating the damage assessment process during the emergency phase.
- Communication of the PPI and SEPI results to decision-makers and stakeholders involved in building reconstruction.
- Facilitate coordination among NGOs and public authorities in the legal permit procedure, thereby reducing conflicts and project recurrence.
- Enable all stakeholders to monitor reconstruction projects, enhancing transparency and mitigating corruption and favoritism in aid allocation.

The architecture and the technical description of the platform, are detailed in the Appendix.

The first section presents the data collection process and argues the data collection method. Subsequent sections describe the data sample and descriptive statistics. For data collection, crowdsourcing was selected as the prior source, and the choice is justified in this section. The second section delves into data analysis and offers insights into the condition of the assessed buildings in Beirut. These findings constitute a tool for decision-makers within Beirut and Lebanon to effectively organize and execute post-disaster reconstruction efforts while prioritizing the most vulnerable community groups. The last section discusses the results some case studies and the limitations of the method.

4.2 Data collection

4.2.1 <u>Use of Crowdsourcing</u>

Crowdsourcing is defined as outsourcing tasks to the public domain and harnessing the collective intelligence of the citizens/crowd for inferring/obtaining the desired information (Khajwal & Noshadravan, 2021). It is a type of participative online activity in which an individual, institution, or company proposes to a group of individuals of varying knowledge, heterogeneity, and number via a flexible open call voluntary undertaking of a task (Estellés-Arolas & González-Ladrón-De-Guevara, 2012). It uses the power of the internet and social media to virtually harness the power of individuals and bring them together in support of a disaster (Riccardi, 2016). It capitalizes on the power of the masses or crowds and relies on citizen participation to achieve its goals (Kamel Boulos et al., 2011).

(Kankanamge et al., 2019) found an increasing focus on volunteer crowdsourcing in the disaster risk reduction literature between 2006 and 2018. Their study suggested that volunteer crowdsourcing can assist policymakers and disaster risk managers to make informed decisions before, during, and after disasters. (Sukhwani & Shaw, 2020) suggested enhancing community outreach and promoting Global Positioning System ‘GPS’ based apps to fill the lack of real-time data on disasters, restraining the decision maker's ability to counter its impacts. Crowdsourcing has become a quick and efficient solution to social and economic actions, fundraising, and numerous issues that affect both the private and the public sectors. For instance, US government is now actively using crowdsourcing to solve complex problems previously handled by a limited circle of experts such as disaster response problems (Becker & Bendett, 2015). (Harrison & Johnson, 2016) found that crisis crowdsourcing plays a role in all phases of the disaster management cycle by government agencies in Canada and the USA. (Song et al., 2020) showed, by using the Complex Adaptive System theory, that crowdsourcing strengthens communication and coordination, optimizes emergency decision-making, improves the ability to learn and adapt, and promotes disaster resilience.

Using crowdsourcing as the primary data source aligns with the objectives of the smart post-disaster reconstruction framework:

- It allows the participation of the affected community in the post-disaster reconstruction process, which is a core objective.
- It provides real-time data about damage assessment which allows decision-makers to take informed decisions and monitor the reconstruction projects.
- By allowing the volunteer crowdsourcing, data collection process would be faster, which can save stakeholders time in conducting reconstruction projects, as time is a crucial constraint in emergency phase.
- Crowdsourcing can be executed via mobile applications, thus it is cost-effective, especially in contexts that lack financial and human resources for other expensive data collection methods.

However, crowdsourcing presents limitations, particularly regarding data reliability and quality, and managing larger data volume. Scholars discussed the crowdsourcing challenges in disaster management (Ogie et al., 2019; Poblet et al., 2018; Schimak et al., 2016). The main challenges are:

- information extraction and uncertainty of the data gathered by citizens brings additional issue of machine-interpreting the messages written by and for humans. This challenge can be overcome by crowd-tasking use, meaning that volunteers well-known scientists are asked to do well-defined observations that are easy for the machines to verify.
- self-organization challenge, which is about finding a balance between total control of crisis managers and decision-makers on one side, and full self-organization of the web platforms or mobile applications for managing the resources or the recovery activities on the other side.
- incentives for participation because people are not always bound to participate in crowdsourcing tasks.
- and ethical considerations that encompass privacy and misuse of data stored in user profiles or misuse of user tracking information.

To address these challenges, the developed web-based platform mandates participant membership for data collection before survey access, enhancing the reliability of responses compared to random participants. This approach fosters greater trust in the data collected. The platform visually represents the Priority Index of buildings, empowering reconstruction stakeholders to make more informed decisions autonomously by prioritizing higher Priority Index and the most vulnerable buildings. To safeguard data privacy, the survey was designed using the Survey123 application within ArcGIS, a secure platform for data storage. Survey questions are designed to be accessible to all citizens, aligning with the inclusive nature of crowdsourcing and participatory reconstruction concepts.

The questions are addressed to the participants, and the answers enable the calculation of indicators for physical building properties and the socio-economic profile of residents for each selected building. The list of questions is presented in Table 4-1Table **4-1Table 4-1.** List of questions (indicators) in the Beirut survey used for data collection.

Nº	**Question**
Physical Characteristics of the Building	
1	What is the building type (residential, commercial, cultural, education, healthcare,…)
2	What is the number of floors?
3	What is the damage level?
4	Is it cultural heritage or not?
5	What is the current status of the building? (recovered, still damaged, recovery ongoing)
6	Upload an image of the building
Socio-Economic Profile of the Residents	
Building Scale	
7	What is the estimation of the renovation costs of the building in dollars?
8	To what level are the owners capable of affording renovation costs?
Shared Space Scale	
9	What is the estimation of the renovation costs of the shared space in dollars?
10	What is the value of the funding?
Personal Unit Scale	
11	To what level is the owner capable of affording renovation costs?
12	What is the estimation of the renovation costs of the personal unit in dollars?
13	What is the value of the funding?
14	Do the households have a temporary shelter?

4.2.2 Overview of collected data

According to the Disaster Risk Management Unit of the Lebanese Government, the Lebanese Army assessed 37044 units (Disaster Risk Management, 2020). The assessment included physical characteristics of the building, such as the number of floors and units, the damage level, and the NGOs working on the building. However, their assessment ignored the socio-economic situation of the residents. The UN-Habitat evaluated the socio-economic vulnerability of Beirut's operational zones following the blast, but the results were visualized by zones rather than by individual buildings, which poses limitations considering Beirut's highly diverse socio-economic fabric (UN-Habitat, 2021). The Order of Engineers and

Architects in Beirut (OEA) conducted a structural assessment of the affected buildings, but it was a technical assessment that experts performed including the damage level, the current stability of the building and the potential need for scaffolding (OEA, 2020).

In this research, 159 buildings were assessed in four severely impacted zones: Karantina, Mar Mikhael, Rmeil, and Gemmayzeh (Figure 4-1), which were selected for the following reasons:

- It is the nearest residential zone to the explosion's epicenter within a range of 500 m to 900 m.
- It includes a high proportion of cultural heritage buildings.
- It underwent massive destruction following the disaster, and many buildings were structurally damaged.
- A large number of buildings are still damaged three years after the blast.
- The percentage of vacancies in residential lots is alarming; a lot of buildings were emptied of their residents, adding to the high number of victims, which makes it harder for their families to return to their homes.
- It constitutes a rich cultural and mixed social hub in Beirut center, attracting many economic and social activities, events, and tourists.

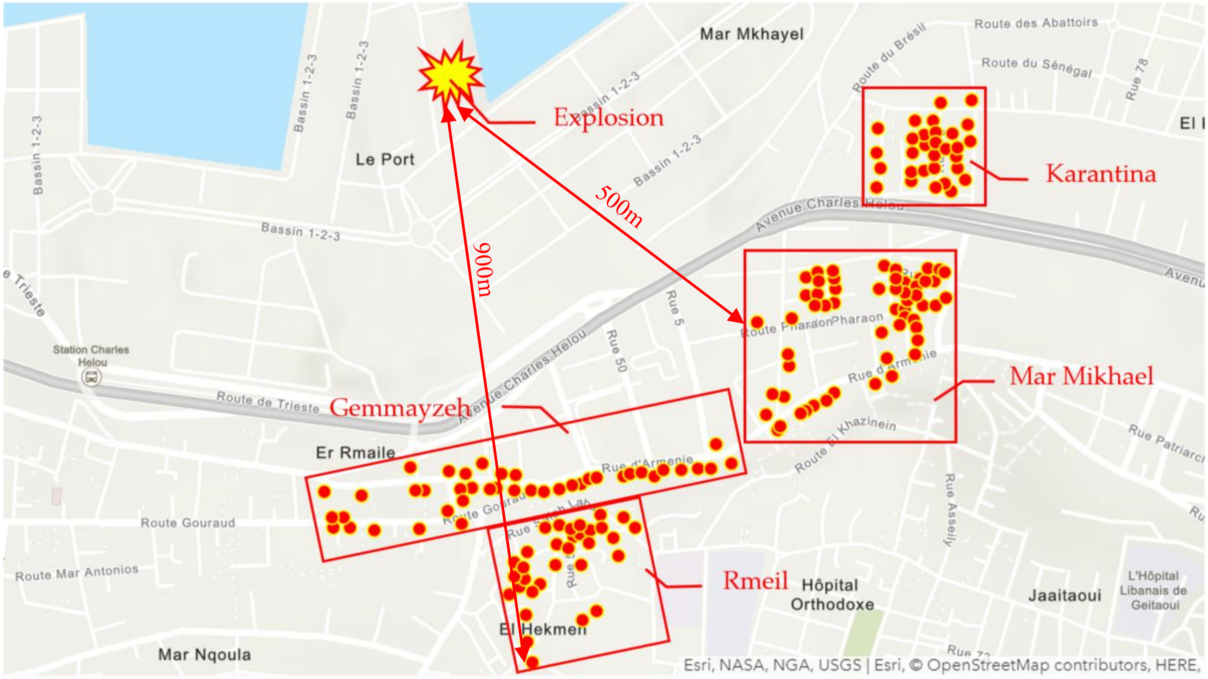


Figure 4-1. Selected zones for data collection and assessed buildings.

Data collection was facilitated through the collaboration of residents and citizens. The author personally conducted the survey, engaging with one or more residents from each building. The physical characteristics questions were straightforward and could be easily observed by visually inspecting the building. These questions included:

- Building Type: Residential, commercial, cultural, education, healthcare, etc.
- Number of Floors
- Damage Level
- Cultural Heritage Status
- Current Status of the Building
- Upload an Image of the Building

In contrast, the socio-economic profile questions posed a more significant challenge. For instance, estimating renovation costs and renovation costs per square meter required input from local experts. The costs were determined based on the local market and prices, with the following estimates:

- For non-structural damage: \$200/m^2
- For structural damage: \$300/m^2
- For total collapse: \$400/m^2
- If the building is considered cultural heritage, add \$100/m^2

Addressing the owner(s)' capacity to afford renovation costs involved responses on a 5-level Likert scale, with answers contingent upon each household's unique circumstances. While the reliability of these responses can be subjective, it is essential to acknowledge the high economic disparity among residents. This disparity could be evaluated based on house size, design, and appearance. Despite the potential subjectivity, this indicator is important as the survey's primary goal is to identify the most vulnerable groups and prioritize their needs.

Various funding sources, including insurance companies, government aid, and international or local NGOs, were considered for reconstruction. However, the allocation of funds varied due to factors such as the iconic status of certain buildings, such as Sursok Museum, leading to increased attention and financial support. Instances of favoritism and corruption, especially in government aid, further influenced fund distribution. Insurance companies also had specific considerations and rules for assisting their customers. During the survey, residents were directly queried about the funds they received.

Determining the presence of temporary shelter was a straightforward question, relying on whether residents had alternative housing options, such as homes in the village or family members willing to host them during the reconstruction period. Notably, some residents chose to remain in their damaged houses despite having temporary accommodation, driven by concerns about robberies occurring in unoccupied and open houses during that period.

4.3 Descriptive statistics

This section presents the descriptive statistics of the collected data sample, first concerning each physical indicator and then concerning each socio-economic indicator.

- Physical indicators

Most of the buildings are either residential or mixed-use (commercial/residential), as shown in Figure 4-2. 82 buildings (52%) were residential, and 60 (38%) were mixed-use commercial and residential.

The area is characterized by a high number of cultural heritage buildings: around 46% of the buildings are classified as cultural heritage (Figure 4-3). The distance separating the buildings of our sample from the explosion epicenter ranges between 500 m and 900 m. Therefore, 133 buildings (84%) experienced significant or structural damage, whereas 24 (15%) faced non-structural damage. Only 2 buildings (1.25%) were destroyed (Figure 4-4). Although the current status of the building is not an indicator for the Priority Index, this information was collected to track the recovery process. Two years and a half after the explosion, 61% of the assessed buildings were recovered, 29 % were still damaged, and 9 % were under renovation (Figure 4-5).

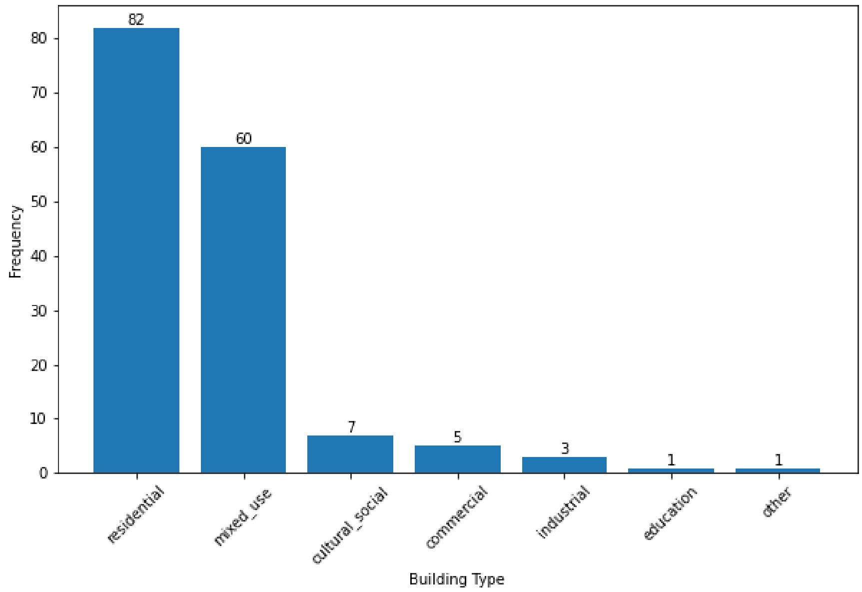


Figure 4-2. Distribution of buildings types across the assessed buildings.

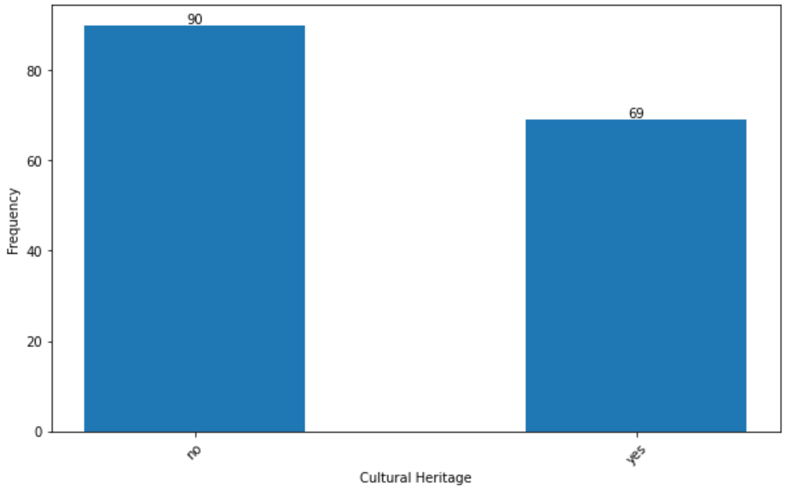


Figure 4-3. Distribution of cultural heritage status across the assessed buildings.

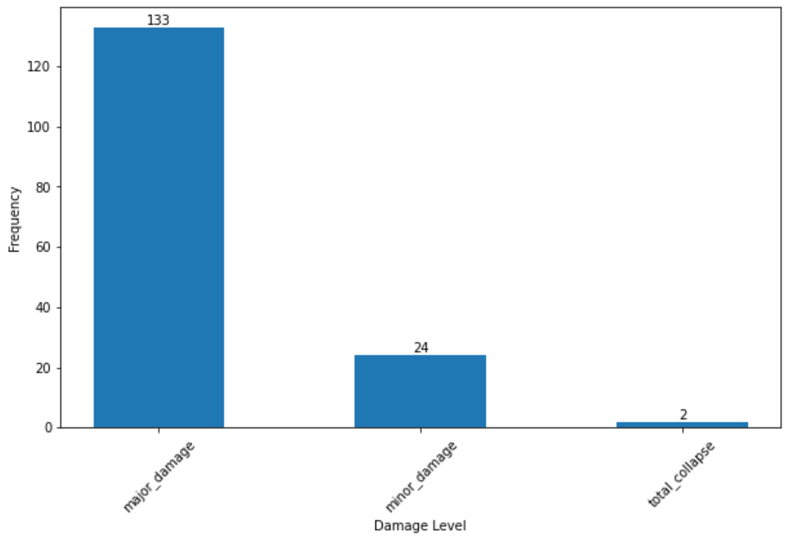


Figure 4-4. Distribution of damage level across the assessed buildings.

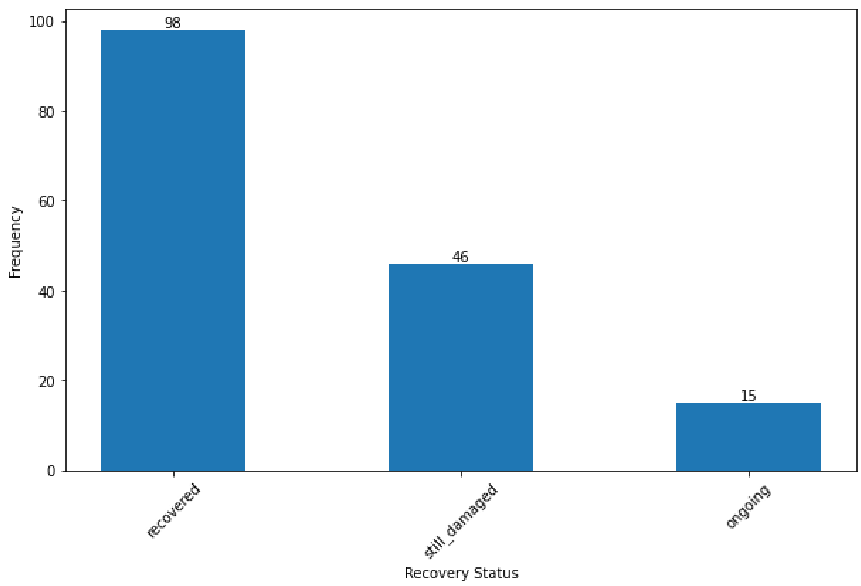


Figure 4-5. Distribution of recovery status across the assessed buildings.

- Socio-economic indicators

Figure 4-6 represents the distribution of the buildings' renovation costs. Half are below 231000 US $, while the average is 273100 US $, with a standard deviation of 207667 US $.

Figure 4-7 illustrates the distribution of the pre and post-disaster occupancy ratios. It shows that the most frequent value is 0%, which means that the number of occupied units remains unchanged after the disaster. Following that, the next value is 100%, indicating that all previously occupied units are currently vacant. The remaining values range between 0 and 100%. Notably, only one building shows more occupied units after the disaster. This building attracted residents due to its significantly improved aesthetic appeal after renovation. Several buildings, marked by an occupancy ratio of 100%, remain unoccupied even three years after the disaster. The increase in vacancy can be attributed to the fact that many residents were renters, and were not responsible for the renovation expenses. Consequently, when building owners did not proceed with renovations, the renters vacated their apartments. Among the 98 renovated buildings, there are 39, where all previously occupied units are now vacant. In these cases, the residents, who were also renters, chose to relocate elsewhere after the disaster. It is worth mentioning that several owners opted to convert their apartments into Airbnb rentals rather than renting them to individuals or families, as it proved to be more financially advantageous. While for some buildings, residents are traumatized and find it hard to return because they lost family members following the explosion.

Figure 4-8 and Figure 4-9 show that the majority of the owners cannot afford the estimated renovation costs of the shared space and the personal units. The economic crisis worsened the situation of the residents, in addition to the unlawfully restricted depositors' access to their own money in the banks, limited the capacity of owners to afford the costs.

Figure 4-10 and Figure 4-11 reveal that for the majority of the renovated buildings, the costs were covered by NGOs. In fact, as a result of the corruption and the lack of governance in Lebanon, the external and internal funding went in majority to international and local NGOs. Therefore, the NGOs were the major leaders of the reconstruction projects in Beirut.

Most residents found a temporary shelter thanks to strong social bonds (Figure 4-12). Despite the risks, many individuals, particularly men, opted to stay home during the reconstruction process.

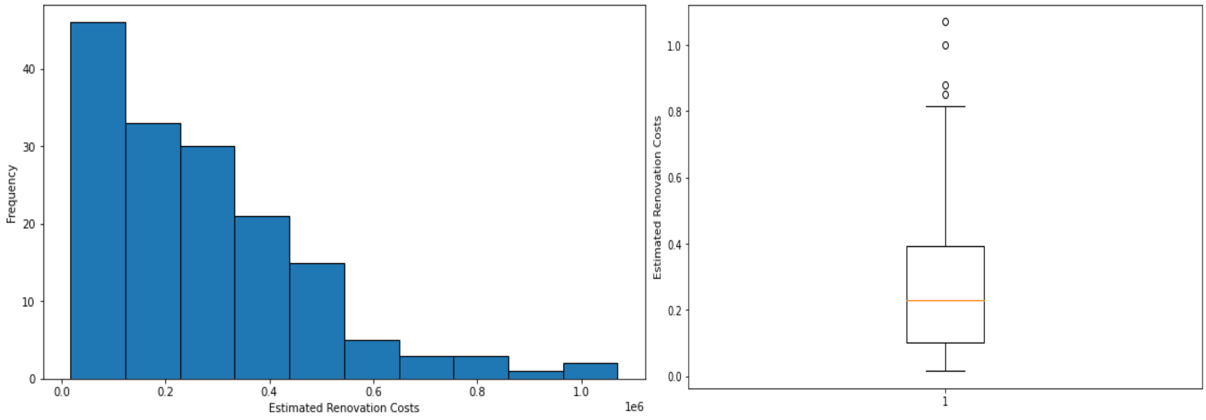


Figure 4-6. Distribution of buildings estimated renovation costs across the assessed buildings.

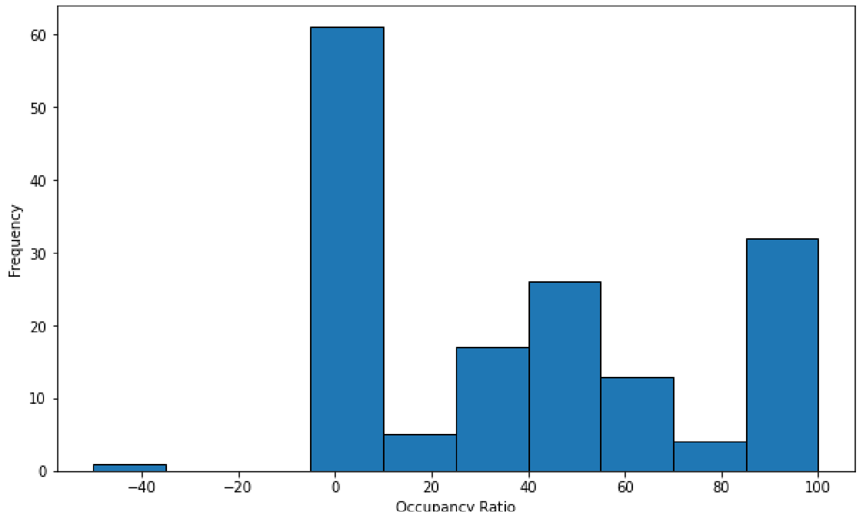


Figure 4-7. Distribution of occupancy ratio across the assessed buildings.

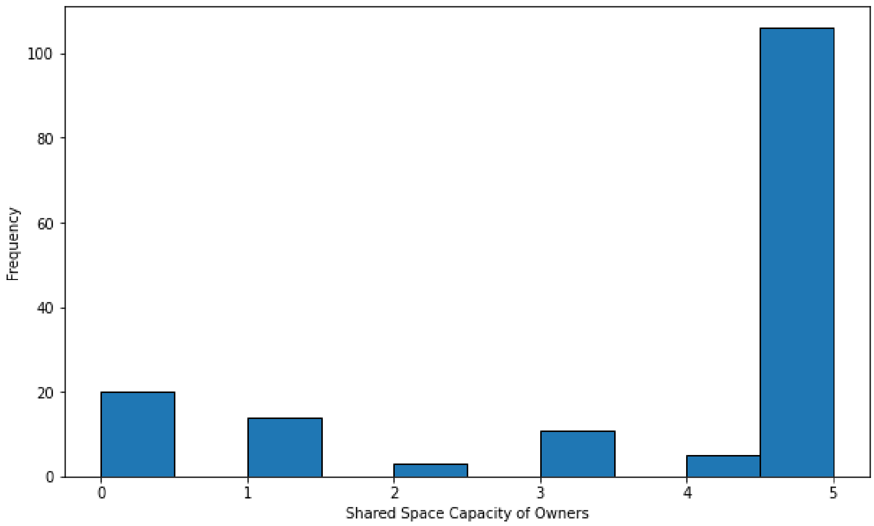


Figure 4-8. Distribution of owners' capacity to afford shared space renovation costs across the assessed buildings.

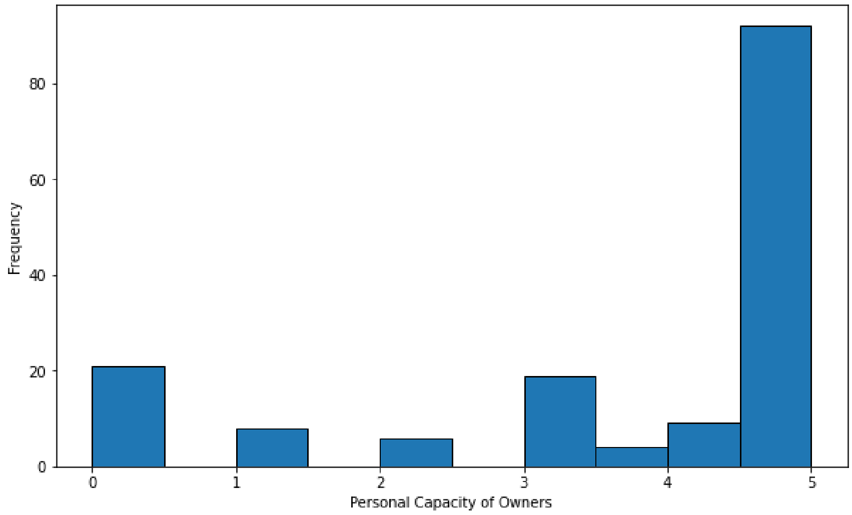


Figure 4-9. Distribution of owners' capacity to afford their personal unit renovation costs across the assessed buildings.

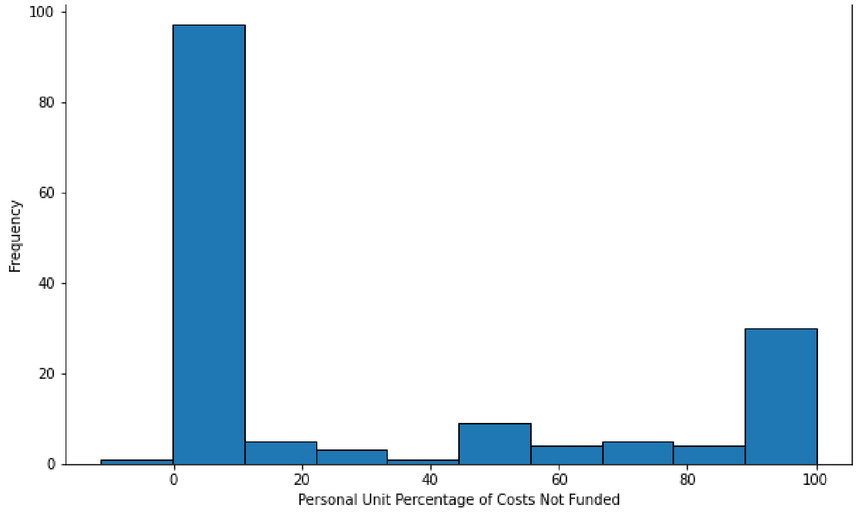


Figure 4-10. Distribution of personal unit percentage of costs not funded across the assessed buildings.

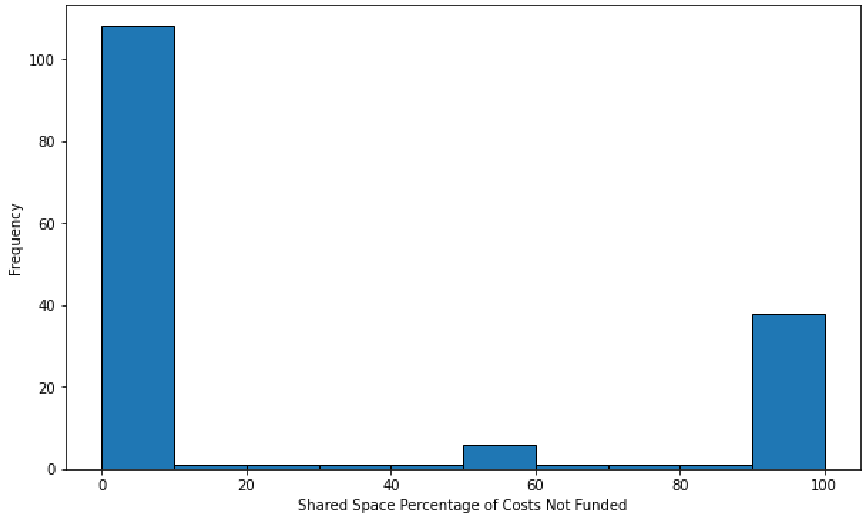


Figure 4-11. Distribution of shared space percentage of costs not funded across the assessed buildings.

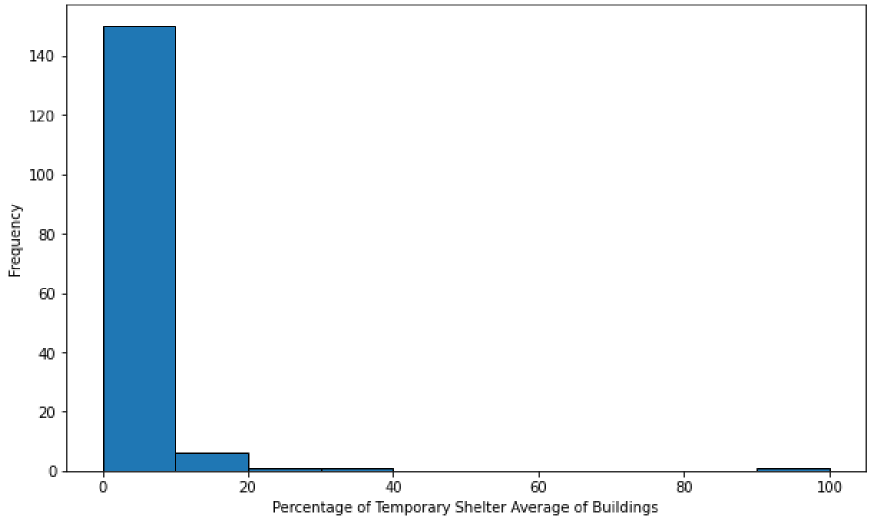


Figure 4-12. Distribution personal unit percentage of residents with no temporary shelter across the assessed buildings.

4.4 Results

Python in the ArcGIS API was used to analyze the data and calculate the Physical Priority (PPI) and the Socio-economic Priority (SEPI) indices for each building. The PPI is the Physical Priority Index for buildings, which considers the building destination, the damage level, and the fact that it is cultural heritage or not. The SEPI is the Socio-Economic Priority Index that accounts for the estimated rehabilitation costs, the capacity of the owners to afford the costs, the compensation from funding, and the presence of a temporary shelter. The PPI and SEPI were calculated using the following formulas:

$$PPI = w_{BT} \times BT + w_{DL} \times DL + w_{CH} \times CH \tag{8}$$

$$\begin{aligned} SEPI = {} & w_{OR} \times OR + w_{BRC} \times BRC + w_{SOC} \times SOC + w_{SRC} \times SRC + w_{SCF} \times SCF \\ & + w_{POC} \times POC + w_{PRC} \times PRC + w_{PCF} \times PCF + w_{TS} \times TS, \end{aligned} \tag{9}$$

The method for calculating the PPI and SEPI was detailed in Chapter III.
The next paragraph presents the results of the PPI and SEPI of the assessed buildings in Beirut.

4.4.1 Physical Priority Index

Figure 4-13 illustrates the variation of the PPI with the building type. The inclination of residential or mixed-use buildings exhibits an increase in PPI. Figure 4-14 demonstrates that the severity of damage correlates with a higher PPI, while Figure 4-15 highlights a distinct rise in PPI based on the cultural importance of the buildings. It is worth noting that the PPI is not only dependent on this factor, but the other three factors influence it. As a result, certain non-cultural heritage buildings may possess a higher PPI than cultural heritage buildings, and buildings with minor damage can have a higher PPI than those with major damage. Figure 4-16 illustrates the PPI distribution. The discrete values are due to the influence of the three indicators on the PPI.

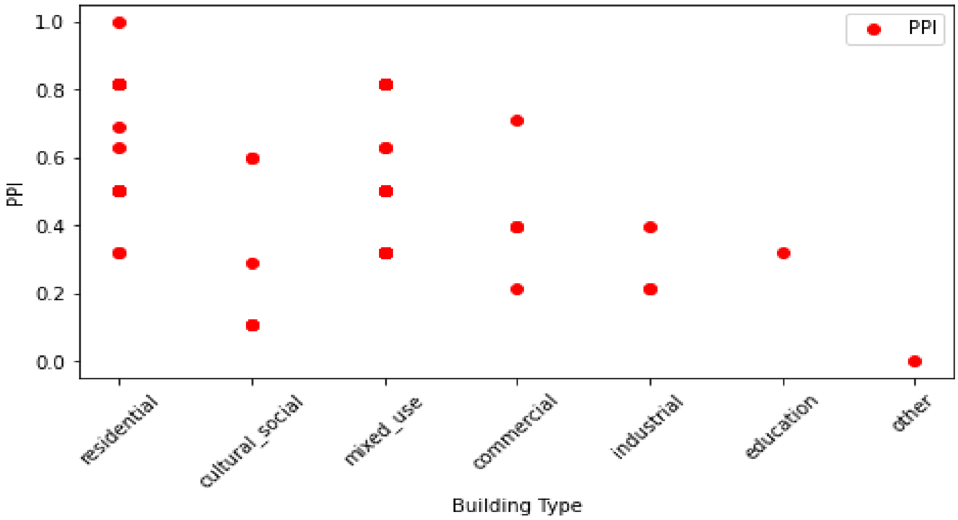


Figure 4-13. Variation of PPI in terms of building type.

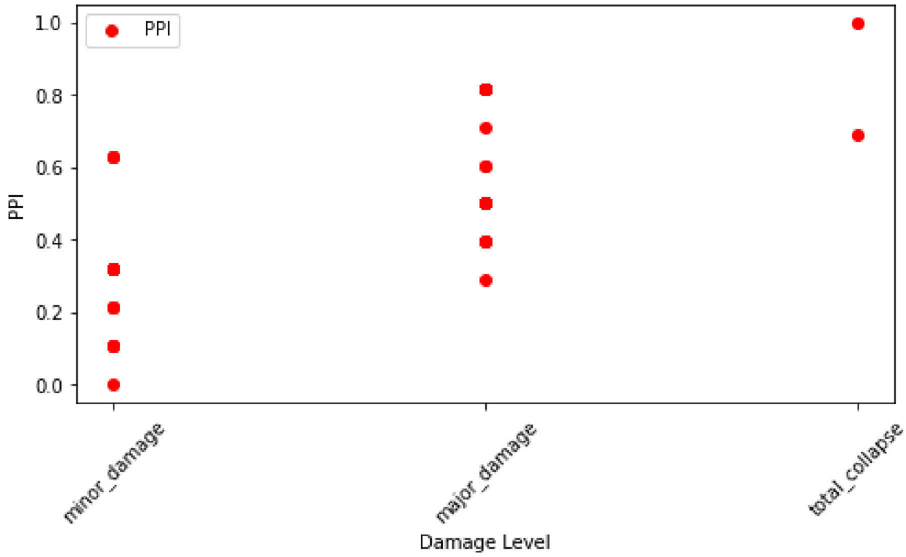


Figure 4-14. Variation of PPI in terms of damage level.

Figure 4-15. Variation of PPI in terms of cultural heritage.

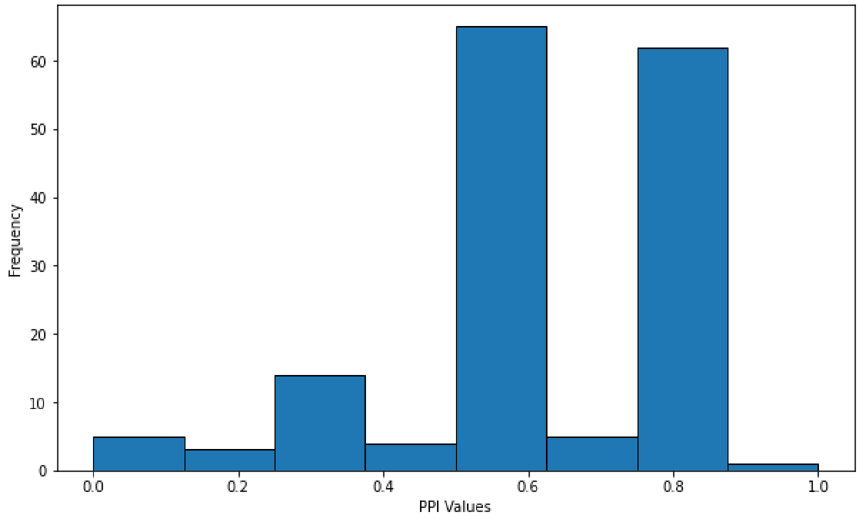


Figure 4-16. Distribution of the Physical Priority Index (PPI).

4.4.2 Socio-economic Priority Index

Figure 4-17 illustrates the variation of the SEPI with the total renovation costs. We observe a tendency for the SEPI to increase with building estimated renovation costs. Figure 4-18 does not indicate a clear relationship between the SEPI and the occupancy ratio. Figure 4-19 and Figure 4-20 show a different variation tendency with the owner funding capacity for the shared and individual spaces.

Figure 4-21 indicates that the SEPI tends to increase with the increase in personal unit renovation costs.

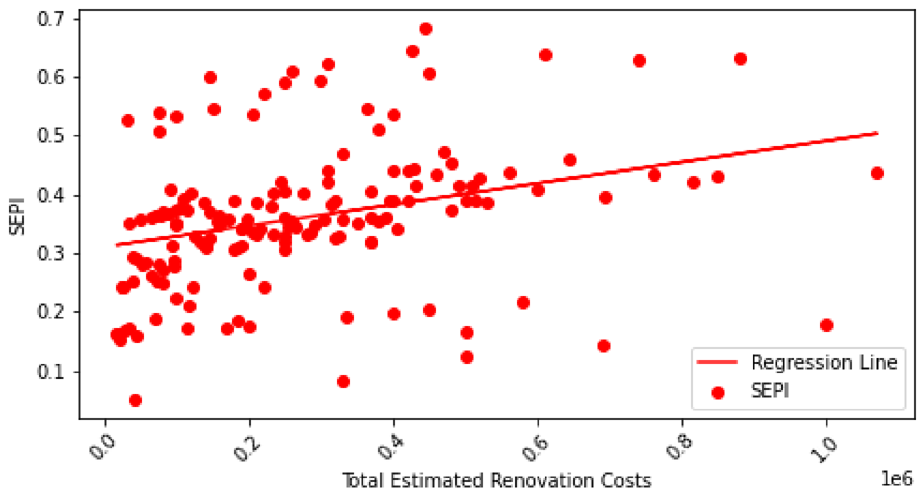


Figure 4-17. Variation of SEPI in terms of buildings estimated renovation costs.

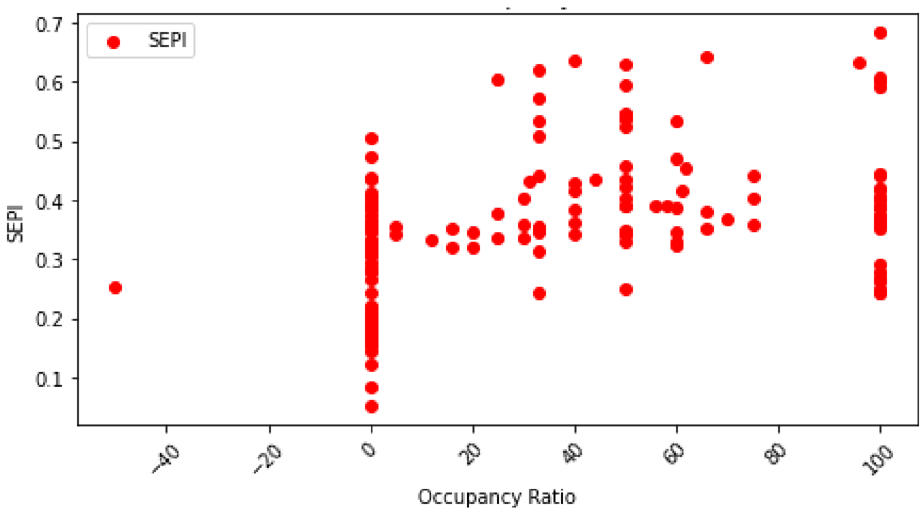


Figure 4-18. Variation of SEPI in terms of occupancy ratio.

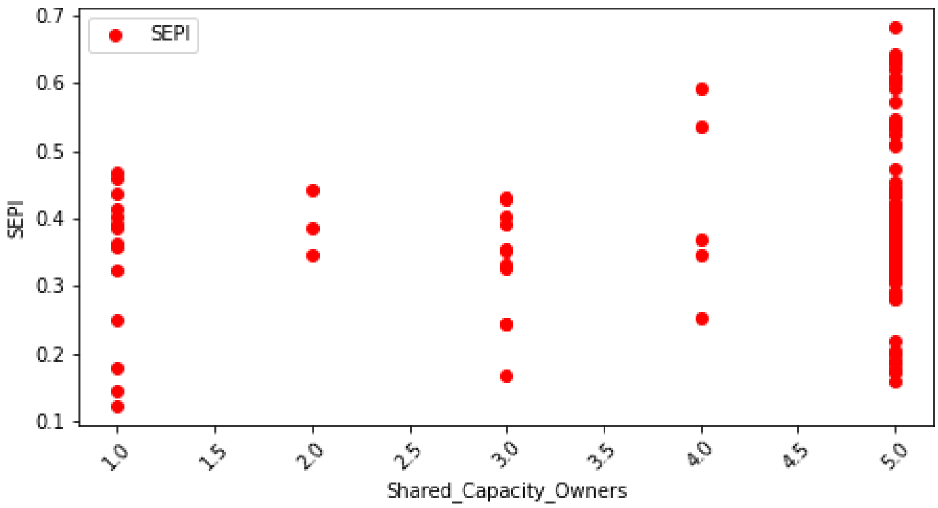


Figure 4-19. Variation of SEPI in terms of owners' capacity to afford shared space renovation costs.

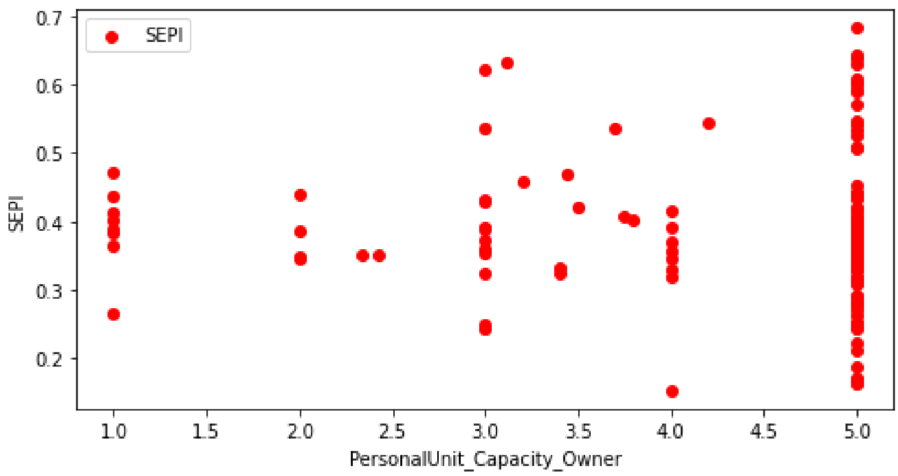


Figure 4-20. Variation of SEPI in terms of owners' capacity to afford personal unit renovation costs.

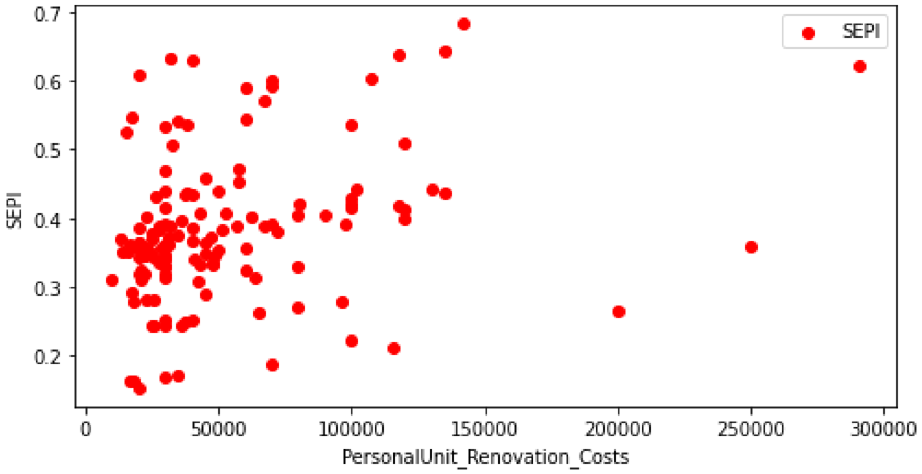


Figure 4-21. Variation of SEPI in terms of personal units estimated renovation costs.

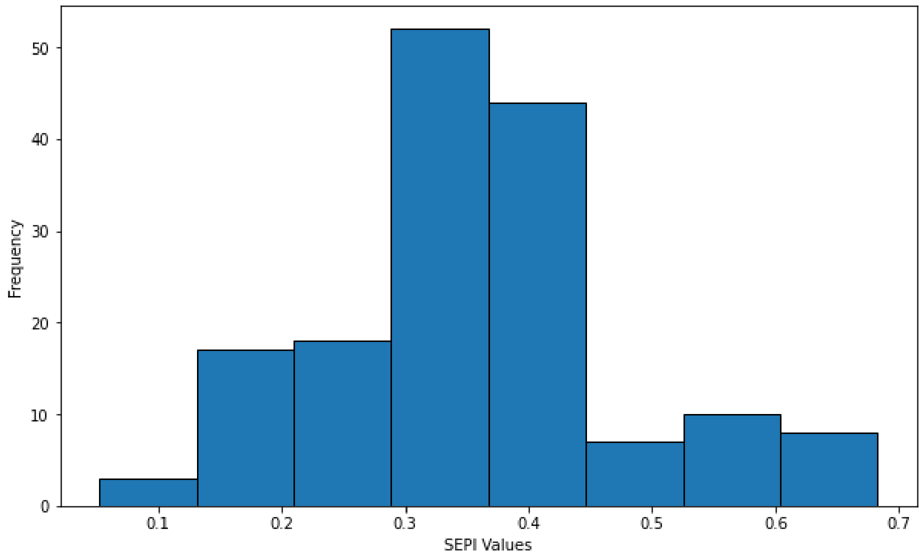


Figure 4-22. Distribution of the Socio-Economic Priority Index (SEPI).

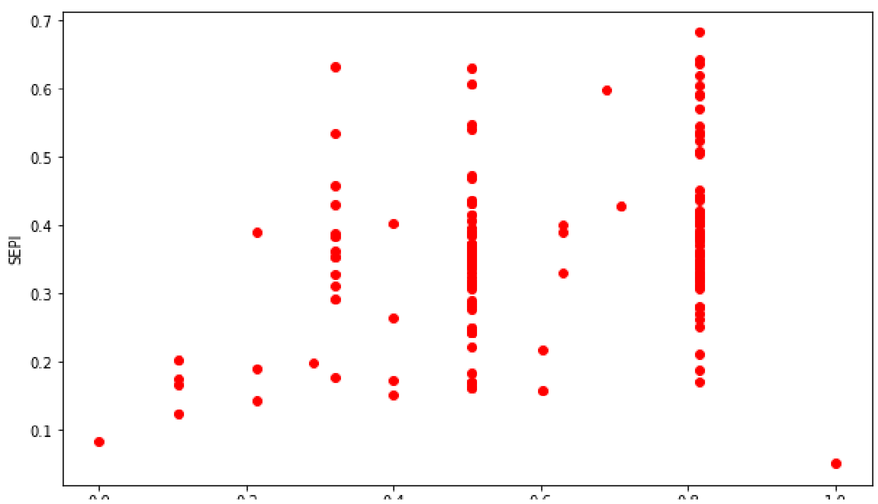


Figure 4-23. Values of the SEPI and PPI for the set of buildings.

4.4.3 PPI and SEPI spatial distribution

Figure 4-24 shows the heatmap of the PPI. It indicates that Mar Mikhael and Karantina zones have the highest PPI, followed by Rmeil and Gemmayzeh. In this area, most buildings endured significant structural damage. Since the study area is residential, the building type with the highest frequency is residential and mixed-use (residential and commercial). It is important to mention that mixed-use buildings are typical in Lebanon, especially in Beirut. Stores and markets usually occupy the ground floor, and residential units are on the other levels. The PPI does not vary significantly in this area because most buildings are residential or mixed-use and severely damaged. The status of cultural heritage makes the difference.

Figure 4-25 shows the heatmap of the SEPI. Since this index considers nine indicators, the results vary widely. It indicates that Mar Mikhael and Karantina also record the highest SEPI.

4.4.4 Discussion

Analyses of the PPI and SEPI priority indices for the selected case show the complex relationship of these indices with the related indicators. The results are presented in the

Figure 4-16 shows the distribution curve of the PPI. It indicates a concentration around two intervals [0.5, 0.625] and [0.75, 0.875]. The mean value is 0.597, and the median value is 0.505. The standard deviation is 0.206 and the standard error is 0.016, indicating that the mean of the PPI is a reliable estimate of the population mean. The Kurtosis value is -0.531 which indicates a slightly platykurtic distribution. This means the PPI values have a lighter tail and are less peaked than a normal distribution. It suggests that the distribution is somewhat flatter, with a smaller proportion of extreme values. The Skewness value is -0.393, indicating a slightly negatively skewed distribution. This means that the distribution of PPI values is slightly skewed toward lower scores, indicating that within the physical dimension, most of the assessed buildings represent the same characteristics and, therefore, the same priority level.

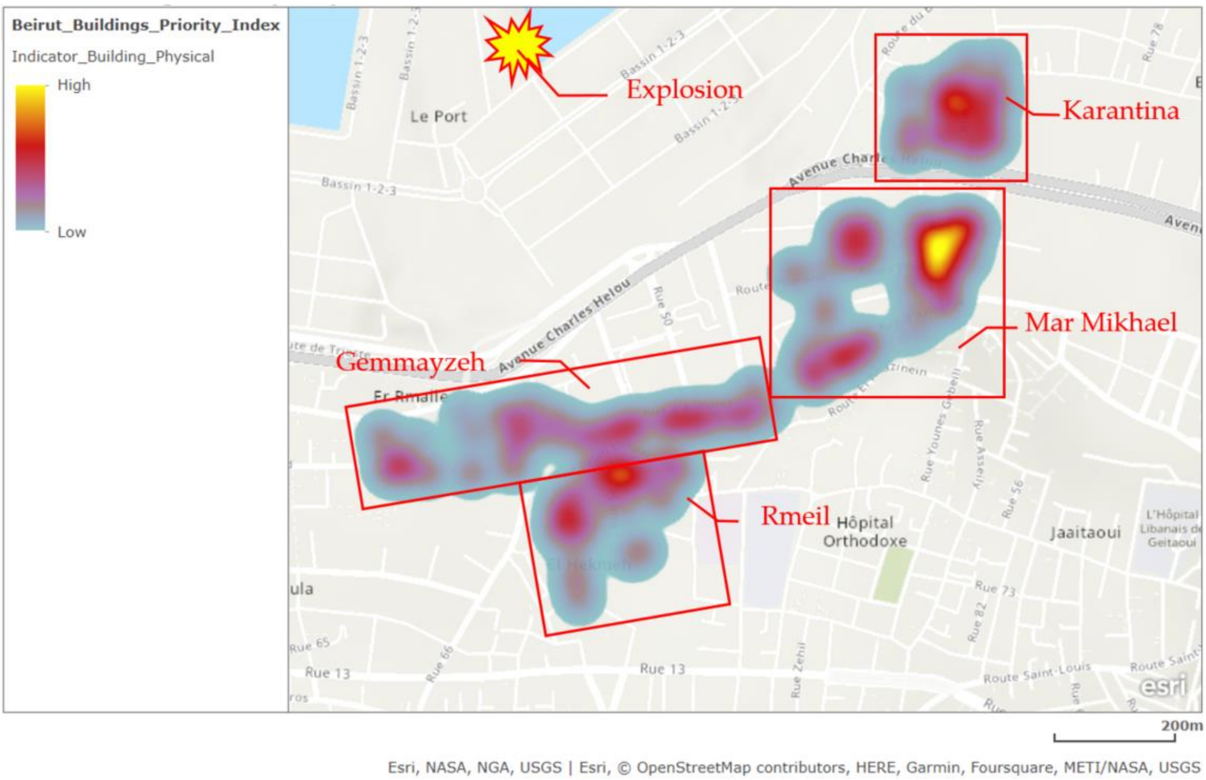


Figure 4-24. Heatmap of the priority index for physical characteristics of assessed buildings in Beirut.

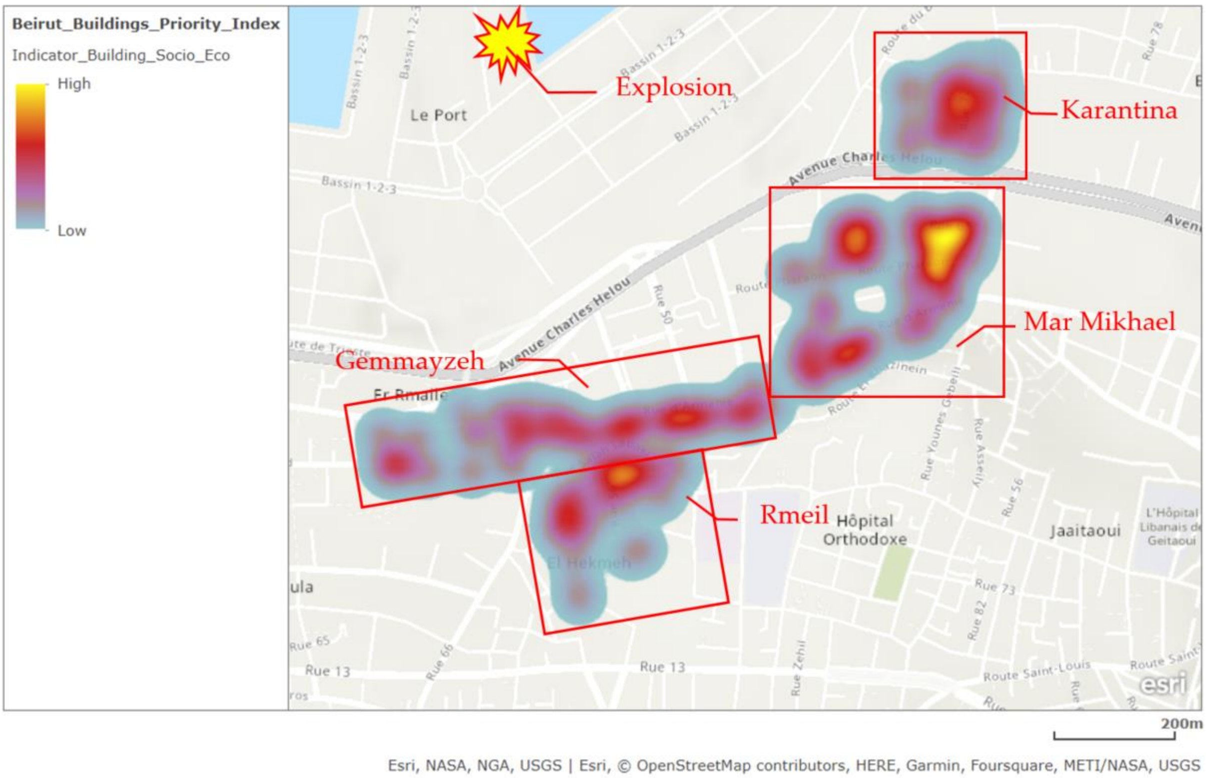


Figure 4-25. Heatmap of the priority index for residents' socio-economic profile of assessed buildings in Beirut.

Figure 4-22 shows a concentration of the SEPI in the interval [0.29, 045]. The mean value is 0.359, and the median value is 0.357. The standard deviation is 0.12 and the standard error is 0.0095, indicating that the mean of the SEPI is a reliable estimate of the population mean. The Kurtosis value is 0.32, which indicates a slightly platykurtic distribution. This means that the SEPI values have a lighter tail and are less peaked than a normal distribution. It suggests that the distribution is somewhat flatter, with a smaller proportion of extreme values. The Skewness value is 0.264 indicates a slightly positively skewed distribution. This means that the distribution of SEPI values is slightly skewed toward higher scores, indicating that some assessed buildings have higher SEPI values and, therefore, are more vulnerable when considering the socio-economic dimension.

Table 4-2. Descriptive statistics of PPI and SEPI values; Source: Author.

PPI		SEPI	
Mean	0.597159329	**Mean**	0.359528523
Standard Error	0.016300136	**Standard Error**	0.009552701
Median	0.505	**Median**	0.357040923
Standard Deviation	0.20553689	**Standard Deviation**	0.120454972
Sample Variance	0.042245413	**Sample Variance**	0.0145094
Kurtosis	-0.530111316	**Kurtosis**	0.320804146
Skewness	-0.392765399	**Skewness**	0.264197427

Figure 4-23 illustrates the values of SEPI and PPI for all the buildings. It shows a weak correlation between these indices (Standard correlation = 0.3369). This result shows all the difficulties in establishing a global PI by combining PPI and SEPI. After analyzing the results and identifying the barriers to post-disaster reconstruction in Chapter II, the socio-economic issues appear to be very pronounced in Beirut. Therefore, the SEPI could be dominant in the post-disaster reconstruction decision-making.

Special cases of buildings

1) The highest SEPI index concerned a three-story cultural heritage residential building (0.683). This building became completely vacant after the disaster (all the units were left after the disaster). The owners could not afford the reconstruction costs, and they did not receive any sort of funding. It also has a high value of PPI (0.815). The information about the building is gathered in Table 4-3.

Table 4-3. Data attributes of building 1 case; Source: Author.

Item	73
Select the building type	Residential
What is the total number of units in the building?	3
What is the damage level?	Major collapse (between 25% and 50% of the building damaged)
Is it a cultural heritage or no?	YES
What is the number of occupied units before the disaster?	3
What is the number of occupied units after the disaster?	0
What is the estimation of the renovation costs of the building in dollars?	445000
To what level is the owner capable of affording renovation costs?	Cannot cover any cost
What is the estimation of the renovation costs of the shared space in dollars?	19000
What is the value of the funding?	0
What is the current status of the building?	Still Damaged
What is the number of floors?	3
Indicator_Building_Physical	0.815
Indicator_Building_Socio_Eco	0.683

2) Another example of a building with a SEPI index of 0.6081 is a severely damaged mixed-use building. Like the previous case, the owner could not afford the necessary renovations, leaving the renters without shelter. As a result, the building remains vacant while the renters have found alternative housing solutions. The information about the building is gathered in Table 4-4.

Table 4-4. Data attributes of building 2 case; Source: Author.

Item	82
Select the building type	Mixed-use Commercial/Residential
What is the total number of units in the building?	12
What is the damage level?	Major collapse (between 25% and 50% of the building damaged)
Is it a cultural heritage or no?	NO
What is the number of occupied units before the disaster?	12
What is the number of occupied units after the disaster?	0
What is the estimation of the renovation costs of the building in dollars?	260000
To what level is the owner capable of affording renovation costs?	Cannot cover any cost
What is the estimation of the renovation costs of the shared space in dollars?	20000
What is the value of the funding?	0
What is the current status of the building?	Still Damaged
What is the number of floors?	4
Indicator_Building_Physical	0.505
Indicator_Building_Socio_Eco	0.608

3) The building with the lowest SEPI (0.052) was abandoned even before the disaster. Despite having the maximum PPI value due to its cultural heritage and intended use for housing, the building suffered a total collapse. No one lived in it during the disaster, so it recorded the minimum SEPI. The information about the building is gathered in Table 4-5.

Table 4-5. Data attributes of building 3 case; Source: Author.

Item	94
Select the building type	Residential
What is the total number of units in the building?	1
What is the damage level?	Total collapse (more than 50% of the building damaged)
Is it a cultural heritage or no?	YES
What is the number of occupied units before the disaster?	0
What is the number of occupied units after the disaster?	0
What is the estimation of the renovation costs of the building in dollars?	42000
To what level is the owner capable of affording renovation costs?	
What is the estimation of the renovation costs of the shared space in dollars?	
What is the value of the funding?	

What is the current status of the building?	Still Damaged
What is the number of floors?	1
Indicator_Building_Physical	1
Indicator_Building_Socio_Eco	0.0522

It is worth mentioning that the difference between the first and the second case is the renovation cost, which depends on the state of cultural heritage, the damage level, and the area of the building. This explains why the first case scored a higher SEPI value.
The data spatial analysis shows that Mar Mikhael is the most vulnerable zone in the PPI and SEPI assessments. Cultural heritage buildings mark this area, which suffered extensive structural damage. The population relocation in this zone has been relatively slow. Furthermore, the area experienced many casualties, intensifying the trauma and making it even more challenging for the affected families.
For the visualization of spatial results in this manuscript, we avoided including personalized information on the maps, as it may pose privacy concerns. Hence, the PPI and SEPI values were represented through a heatmap rather than individual point-by-point categorization based on color or size. These results can only be visible to stakeholders involved in the reconstruction projects of the buildings. For instance, the decision-makers, represented by the Municipality of Beirut in this case, the well-known NGOs active on the ground before and after the explosion, and the international organizations. In this framework, the platform gives registered NGOs and the Municipality of Beirut access to the PPI and SEPI results. The most vulnerable buildings can be tracked and prioritized according to their SEPI values. The legal permit given by the public authority to NGOs for a building renovation can be managed via the platform application form.

4.4.5 Limitations of the tool

The application of the tool was limited to 159 buildings in four operational zones in Beirut that were the nearest to the explosion epicenter. The data collection process faced several limitations:

- Residents declined cooperation, often due to a lack of support from the state and NGOs, which led to suspicion towards individuals inquiring about the recovery process.
- Obtaining details about vacant buildings and dealing with the trend of converting apartments into Airbnb rentals posed challenges. Many owners turned their apartments to AirBnb rentals, and the temporary residents usually have no information about the building. Leveraging neighborhood ties and bonding proved beneficial in some cases, where some individuals possessed information about their buildings and neighboring vacant structures.
- NGOs declining cooperation also complicated the task. However, one local reputable NGO accepted to help, and the collaboration was sought to mitigate some challenges, provide assurance to residents, and encourage survey participation.

However, the data volume escalates when expanding the scope to encompass the entire city, necessitating a more intricate data management system to handle storage, security, and analysis effectively. Additionally, the data quality becomes harder to control even when the participants are regular and certified platform members with access to the survey.
Regarding the development of PPI and SEPI, certain aspects should have been considered in the analysis despite their potential impact on building vulnerability and priority, such as access

to essential services (electricity and water). These indicators were omitted to strike a balance between the number of questions for crowdsourcing, avoiding discouragement of participation, and prioritizing the most critical factors. Anyway, the selected indicators underwent validation by local experts, and they approved the list. The SWARA method was used for calculating the weights of indicators. While other methods like AHP could have been utilized, time constraints, evidenced by a two-month delay in expert responses, influenced the research process. It's important to note that the indicator system, drawn from a systematic literature review and contextual study of Beirut, remains subject to change, necessitating periodic review and updates to reflect the specific situation.

Furthermore, this research focused solely on buildings, yet post-disaster reconstruction involves numerous city or country systems such as infrastructure, environment, social fabric, and economic conditions, which reconstruction is as important as building reconstruction to achieve a successful post-disaster recovery.

General Conclusion

Objective and methodology of the research

The objective of this research was to develop an innovative framework for assessing the buildings in the aftermath of a disaster with a focus on Beirut case. The proposed framework covers the physical and socio-economic dimensions of the building, and offers a tool for decision-makers to monitor and prioritize the reconstruction projects. While other assessment tools are confined to one dimension, or specific to some environments, this framework can be adapted to any context, particularly the complex geopolitical or post-conflict contexts.

In order to achieve the research objective, the applied methodology started with an extensive literature review, including the analysis of relevant research in the field, the post-disaster reconstruction frameworks such as SFDRR, and the existing assessment tools for buildings or other cities' subsystems. Subsequently, Beirut was selected as a case study following the port explosion on the 4th of August, in addition to its complex political conditions (poor governance, geopolitical instability and tensions, etc.), and socioeconomic conditions (such as poverty, unemployment, immigration, lack of financial resources for the reconstruction). After analyzing Beirut context, a comprehensive framework for assessing the post-disaster condition of buildings was proposed. Based on the selected indicators and their weights, an assessment of the physical characteristics and socio-economic profile of the buildings in Beirut was conducted, including data collection through questionnaires. The collected data was analyzed and results were discussed.

General Findings of the Framework

Post-disaster reconstruction has seen the emergence of a novel approach known as Smart Post-Disaster Reconstruction (SPDR), which integrates the principles of smart city development with the reconstruction process. This comprehensive approach addresses various dimensions of the reconstruction process:

- Governance: Instead of relying on centralized top-down approaches, SPDR promotes data-informed decision-making to better align policies with local community needs.
- Management: It enhances coordination among stakeholders to minimize conflicts and promote synergy, thereby improving the efficiency of reconstruction projects.
- Financial and Economic: SPDR aims for equitable allocation of financial resources and donations, prioritizing aid to the most vulnerable groups.
- Social: By integrating the affected community into decision-making and project management, SPDR emphasizes a human-centered approach and encourages community participation.
- Technological: SPDR leverages smart technologies and digital tools to aid in the recovery process, though it requires balancing the cost of these tools with available resources.
- Development: SPDR aims to enhance both physical infrastructure and community resilience to better withstand future disasters.

However, SPDR faces certain limitations:

- Contextual Complexity: The uniqueness of each post-disaster context presents challenges, requiring customization of SPDR frameworks to local conditions and continuous updates.
- Technological Constraints: Availability of digital tools and smart technologies, especially in developing countries, poses challenges. Additionally, ensuring data reliability, especially when relying on crowdsourcing, is crucial.
- Community Participation: While community involvement is central to SPDR, it can slow down decision-making and project implementation compared to top-down approaches.

In the case of Lebanon, applying the SPDR framework becomes particularly crucial due to the country's challenging context:

- Ineffective Governance: Lebanon lacks an effective governance system, hindering decision-making processes. SPDR can help by introducing a priority index for buildings and improving aid allocation to address corruption and favoritism.
- Data Transparency: The lack of reliable data collection systems and transparency complicates project monitoring and affects community trust.
- Economic Challenges: Economic crisis and political instability in Lebanon further complicate post-disaster reconstruction efforts, limiting financial resources and coordination among stakeholders.

To overcome these challenges, a web-based platform was proposed and implemented in Beirut:

- The platform utilizes crowdsourcing apps for cost-effective data collection, even in areas with limited internet connectivity.
- A set of 12 indicators was chosen to facilitate community participation and limit the data volume.
- The platform facilitates coordination between authorities and NGOs, leveraging trusted organizations to rebuild trust within affected communities.

In summary, while SPDR offers a promising approach to post-disaster reconstruction, its successful implementation requires adaptation to local contexts and addressing technological, community, and governance challenges. In Lebanon, the application of SPDR through innovative platforms aims to overcome these barriers and foster more effective and inclusive reconstruction efforts.

General findings of the application

This research confirmed the fulfillment of its main objective as follows. For Beirut buildings, the framework included 12 indicators covering two categories: 3 indicators in the physical condition of the building, and 9 in the socio-economic profile of the residents divided into 3 scales (building scale, shared space scale and personal unit scale). Expert opinions emphasized the importance of indicators from the two categories: the damage level having the highest score from the physical dimension, and the Occupancy ratio before and after the disaster, Estimated rehabilitation costs of the building, and Compensation from funding at the shared space level from the socio-economic profile.

Applying the proposed framework to a sample of 159 buildings in Beirut that were damaged by the blast, revealed important findings. The results for PPI indicate that Mar Mikhael and Karantina zones have the highest scores, followed by Rmeil and Gemmayzeh. In this area, buildings have suffered from severe structural damage, where many of them were identified as cultural heritage. In these areas, the PPI does not vary significantly because most buildings are residential or mixed-use and severely damaged. The status of cultural heritage makes the difference. The results for SEPI indicate that Mar Mikhael and Karantina also record the highest scores. These findings highlight the intricate socio-economic and financial challenges faced by citizens, particularly in the aftermath of the crisis that began by the end of 2019. Additionally, the data underscores a troubling increase in vacancy rates post-explosion, with property owners leaning towards listing their apartments on AirBnb. This pattern exacerbates the exodus of residents from the city, demanding urgent attention and action from public authorities.

Future research

This study focused on 159 buildings in Beirut within four operational zones near the explosion epicenter. However, there are several avenues for improvement. Firstly, expanding the study's geographic scope could provide a more comprehensive understanding by including a broader range of building types. Secondly, enhancing the framework entails incorporating a more diverse panel of experts, particularly those specializing in social and economic aspects, to ensure a more holistic approach. Additionally, while the framework primarily addressed the reconstruction of buildings, post-disaster reconstruction should encompass all sectors of the city. Therefore, developing frameworks for other systems such as infrastructure and environment is essential and should be integrated with the proposed framework. Furthermore, while crowdsourcing served as the primary data source, leveraging additional data sources like sensors, LiDARs, drones, satellite imagery, and social media scraping, supported by Artificial Intelligence and Machine Learning, can enhance data collection and analysis. Lastly, the platform used for data collection and visualization could be enhanced by incorporating features to facilitate community engagement and trust-building. This includes integrating frameworks for various aspects such as routes, public transport, and utility networks, and upgrading it to a 3D city model to allow for better project management by all involved stakeholders.

The insights learned from this study offer a thorough understanding of the barriers and potentials inherent in post-disaster reconstruction, especially in environments struggling with difficult crises. Despite its limitations, this study serves as a significant starting point for future exploration and advancement. Achieving effective smart post-disaster reconstruction entails an ongoing journey of learning, adjusting strategies, and fostering collaboration among stakeholders.

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Appendix

Introduction

As discussed in chapter IV, a platform is developed to conceptualize the proposed smart post-disaster reconstruction framework in this research. It is designed to monitor the process from the emergency phase to the long-term recovery, as well as improve disaster risk reduction in case of future events. The platform performs the following:

- Create a connection between different stakeholders involved in reconstruction process: public authorities, community and organizations.
- Monitor the data collection process, via a crowdsourcing survey, addressed to volunteers from the community or the organizations.
- Visualize the results of Physical Priority Index and Socio-Economic Priority Index of the assessed buildings on a dashboard. This feature is only accessible to the public authorities and confirmed organizations.
- Organize the NGOs renovation projects by allowing them to apply for a specific project after viewing the buildings index on the dashboard, and getting a permit from the public authorities to proceed with the works.
- Offer the possibility to the community to engage in the reconstruction process and monitor the projects and the NGOs works.

This appendix describes the platform architecture, its features, options and functions, as well as its work flow. The general architecture is presented in Figure A-1, and the work flow in Figure A-2.

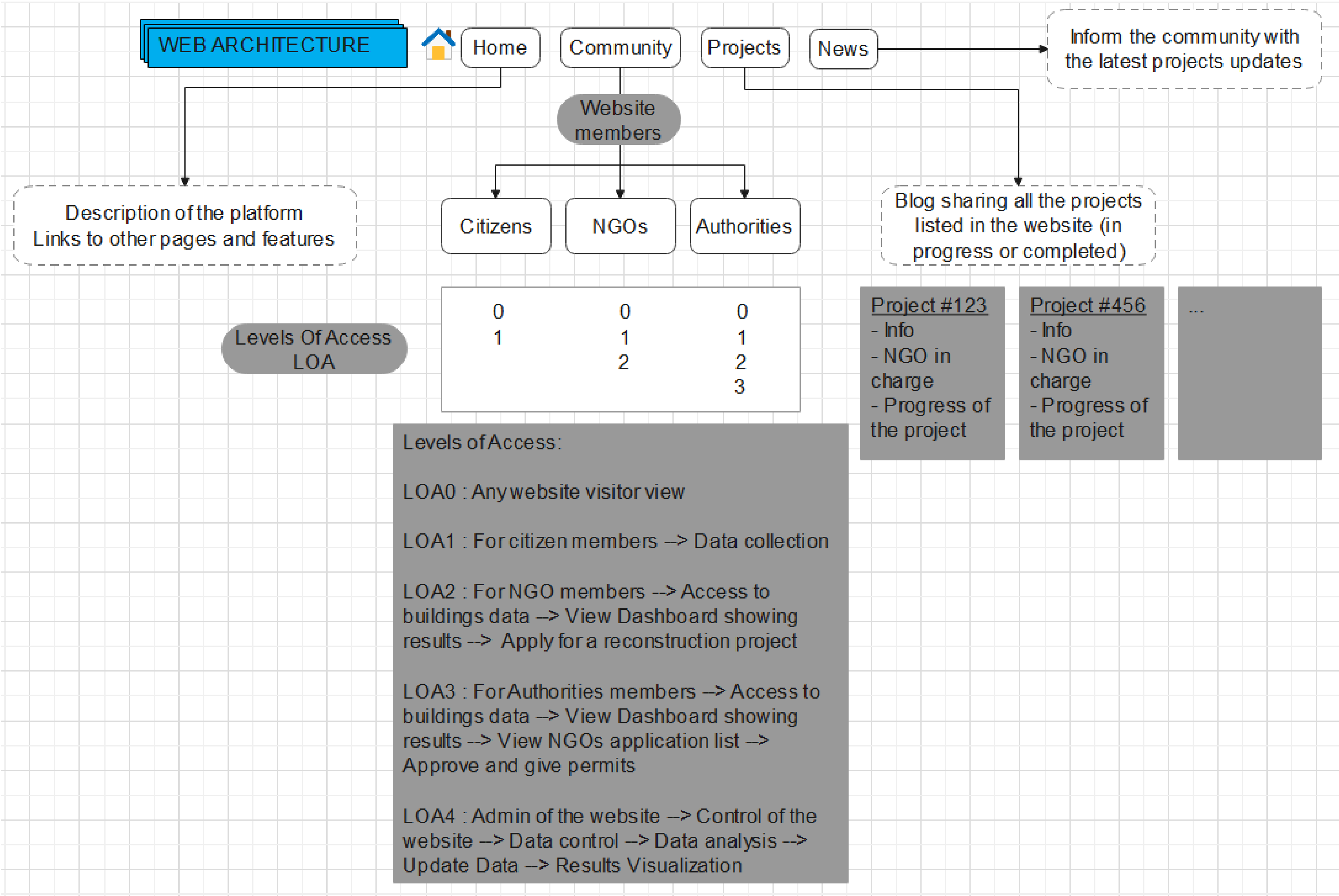

Figure A-1. General Architecture of the web-based platform; Source: Author.

Figure A-2. Platform work flow; Source: Author.

Structure of the platform

Home Page

As for any website, the platform has a home page that describes it, its objectives, the related pages with links that connect the user to them, sign in and sign up options, copyrights, as shown in Figure A-3 and Figure A-4.

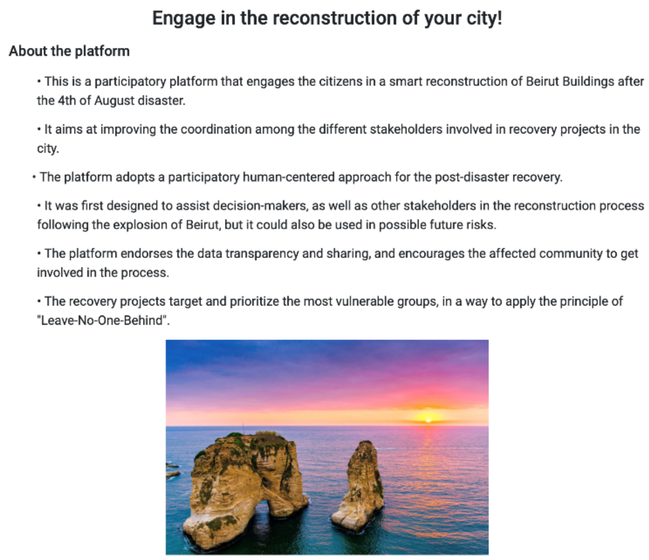

Figure A-3. Home page (1) of the platform; Source: Author.

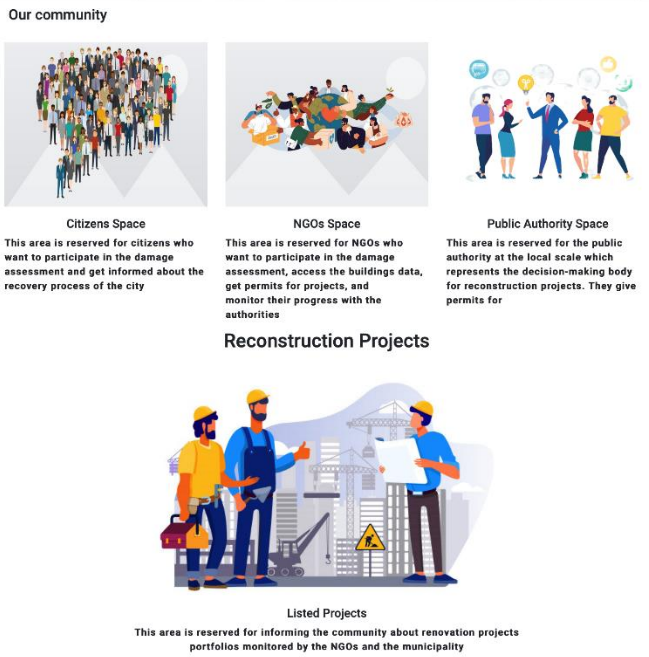

Figure A-4. Home page (2) of the platform; Source: Author.

Community

The objective of the platform is to include all the stakeholders involved in the reconstruction process, mainly the decision-makers (municipality), the NGOs (or organizations leading renovation projects), and the affected community.

After registering to the platform, members have different levels of access according to their membership type.

i) Level of access 0 (LOA0)

This is the basic level of access that any website visitor can view. It only includes the platform description, and the links to register (Sign Up). Decision-makers, NGOs and citizens can register using the form shown in Figure A-5. In the role tab, they choose public authority, citizen or NGO, which determines their level of access and role in the platform.

Once registered and approved by admin, members can login to their members area via the login form (Figure A-6).

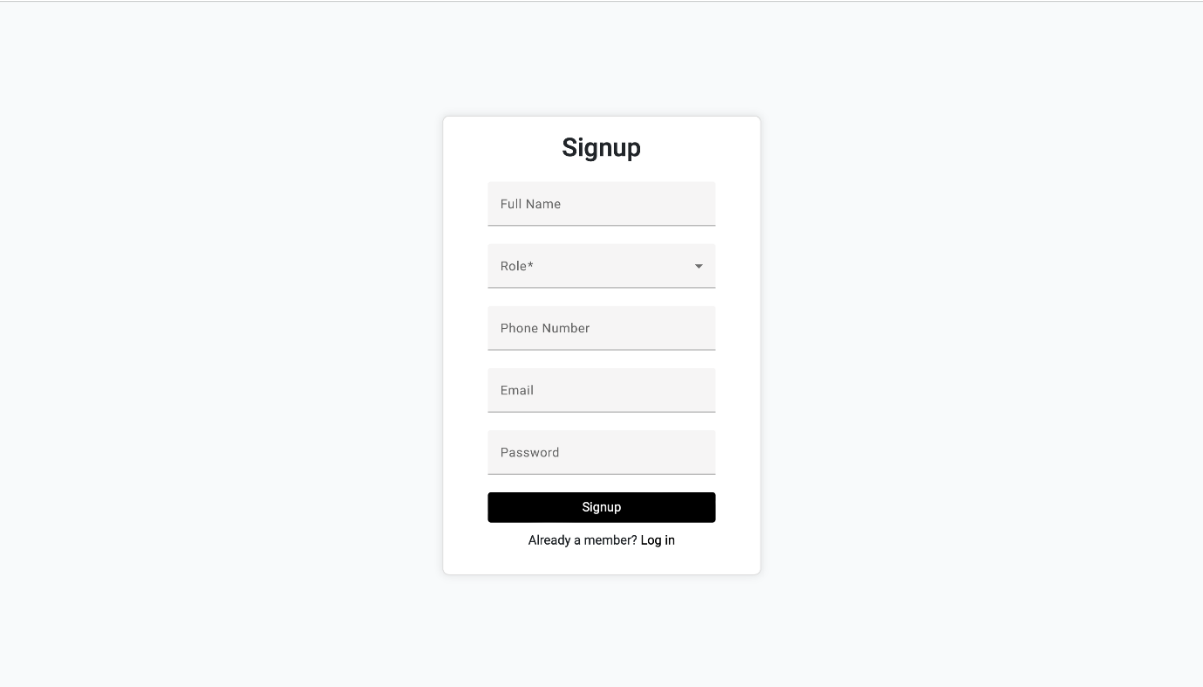

Figure A-5. Sign up form of the platform; Source: Author.

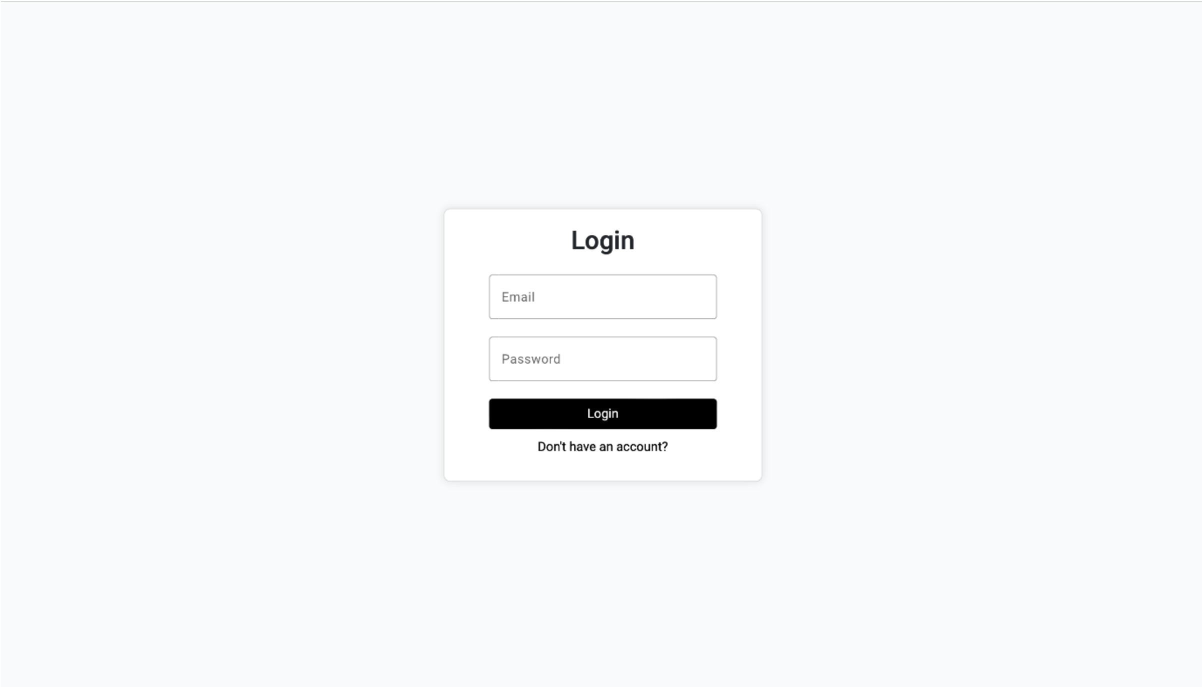

Figure A-6. Login form of the platform; Source: Author.

ii) <u>Level of access 1 (LOA1)</u>

This is the level of access of all membership types, it includes the access to data collection survey, and the ongoing projects dashboards. Citizens, NGOs and public authorities can view the progress of the reconstruction projects monitored by the NGOs (Figure A-7).

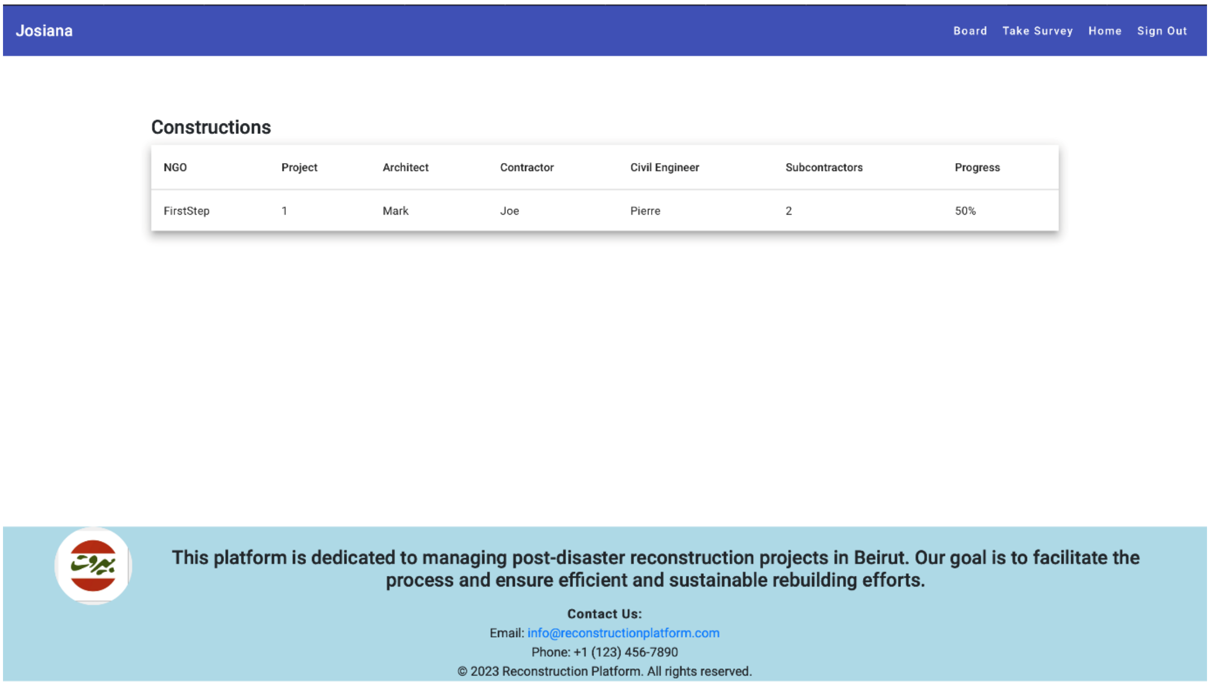

Figure A-7. Reconstruction projects monitoring of the platform; Source: Author.

They can access the data collection form in Survey123 and assess buildings and submit the data (Figure A-8, Figure A-9 and Figure A-10).

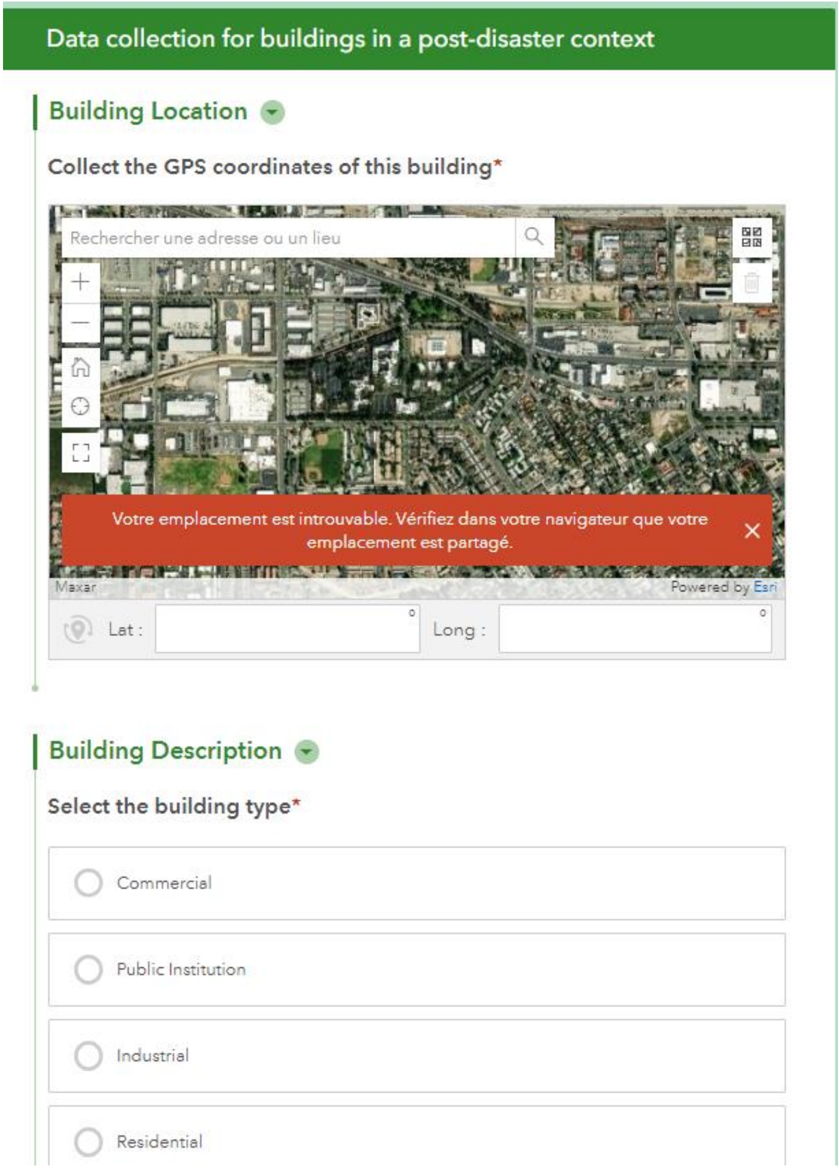

Figure A-8. Data collection survey for buildings assessment (1) ; Source: Author.

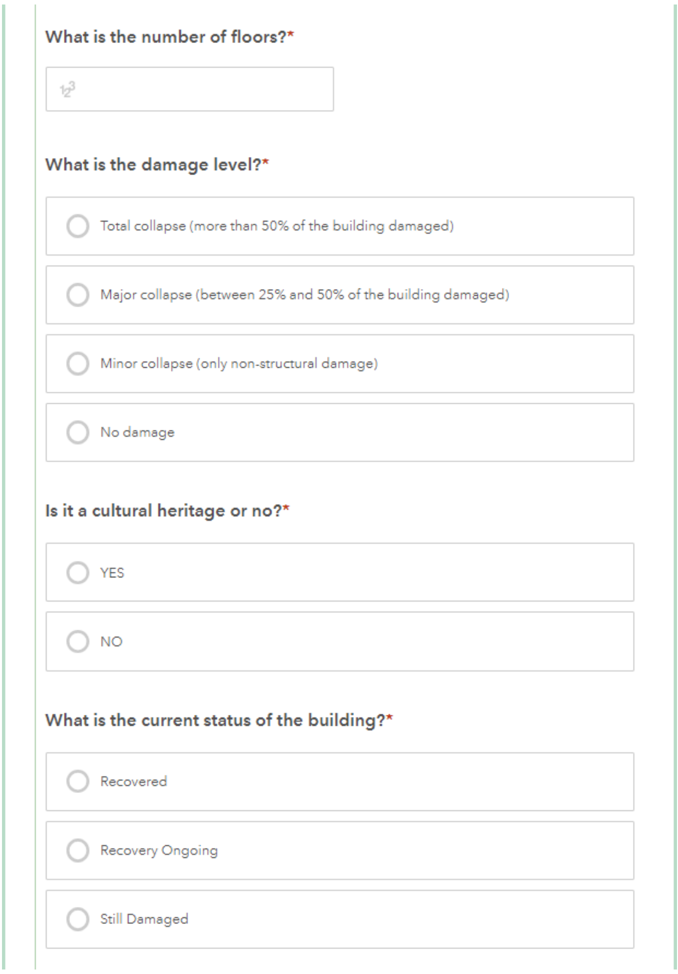

Figure A-9. Data collection survey for buildings assessment (2) ; Source: Author.

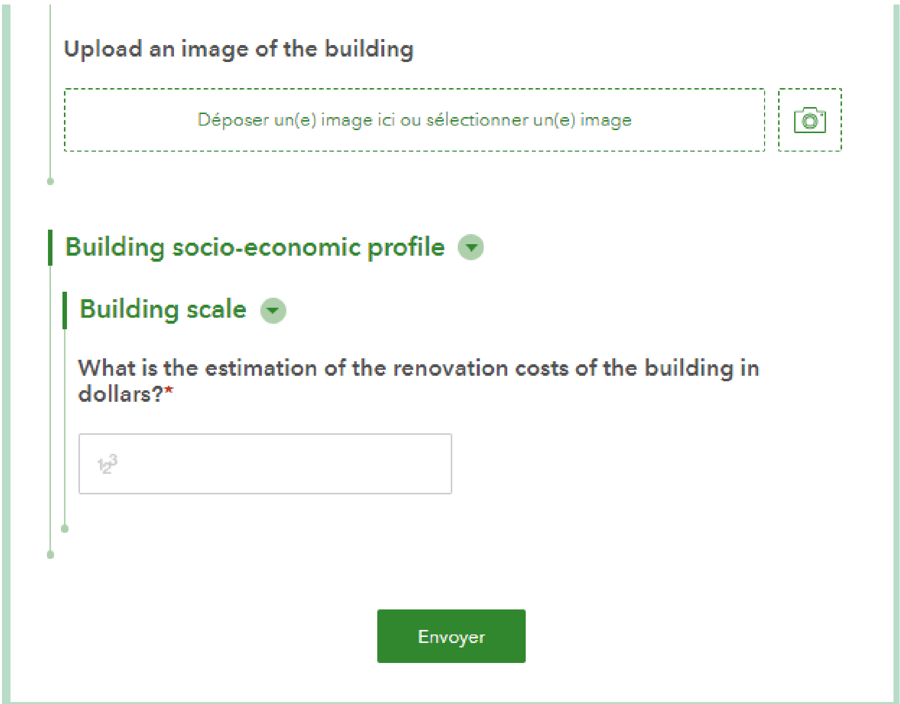

Figure A-10. Data collection survey for buildings assessment (3) ; Source: Author.

iii) Level of access 2 (LOA2)

This represents the NGOs and public authorities level of access to the platform. It englobes the LOA1, therefore they have access to data collection survey, and projects monitoring dashboard. In addition, they can view the data and the results of the assessed buildings via the dashboard (Figure A-11). Then, they can fill an application to a specific buildings reconstruction project, with the required information (Figure A-12, Figure A-13 and Figure A-14). A list with projects application is then created and stored.

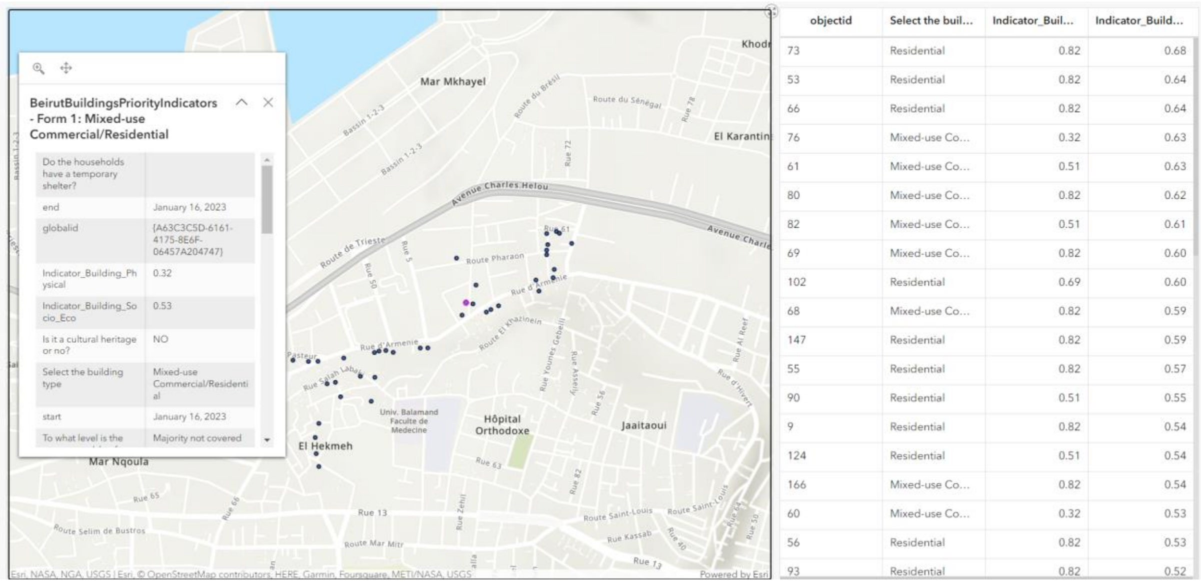

Figure A-11. Buildings Information Physical Priority Index and Socio-Economic Priority Index; Source: Author.

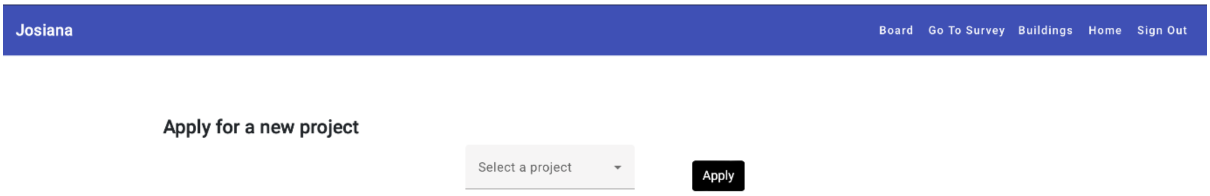

Figure A-12. Apply for a new reconstruction project form by NGOs (1) ; Source: Author.

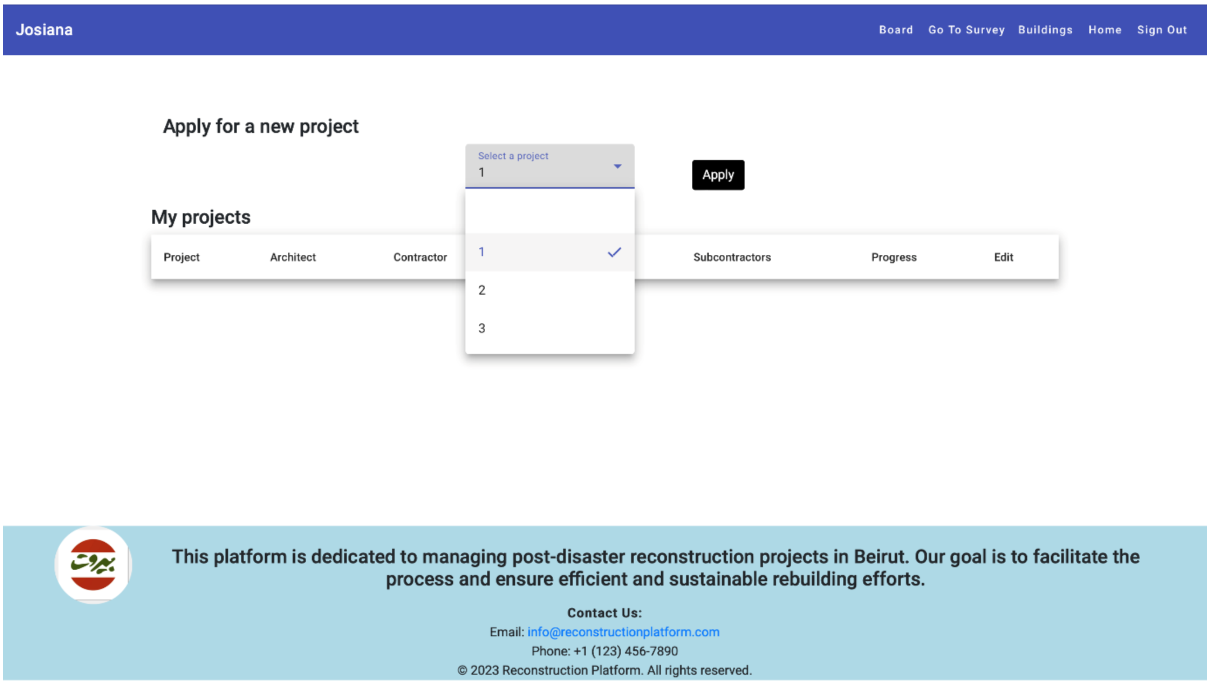

Figure A-13. Apply for a new reconstruction project form by NGOs (2) ; Source: Author.

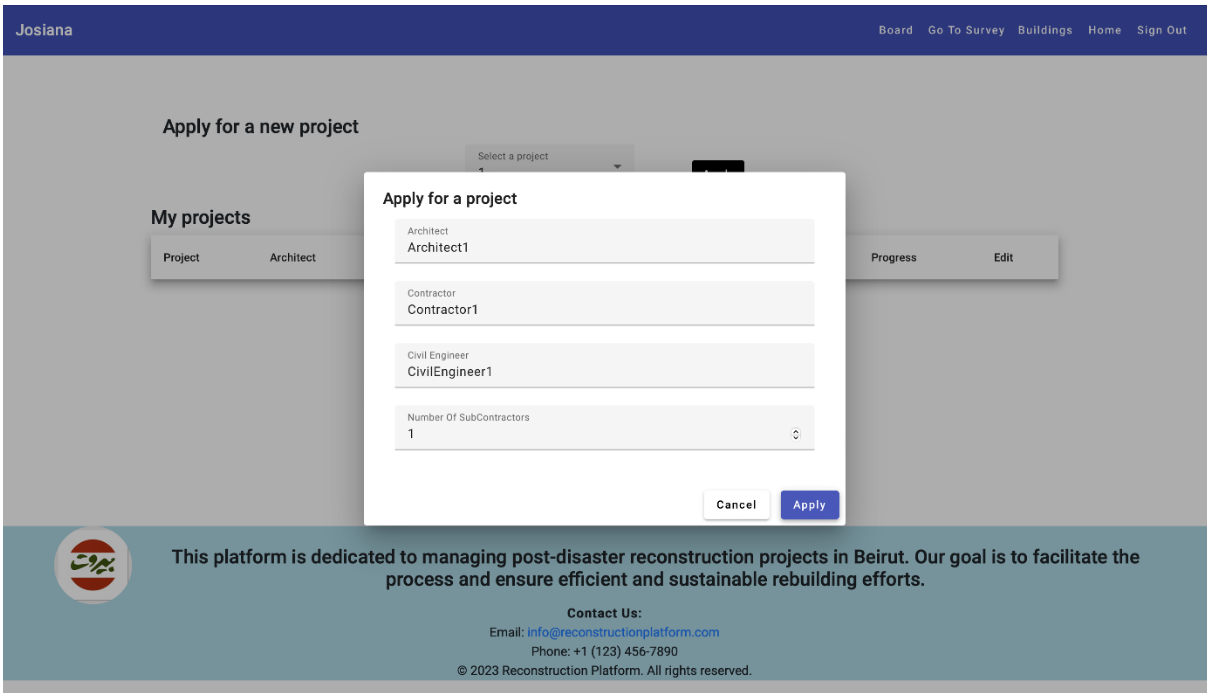

Figure A-14. Apply for a new reconstruction project form by NGOs (3) ; Source: Author.

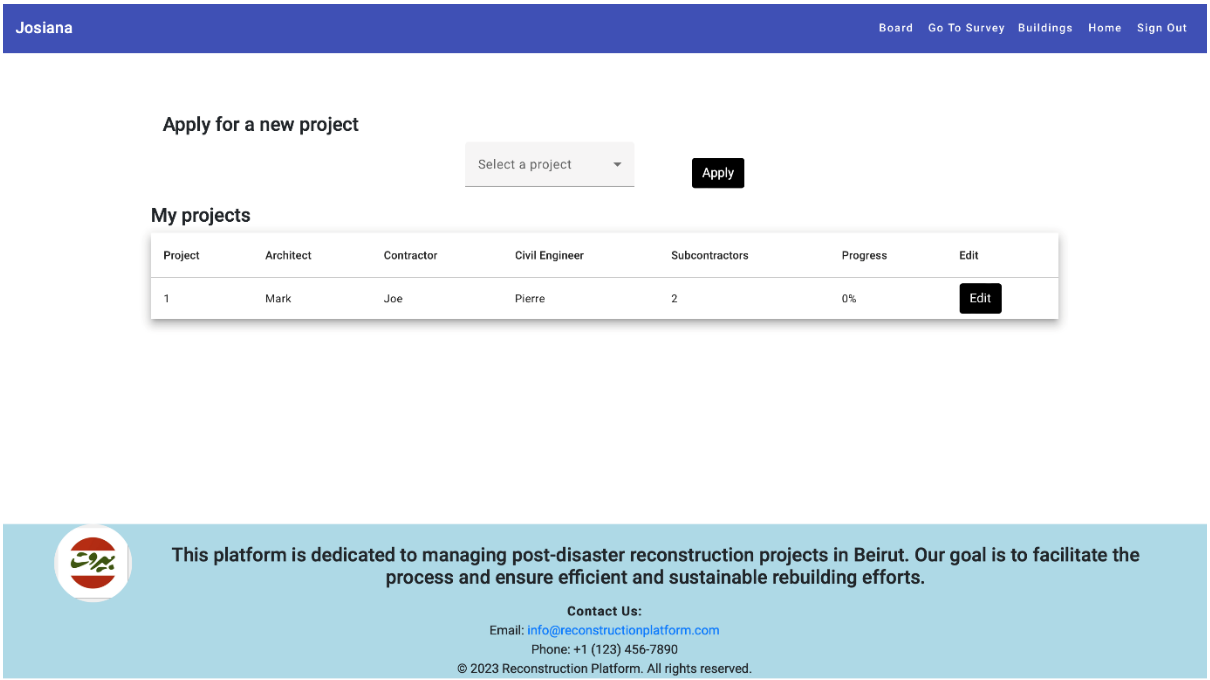

Figure A-15. List of reconstruction projects for which the specific NGO applied; Source: Author.

Once the public authority approves to give this NGO the reconstruction permit they applied for, the NGO can update and edit the information regarding the reconstruction progress Figure A-16).

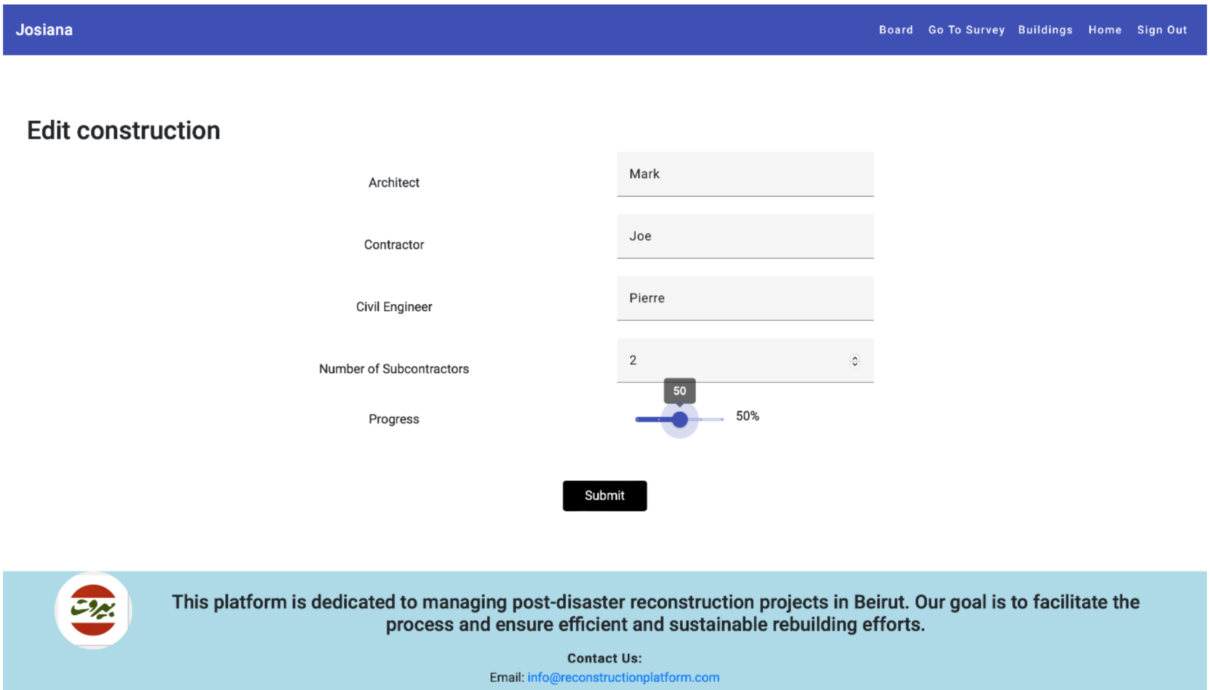

Figure A-16. Edit reconstruction project information by the NGO in charge; Source: Author.

iv) <u>Level of access 3 (LOA3)</u>

This level of access is reserved for the public authority, that is concerned with the decision-making process regarding the reconstruction projects permits. In the case of Beirut, it is the

Municipality. They can view the list of projects application by the registered NGOs. They can contact them for more details about the projects and the feasibility of their proposal, and if they approve their application, they proceed to the legal permit procedure (Figure A-17). Once the legal permit is issued, the corresponding NGO is allowed then to proceed to the execution phase of the projects with the necessary actors: architect, engineers, contractors and sub-contractors, … The public authority creates a dashboard for the project where the NGO can upload information about it, and give updates about the work progress. This dashboard could be viewed by all the members of the platform, which reinforces the transparency of the reconstruction process.

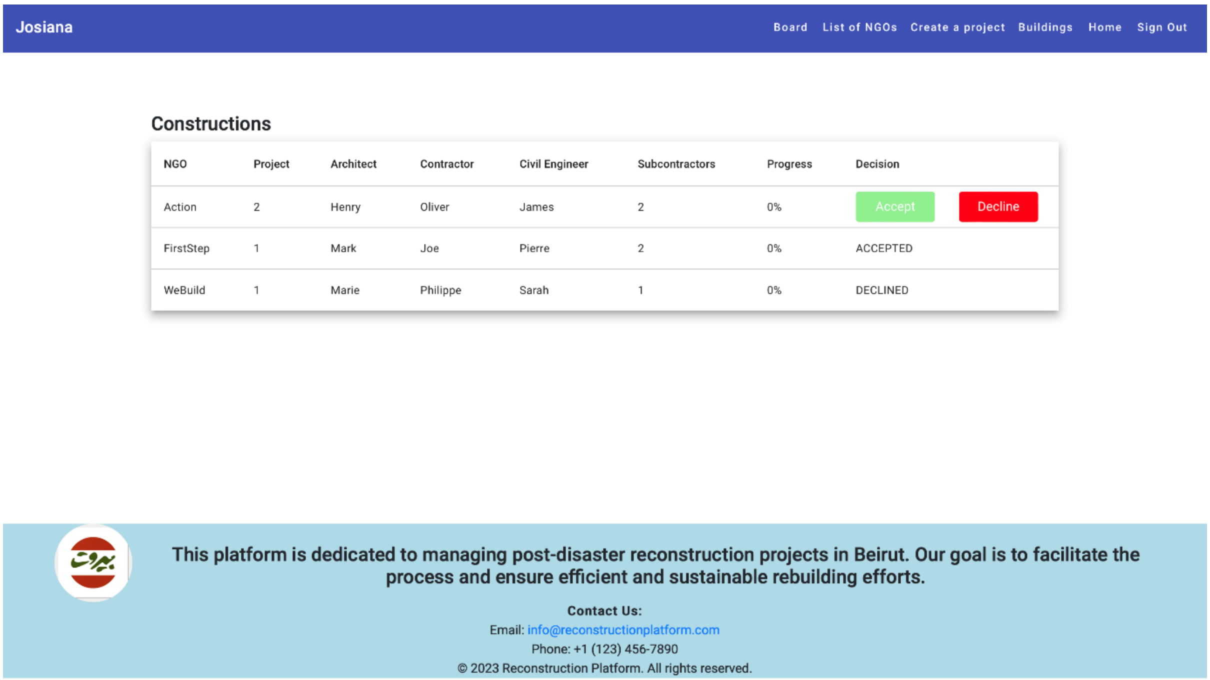

Figure A-17. List of NGOs projects application as seen by the public authority ; Source: Author.

v) <u>Level of access 4 (LOA4)</u>

The last level of access is the for the website admin. This level controls the buildings' data set, processes the data analysis and updates the results visualization on the dashboards.

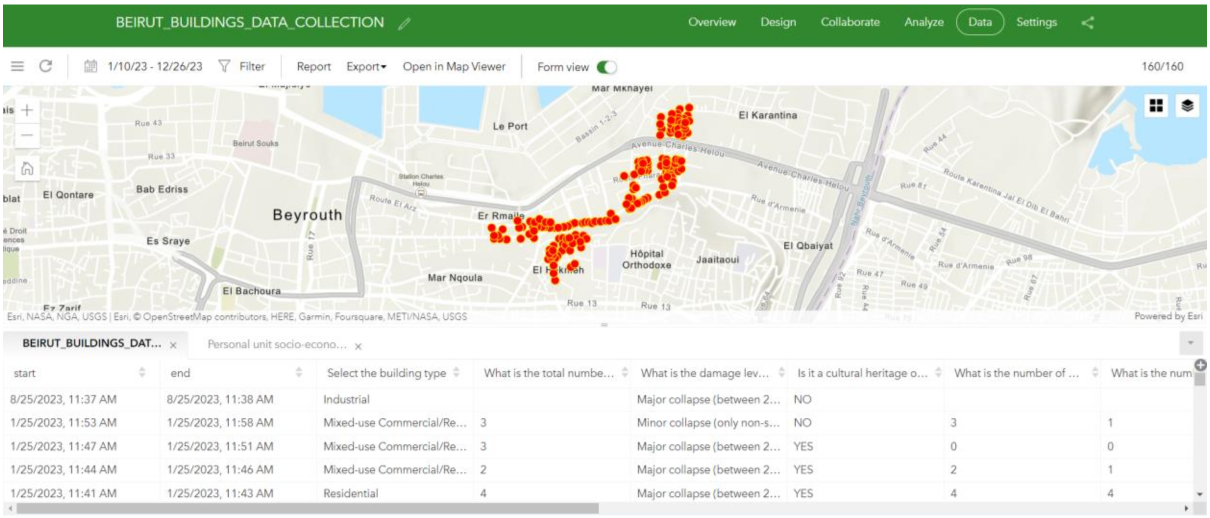

Figure A-18. Dataset of the assessed buildings in Beirut.

Endpoints

<u>Authentication Endpoints</u>

<u>Login Endpoint</u>

- URL: /auth/login
- Method: POST
- Consumes: application/json
- Description: Authenticates a user based on the provided credentials (email and password). If successful, it returns a JWT token along with user information.

<u>Signup Endpoint</u>

- URL: /auth/signup
- Method: POST
- Consumes: application/json
- Description: Registers a new user with the provided information.

<u>Construction Endpoints:</u>

<u>Create Construction Endpoint</u>

- URL:/constructions
- Method:POST
- Consumes:application/json
- Description: Creates a new construction project. Requires the ID of the NGO applying for the project.

<u>Accept/Decline Construction Endpoint</u>

- URL: /constructions/{constructionId}/decision

- Method: PUT
- Path Variable: constructionId - ID of the construction project
- Request Parameter: accepted - Boolean indicating whether the construction is accepted or declined.
- Description: Accepts or declines a construction project based on the provided decision.

Get Constructions by NGO Endpoint

- URL: /constructions/ngo/{ngoId}
- Method: GET
- Path Variable: ngoId - ID of the NGO
- Produces: application/json
- Description: Retrieves a list of constructions associated with a specific NGO.

Edit Construction Endpoint

- URL: constructions/{constructionId}
- Method: PUT
- Path Variable: constructionId - ID of the construction project
- Consumes: application/json
- Description: Edits the details of a construction project.

Get Constructions with NGOs Endpoint

- URL: /constructions
- Method: GET
- Produces: application/json
- Description: Retrieves a list of constructions with associated NGOs.
- Response (JSON Array of GetConstructionsWithNgos):**

Get Construction by ID Endpoint

- URL: /constructions/{constructionId}
- Method: GET
- Path Variable: constructionId - ID of the construction project
- Produces: application/json
- Description: Retrieves details of a specific construction project by its ID.

Project endpoints:

Get All Free Projects Endpoint

- URL: /projects
- Method: GET
- Produces: application/json
- Description: Retrieves a list of all available projects.

Create Project Endpoint

- URL: /projects
- Method: POST
- Consumes: application/json
- Description: Creates a new project based on the provided ID.

Limitations and future improvement

This web platform represents a straightforward implementation of the smart post-disaster reconstruction framework outlined in Chapter IV for Beirut. The platform has certain limitations, including the following:

- While crowdsourcing is a promising avenue for data collection, engaging the community and generating a substantial amount of data, its reliability remains uncertified due to being sourced from community members. To mitigate the risk of false data, the platform requires member registration before data collection, with administrative approval for both registration and data points. A future enhancement may include a tool to assess the quality of member contributions.
- The platform utilizes an ArcGIS application for data collection, analysis, and visualization of results, necessitating the purchase of software and built-in applications. Developing a customized application from scratch, rather than acquiring an ArcGIS license, is a feasible alternative.
- The Physical Priority Index and Socio-Economic Priority Index are tailored to the Beirut context pre- and post-explosion, with indicators chosen and evaluated by local experts. However, cities are dynamic and intricate systems that evolve over time, requiring regular revisions and updates to indicators and indices to align with current situations.
- Recognizing the sensitivity of building data, a robust security system is imperative before publishing and making the application operational.
- To enhance usability, a mobile application should be developed alongside the web platform, enabling offline data collection during internet outages, with subsequent uploads when connectivity is restored.
- Consideration should be given to adding a page for disseminating city updates, as well as information on disaster awareness and prevention programs to improve community resilience and social cohesion.
- While contemplating additional dimensions such as environmental conditions and infrastructure functionality, it is crucial to maintain simplicity in question volume and complexity to prevent community discouragement from participation.

Conclusion

In this appendix, a straightforward implementation of the smart post-disaster reconstruction framework in Beirut was presented. This application has the potential to serve as a foundational element for a city platform that actively involves various stakeholders, ranging from the local community to decision-makers. The transparency of data plays a pivotal role in mitigating corruption, especially in the allocation of funds. By encouraging citizens and volunteers from non-governmental organizations (NGOs) to participate in data collection, the process can be expedited, proving to be invaluable in post-disaster scenarios. It's crucial to note that this platform is not exclusively designed for the post-explosion reconstruction of Beirut; rather, it can function as a versatile post-disaster platform, applicable in the aftermath of any potential future event.