Natural Hazards Research Australia

Natural hazards and resilience in complex urban systems

Final Report

August 2026

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Version	Release history	Date
1.0	Initial release of document	14/08/2026

Australian Government

Natural Hazards Research Australia receives grant funding from the Australian Government

We acknowledge the traditional custodians across all the lands on which we live and work, and we pay our respects to Elders both past, present and emerging. We recognise that these lands and waters have always been places of teaching, research and learning.

Publisher:
Natural Hazards Research Australia

ISBN: 978-1-923057-62-3

Report number: 90.2026

August 2026

Cover: Sander, Adobe Stock

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List of Acronyms

AIDR	Australian Institute for Disaster Resilience
CBA	Cost-benefit analysis
CG	Commonwealth Government
COAG	Council of Australian Governments
DRF	Disaster Ready Fund
DRR	Disaster risk reduction
EOI	Expression of interest
FAQ	Frequently asked questions
IPCC	Intergovernmental Panel on Climate Change
LG	Local Government
MCA	Multi-criteria analysis
NEMA	National Emergency Management Agency
NERAG	National Emergency Risk Assessment Guidelines
NG	Non-government
NGO	Non-government organisation
NSW	New South Wales
PMC	Project Management Committee
PS	Private sector
Qld	Queensland
RMIT	Royal Melbourne Institute of Technology
RS	Research sector
SA	South Australia
SAG	Stakeholder Advisory Group
SG	State Government
UN	United Nations
UNDRR	United Nations Office for Disaster Risk Reduction
Vic	Victoria
WA	Western Australia

Acknowledgements

The project team acknowledges the people of the Woi wurrung and Boon wurrung language groups of the eastern Kulin Nation on whose unceded lands we have conducted the research for this project, and the traditional owners and custodians of Country throughout Australia. We pay respects to Ancestors and Elders past and present who have always been caring for Country. We honour the work of emerging leaders standing strong for Country. We pay our respects to Country, the lifeworld that sustains us all.

We would like to thank everyone who contributed to the study, particularly the interview and focus group participants, our Stakeholder Advisory Group and the Project Management Group (Melanie Rebane Reconstruction Authority New South Wales, John Richardson Australian Institute for Disaster Resilience (AIDR), Kieran O'Donnell National Emergency Management Agency (NEMA)), and Natural Hazards Research Australia (the Centre) staff (particularly Dr Mary Cadeddu, Vana Demetriou, Joanna Wood and Dr Blythe McLennan (now AIDR)). We would also like to thank Júlia Millán Ceballos who supported the project during her internship at the Centre for Urban Research, RMIT University.

Executive summary

Australia is one of the world's most urbanised countries, with around 86% of its population living in cities, and nearly 60% in Sydney, Melbourne, Brisbane and Perth. Urban expansion, climate change, and socio-economic shifts are increasing exposure to natural hazards (e.g., heatwaves, floods, bushfires), which can interact to produce multidimensional, cascading and compounding disaster impacts. These complex impacts demand a systems-based understanding of disaster risk and vulnerability in urban systems to successfully build resilience.

This report presents findings of the Natural Hazard Research Australia-funded and supported project *Natural hazards and resilience in complex urban systems*. The project comprised four project phases. Phase 1 analysed the state of knowledge of multidimensional, compound and cascading disaster impacts in major urban areas, including the ways in which urban disaster risk emerges from the complex interplay of the many systems and subsystems that make up a city and the resultant need for resilience building. Phase 2 explored current and emerging practices for conceptualising and mapping vulnerabilities and resilience. Phase 3 investigated current practices of prioritising and influencing urban resilience investments. Phase 4 translated the research of Phases 1 to 3 into a Practical guidance tool for conceptual mapping of resilience and vulnerability in complex urban systems (including a proof-of-concept study), Principles and Recommendations for Urban Resilience Investment and a guidance document on monitoring and evaluating of resilience investments. This phase furthermore involved presentations, webinars and developing communication products.

The research design included literature reviews, document and policy analysis, stakeholder surveys and 39 interviews across Australian government, NGO, private and utility sectors, plus stakeholder engagement through a Stakeholder Advisory Group (SAG) and a Project Management Committee (PMC), and presentations at professional and academic conferences.

Many concepts and findings described in this report are relevant to both urban and rural areas. However, the focus of this research is on complex urban systems, and some concepts and characteristics are unique or particularly pronounced in urban systems. Specific characteristics of urban systems include: the concentration of assets and people amplifying disaster consequences, including feedback loops and cascading impacts; the number and diversity of actors; and complex governance situations. These characteristics mean that a systems approach to natural hazards in resilience and collaboration on the city-regional level is warranted.

The current status and barriers for understanding natural hazards and resilience in complex urban systems

Australian policy and practice increasingly recognise the necessity of multi-hazard, multi-risk and place-based approaches to disaster risk reduction, particularly in complex urban systems – driven by international agreements (Sendai Framework) and Australian strategies (e.g. National Strategy for Disaster Resilience), and recent experiences of multidimensional, compound and cascading disaster impacts. However, while there is an understanding that these types of connected and interdependent disaster impacts need to be understood better to increase resilience and reduce disaster risk, the terms are often vague or inconsistently applied, both in policy and research. Similarly, while practitioners and policymakers understand the importance of systems thinking – and understanding thresholds and feedback loops – our interviews revealed that there is not an equally deep understanding of the characteristics of systemic risk in Australia nor of the impacts of the nature of urban systems as open not closed, and as dynamic not static, or at least not an understanding of how to work with these characteristics.

Based on the research we can identify gaps and barriers in knowledge and understanding of disaster impacts in complex urban systems and why it is so difficult to understand and predict compound and cascading disaster impacts. Barriers include the difficulty of integrating thinking across multiple systems, hazards and timeframes. Specialists (e.g., engineers, planners, and public health practitioners) tend to focus on their domains, potentially overlooking wider system interactions and consequences. Another barrier is the uncertainty or unpredictability of hazard impacts and feedback loops between systems, particularly in the context of shifting magnitude, frequency, intensity and duration of hazard events. When looking at resilience building, barriers or challenges

are also trade-offs between different measures. For example, while establishing green infrastructure may contribute to reducing heat in an urban area, it might also increase the risk – or the risk of higher impacts – of bushfires. Gaps in knowledge include the comprehension of some interdependencies, how to moderate the severity of long-term impacts on communities, limited situational awareness through insufficient data collection, and integration of local knowledge and capacity.

A challenge of complex urban systems is that they comprise a multitude of actors, some of them directly involved in disaster management or climate change adaptation and others not. The decisions of all these actors play into building resilience and reducing disaster risk in the urban system. Thus, the inclusion and involvement of all actors is vital but challenging at the same time.

Due to the diversity of actors, there is also diverse landscape of conceptualisations of vulnerability and resilience. Here, it would be helpful if key terms (e.g. vulnerability, resilience) were more clearly defined when they are used, or if a common ground could be established to reconcile differences. The 'clearer' definition can entail highlighting the particular context in which the term is utilised ('to what' and 'of what'), such as using 'community resilience to disasters' or 'asset vulnerability to sea-level rise'.

Promising approaches to bring actors together include the establishment of relevant networks or specific events or forums. These could for example be place-based to improve the resilience of certain areas in the city and bring local actors together. Furthermore, increased coordination between government agencies, private sector actors, and local communities can lead to potential joint approaches to building resilience as well as to increased efficiencies in disaster response. The events or forums could be supported by capability building tools for resilience which can assist in increasing awareness of the need for resilience and how to possibly achieve it. Inclusion of resilience considerations in government budgets and mandatory climate or disaster reporting can also drive systemic change by making resilience an essential part of every-day decisions.

Prioritising and influencing resilience investment

Resilience investment has come more into focus in recent years. Resilience investment aims to decrease asset and community losses caused by natural hazard events, create value and enhance long-term urban sustainability. Influencing investment as one element of resilience investment aims to move investment into the 'right' direction and is often undertaken by government funding particular programs, but also by funding applicants to influence what types of activities are funded. Prioritising investment as another key element of resilience investment is necessary due to limited budgets and to achieve the best possible outcome. Examples of approaches to prioritising resilience investment include:

- identifying place-based vulnerabilities (e.g. areas with a high risk of natural hazards)
- determining specific thresholds or stressors (e.g. in a drought prioritising keeping green infrastructure alive)
- identifying ways to support the majority of residents
- identifying critical infrastructure and system nodes
- identifying where the investment can achieve the most benefit (e.g. based on resilience principles)
- adding funds to general investments to increase resilience of the investment.

In Australia, investment mechanisms include government funding programs across national, state and local levels. Private sector investment occurs to a lower extent and is often related protecting business assets.

Several frameworks and approaches to resilience investment have been developed in recent years both by public and private stakeholders and are constantly advanced to bring 'resilience thinking' into budget considerations. These frameworks include consideration of the interconnectedness of risks, vulnerabilities, and impacts across different systems and sectors by considering multidimensional impacts, including social,

economic, environmental and infrastructural consequences. However, implementation of these existing frameworks is slow, and it seems that political will and/or high risk of disasters in an area are key prerequisites for implementation. Potentially, regulation around the necessity of a systems approach to government investment could support implementation.

Understanding the impact of resilience investment is a vital element of prioritising investment. Procedures for understanding the impact include assessment before implementation (e.g. through cost-benefit analysis (CBA)), during the initiative (through monitoring) and when an initiative has been completed (through evaluation). Insights from monitoring and evaluation can then be used for subsequent investments. Outputs of urban systemic risk assessments can also provide valuable input into decision-making. This includes assessment of current risks as well as emerging and future risks (e.g. through scenario planning). However, we found that in practice monitoring and evaluation of resilience investment is often conducted with a focus on outputs rather than the desired resilience outcomes (i.e., on-time/budget vs resilience impact). Reasons for this situation include challenges for monitoring and evaluation of resilience investment which comprise a lack of standardised approaches and guidelines for measurement/quantification of resilience benefits; the lag between investment and realised benefits; that causality may only be evident after disaster events; a possible change of expectations during the evaluation period due to new information or social change; and low availability of data. The risk of maladaptation (i.e., well-intentioned projects having unintended adverse effects) also needs to be included in scope of evaluations to ensure that possible detrimental outcomes are not omitted in the process.

Despite these challenges, useful approaches for monitoring and evaluation of resilience investments exist and are described in the project's guidance document on monitoring and evaluating of resilience investments. To incorporate disaster resilience into general decision-making, resilience metrics will need to be mainstreamed into general decision-making tools, such as CBA. Policies that require the monitoring and evaluation of resilience investment – that is, their resilience outcomes, would help develop more standardised approaches. Furthermore, finding ways to evaluate resilience outcomes regardless of a hazard event is necessary.

Opportunities for enhancing understanding of complex urban systems and building resilience

Starting from 'what we value' in systemic risk assessment can assist in enhancing approaches to building resilience in complex urban systems. By focusing on what we value, we can move to a multi-hazard approach and by seeking to define what it is that we value, we can go beyond the concepts of life and property to also consider critical system properties and functions, such as liveability, social equity and livelihoods. In this context, a multi-risk approach can help ensure that a place-based approach is taken to disaster risk management rather than focusing on the hazard(s) alone.

Preparations for potential risks in non-linear systems, such as a city, require a shift from definitive prediction to probable outcomes. Guidelines (such as NERAG) and tools (such as Monte Carlo analysis) can assist in understanding risk and uncertainty and support understanding of compound and cascading disaster impacts in complex urban systems. Preparing adaptive resilience planning strategies that include attention to the precautionary principle, anticipatory action and adaptive governance can support the approach to deal with probable outcomes. Resilience planning should include different approaches to resilience, such as engineering, socio-ecological or adaptive and transformative resilience.

To develop place-based multi-hazard approaches, resilience planning strategies and effective resilience investment, there is a need to collaborate on the city-regional level and develop a city-wide awareness of systemic risk. To improve city-wide approaches there may need to be some sort of regulation for cooperation on city-wide risk assessments and also resilience investment decisions.

Yet, equally important to developing resilience planning strategies and resilience-building measures is the need for adequate funding (or an understanding of how to best prioritise limited funds), trained personnel and informed community members (showing a need for capability building resources) and necessary infrastructure

(which is partly related to funding) to be able to develop and implement resilience-building strategies and disaster risk reduction frameworks.

Disaster risk reduction includes reducing exposure to future hazard risk, for example through proactive risk reduction (e.g., risk considerations embedded in all development planning), or corrective risk reduction (e.g., through land use planning decisions as relocation from a high-risk area or through engineering works such as levees). However, it also includes reducing vulnerability, for example through reducing socio-economic and political drivers of vulnerability. Mapping exposure risk and social, economic and demographic dimensions can assist in understanding how vulnerability is experienced and what drivers of vulnerability are. Once the experiences and drivers are well understood, the sensitivities and vulnerabilities that intensify future disaster risks can be mitigated. Importantly, within complex urban systems, disaster risk reduction must not only take account of the biophysical systems, such as weather systems, but also the people who live in them and the built, digital and human infrastructure systems they have created. As such, the multidimensional impacts of natural hazard events are exacerbated and intensified through feedback loops within and between those systems, bringing with it additional dimensions and challenges of exposure and vulnerability. Thus, disaster risk reduction and resilience-building must move upstream, for example through integrated, adaptive, and anticipatory frameworks that are multidimensional, and account for cascading and compounding risks.

Social learning can also assist in understanding and developing approaches to resilience building in complex urban systems. Social learning builds on reflection of disaster experiences at community and agency levels and the consolidation of the resulting knowledge, skills and values into new community-wide mental models of the relationships between human and natural systems. Formal inquiries and royal commissions after disasters can serve a similar purpose by analysing where the system was not sufficiently prepared for a disaster and what resilience-building measures are necessary to avoid hazard impacts in the future.

Finally, the produced outputs from the project aim to assist in the understanding of natural hazards and approaches to building resilience in complex urban systems. These outputs include a Practical guidance tool for Conceptual Mapping of Resilience and Vulnerability in Complex Urban Systems, Principles for Prioritising and Influencing Resilience Investment and a guidance document on monitoring and evaluating resilience investments.

The Practical guidance tool provides the conceptual basis for understanding the complexity of risks in urban areas. It is organised around five modules and a glossary and provides end-users with a flexible way to approach key concepts that support resilience, vulnerability and systemic risk assessments. The tool presents a visual and textual conceptualisation of resilience and vulnerability, as well as a typology of disaster impacts and key terms. It also includes a library of current and emerging practices in this space, and a section that supports self-reflection on own practices (see Appendix 1 for an overview). The Practical guidance tool was tested through a proof-of-concept study.

The Principles for Prioritising and Influencing Resilience Investment are normative statements, designed to guide investment decisions by promoting holistic approaches that embed resilience considerations at every stage of development and policymaking. The overarching principles are specified further through statements (‘processes’), to increase tangibility. Recommendations provide further detail for policy and decision-making and activities for resilience investment. Additionally, a checklist entails more detailed questions for reflection and assessment (see Appendix 2 for a list of the principles and Appendix 3 for the recommendations).

The guidance document on monitoring and evaluating resilience investments provides processes and questions that end-users can employ to undertake monitoring and evaluation of resilience investments and ensure learning from those investments. The guidance document provides a brief overview of monitoring and evaluation and specific requirements and challenges in the context of resilience investment, and a description of relevant tools for monitoring and evaluation. It then presents several elements (i.e. steps and tools) that can be utilised to monitor and evaluate resilience investment. These tools assist in assessing whether a project or

initiative has achieved its resilience objectives as well as long-term returns and value across sectors (see Appendix 4 for a brief overview).

These tools hold the potential to support project development, capacity development, assessment of vulnerability and resilience, risk assessment, disaster adaptation planning and decision-making for resilience investment particularly in complex urban systems.

End-user statement

Melanie Rebane, Disaster Risk Reduction & Adaptation, NSW Reconstruction Authority:

"The NSW Reconstruction Authority's (RA) involvement in the RMIT project, led by Natural Hazards Research Australia, has improved understanding of applying systemic risk in disaster risk reduction and adaptation planning, showing how natural hazards interact with infrastructure, land use and social systems. The RA helped test and adapt the draft Practical guidance tool for systemic risk assessment in complex urban systems, making it more practical for use in disaster adaptation planning (DAP). The tool helps tackle real world challenges like cascading impacts, interdependencies, data gaps and uncertainty, supporting practitioners in making informed decisions and strengthening resilience in high-risk urban areas."

Introduction

Australia is one of the world's most urbanised countries with a little over 86% of its total population living in a major urban centre. Just under 60% of the population live in the four largest cities: Sydney, Melbourne, Brisbane and Perth. It is expected that 75% of Australia's projected future population growth will occur in these four cities (Infrastructure Australia, 2018).

Australia's urban areas are variously exposed to multiple and interacting natural hazards, such as extreme heat, severe rain and hail events, storm surges and coastal inundation, floods, tropical cyclones, bushfires on their outskirts and earthquakes. Such natural hazards can lead to disasters when they trigger multidimensional, cascading and compounding impacts that exceed the coping capacities of urban systems. The frequency and intensity of some of these natural hazards are projected to increase due to climate change while rapid urbanisation, and demographic, social and economic shifts change urban landscapes and systems. In the face of this future hazard intensification, "a more mature understanding of the root causes and effects of disaster risk and systemic vulnerability is needed, so that our efforts to mitigate the risk and build resilience can meet the challenges of the future" (Department of Home Affairs, 2018a, p.4).

This report summarises the findings of the Natural Hazards Research Australia-funded project *Natural hazards and resilience in complex urban systems*. The project is grounded conceptually in the concept of 'the city as a system of systems' and the complex interactions and relationships between urban systems. This complex, tightly interconnected and dynamic nature of urban systems complicates risk assessment and disaster risk reduction in urban settings, as decisions, coordination and action by multiple levels of government, businesses, community organisations and households impact on risk and risk management. Moreover, urban areas are highly diverse – not only spatially, physically and economically, but also socially, culturally and politically. The impacts of a natural hazard event on an urban system, including its people and the built environment, therefore depends on "where, when and to whom it occurs" (Gabriel et al., 2019, p.1) – and in terms of building resilience to hazard and disaster risk in cities, the issue of "whose resilience and whose city" becomes important (Vale, 2013, p.191).

A systems perspective can identify significant issues and the root causes of urban hazards and disaster risk, and enable us to identify ways of reducing or mitigating those risks. Meadows (2008) defines a system as "an interconnected set of elements that is coherently organised in a way that achieves something". In context of urban environments, systems thinking provides concepts and tools that go beyond studying the individual elements of a system to comprehend the full extent of its complexity – and to appreciate that the seemingly intractable problems and crises brought on by exposure and vulnerabilities to hazard events are created by the very systems in which they arose (Cabrera & Cabrera, 2023; Forrester, 2022; Meadows, 2008). An important first step in building urban resilience is increasing our understanding of the systemic nature of risks and vulnerabilities. At the same time, it is necessary to understand the context of current thinking, actions and decision-making to improve our actions, processes and procedures towards risk reduction and building resilience.

The findings of the project are intended to help us better understand how to prepare urban environments and those who live in them to be resilient to natural hazards and their cascading impacts. The study had three aims:

1. To increase understanding within the emergency management sector of:

- the systemic nature of urban centres and the multidimensional, compounding and cascading impacts arising from natural hazard events for communities located in major urban areas in Australia
- the ways in which these impacts may change over time under the influence of climate change, rapid urbanisation, and other factors to influence urban resilience
- the nature, scope and purpose of urban resilience policies and strategies.

2. To develop guidance for local and state governments, emergency services and community organisations to conceptually map vulnerabilities and resilience within urban systems at local scales; and demonstrate its application with a proof-of-concept case study.

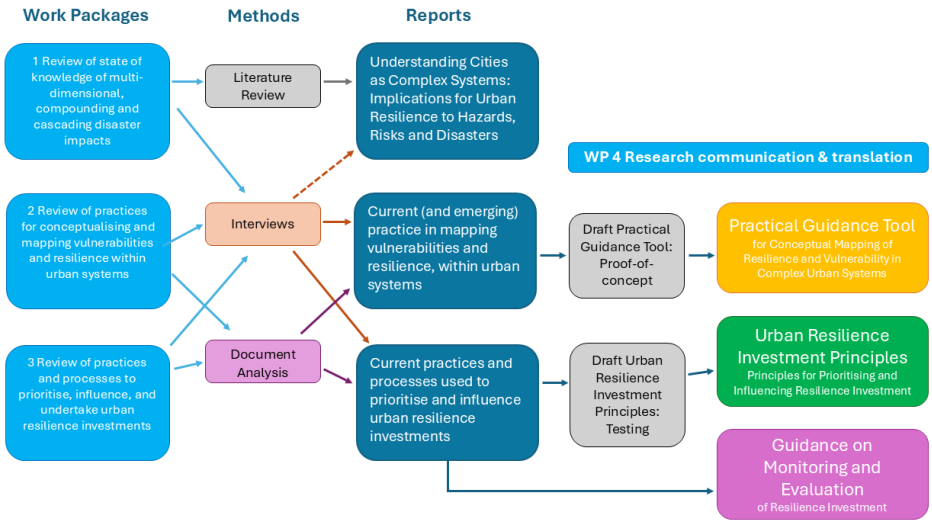
3. To develop process principles and standards for use by local and state governments, emergency services and community organisations to effectively prioritise and influence urban resilience investment at local, state and federal levels; and monitor and evaluate the outcomes of investment decisions.

To address these three objectives, three project phases (or Work Packages) were undertaken, complemented by a fourth phase involving dissemination, communication and capacity building activities to support the translation and adoption of research findings of the project.

- Phase 1 has analysed the state of knowledge of multidimensional, compounding and cascading disaster impacts in major urban areas, how these impacts may change over time, and the ways urban disaster risk is a product of the complex interdependencies among urban systems and subsystems, thereby emphasising the need for resilience building.
- Phase 2 has explored current and emerging practices for conceptualising and mapping vulnerabilities and resilience and reflected upon practices and how resilience thinking and practice may be advanced employing a systemic view of cities.
- Phase 3 has investigated current practices of prioritising and influencing urban resilience investments and considered principles and processes for decision-making for investing in different strategies for building urban resilience.
- Phase 4 has translated the research of Phases 1 to 3 into a Practical guidance tool for conceptual mapping of resilience and vulnerability in complex urban systems (including a proof-of-concept study), Principles and Recommendations for Urban Resilience Investment and guidance on monitoring and evaluating resilience investments. The Phase furthermore involved presentations, webinars and developing communication products.

Figure 1 presents the project design which is also the basis for the structure of the report. The report presents the findings in different sections, starting with a brief background section and the research approach. It then gives an overview of the research findings, starting with a brief description of findings from Phases 1-3, and then bringing those finding together and describing outputs based on the research findings. The Discussion highlights important themes from the research, while the Implications section presents next steps and conclusions. Appendix 5 provides definitions for relevant terms used in this report. The further appendices will be introduced in the text.

FIGURE 1 OVERVIEW OF THE PROJECT DESIGN



Background

The global population is rapidly urbanising (UN-Habitat, 2022; World Bank, 2024) and impacts of and losses due to natural hazards are increasing. Australia is no exception in this regard. It is a country that is prone to natural hazards with the most common hazards being bushfires, floods, storms and cyclones and many larger cities located in coastal areas or floodplains. Since colonial settlement, Australia has been an urbanised country – with about 86% of its population currently living in a major urban centre (Infrastructure Australia 2018). In addition, overall population numbers have been increasing consistently in the last decades and are forecasted to increase further, with over 75% of future population growth in the next two decades predicted to be in the four largest city regions (Centre for Population, 2023).

Cities as complex systems with multi-dimensional, compounding and cascading disaster risk

In large cities, hazard events are more likely to turn into a disaster – that is, serious disruption, death, damage to property and environmental losses, which require a government response to facilitate recovery – as the number of people and assets being impacted is larger than in rural areas, meaning that larger numbers of people may be impacted or may die, and costs of damages are higher (Stolte et al., 2024). The complex, tightly interconnected and dynamic nature of urban systems means that disruptions to supply chains and delivery mechanisms can be exacerbated by cascading and compounding impacts and heavily impact critical lifelines of water, energy, food, shelter, transport, communications, and livelihoods (Coaffee & Clark, 2017). For example, if a bushfire impacts the electricity network of a city, this impact cascades to traffic lights, street lighting, public transport, water supply, emergency and health services, food distribution, electronic payments, and telecommunications; greatly affecting the overall functioning of the urban system (Rehak et al., 2022). In addition, consequences can be more intensive for population groups with a higher risk of exposure and fewer opportunities to develop adaptive capacities, for example people with disabilities, low incomes and marginalised urban communities who have reduced access to information. Importantly, hazard event impacts include not only physical damages but also economic, social, health and other intangible impacts, while cities are incredibly diverse: spatially, physically, economically as well as socially, culturally and politically. The impacts of a natural hazard event on an urban system, including its people and the built environment, therefore depends on “where, when and to whom it occurs” (Gabriel et al., 2019, p. 1).

As cities grow outwards, they spread into more hazardous areas, such as coastal areas, flood plains and areas prone to bushfire, becoming more vulnerable to natural hazards. At the same time, with impacts of climate change extreme weather events become more frequent and intense, such as heat waves becoming longer, hotter and more common, increased frequency and severity of flooding, more unpredictable and damaging tropical cyclones and bushfires, and extended storm surges and coastal flooding due to sea level rise and coastal land subsidence (IPCC, 2021; Commonwealth of Australia, 2024).

With existing stressors and preceding hazard events, it becomes more common that exposure to non-extreme hazards, such as heavy rain over an urban catchment or a comparatively low-intensity bushfire in peri-urban areas can result in extreme consequences and disasters (Cutter, 2021). This is related to the fact that risks as well as impacts of natural hazards in urban systems can be multidimensional, compounding and cascading and feedback loops between systems and events can increase but also decrease impacts. In other words, impacts that cross the geographic (i.e., from place to place; for example, a disruption of supply chains impacting other locations) and sectoral (e.g., social, economic or environmental) boundaries of systems can create new, increased and more fragile interdependencies within and across systems. For example, flooding in a city can lead to inundated industrial premises causing fires and toxic smoke emissions impacting the environment as well as industrial production and with this employment and livelihoods. These effects can lead to longer-term

contamination of soil and water, impacting the health of communities and flora and fauna, making them more susceptible to further impacts or events. These interconnections can be based on events happening at the same time or shortly after each other in the same location (compound disasters, for example a storm event followed by a bush fire; or a strong rainfall during drought conditions) or when a first hazard event triggers a second event either in short succession (e.g. flooding from storms) or also over time (e.g. environmental degradation) (cascading disasters).These types of disaster impacts are discussed in more detail in the Research Findings section. Additionally, Figure 1 in this section visualises the different types of impacts. The potential for interdependencies and their impacts is something that needs to be considered in risk assessment and disaster management, particularly in complex urban systems, but is often also difficult to grasp and to model. However, as "(c)ompound and cascading risks, hazards and disasters are the new normal" (Cutter cited in NASEM, 2022), systemic risk assessment and multi-hazard approaches become necessary.

Cities as complex and adaptive systems

As cities are complex systems as well as adaptive systems, as systemic approach to disaster risk reduction and disaster preparedness is necessary, albeit not easy. The term 'complex' reflects that urban systems are dynamic, with complexity arising from sets of interconnected elements forming subsystems that interact with each other. This creates unexpected or uncertain outcomes that result in a system exhibiting properties and interactions different from the original elements and subsystems (Alaimo, 2021). The term 'adaptive' reflects that urban systems operate as a dynamic entity "capable of evolving and adapting to the environment" (Alaimo, 2021, p. 2). As such they can be said to be self-organising, adaptable and co-evolving but also unpredictable due to the systemic processes of interacting feedback loops, time lags and legacy effects, and thresholds and tipping points (Liu et al., 2007, 2021). In the case of natural hazards, the non-linear outcomes of such systemic interactions in complex urban systems increases the potential of hazards and risks to lead to disasters. These non-linear outcomes can be seen in the example of natural hazard impacting the electricity network mentioned above. Another example is an earthquake having direct damage such as mortality, morbidity and destruction of critical assets such as bridges or hospitals or telecommunications, which has indirect and often non-linear disruptions stemming from such direct damages, as impacts of telecommunication on emergency services such as hospitals, fire departments and police stations, causing difficulties in coordination and delaying assistance to populations in need. Furthermore, it could have long-term impacts on society and the economy from damage to supply chains, such as businesses experiencing disruptions due to a lack of information between customers and suppliers; and individuals unable to contact essential support services as well as their families, friends and caregivers. Flow-on impacts of damage to telecommunication networks could also lead to a lack of accurate information and with this the spread of fake news, which could trigger civic unrest. Understanding cities as complex adaptive systems assists in understanding the impacts of hazards and vulnerability in cities and how resilience may be developed as a successful approach to managing disaster risk in cities.

Disaster (risk) management approaches

Globally, disaster management has changed from a focus on the management of disasters to a focus on disaster risk management. The focus on disaster risk reduction has gained significance with the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR, 2015) which was adopted by Australia and other members of the United Nations at the third United Nations World Conference on Disaster Risk Reduction. The Framework was designed to work in concert with the UN Sustainable Development Goals and the Paris Agreement (also adopted in 2015), emphasising the interconnectedness of disaster risk management and climate change mitigation and adaptation. The Sendai Framework emphasises the importance of "the cooperation of diverse institutions, multiple authorities and related stakeholders at all levels" (UNISDR, 2015,

p. 21), and has an increased focus on building community resilience and on vulnerability (Raikes et al., 2022). Furthermore, it highlights the importance of risk-sensitive investments to prevent new risks and promote resilience (UNISDR, 2015). Similarly, Australia's National Strategy for Disaster Resilience (COAG, 2011), promotes a whole-of-government approach and highlights that disaster resilience is a shared responsibility and emphasises the need for a greater focus on prevention, mitigation, preparedness and building capability. Based on this, the National Disaster Risk Reduction Framework (Department of Home Affairs, 2018b) – co-designed by all states and territories, local government and key private sector representatives – outlines the 2030 vision for disaster risk reduction in Australia, while the Australian Disaster Preparedness Framework (Department of Home Affairs, 2018c) is a guideline for all jurisdictions to develop capabilities to effectively prepare for and manage severe to catastrophic disasters. Similarly, the Second National Action Plan for Disaster Risk Reduction (NAP2) (NEMA, 2023), which aims to implement the National Disaster Risk Reduction Framework, highlights four priorities for reducing systemic disaster risk, including 'Understand disaster risk' (Priority 1) and 'Enhanced investment (Priority 3).

The diverse landscape of resilience

Disaster risk reduction and the concept of resilience are closely connected, and resilience has been the focus of the Hyogo Framework for Action 2005-2015: Building the Resilience of Nations and Communities to Disasters (UNISDR, 2005) which preceded the Sendai Framework and the above-mentioned National Strategy for Disaster Resilience. These documents highlighted the importance of knowledge of risk in 'promoting a culture of disaster resilience' (UNISDR, 2005, p. 7), showing the connection to disaster risk reduction. As such, this report focuses on urban resilience and disaster risk reduction as well investment in resilience building and disaster risk reduction.

Enhancing urban resilience is positioned internationally as an important approach for "dealing with future disaster/climate uncertainties and systemic risks such as pandemics, and for promoting and sustaining development" (Cao et al., 2021, p. 8). Overall, resilience is a broad and multi-faceted concept that has been used in a wide range of different professional and academic fields, including engineering, psychology, health, economics, organisational behaviour and risk management, among others (Koliou et al., 2018). Numerous authors have traced the diverse and changing definitions of the concept over time and its application in various fields (see, for example, Meerow, et al., 2016; Rogers, 2020). The result is that there is a diverse landscape of interpretations of the concept of resilience and varying degrees of clarity regarding what or who is the subject of resilience assessments ('resilience of what') and what is the point of reference being considered for such assessments ('resilience to what'). Sometimes, however, these aspects are more clearly specified, for example 'community resilience to disasters', 'settlement resilience to climate change'. For urban resilience the common theme in the perspectives is that resilience is considered a process for dealing with the systemic risks faced by cities due to their complexity and the compound and cascading effects of environmental hazards.

Urban resilience in this report

In the context of this report urban resilience is understood as[1]: The ability of a complex urban system to maintain identity and continuity while undergoing change in response to past, current and projected shock and stress disturbances. It relies on the system's capacity to absorb, accommodate, and adequately manage such disturbances across temporal and spatial scales, including their cascading and compounding impacts, through due consideration of current and emerging riskscapes. It also presupposes the system's capacity:

[1] See Appendix 6 for more detail on this definition.

- to re-organise, adapt and undergo transformation towards sustainability and climate responsibility in an efficient, synergetic and timely manner, including due consideration of risks emerging as a result of these changes
- to respect, support, integrate and be informed by diverse and relevant knowledge systems that are critical to these tasks
- to retain or enhance valued critical system functions, structures and feedbacks that support essential social-ecological processes serving human and biodiverse needs in a social-environmentally equitable, culturally respectful and ethical way

This comprehensive definition reflects the definition of resilience from the Global Resilience Partnership:

> *... the capacity to live and develop with change and uncertainty, which is well beyond just the ability to 'bounce back' to the status quo. It involves the capacity to absorb shocks, avoid tipping points, navigate surprise and keep options alive, and the ability to innovate and transform in the face of crises*. (Rockström, et al., 2023, p. 897)

In Australia, examples of considerations of urban resilience include, for example, the development of an Australian urban resilience framework (Lowe, et al., 2021) and the resilience strategies and associated activities of networks of local councils in Sydney, Melbourne and other cities (City of Melbourne, 2024; City of Sydney, 2025). However, despite attention to urban resilience in recent years, the complex, multiscale, nonlinear and variable way that urban systems interact with natural hazards, and with other shocks and stressors, has left a persistent gap between the aspirational goals and discourse of urban resilience on one hand, and the capacity that exists to enhance urban resilience in practice on the other. Further reasons for this gap include inadequate funding, trained personnel, necessary infrastructure or empowerment of stakeholders, particularly on the local level; a reactive rather than proactive footing (both due to reliance on traditional models and increasing frequency and intensity of events); governance silos between government levels as well as sector agencies; fragmented coordination between government, private sector actors and local communities and top-down governance (Fien et al., 2026; Angheloiu & Tennant, 2024). Actioning urban resilience initiatives in this complex context requires answers to the questions: "Resilience for whom and to what? When? Where? And why?" (Meerow et al., 2016).

Vulnerability in this report

Closely related to resilience is vulnerability – noting that it is not the inverse of resilience as is sometimes implicated – and increasing our understanding of vulnerabilities to multidimensional, compounding and cascading disaster impacts within complex urban systems is an important enabler for actioning urban resilience. As with resilience, vulnerability is conceptualised differently by different actors. As an example, UNDRR defines vulnerability as the "conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards" (UNDRR, 2017). In the Australian context, the 2018 report *Profiling Australia's Vulnerability: The interconnected causes and cascading effects of systemic disaster risk* prepared by the National Resilient Taskforce (Department of Home Affairs, 2018a) highlights that individual vulnerabilities can translate as collective vulnerability and that we need to ensure equity becomes an integral part of processes of resilience-building. Importantly, vulnerability used in the context of specific groups or people can be experienced as stigmatising so that care needs to be taken when talking about vulnerability. Current Australian practices and processes for conceptualising vulnerability will be discussed in more detail under research findings.

Investment for disaster risk reduction and resilience

The Sendai Framework not only emphasises a focus on managing disaster risk; one of its four targets is also related to investing in disaster risk reduction for resilience. Similarly, one of the four priorities of the Australian National Disaster Risk Reduction Framework (Department of Home Affairs, 2018b) is 'Enhanced investment'. The importance of investment in disaster risk reduction or resilience has been increasingly acknowledged in recent years, for example through the Productivity Commission (2014) which recommended that support for mitigation should be increased – from a 3% share of Australia's overall disaster funding. Similarly, projections suggest that investment in resilience measures could reduce the costs of disaster relief and recovery by more than 50% by 2050 (Deloitte Access Economics, 2024) – an estimate which did not include less visible, indirect (such as the costs of mental health impacts or unemployment or family violence) and intangible costs (such as the inherent value of cultural heritage and environmental values) due to disaster impacts.

This report considers both, investment in disaster risk reduction and investment in resilience initiatives under the broader label of resilience investment. However, there is an important distinction to make. Disaster risk reduction investments are focused on reducing existing risk or preventing new risk, for example through investment in land use zoning, improving the safety of existing infrastructure, early warning systems. These investments are predominantly related engineering approaches. In contrast investment in resilience initiatives is focused on capacities and capabilities of people, institutions, infrastructure and ecosystems, for example through investment in social protection, governance, preparedness trainings, ecosystem management and continuous integration of disaster risk management in planning.

The argument for providing funding into disaster risk reduction and resilience initiatives is that this funding will ultimately save money when a disaster hits, as it will contribute to lower impacts or even the avoidance of disasters, and with this, a decrease in spending on disaster response and recovery. Yet, resilience investment has its difficulties, as disaster risk is based on probabilities and eventualities, which may be difficult to incorporate into business cases or into political decisions. While risk in general is often included into business cases and political decisions, disaster risk in complex urban systems is challenging to model and predict, and sometimes also missing the relevant data sources. Additionally, it seems that for some policy makers and political decision makers, disasters are still perceived exceptional circumstances and are therefore not always considered in political decisions and policies (Kroen et al., 2025). An important point in this context is that resilience investment does not only help avoid damage but can also unlock economic opportunities and deliver broader social and economic benefits (Department of Home Affairs, 2018b). These co-benefits of resilience investment can include increased infrastructure reliability, safeguarding biodiversity, reduced emissions and pollution, improved climate change adaptation, heightened community building, enhanced public health (e.g. due to less pollution and increased social cohesion), improved labour skills, and the potential for lower insurance premiums (Helgeson et al., 2025; Resilient Futures Investment Roundtable & Climate KIC 2024) – an argument that needs to be further amplified. A further complexity of resilience investment, particularly in the context of urban resilience, is that interdependencies and feedback loops within (urban) systems need to be taken into account, to avoid maladaptive investment, that is, investment that might lead to positive outcomes for one sub-system or location but may impact other sub-systems or locations negatively. As such, a systems approach and systemic risk assessment are important prerequisites for resilience investment. Current Australian practices and processes for influencing and prioritising urban resilience investment will be discussed in more detail under the research findings.

Before presenting the research findings, the next section describes the research approach.

Research approach

This research comprised two research phases. The first research phase encompasses the initial research undertaken to understand the status of knowledge and the current practices and processes of conceptualising and mapping vulnerability and resilience as well as prioritising and influencing resilience investment. The second research phase includes the proof-of-concept and testing of outputs developed from the first research phase. Ongoing stakeholder engagement ensured timely feedback and applicability of the research to end-users, as preliminary results of the research have been shared and discussed in SAG and PMC meetings.

Research Phase 1

The first research phase comprised a literature review on the status of knowledge of complex urban systems and cascading and compounding disaster impacts, desktop research and document analysis in relation to current practices and processes in Australia, stakeholder interviews and an online survey.

Literature review

A narrative literature review was undertaken to generate an understanding about systems thinking concepts related to hazards and risks in urban settlements. Narrative literature reviews aim to provide an interpretation of fields of knowledge that are characterised by extensive and complex research findings and thus require a detailed, but nuanced, summary and interpretation. As such, they are useful in state-of-the-art reviews aimed at providing a summary of the current state of understanding of a field to underpin both evidence-based field applications and future research (Ferrari, 2015; Bourhis, 2017). Narrative reviews utilise a purposive sampling of literature sources based on their relevance to the research goal, which was to identify the implications for building disaster resilience in cities based upon an appreciation of the systemic interactions that contribute to the multidimensional, compounding and cascading impacts of hazard risks and to urban resilience. Further detail on the literature review is provided in the report 'Understanding cities as complex systems: Implications for urban resilience to hazards, risks and disasters' (Fien et al., 2026).

Desktop research and document analysis

To source relevant documents and frameworks, desktop research was undertaken, including the use of Wayback Machine and National Library of Australia Trove and State level equivalents. Relevant documents and frameworks included government, consultancy, scientific and NGO reports, webpages and databases, including mapping visualisation tools and platforms. Further documents were identified through the online survey (see below), and recommendations from members of the SAG and PMC. The research focused on the five major urban areas in Australia, namely, the metropolitan areas of Melbourne, Sydney, Adelaide, Perth and South East Queensland, including Brisbane and Gold Coast, as well as state and national government policies, guidelines and tools. Further detail on the desktop research and document analysis is provided in the project reports 'Current (and emerging) practice in mapping vulnerabilities and resilience, within urban systems' (Nogueira de Moraes et al., 2026a) and 'Current practices and processes used to prioritise and influence urban resilience investments' (Hosseinioon et al., 2026).

Stakeholder interviews

The project team conducted 39 semi-structured interviews between 28 October 2024 and 11 April 2025. These interviews were focused on obtaining a deeper understanding of the status and use of urban resilience frameworks and current and emerging practices in conceptualising vulnerabilities and resilience as well as in

prioritising and influencing resilience investment. Depending on the professional background and role of the interviewee, interviews focused on certain aspects. Interviewees were identified through an online survey, document analysis and recommendations by the SAG and PMC, and were contacted via email to ask whether they would be available to participate in the interview.

Interviewees worked in local government (5), state government (10), national government (3), NGOs (5), the private sector (10), the research sector (3), and for utility providers (3). Interviewees have been coded according to their work area, for example LG1 is an interviewee working in local government. Interviews were conducted using Microsoft Teams, except for one face-to-face interview, and had a duration of an hour on average. Interviews were recorded and transcripts were automatically generated by Microsoft Teams and Microsoft Word. Interview transcripts were coded in NVivo and Word. The interview guide can be found in Appendix 7.

Online survey

In October 2024, an online survey was distributed to SAG members with the request to respond to the survey and to distribute it to relevant networks. The survey aimed to develop a first understanding of processes and frameworks used for conceptualising vulnerabilities and resilience, and for prioritising and influencing resilience investment. It focused on sourcing relevant references to the study and to gain a bird's eye view of the landscape of current and emerging practices. Furthermore, survey respondents were asked whether they would be available to participate in an interview. The survey received 13 responses from end-users working in state government, consultancies, infrastructure providers, NGOs and academia. The survey questions can be found in Appendix 8.

Research Phase 2

Based on the research findings in the first research phase, the research team developed three background reports: 'Understanding cities as complex systems: Implications for urban resilience to hazards, risks and disasters' (Fien et al., 2026), 'Current (and emerging) practice in mapping vulnerabilities and resilience, within urban systems' (Nogueira de Moraes et al., 2026a) and 'Current practices and processes used to prioritise and influence urban resilience investments' (Hosseinioon et al., 2026). These reports are available on the project website[2]. The project team also developed three outputs based on the research, a draft Practical guidance tool, draft Principles for urban resilience investment and a draft Guidance on evaluation and monitoring. These will be further described in the Discussion section and an overview is presented in Appendices 1-4. Research Phase 2 comprised a proof-of-concept study of the Practical guidance tool, and testing of the principles for urban resilience investment, including the recommendations and the checklist connected to the principles.

Recruitment

Participants for the proof-of-concept study and the testing of the urban resilience investment principles were recruited via the SAG, interviewees, a project presentation at the Natural Hazards Research Australia Research Forum, an invitation during the Hazardous Webinar to the project and via snowballing. An email was sent to the SAG members and interviewees with information on the Practical guidance tool and the principles for urban resilience investment and on the process of testing the tool and principles. The email asked recipients to register their interest in testing one or both of the products through an online form, and to forward the email to anyone they thought could be interested in participating. Similarly, during a presentation at the Research Forum and the Hazardous Webinar, attendees were given information on the testing process and a QR code

[2] https://www.naturalhazards.com.au/research/research-projects/natural-hazards-and-resilience-complex-urban-systems

and link to the online form for registering interest. Overall, 48 people registered their interest for participating in the proof-of concept (39 EOIs) and the testing of the principles (20 EOIs).

Proof-of-concept study

The proof-of concept study started with an online introduction to the process and the Practical guidance tool which was recorded and then added to the website of the proof-of-concept study so that participants who joined the process later or were not able to attend the introduction, could watch the video before starting testing the tool. The Practical guidance tool was made available as a SharePoint Website to which people were invited when they registered their interest. This way the tool was not publicly available but those who were interested in testing the tool were able to do so. Participants were able to provide feedback via an online survey, comments on the website itself, a focus group and workshops. An online survey, commenting function and focus group were open to all participants, while the workshops focused on two participating organisations, City of Melbourne and Reconstruction Authority New South Wales. The online survey asked questions about the useability and usefulness of the tool overall and also the different modules and building blocks (see Appendix 9). Four participants took part in the online survey, while two participants used the online commenting function. Three participants took part in the focus group, which discussed feedback on the tool, potential audiences, utilisation options and opportunities for improvement. The workshops had three and four participants respectively and also discussed feedback, utilisation options and opportunities for improvement. Utilisation options were also considered in more detail by asking for (hypothetical) examples based on the daily work of the participants.

Overall, the proof-of-concept had 16 participants with ten of those participating in workshops or a focus group with the option for detailed feedback and testing. Feedback collected was summarised in a proof-of-concept report and incorporated where possible. Due to the expected move of the Practical guidance tool Website from RMIT to Natural Hazards Research Australia, changes were not directly made on the SharePoint Website but collated in a Word document.

Testing of the principles for urban resilience investment

For the testing of the principles for urban resilience investment, documents comprising the principles, the connected recommendations and a checklist were distributed to the interested parties via email, with a link to an online survey where participants were able to provide feedback. Participants were also able to send feedback via response email. The online survey asked questions about the applicability and practicality of the principles for the respondent's work environment, whether the respondents would suggest further topic areas or any other changes to the structure. It also asked in which area they worked (see also Appendix 10). Three participants provided feedback via the online survey, one participant via email and one participant via an online meeting. Additionally, the Principles were presented and discussed in one of the SAG meetings. The feedback collected was summarised in a Word document, and where possible feedback was incorporated into a new version of the three documents.

Ongoing stakeholder engagement

The research approach included ongoing stakeholder engagement through the SAG and the PMC. The SAG was a group of about 25 practitioners and met five times over the course of the project. Additionally, some SAG members took part in research phase 1 and 2, as described previously. The PMC had three end-user members plus two Natural Hazards Research Australia staff and three project team members and met eight times over the course of the project. Preliminary results of the research have been shared and discussed with end-users through SAG and PMC meetings. This provided valuable feedback for potential modifications to the approach

and to the presentation and dissemination of the findings. Further stakeholder engagement occurred through a presentation at the Natural Hazards Research Australia Research Forum 2025, a presentation at the Australian Disaster Resilience Conference 2025, and a Hazardous Webinar in August 2025. Presentations and workshop sessions at other conferences included the Adaptation Futures Conference 2025, and the State of Australasian Cities Conference 2025.

Research findings

The focus of this research is on resilience and natural hazards in complex urban systems. As will be described in the following sections, natural hazard events in complex urban systems have multidimensional impacts and these can be exacerbated and intensified through feedback loops within and between systems, leading to cascading and potentially compounding hazard events or disaster impacts. These are critical elements to systemic risk assessments and to processes of building resilience within those complex urban systems.

Some of the findings described in this section can be seen as relevant and fitting for urban and rural areas, and there are obvious similarities and overlaps between building resilience and understanding hazard risks in these types of areas. For example, the concepts of cascading disaster impacts or compound disaster risk do not differ across urbanised and rural areas. Similarly, the conceptualisation and understanding of vulnerability and resilience are comparable between those areas, and resilience investment is also first and foremost an investment in disaster risk reduction in different geographic areas.

Indeed, in the interviews, participants often did not differentiate between urban systems and rural areas. One reason for this is the context of their work and the natural hazards with which they have had experience in their practice. For example, an energy provider may focus on regional areas where power lines run through and where these are at risk of bushfire, flooding or other hazards. They may have had less experience with hazards in the context of an urban system. Similarly, staff of an inner-city council may have different views on resilience and hazard risk than staff in a council on the urban fringe. Equally, practitioners working on the national level may have a high-level focus on resilience and consider both urban and rural areas. For example, the recent Australian National Climate Risk Assessment (Australian Climate Service, 2025) considers urban, regional and remote communities, both regarding their specific and overlapping risks.

However, while some of the findings are similar between urban and non-urban areas, other findings and subsequent approaches are quite specific to complex urban systems. The understanding of the complexity of the systems within urban systems and their interdependencies is unique to urban areas. As will be described, this complexity requires a systems approach as well as an understanding of the feedback loops between hazard impacts as well as emergency/disaster arrangements. This is a complex task that requires scenario planning and modelling as well as learning from previous disasters and evaluations of resilience-building activities.

The ‘system of systems’ characteristics of urban systems means that discussions of urban hazards must not only take account of the biophysical systems, such as weather systems and the water and carbon cycles, but also the people who live in them and the built, digital and human infrastructure systems they have created to meet their wants, needs and values. At the heart of the systems perspective is the recognition that cities are complex, dynamic and adaptive entities. Understanding cities as systems of systems transforms how we think about urban risks and resilience. This approach highlights the need for integrated, adaptive and anticipatory frameworks that consider the interplay of social, ecological and infrastructural systems, the non-linear and emergent nature of risk, and the centrality of learning and adaptation. Disaster risk reduction and resilience-building must move upstream, be multidimensional and account for cascading and compounding risks. With appropriate policy, planning and community action, cities can reduce vulnerabilities, absorb shocks and adapt to both chronic and acute disruptions—thus safeguarding urban life now and into the future.

This section outlines general findings from the first three work packages of the project. The implications of the findings will be further discussed in the following section, which will also present the outputs developed from the research findings – which belong to the fourth work package.

Status of knowledge of complex urban systems and cascading and compounding disaster impacts

The hazard and disaster risk management sector has gradually been moving towards a multi-hazard and systems approach, particularly since the adoption of the Sendai Framework for Disaster Risk Reduction (UNISDR, 2015) and in Australia, the National Strategy for Disaster Resilience (COAG, 2011) and the National Disaster Risk Reduction Framework (Department of Home Affairs, 2018b). Prior to this, the emphasis was on single hazard events and managing disasters and the emergencies they trigger. Due to this emphasis but also because of existing research and professional specialisations, research attention was largely on the different specific hazard types, measuring loss and damage and improving the safety and efficiency of emergency and relief efforts. While these are important research areas, this meant that multi-hazard studies of different locations (i.e., area-based studies) or different types of geographical locations (e.g., coastal, tropical, rural, remote and urban settings) have been neglected.

This situation has been changing with the rise of resilience studies in hazard and disaster research and as shortcomings of this approach have become more and more obvious (Tiernan et al., 2019). Research on hazards and disasters has increasingly adopted a systemic, multi-hazard and area or region-based approach. Changes in policy and frontline practices are beginning to accrue from this although the full implications of systems practice have not been recognised yet or have not been found easy to implement (Ward et al., 2022; Šakić Trogrlić et al., 2024).

With an increased awareness of the need for systems thinking and multi-hazard approaches in disaster management, and an increased focus on resilience, the topic of complex urban systems and urban resilience has come to the fore in research as well as practice. The study of urban resilience from a 'system of systems' perspective has been a rapidly growing area, with conceptualisations of urban systems, the interdependencies of the systems within the overarching urban system, feedback loops between those systems and a number of definitions of urban resilience – which often build on previous definitions (e.g. Bai et al., 2016; Burger et al., 2021).

Nevertheless, research on urban disaster risk in Australia and analyses of the outcomes of resilience building strategies are still a relatively new field. Early work focused on the management of particular types of risks, such as studies of urban planning in relation to bushfire management in Victoria (Gonzalez-Mathiesen et al., 2019) and the impacts of floods and cyclones in Queensland (Smith & Loh Choy, 2014). More recent work has focused on conceptual and operational issues, including, for example, the development of an Australian urban resilience framework (Lowe et al., 2021). In the context of systemic risk, Australia was ahead of much of the world in the publication of guidance on responding to systemic risk (AIDR, 2021). This includes government guidance on 'interconnected causes and cascading effects of systemic disaster risk' (Department of Home Affairs, 2018a).

Yet, interviews with policy makers and practitioners in Australia revealed that many lack a deeper understanding of the characteristics and drivers of systemic risk and the impacts of urban systems as open not closed, and as dynamic not static. Similarly, there seems to be little understanding of the processes of self-organisation and emergence that occur when systems respond to the disruptions that result from the interaction of the shocks and stressors in urban systems. Consequently, the strategies required to act on the implications of systemic risk are not well-developed or in widespread use. Among the reasons for this could be the diverse definitions of resilience that abound, and the normative treatment of resilience as a desirable end-state for a community or city rather than as a range of processes for mitigating risk, limiting disaster impacts and building back faster, safer and stronger after a disaster. Transformative approaches to resilience that seek to build the resources and capacities of less advantaged and marginalised groups in society do seem to be the least represented in urban resilience plans in Australia.

Awareness of this led to a strong emphasis on equality and social justice in the new 2025-2030 Resilience Strategy developed by the City of Sydney. Overall, there is a need to strengthen understanding of the implication of systemic risk in Australia, especially in its cities.

Cascading, compound and multidimensional disaster impacts

In recent years, particularly in relation to urban systems, but also in other disaster research, the concepts of cascading and compounding as well as multidimensional disaster impacts have become more noticeable in the discussion (Ahamed et al., 2023). Reasons for this include the shifting frequency, intensity, duration, distribution and severity of hazard events which can lead to temporal and spatial overlapping of hazard and disaster events.

In this context it should be noted that the adjectives 'cascading', 'compound' and 'multidimensional' are often used with different nouns (Cutter, 2018) and the differences in these nouns and also adjectives are not always clearly defined which can cause ambiguity and confusion. Thus, there is discussion about, for example, compound hazards, compound risks and compound disasters, multidimensional risk and cascading disasters, cascading risks and cascading impacts. Researchers also differentiate between independent, aggregate, and fast- and slow-onset disasters (Drakes & Tate, 2022). Indeed, Nemeth et al. (2024) have identified more than 20 terms in the literature as synonyms for compound disasters alone. Figure 2 visualises different types of disaster events.

This semantic ambiguity may be the result of the close systemic relationships between 'hazards', 'risks', and 'disasters' and their drivers and timing. For example, by their very name, compound disasters arise from compound or multiple hazards (whether they are of the same type or not) and may lead to cascading impacts. Another reason may be that people do not always clearly define the terms they use, particularly in every-day and potentially professional language. Another example of this is the term resilience which – although defined in many different ways in the academic literature – is rarely clearly defined in the context of policies, frameworks or projects (see also the next section). The following aims to summarise and clarify existing definitions and use of the terms.

Compound disasters relate to occasions when multiple hazards or risks lead to more than one disaster impacting a region either at the same time or in close succession, potentially leading to amplified impacts. Definitions vary as to whether these disasters need to be of the same or different types, over how short a period they need to occur to be seen as related, and over how small or large the impacted area needs to be to be counted as a compound disaster (Mocatto et al., 2024; Nemeth et al., 2024). Broadly, it can be said that compound disaster events have an independent cause but interacting impacts as they occur in the same (or a proximate) region and close in time to each other. The 2019/2020 Australian Black Summer and the COVID-19 Pandemic are an example of this. Other examples, which are highly likely to impact cities, are the co-occurrence of droughts and floods (Pizzorni et al., 2024) and droughts and heatwaves (IPCC, 2021). The existing drought conditions can lead to flash flooding due to increased rain run-off on dry soil, or in the context of heatwaves the conditions may have impacted the health of plants, increasing the urban heat island effect. Compound disaster events can impact and overload emergency/disaster/crisis management arrangements.

Cascading disasters occur when the impacts of a disaster in one system ripple outwards and impact on other interconnected systems in a chain reaction. Cascading disaster events can be understood as having a connected cause, for example the impacts of the first disaster event can trigger a second disaster event. In other words, they can involve a primary hazard, such as heavy rainfall or a bushfire, that triggers a chain of diverse impacts – that may be more or less severe than the original shock – but that have a combined impact more severe than if they had occurred separately (Lawrence et al., 2020). An example of cascading disaster impacts are the 2015 Wye River Fires and the 2016 Great Ocean Road Landslides where, as a result of loss of vegetation cover due to the bushfires, the terrain became more vulnerable to landslides, which were subsequently triggered by heavy rainfall. Another example with a particular relevance to cities are the cascading impacts of a rapid onset flood that inundates a power station (IPCC, 2022). As the rising water levels

disrupt the production of energy this can shut down traffic management systems and slow the transport of emergency services, people and goods. It can also impact the internet and digital payment systems, leaving families unable to connect with each other and forcing businesses to close and hospitals to reduce urgent medical services, exactly when they have to deal with increased emergency demands. These chains of impacts are driven by the interdependence of the systems and subsystems in a city, which in turn make it difficult to distinguish risks and can lead to an underestimation of risks.

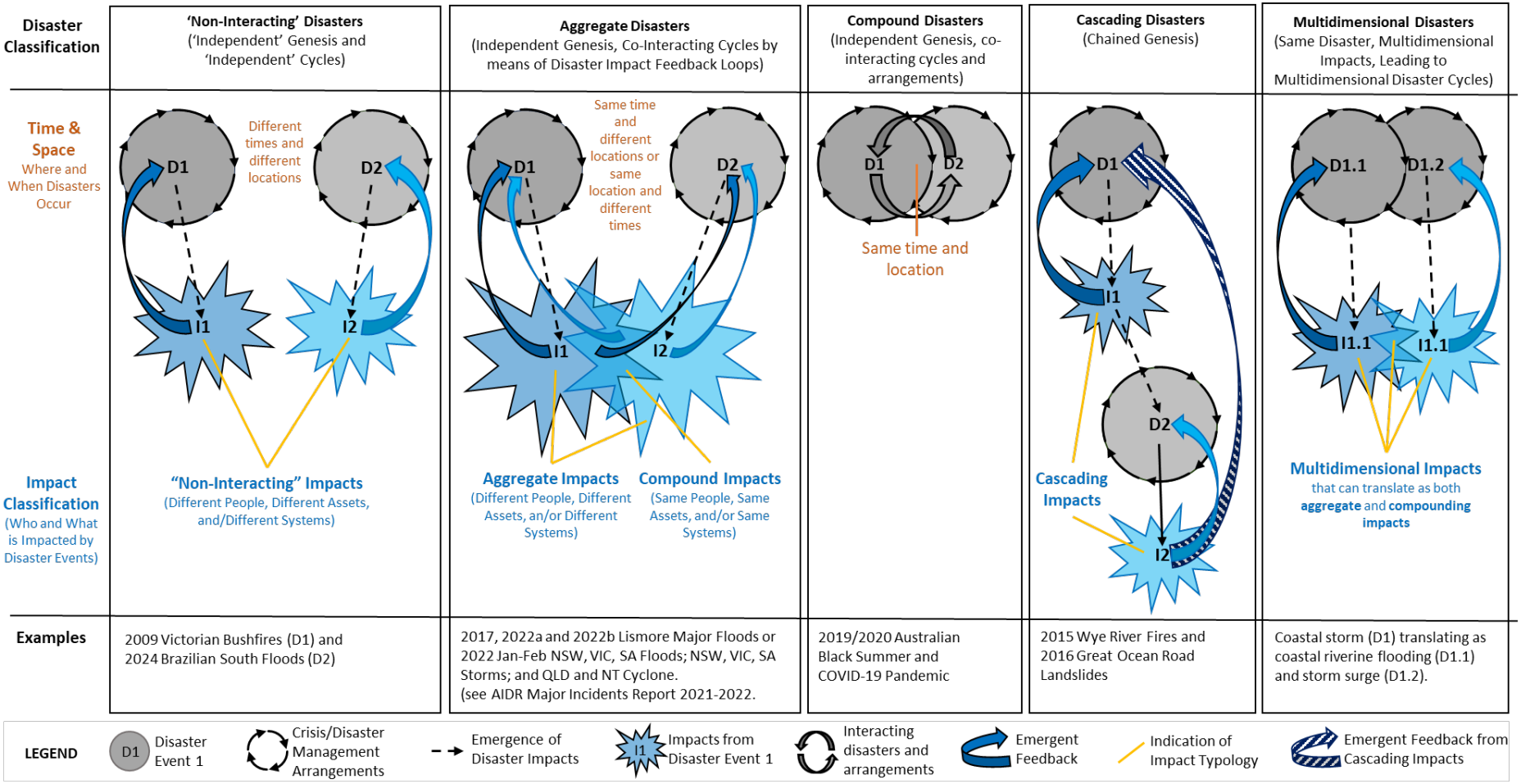
Finally, the terms **multidimensional hazards, risks and disasters** are often used loosely as a synonym for situations where there are multiple hazards and risks, as in multi-hazard or multi-risk approaches to disaster risk management (Zobel & Baghersad, 2020), or in situations where multiple shocks and stressors intersect as in "multidimensional vulnerability" (da Silva et al., 2020). It is also used differently in different fields. The use and meanings of multidimensional risk speak to the need to go beyond a single hazard or single risk approach, to consider the contributions of multiple, interacting and mutually reinforcing hazards as complex shocks that are intensified by social, economic and environmental vulnerabilities.

Multidimensional disaster events can be understood as highly interconnected events that lead to multidimensional impacts. An example of this are coastal storms and tropical cyclones, as these can unfold as extreme rainfall and destructive winds affecting both marine and land areas, translating as storm surges, coastal riverine and overland floodings with multidimensional impacts such as the inundation of coastal areas by sea water, riverine flooding or extreme rainfall. Examples of cyclones leading to flooding in a large city, include the January 2011 Brisbane Flood which was caused by heavy rainfall from Tropical Cyclone Tasha, and the 1974 Brisbane Flood which was caused by Cyclone Wanda. Multidimensional disaster events hold great potential to result in cascading disaster events and impacts.

In the context of these cascading, compound and multidimensional disaster impacts, the concept of **thresholds** is key to conceptualising and understanding risk. As an example, urban areas experiencing extended droughts can have their urban forests adversely affected, leading to the die-off of many trees, thus making the process of recovery of critical green infrastructure – which is essential for heat resilience - much more challenging. However, if the threshold of trees dying off is not reached there is opportunity for recovery. Slow-onset climatic changes can play an exacerbating role in this context, as these are reducing overall recovery threshold levels – in the example of the urban forest climate change causes additional stress to trees, making them more vulnerable to drought conditions.

Feedback loops are another important concept. While there is a good understanding of the significance of feedback loops, we are still far away from understanding all of them, and indeed this might not be possible. Feedback loops are a key characteristic of complex systems, allowing them to self-regulate and adapt to changing environmental conditions but potentially also triggering strong changes in the system. Natural hazard events showcase these relationships well, demonstrating how different events can grow in magnitude, quickly dissipate or keep momentum for long periods as a result of the interplay between self-attenuating and self-reinforcing feedback. When self-reinforcing feedback prevails, these events are likely to escalate in magnitude and severity. Feedback loops occur in nature (e.g. the relationship between numbers of predators and prey) as well as in human-made/influenced environments (e.g., the relationship between building roads, induced traffic demand and congestion). Feedback loops can be reinforcing (positive feedback) or balancing (negative feedback). A positive feedback loop amplifies change and can be seen as a virtuous or vicious cycle, a negative feedback loop stabilises a system, as in the predator and prey example. An example of a reinforcing feedback loop in the context of urban systems is the relationship between the urban heat island effect, air conditioning and increasing temperatures. As urban areas become hotter due to the urban heat island effect, the demand for air conditioning increases, which in turn releases more waste heat and greenhouse gases, leading to higher temperatures – in the short term and the long term – which then require further cooling. This self-reinforcing cycle often intensifies during heatwaves, increasing energy demand and thus the risk of a power outage. water supply system, heightening systemic risk. Another example is the above-mentioned impact of heat on urban forests and the impact of trees dying off on the urban heat island effect.

FIGURE 2: A CLASSIFICATION OF DISASTERS AND IMPACTS IN COMPLEX URBAN SYSTEMS



Source: Nogueira de Moraes et al. 2026b

Awareness and definitions

In summary it can be said that in the academic as well as in the practitioner literature there is awareness of the need to use multi-hazard and systemic approaches. There is also awareness about compound and cascading disaster impacts and risks, their increasing importance and the need to take them into account, particularly in complex urban systems. However, the definition of compound and cascading disaster impacts is not always clear, and these terms are sometimes used interchangeably or in a vague manner. The same is true for multidimensional disasters and disaster risks. Here, the term is often even less defined and used more generally to refer to the different impacts on different sectors a disaster can have.

Clearer definitions of the terms could potentially help practitioners in understanding, predicting and visualising these disaster impacts – or at least in people speaking the same language when referring to these impacts. However, as the literature as well as the practitioners we interviewed acknowledge, planning for and taking into account cascading and multidimensional disaster risks and impacts in disaster risk reduction, climate adaptation and resilience-building is not easy, particularly in complex urban systems, due to feedback loops that we may not fully understand and thresholds of impact which if exceeded may then lead to feedback loops and cascading impacts.

Taking into account the risk of compound disasters in risk assessment seems somewhat easier, as disasters that can occur and might occur at the same time are somewhat better understood. However, these compound disasters can then lead to cascading impacts and affect recovery due to their impacts on the resilience of a city and its residents. Overall, it seems that the understanding is progressing through lessons learned from preceding disasters and through improved modelling and scenario planning but that there is still a lot to learn and a need to take these insights into 'every-day' life, for example, sectors outside of emergency management and climate adaptation, people's personal and working lives, and public policy.

Overall, an improved understanding of multidimensional, cascading and compounding disaster impacts will assist in recognising vulnerabilities within the system and of the different systems. In turn this supports understanding of how to build resilience which can support prioritising resilience investment.

Current practices and processes of conceptualising and mapping vulnerability and resilience

Addressing vulnerabilities to disasters and climate change is critical to building the resilience of complex urban systems to natural hazards, in particular because – similar to compounded hazards with cascading impacts – vulnerabilities can intensify hazard risks when they interact and can amplify negative impacts. However, little is known about how society's vulnerabilities interact or about the ways in which risk is intensified by interacting vulnerabilities (Drakes & Tate, 2022). Furthermore, both terms, vulnerability and resilience, have been defined and conceptualised differently across sectors and contexts. These difference as well as the 'lax' use is discussed in more detail in one of the project reports (Fien et al., 2026). As an example, in the context of natural hazards vulnerability can be generally understood as "the degree to which people, places, [assets], institutions and sectors are susceptible to, and unable to cope with, climate change impacts and hazards" (UN-Habitat, 2014, p. 7). Key variables for understanding vulnerability include 'exposure to hazards', 'sensitivity to hazard impacts' and 'coping' and 'adaptive capacities' (see Appendix 5 for definitions of these terms).

Resilience is sometimes presented as the opposite of vulnerability. However, people in contexts of vulnerability can also be more resilient than those who are not usually in that situation – therefore this view is too simplistic. One interviewee suggested this can be observed when residents in their municipality who live on an island, and residents living on the mainland are contrasted in relation to their vulnerability and resilience to storms. While the island is more likely to be hit by a storm, islanders can also be more prepared and self-sufficient in the

event of a storm, as they can better anticipate weather conditions and know that help from the mainland will not be available immediately (Interviewee LG 4).

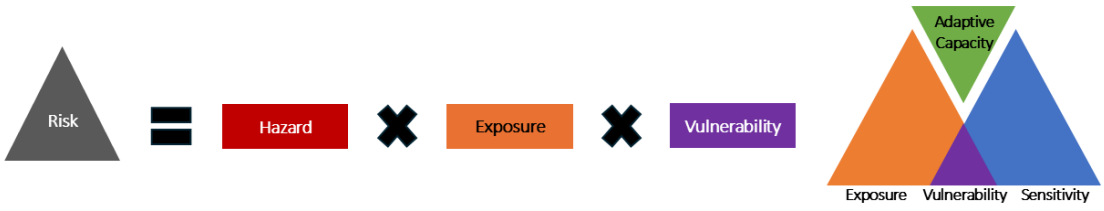
Vulnerability is also discussed differently between referring to assets and referring to people or groups of people. While assessing the vulnerability of assets or infrastructure is largely 'objective', the assessment of people or groups as vulnerable can be perceived as stigmatising. An interviewee reported a situation where the residents of a town objected to being called vulnerable (Interviewee LG1), while other interviewees also highlighted that they would rather talk about groups being at higher risk of exposure than referring to them as vulnerable groups and that vulnerability depends on the context (Interviewees NG5, CG1, SG2, LG5). However, while the vulnerability of assets is a less 'burdened' discussion, the conceptualising and mapping of vulnerability of infrastructure in complex urban systems entails considerable challenges due to the interconnected nature of the systems, as has been shown in the discussion of cascading impacts and feedback loops above.

A document analysis of academic and non-academic literature and tools, as well as interviews with practitioners were conducted to understand the current and emerging practices and processes of conceptualising and mapping vulnerability and resilience in Australia in the context of compound, cascading and multidimensional disaster impacts on complex urban systems. The findings from this research and current practices and processes have been presented in a background report (Nogueira de Moraes et al., 2026a). This section gives a broad overview of the findings.

Shifting conceptualisations of vulnerability

The research identified two major approaches to conceptualising 'vulnerability': (1) a traditional disaster risk reduction (DRR) approach that understands vulnerability as one of three risk variables alongside 'exposure' and 'hazard'; and (2) a traditional public health and climate adaptation approach that understands 'vulnerability' as a function of 'sensitivity', 'exposure', and 'adaptive capacity'. The conceptualisations are presented in Figure 2. However, given shifts in how IPCC reports approach vulnerability, it seems that the conceptualisation of vulnerability in the climate adaptation sector is moving more towards the DRR approach (see Estoque et al., 2023). For example, the IPCC's representation of risk variables grouped into 'hazard', 'vulnerability' and 'exposure' brings greater alignment with DRR approaches to understanding risks, as 'vulnerability' is considered separately from 'exposure' (IPCC, 2022).

FIGURE 3: CONCEPTUALISATION OF VULNERABILITY – TRADITIONAL DRR APPROACH (LEFT) AND TRADITIONAL CLIMATE ADAPTATION APPROACH (RIGHT)



Source: Nogueira de Moraes et al. (2026a) based on NSW RA (2025) and UN-Habitat (2014).

Yet, as some interviewees mentioned, this shift could be considered problematic – insofar as it might inadvertently lead to over-emphasising sensitivity and inherent individual or group characteristics in understanding what constitutes vulnerability (Interviewees NG5, SG2). There was a concern that this may stigmatise specific communities or groups with the negative connotations of being 'vulnerable'. It also means that the term 'vulnerability' is sometimes used in situations where 'sensitivity' might be more appropriate.

Context is important for conceptualisations of resilience

Similar to vulnerability, the concept of resilience is also conceptualised and interpreted in a diverse manner[3] and the conceptualisation can be vague regarding what or who is the subject of resilience assessments

[3] See Background and the previous subsection.

('resilience of what') and the point of reference being considered for such assessments ('resilience to what'). Defining more clearly the context in which the term resilience is utilised would assist stakeholders, practitioners and communities to better understand what is meant by resilience, and also to define project or policy objectives more clearly. For example, objectives could be phrased as 'to build community resilience to disasters', 'settlement resilience to climate change', or 'asset vulnerability to sea-level rise'.

When looking at current practices and processes, explicitly defined uses of the terms resilience and vulnerability include Climate Resilience (including resilience to heatwaves and sea-level rise) and Disaster Resilience (including flood resilience, bushfire resilience, etc.) as overarching examples of 'resilience to what'. Other examples are the context of systems (e.g. resilience of local economies, the resilience of governance systems), system elements (e.g. infrastructure resilience, asset vulnerability) or both (community resilience as an attribute of a system element and of a system). The context of systems and system elements are particularly relevant in complex urban systems due to the multitude of systems that can be encountered here.

Loose definitions versus specific definitions

At the same time, working definitions of vulnerability and/or resilience are not always made clear when approaches to their operationalisation are stated or adopted. While loosely defining these terms can allow for a unifying, yet abstract goal, it can also lead to misalignment of actions and ineffective communication between stakeholders. A 'workaround' is suggested by an interviewee who stated that they purposefully do not mention the term resilience to avoid misunderstandings but rather talk about the objectives and actions that they want to achieve with their program or project (Interviewee RS1). Others tried to use different, more specific words (Interviewee CG1). Depending on the context in which it was used, some interviewees felt that using resilience as an overarching goal without a specific definition was a workable option (Interviewees SG7, SG10, RS3). However, for vulnerability, contexts and definitions used were often more specific – yet differed between sectors and as well as specific programs or projects (e.g. vulnerability of a power line, vulnerability of certain areas to certain hazards, risk of exposure of specific population groups, need for support in an event of specific population groups). Compound, cascading and multidimensional disaster impacts and risks were sometimes taken into account in practices and processes but generally not in detail and sometimes not at all.

Adopted approaches

We found that conceptual and spatial mapping are widely adopted practices that are often intertwined[4] and developed using both statistical and qualitative data, although not always integrating these data sources. Some approaches are place-based – that is, they focus on the resilience and/or vulnerability of a certain area, while others are more conceptual. Qualitative approaches to mapping carried out in collaboration with individuals and communities often allow the identification of resilience and vulnerability drivers that should be addressed, such as meeting spaces and vital infrastructure. They are also valuable approaches for due consideration of context, and the spatial identification of hard (or physical) and soft infrastructure that can play a critical role in dampening or leveraging coping, adaptative and recovery capacities.

Quantitative approaches are also used to support the spatial visualisation of resilience and vulnerability and help practitioners develop business cases for investment. However, both qualitative and quantitative approaches often lack precision in the use of terms such as resilience and vulnerability, as well as how these two are connected and related to other concepts such as adaptive capacity and sensitivity.

Importantly, with very few exceptions, current practice tends to look at impacts of specific hazards or climate stressors on specific system elements (e.g. assets or specific population groups), without considering systemic resilience and vulnerabilities. An exception includes for example a project within the City of Melbourne 'City Engine' (EAGA et al., 2021, pp. 55-56), which advances understanding of the cascading impacts of specific hazards on critical infrastructure and how that affects urban systems. Another example is the Theory of Change

[4] Conceptual frameworks informing spatial visualisations and, in turn, the latter helping inform how resilience and vulnerability are conceptualised in practice.

of the Resilient Sydney Strategy (City of Sydney, 2025). When systemic resilience is addressed, cascading impacts are generally only considered linearly, without the identification of feedback loops, which are an integral part of complex urban systems and can greatly affect disaster risk.

When looking at differences between urban and rural areas in conceptualising and mapping vulnerabilities, in both the interviews and document analysis it was apparent that there are differences as well as similarities. The high-level understanding of vulnerability in relation to exposure and adaptive capacities can be considered similar between urban and rural areas. However, the specific understanding of vulnerability of the built, social, natural and economic environment of a city is often different to rural areas and can even be different among various urban systems. Again, the vulnerability of a community or of the natural environment in the city will depend on the interdependencies between the systems as well as on the current status of these systems. Similarly, activities to increase resilience or decrease vulnerabilities will need to take into account the context of the system as well as the situation and risk in specific (geographic) areas of the city.

The findings of this research phase have been used to develop a Practical guidance tool for conceptual mapping of vulnerabilities and resilience at local scales – which will be presented in more detail in the final section of the discussion chapter.

Current practices and processes of prioritising and influencing resilience investment

The Sendai Framework and the Australian National DRR Framework emphasise both DRR and the importance of *investment* into DRR and resilience. As investment into DRR and preparedness has been shown to be more cost-effective in comparison to spending on response and recovery (although recovery activities can be embedded in DRR investment), there is a clear case for resilience investment. However, while the logic of investing in DRR to avoid spending large sums on disaster response is clear, there are the difficulties of finite budgets and competing priorities – for both government and private investment – and circumstances where an investment is seen as cost-effective only if a disaster occurs. As such, it is necessary to *prioritise* resilience investment, develop approaches with clear co-benefits (i.e. benefits that occur regardless of a disaster occurring), and understand benefits and outcomes of implemented programs and projects better via evaluation.

Influencing resilience investment is generally undertaken by government actors by providing grants that support identified activities. Philanthropic organisations may also influence resilience investment through their programs. Similarly, grant applicants could influence resilience investment by trying to influence topic areas to be funded through grants. In the context of resilience investment, 'investment' and 'funding' are often used interchangeably due to the long-term, intangible nature of many resilience projects meaning that they do not yield immediately quantifiable returns. Resilience investments materialise benefits over years or decades, differing from traditional investment models (Clarvis et al., 2015).

Resilience investment in cities as complex adaptive systems requires a systemic approach by considering the interdependencies and adaptation cycles within these systems. Complex adaptive systems in cities include the built environment, encompassing physical and social infrastructure assets such as transport, energy, telecommunications, water utilities, housing, cultural and commercial precincts and other assets and their complex interaction with the natural and social environment. The social environment involves socio-economic and demographic trends, social networks and relationships, cultural practices, technology, innovation, wellbeing, essential services such as health and education, and lifestyles. The natural environment refers to natural assets such as wetlands, rivers, land, forests, oceans, other complex natural ecosystems, agriculture and water sources. The economic environment includes public sector, private sector and individual economic activities; workforce participation; credit, debt, and finance; and small, medium, national, and multinational businesses (Department of Home Affairs, 2018b).

To understand the current practices and processes used to prioritise and influence resilience investment in the context of complex urban systems in Australia, we conducted a document analysis of academic and non-academic literature, government policies and funding mechanisms, approaches and frameworks for prioritising resilience investment, as well as interviews with practitioners. A focus of our analysis were government actors at the national, state and local levels as these often provide funds for resilience investment to lower government levels, communities and businesses. However, we also aimed to understand to what extent the private sector, that is, businesses and other organisations outside of government, invest in resilience. While investment of private households was relevant for some points, our focus was on resilience investments by larger organisations, businesses and government. The findings from this research and current practices and processes have been presented in a separate report (Hosseinioon et al., 2026). This section gives a broad overview of the findings.

Loss prevention, value creation and (perception of) costs

Resilience investment can be understood as loss prevention and value creation. Loss prevention arises from reducing disaster- and exposure risk through prevention, mitigation, and adaptation measures and thus preventing or decreasing issues, such as environmental degradation, asset loss and damage, supply chain disruptions, livelihood and heritage loss. Value creation refers to broader social and economic benefits, such as increasing community resilience towards impacts of sudden shock and chronic stressors, economic uplift, improved service performance, increased equity, safeguarding biodiversity, increased infrastructure reliability and upgrades of assets (Helgeson et al., 2025; Resilient Futures Investment Roundtable & Climate KIC 2024, Department of Home Affairs, 2019). The loss prevention can also be considered value creation as damages are avoided when a hazard event happens. Value creation is also framed as co-benefits of resilience investment and is an important argument for resilience investments. Value creation and loss prevention includes all types of capital, such as economic, social, human, cultural and natural capital. Funds can be invested in physical infrastructure, civic and public and private services as well as community engagement and education.

An important consideration in the context of resilience investment are the costs of the investment. As noted, several studies highlight the high return of resilience investment if disaster damages are avoided or decreased and therefore the logic behind investment (e.g. Deloitte, 2024) and this was also common knowledge across all interview participants. However, the difficulty of quantifying avoided costs were often mentioned in this context as a barrier to investment as well as the up-front costs of resilience investment which are often perceived to be quite high (Interviewees LG3, RS1, SG5). Yet, it was also mentioned that while large infrastructure projects will be expensive, there are also many effective resilience-building measures which are low-cost, including measures focusing on planning, early warning systems, education, and strengthening community connections but also smaller improvements to buildings (Interviewees PS3, RS3).

Tangible and intangible benefits

The literature as well as the interviews highlighted that the benefits of investment in infrastructure, assets and the built environment are generally more tangible and easier to quantify than benefits of investment in community aspects, such as building community resilience to disasters or climate change. This means highlighting benefits of physical infrastructure is often easier in decision-making processes, such as business cases, which can mean that prioritising funding towards community projects can be more difficult. This is related to the finding in the previous section that vulnerability of infrastructure is easier to define than the vulnerability of population groups or communities. However, even if benefits of physical infrastructure are easier to quantify or describe, presenting the benefits of resilience in a decision-making process, such as a business case, can still be difficult as the concept of avoided losses should a hazard event or disaster occur is a probabilistic concept and not necessarily expressed in a straightforward manner. While the benefit of the investment will be easily visible should a disaster occur, it may seem as ‘extra cost’ if a disaster does not occur. In other words, making decisions about investing in resilience requires information about trade-offs, disaster risk, potential impacts and feedback loops between impacts, response and hazard events.

Investment mechanisms and governance structures

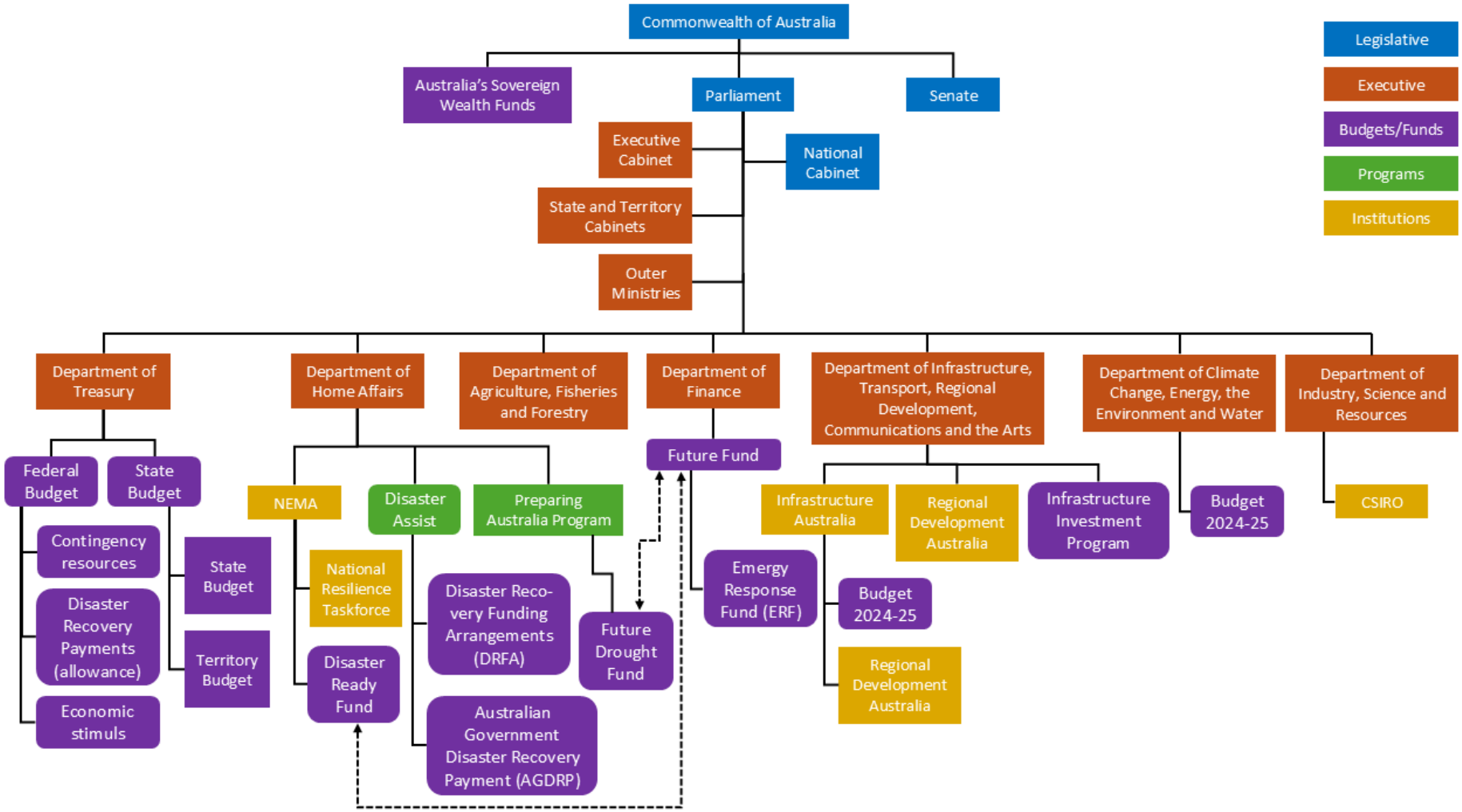
Investment mechanisms in Australia for disaster resilience involve a combination of government funding programs, public-private partnerships, insurance frameworks (i.e. insurance for when damage occurs), and community-based initiatives. These mechanisms aim to enhance urban resilience by reducing the impacts of disasters, mitigating the risks associated with disasters, enhancing community resilience to disasters, and ensuring sustainable development practices.

The investment from government is crucial for enhancing community, nature and asset protection against rising risks. By allocating resources to resilience efforts, these investments focus on long-term, preventative measures. The Australian governance structure for investment in resilience involves multiple levels (see Figure 3). The national government level sets overarching strategies and provides funding for resilience investment for lower levels – that is, states, territories, local government as well as communities and businesses. The states and territories have their own policies, funds, legislative mandates and acts relevant to resilience investment, based on the principles set out in the National Strategy for Disaster Resilience (COAG, 2011). Local government invests in resilient infrastructure through their general budget or through state or national grants and also undertake work and provide grants for resilience building of the community. Our analysis showed that government funding for resilience is evolving constantly, and that there are several funds that support resilience building, particularly at the national level.

Urban resilience investment is undertaken to enhance the ability of cities to withstand and recover from various shocks and stresses, such as disasters, economic disruptions and social challenges. Current practices in prioritising and influencing urban resilience investment typically involve a combination of strategic planning, decision-making processes (e.g. CBA), stakeholder engagement, and data analysis and is sometimes supported by innovative financing mechanisms. Climate adaptation strategies that aim to address the long-term impacts of climate change can also impact resilience investment as they include measures to protect critical infrastructure, support vulnerable communities and promote sustainable land management practices. A practical process that was mentioned in the interviews (e.g. Interviewees LG1, LG2, PS4) and also in some documents (e.g. Infrastructure Australia, 2021; Infrastructure NSW, 2022; City of Sydney, 2025) is to embed resilience into the 'general' budget or asset management, for example when building new infrastructure resilience principles are embedded in the standard process (Infrastructure NSW, 2022; Interviewee LG1). However, this process seems to be largely in its early stages and has not been applied on a wider scale yet.

While the processes of resilience investment and prioritisation of resilience investment appear to be similar between urban and rural areas from the analysis, the actual resilience initiatives to consider and the consideration of interdependencies between systems and between initiatives are the principal difference. Interviewees mentioned the complexity of potential impacts/outcomes, the path dependence of the urban form and built environment in cities, traditional sectoral approaches and the high number of stakeholders and organisations leading to coordination and collaboration problems as specific to urban environments (Interviewees LG2, RS1, PS1). They also mentioned as an advantage that in urban areas there are often more resources and information available, referring to funding, data and staff and more diverse staff capabilities due to the higher numbers. Interviewees also argued that investment cases were easier to build due to high population numbers as these numbers are a relevant consideration for investment (Interviewee RS1).

FIGURE 4: HIERARCHY OF DISASTER RESILIENCE FUNDING GOVERNANCE IN AUSTRALIA



Source: Hosseinioon et al. (2026)

Resilience investment frameworks

Several frameworks and approaches for resilience investment have been developed in recent years and are constantly being developed further to bring 'resilience thinking' into budget considerations but also overall local and state strategies (e.g. Wise et al., 2022; Resilient Futures Investment Roundtable & Climate KIC, 2024; Department of Home Affairs, 2019). Long-term planning and adaptability are emphasised, incorporating climate projections and embedding active learning practices to respond to changing dynamics. Challenges of these frameworks include that their implementation takes time and resources, which are often not available in local government and state government. Another challenge is the uncertainty of outcomes and the difficulty of considering feedback loops, and cascading and compound disaster impacts. However, with the development and testing of these approaches, necessary steps and requirements become clearer, and approaches can be further improved.

Investment outside of government grants

Overall, despite the growing recognition of the urgent need to build resilience, there remains a substantial shortfall in funding for resilience solutions. As mentioned, government and particularly the Commonwealth Government, plays a key role in selecting and approving grant funding and influencing DRR policy for resilience projects, with a strong influence on state and local policy. However, given budget constraints and the advantage of diversifying investment channels, it is necessary that other entities, such as private businesses also invest in resilience. Currently, there is a reliance on grant-based funding which supports specific activities but generally neglects to support sustained and strategic activities and investments. The risk of maladaptation is another key point, referring to well-intentioned projects that have detrimental outcomes (Schipper, 2020). Ensuring that resilience investment does not lead to negative outcomes in other areas and learning from contingent negative impacts are essential.

The findings have been used to develop principles for prioritising and influencing resilience investment and guidance on monitoring and evaluating resilience investments – which will be presented in more detail in the final section of the Discussion chapter.

Discussion

This section discusses the research findings with a focus on the challenges and opportunities for end-users and prospective activities and processes to increase understanding of the implications of compound and cascading disaster impacts in complex urban systems and achieving improved resilience of cities, communities and infrastructure.

Understanding complex urban systems and cascading and compounding impacts

As discussed in the previous sections, urban centres and city regions are complex adaptive systems and are comprised of multiple components, subsystems and systems held together by their constant interconnections and interactions. As a result, they are dynamic and volatile, not static and, although they possess a degree of inherent resilience, they also contain a range of vulnerabilities and stressors. Urban systems are also open systems, not closed and, thereby subject to external shocks that cascade through the interconnections and make cities dynamic, and volatile, not static. The effects of such impacts are non-linear, that is, they do not produce direct, one-for-one, input-output results, and through feedback loops the different impacts and systems influence each other and output results can be difficult to predict. In this dynamic state, especially when the balance of inherent resilience and vulnerabilities is too weak to cope with the force and impacts of external shocks, systems undergo multiple forms of re-organisation that produce new, unexpected and unpredictable drivers of change and new patterns of interactions (Cabrera & Cabrera, 2023; Porqueddu, 2022; Liu et al., 2021).

Gaps and barriers in knowledge and understanding

From the research we can identify gaps and barriers in knowledge and understanding disaster impacts in complex urban systems and why it is so difficult to understand and predict compound and cascading disaster impacts. Identifying these barriers and the broader context of natural hazards in complex urban systems can assist in identifying steps that can be taken to increase resilience nonetheless and to enhance understanding and knowledge. This section discusses the barriers, gaps and challenges of understanding complex urban systems and cascading and compound disaster impacts. The last sections in this chapter will then consider enablers and opportunities for enhancing understanding, knowledge and resilience.

One barrier to understanding and predicting disaster risk and potential disaster impacts is the complexity of thinking across several systems, hazards and time frames. **While there is awareness in the emergency sector and other sectors that a multi-hazard approach is needed for improved resilience, people are often trained in specific fields.** This means that they understand the potential impacts and what could be done to reduce disaster risk in their field deeply but may not understand how this impacts other systems. This includes, for example, a good understanding of the risk and potential impacts of flooding by water engineers; or the impacts on the transport network by a transport planner; or the potential of green infrastructure to provide heat relief by a public health practitioner. Yet, it is challenging and it needs good coordination and communication to understand potential impacts on other areas and hazard risks.

Multi-risk and unpredictability

In addition, the interplay of hazards, exposure and vulnerability in creating risks means that multi-hazard approaches might even be better replaced by multi-risk approaches. Taking a hazard-focused perspective often results in some hazards being considered independently – despite the multi-hazard approach – whereas a multi-risk approach considers the multiple vulnerabilities of a system or location and the cascading interactions and impacts that result (Gargiulo et al., 2023). In this way, **a multi-risk approach can help ensure that an area- or place-based approach is taken to disaster risk management rather than focusing on hazards alone** and, thus, could be seen as a more suitable approach for urban systems (Komendantova et al., 2016). While the

challenges of coordination, communication and well-organised governance systems remain, this approach holds potential for enhancing the understanding of complex urban systems and the risks of cascading and compounding impacts.

A related barrier to understanding disaster risk and potential impacts is the uncertainty or unpredictability of some feedback loops between systems, particularly in the context of shifting magnitude, frequency, intensity and duration of hazard events (Burger et al., 2021). In this context, limited knowledge or limited knowledge exchange about thresholds for non-reversible changes, is a gap for understanding resilience and disaster impacts in complex urban systems (Zhang et al., 2019; Parsons et al., 2021). An example of such a threshold is that at some point during a drought, trees will be impacted that strongly that they will not be able to recover. This would then lead to less green infrastructure and a higher risk for extreme heat in the impacted area and potentially also a higher bushfire risk. Thus, achieving and communicating as much knowledge as possible about possible feedback loops and relevant thresholds is necessary to be able to build resilience. At the same time planning for possible impacts on and breakdowns of systems within urban systems is necessary.

Trade-offs

When looking at resilience building, a barrier or challenge are also trade-offs between different measures. For example, while establishing green infrastructure may contribute to reducing heat in an urban area, it might also increase the risk or the risk of higher impacts of bushfires. Similarly, a levee may reduce flood risk in an area but may increase risk in another area or can lead to environmental degradation (Yarina, 2018). Understanding and discussing these trade-offs is essential to make well-grounded decisions. This is particularly important in the context of prioritising resilience investment, where these trade-offs will need to be weighed and taken into account.

Concurrence and longer-term impacts

Addressing the temporal overlapping of natural hazard events (as in compound disasters) but also the different time frames of these events (as in sudden-onset and slow-onset disasters) is a challenge in relation to emergency and crisis management arrangements as well as preparedness (Drakes & Tate, 2022). Compound disasters will impact the resilience of systems and communities and also the capacity to respond through disaster management arrangements – given that the workforce may already respond to a first disaster or may be fatigued from previous response activities. Sudden-onset disasters may impact slow-onset disasters (e.g. flooding may lead to long-term erosion) and vice versa (e.g. a drought may increase bushfire risk) – these impacts will need to be monitored and responded to where possible (e.g. Barneveld et al., 2025). Long-term challenges from disasters can also include reduced education and workforce participation, increased crime, and decreasing levels of physical and mental health (Deloitte, 2021). These impacts are often felt disproportionately by groups experiencing disproportionate situations of vulnerability due to factors such as health and wellbeing, economic resources, social capital and knowledge influence a person's ability to prepare for, respond to and recover from disasters. While there is increased understanding of these impacts, there is still a gap in knowledge regarding how to increase resilience of communities and how to decrease the severity of the long-term impacts. What is necessary is to mitigate the sensitivities and vulnerabilities that intensify disaster risks and impact disproportionally on those with the least capacities to cope with them. This transformative resilience requires wide-ranging actions changing the (social) structure and dynamics of urban systems, and going beyond the emergency sector (see Fien et al., 2026 for a more detailed discussion on transformative resilience). This understanding also impacts definitions of what counts as resilience investment and how resilience investment should be prioritised.

Further challenges, barriers and gaps that are not specific to complex urban systems but still influential include a limited situational awareness through insufficient data collection prior to emergencies and communication breakdowns and top-down governance as disaster management is often centralised, limiting local communities' ability to adapt solutions to their specific needs. Local knowledge and capacity are frequently overlooked (Fien et al., 2026).

Dealing with a broad spectrum of actors and tasks

Complex urban systems comprise a multitude of actors, some of them involved in disaster management or climate change adaptation while others have work which might have at first view nothing to do with DRR, resilience or natural hazards but still is relevant and impactful, and others again are the people living in the urban area. The decisions of all these actors play into building resilience and reducing disaster risk in the urban system. So, how can actors who aim to increase resilience or decrease disaster risk work together with other actors? And how can DRR come more to the fore in every-day life and work?

Interactions and communication

The different actors in the context of natural hazards and resilience in complex urban systems pursue somewhat different tasks and objectives, for example adapting urban environments to climate change impacts, supporting community resilience to disaster impacts and climate change, or improving disaster resilience of infrastructures. When looking at the different sectors that actors work in and the different tasks and objectives, it also becomes clear that understanding of concepts and language used can differ between sectors. For example, our research on current practices and processes of conceptualising vulnerability and resilience identified two major approaches to conceptualising 'vulnerability': (1) a traditional DRR approach that understands vulnerability as one of three risk variables alongside 'exposure' and 'hazard'; and (2) a traditional public health and climate adaptation approach that understands 'vulnerability' as a function of 'sensitivity', 'exposure', and 'adaptive capacity'. We also found that there is a diverse landscape of interpretations of the concept of resilience and varying degrees of clarity regarding what or who is the subject of resilience assessments ('resilience of what') and what is the point of reference being considered for such assessments ('resilience to what') (Vahanvati, 2018). In addition, there are differences in conceptualising resilience and vulnerability between academia, professional practice and communities and between various scales of intervention (e.g. local, state or national level). This became clear in both the document analysis and the interviews (see Nogueira de Moraes et al., 2026a).

In this context, we found that those operating in the interface between different domains of action (e.g. academia and practice, or climate resilience and disaster resilience) often exercise flexibility when communicating ideas across sectors or aim to avoid using definitions altogether and rather describe objectives. Loosely defining terms can allow for a unifying (yet abstract) goal. However, it might also lead to misalignment of actions and ineffective communication between stakeholders. There is a tension between simplifying concepts and frameworks to make them comprehensible and the risk to oversimplify complex concepts. The difference in language and the challenge of communication and joint understanding may also lead to sectoral urban systems being considered in isolation, or as described before, the tendency towards considering hazards independently despite the goal of a multi-hazard approach.

Figure 5 visualises the breadth of actors by showing a high-level description of organisations and roles of our interviewees, noting that we focused on stakeholders in resilience investment, mapping vulnerability and resilience and broader resilience strategies. For example, we did not interview community organisations, so these are missing in the word cloud.

FIGURE 5: ROLES AND ORGANISATIONS OF INTERVIEWEES – HIGH-LEVEL DESCRIPTION

A common ground of conceptualisations

The broad actor spectrum means that it would be helpful if **overarching notions, such as vulnerability and resilience, are more clearly defined when they are used or when a common ground exists where the differences can be reconciled, addressed and/or appropriately acknowledged**. The 'clearer' definition can entail **highlighting the particular context in which the term is utilised** ('to what' and 'of what'), such as using 'community resilience to disasters', 'settlement resilience to climate change', or 'asset vulnerability to sea-level rise'. The 'common ground' we have aimed to support through the development of the **Practical guidance tool where reflections on 'resilience' and 'vulnerability' are provided, concepts visualised and 'what we value' is used as the key starting point**. The user feedback from the proof-of-concept study has shown that still some explanations are easier to understand for people with specific backgrounds than for others, but a first step has been made.

Further approaches to bring actors together and enhance their understanding of each other include **establishment of relevant networks or specific events or forums**. These could for example be **place-based** to improve the resilience of certain areas in the city and bringing local actors together. This could also improve the consideration of local knowledge and capacity and increase local communities' ability to adapt solutions to their specific needs. Furthermore, **increased coordination between government agencies, private sector actors, and local communities can lead to potential joint approaches** to building resilience as well as to increased efficiencies in disaster response. The events or forums could be supported by **capability building tools for resilience** which can assist in increasing stakeholders', government organisations' and communities' awareness of the need for resilience and how to possibly achieve it. Capability building tools can include b**rief and easy-to-understand information on crucial concepts and activities** (e.g. through brochures or online tools) as well as **workshops or training sessions**.

General budgets and reporting

Another opportunity to bring DRR and resilience more to the fore in every-day life and work – and thereby increase the awareness of actors and their collaboration – is to include disaster resilience into 'general' budget decisions of local, state and national government. That means that **every budget decision that is made needs to consider how disaster resilience could be enhanced through this budget item** and what the benefits of this would be. For example, when a new road is built, the business case needs to include evidence on how the road can contribute to reducing disaster risk or increasing disaster resilience as well has how the road itself could be made more disaster resilient. This is already implemented to some extent in some local councils and potentially

at other levels, but could be introduced in a more comprehensive manner (e.g. nationwide). This opportunity is strongly related to the next section on prioritising and influencing resilience investment, but at the same time highly significant to the broad spectrum of actors with their different sector backgrounds and tasks and objectives within their work.

The mandatory climate reporting rules introduced in 2025 which require Australia's largest companies to publish an annual climate statement that outlines material climate risks they may face, their greenhouse gas emissions and information about relevant strategies or risk management plans – and with an expansion to further companies in 2027 – achieve a similar aim of increasing awareness by forcing companies to consider risks and strategies. Similar policies on DRR and related regulation could be helpful in raising awareness but also in providing the basis for more collaboration and coordination between the broad spectrum of actors.

Prioritising and influencing resilience investment

Resilience investment – that is, investment in DRR measures as well as in building resilience against impacts of natural hazard events and climate change – can be made in infrastructure resilience, community preparedness, land use planning, research and innovation, climate change adaptation, Indigenous knowledge and many other areas. It can be undertaken through public-private partnerships, by private investors, government and also communities and individuals. Organisations, authorities, businesses and individuals aiming to invest in resilience measures generally need to ask themselves which type of investment or which specific initiative is the most beneficial one and which investment they should prioritise, given limited amounts of funding. Prioritisation will partly depend on objectives of the organisation or individual but also on which initiative seems to provide the most value for money.

Place-based vulnerabilities or sensitivities

Prioritisation of resilience investment – particularly of government – could for example be based on specific place-based vulnerabilities, such as areas with a high risk of natural hazards or a high proportion of populations at greater risk of exposure and with lower adaptive capacities (Kroen et al., 2025; D'Arcy, et al., 2025; Buchtmann et al. 2023). Related to this are also the multi-risk approaches mentioned earlier in this chapter. For this approach, information and data are necessary about which areas are at high risk, based on disaster risk assessment (e.g. a national or statewide database of natural hazard risk); or which areas have a high population of households which have a low capacity to cope with disaster risks and impact (high-level examples include the National Climate Risk Assessment and the Australian Disaster Resilience Index). Integrating risk assessments into resilience investments ensures that resilience efforts are informed by a clear understanding of potential hazards and vulnerabilities, leading to more targeted and effective interventions. This requires further definitions of high risk and vulnerability. It also requires an understanding of which approaches and, with this, investments would be effective in increasing disaster resilience of a specific area or of communities. An example of a framework that uses this approach is the Enabling Resilience Investment Framework (Wise et al., 2022).

The Disaster Ready Fund Act 2019-22 is an example of a fund that focuses on areas most at risk. It supports projects that address both the physical and social impacts of disasters on communities. Investment categories include infrastructure upgrades to withstand disasters, community resilience programs, research and development for better understanding and forecasting of disasters and enhancing emergency services capabilities. The Act emphasises the need for a transparent process for prioritising and allocating funds, based on centralised data. Additionally, a significant portion of the Disaster Ready Fund is to be directed towards building social and human resilience (Parliament of Australia, 2022).

High priorities in strengthening threshold and coping capacities

Prioritisation of investment could also be based on threshold capacities against specific impacts or stressors. For example, investment in keeping green infrastructure alive during a drought could be assessed as high priority when it is looked at from the perspective of strengthening our threshold capacity to face urban heat. Similarly, reducing bushfire risk through controlled or cultural burning can reduce our potential exposure to bushfire impacts through increasing our threshold capacity. The same logic applies to providing information for households to make their homes more fire- and/or heat-resilient, which increase their capacity to withstand bushfire impacts and extreme heat. In relation to heatwaves there are also further options of facilitating access to cool refuges for the general public and water fountains in public spaces. Both of these measures can increase coping capacity. As with the place-based approach, information and data are necessary, in this case particularly in relation to understanding the thresholds above which impacts manifest and where particular stressors are prevalent. From that information, strategies can be developed to strengthen the system's capacity to absorb shock or stressors without collapsing. In this context, future climate scenarios and projections offer relevant data and information.

Protecting a majority or critical infrastructure

Other organisations might decide to prioritise their efforts according to where they may protect or reach the most people or where they can cover the largest area; rather than focusing on those experiencing the highest levels of vulnerability. Taking this approach has its advantages in terms of potentially safeguarding the largest number of people or assets. However, this needs to be complemented by approaches that support groups with higher levels of exposure risk, and who are more likely to experience severe impacts of disasters on their livelihoods. When these urban communities have reduced access to information and fewer opportunities to develop the capacities needed to cope, let alone thrive, in an era of increasing risk, they are likely to experience the most severe impacts too. Furthermore, investing in the reduction of vulnerability of less-advantaged social groups can be utilised to strengthen the transformative dimension of resilience. Another priority is often the protection of critical infrastructure that is needed to keep the urban system and supply networks going, which is particularly important in complex urban systems due to the cascading impacts of infrastructure failure. As an example, flood risk affecting critical transport hubs can have impacts across the wider transport network, with cascading impact to livelihoods and the economy.

The highest benefit

When looking at value for money, resilience investment could be prioritised according to where the investment can achieve the most benefit. This would require assessment which could be undertaken based on resilience principles, on lessons learned from previous investment and decision-making approaches adapted to understanding disaster risk (e.g. specific CBA approaches, such as the Queensland Disaster Resilience Mitigation Investment Framework or the NSW Disaster Cost-Benefit Framework). Benefits can be defined differently in this context, for CBA benefits would largely be defined as quantifiable costs savings, but more intangible benefits can be included in CBA and can even be a focus of lessons learned from previous investment. The principles for resilience investment and guidance on monitoring and evaluating resilience investments developed by the project team also aim to support assessment of resilience investment and its benefit.

Another option would be to prioritise resilience investment by 'upgrading' general investments, as mentioned in the previous section, that is, investments that the organisation or authority needs to undertake anyway, and adding funds to those initiatives to build them in a more resilient matter. This second option would largely be relevant for investment in infrastructure.

A systemic view of investment

However, in this context it is noted that for resilience investment there is a need to shift from a single asset view to a systemic view of the whole urban system, recognises the interconnected nature and promotes

coordinated, strategic interventions (Resilient Futures Investment Roundtable & Climate KIC, 2024). This also includes to acknowledge the interconnectedness of risks, vulnerabilities, and impacts across different systems and sectors by considering multidimensional impacts, including social, economic, environmental and infrastructural consequences. While taking this systemic view of investment can be complex and needs to include a broader spectrum of actors, useful tools and frameworks have been developed for this approach, such as the Enabling Resilience Investment (ERI) Framework developed by CSIRO in cooperation with Value Advisory Partners (Wise et al., 2022), the 'A pathway towards systemic resilience investment (ABCD) Framework' developed by the Resilient Futures Investment Roundtable (Resilient Futures Investment Roundtable & Climate KIC, 2024) and the Guidance on Prioritisation document by the Department of Home Affairs (2019). In workshops for the Practical guidance tool, participants suggested that the tool could also be used to support investment decisions. However, implementation of these existing frameworks is slow and its seems that political will and/or high risk of disasters is a key prerequisite for implementation. Potentially, regulation around the necessity of a systems approach to government investment could support implementation, yet, in complex urban systems there are also challenges of governance systems, such as 31 local governments deciding on their budgets within the Greater Melbourne area, making decisions for resilience investment for the overall city region challenging.

A long-term view on investment

In a related matter, although many cities and regions in Australia have prepared climate and disaster risk assessments and mitigation plans, they struggle to fund the rising costs of business-as-usual activities, let alone to meet their growing adaptation and DRR needs (Wise, 2023). This shows the so-called policy-practice gap: while policies may outline comprehensive disaster management or climate adaptation frameworks, actual implementation often falls short due to inadequate funding, trained personnel or necessary infrastructure. For cities and regions, this could mean that there is a stronger role for state or national government, for example through financial support but also through relevant regulations. The situation also means that there is a need to prioritise and to consider long-term solutions that provide high value for money and increase resilience rather than short-term fixes and reactive approaches to disaster recovery.

Influencing resilience investment

Influencing resilience investment can refer to national government influencing lower government levels through providing funding for specific initiatives, as well as lower levels of government influencing higher levels through advocacy and information about risk assessment and benefit assessment so that the higher level provides funding for specific areas or invests itself. The same is true for communities, particularly disaster-impacted communities, which can influence resilience investment by highlighting specific needs and calling for measures to tackle impacts from disaster or climate change that they experience. Philanthropic funding also influences resilience investment and philanthropic organisations also advocate specific investment areas to government and private business. Government – largely on the national level but potentially also other levels – can also influence private resilience investment either through government grants or regulation.

Collaboration and negotiation are other avenues of influencing resilience investment. Collaboration can include the private sector and government investing together or local governments making collaborative investment decisions. An example of negotiation could be that government negotiates with the insurance sector that after government investment in resilience in a specific area, insurance premiums will be decreased due to lower risk. Insurance premiums can also be used to influence resilience investments of private households, for example when investment in specific upgrades to buildings leads to insurance premium adjustments.

Finally, research and lessons learned from previous resilience investments can also influence resilience investment as they can show which types of investment and which programs are beneficial.

Understanding the impact of activities and resilience investment

As described in the previous section, understanding the impact of resilience investment and activities, is a vital element of being able to prioritise resilience investment. An analysis and review of the (potential) contribution to resilience can be undertaken when an investment is planned, that is, before implementation (e.g. through cost-benefit analysis (CBA) or multi-criteria analysis (MCA)), during the investment/initiative (through monitoring) and when an investment/initiative has been completed (through evaluation). Insights from the review during and after the investment/initiative can then be used for subsequent investments and initiatives and changes to decision-making tools, such as CBA and MCA.

Decision-making tools

For analysis of resilience impacts before a decision is made on a resilience investment, decision-making tools, such as CBA and MCA, exist. However, these tools often do not consider resilience outcomes specifically as they are used as general decision-making tools. Thus, they would need to be adapted to measure the expected resilience outcomes of an investment. As mentioned, some specific CBA approaches exist in Australia, such as the Queensland Disaster Resilience Mitigation Investment Framework or the NSW Disaster Cost-Benefit Framework. **If disaster resilience is to be incorporated in all decision-making these considerations and approaches will need to be mainstreamed into general investment decision-making.** The principles for resilience investment developed by the project team can also be used to support assessment of resilience investment and its benefit.

To understand how resilience can be improved by investment, an understanding of disaster risk is also necessary. Thus, **the outputs of urban systemic risk assessments can provide valuable input into decision-making aimed at addressing critical vulnerabilities, risk reduction and resilience-building**. This includes assessment of current risks as well as emerging and future risks (e.g. through scenario planning), and calls for consideration of feedback loops in systemic risk assessment and risk-informed decision making that accounts for how riskscapes constantly evolve in response to every decision we make. The National Emergency Risk Assessment Guidelines (NERAG) provide guidelines for emergency risk assessment which can be helpful in this context and uses a scenario-based approach.

Monitoring and evaluation

Decision-making for resilience investment can (and should) also learn from monitoring and evaluation of implemented investments and initiatives. For both monitoring and evaluation of resilience investment, **objectives will need to be defined how the investment/initiative is expected to achieve improved resilience so that it can be assessed whether those are achieved**.

In our research we found that monitoring and evaluation of resilience investment is often not undertaken, aligning with Australian and international evidence (Berrang-Ford et al., 2021; Scott & Moloney, 2022). When it is done it is more likely to be monitoring, with a strong focus on whether the project was on time and budget, but not on the desired resilience outcomes that would be the focus of an evaluation.

We identified four related challenges for monitoring and evaluation of resilience investment. First, **there is not much advice on how to measure outcomes related to resilience, which can often lead to it being neglected in evaluation processes**. Interviewees told us that there are no clear guidelines or standard approaches to measuring these benefits, which provides a barrier to monitoring or evaluating them (Interviewees LG3, PS1, SG7, NG1). From an investment for resilience perspective, the difficulty in quantifying financial and other risks and returns on investment makes it challenging to assess the value and impact of such investments. Additionally, data gaps and the complexity of interpreting disaster risk undermine the ability to monitor progress effectively.

Second, resilience investments often occur in response to risk assessments and identification of likely impacts (New et al., 2022), so that **evaluations are dependent on the timeframe of the assessment** and are also likely to

change (e.g. if hazard or climatic events occur) Interviewees mentioned using the argument of avoided costs in their business cases for projects (as well as co-benefits) (Interviewees LG3, NG3, RS1, SG5), but in evaluation, costs are only avoided if there was an actual impact. Finding ways to evaluate resilience outcomes regardless of a hazard event is necessary. A further challenge is that to evaluate resilience projects following the events they have been designed to mitigate means that the **evaluation most likely needs to occur long after a project is over**. This temporal aspect indicates that the **retention of key staff, with knowledge of the project and its decision-making processes, is important**.

Third, any assessment of decisions taken to invest in resilience **need to take into account social change and other conditions during the evaluation period**. Investment decisions are made based on forecasts and available information and are thus not certain to meet expectations. Resilience investments are particularly prone to variations from expectations, as risk assessment is probabilistic and impacts of hazard events are non-linear.

Fourth, there is an emerging literature on maladaptation, that is concerned with how **often well-intentioned projects can often have detrimental outcomes** (e.g. Schipper, 2020) and this concern has also been reported in our interviews. This has consequences for scoping resilience investment evaluations, to ensure that possible detrimental outcomes are not omitted in the process.

Despite these challenges, approaches to monitoring and evaluation of resilience investments exist. This includes analysing return on investment in resilience (i.e. costs of loss and damage, and impact of investment) and understanding if the risk of impact has decreased. Other types of analysis include whether projects contribute to strategic objectives of the implementing organisation, for example the strategic objective of increasing tree canopy to decrease heat effects and improve air quality. Examples such as tree canopy study show the challenge of the temporal aspect for achieving an objective – while trees have been planted, the actual increase in tree canopy will take years. Guidance on monitoring and evaluating resilience investments (see Appendix 4) developed by the project team describes and suggests a number of possible approaches to monitoring and evaluation, such as capability maturity assessments (CMMs), logic models, triple dividend resilience framework and theory of change for setting objectives. **Policies that require the monitoring and evaluation of resilience investment, that is, their resilience outcomes, would help develop further and more standardised approaches**.

What could assist in enhancing understanding of natural hazards and approaches to building resilience in complex urban systems?

There is a growing effort to adopt multi-hazard approaches that acknowledge the growing likelihood of compound, cascading and multidimensional disaster impacts. This type of approaches requires a shift in practices, **calling for a reflection on what we value as the starting point for systemic risk assessment**. This shift has two implications. First, by focusing on what we value (rather than on specific hazards and what they can impact on), we are able to consider the set of specific natural hazards that can impact what we value and are therefore relevant to systemic risk assessment. Second, by seeking to define what it is that we value, we can extend the consideration of the concepts of life and property (which is the traditional approach of measuring the costs of natural hazard events), to also consider critical system properties and functions, such as liveability, social equity and livelihoods. Starting from what we value can assist in enhancing approaches to building resilience in complex urban systems and reflection of hazards in complex urban systems.

What we value

The approach of starting from 'what we value' can also be considered a multi-risk approach, rather than a multi-hazard approach. A multi-risk approach considers the multiple vulnerabilities of a system or location (i.e. the risk) and the cascading interactions and impacts that result. A **multi-risk approach can help ensure that a**

place-based approach is taken to disaster risk management rather than focusing on the hazard(s) alone and, thus, is a suitable approach for complex urban systems and includes systemic risk assessment.

Understanding risk

This shows that understanding risk is becoming more and more important in the context of disasters and resilience and can support understanding and knowledge of compound and cascading disaster impacts in complex urban systems. Guidelines, such as NERAG, can support the performance of risk assessment and integrating risk assessment into decision-making processes. In the context of decision-making and resilience investment, methods such as Monte Carlo and Real Options Analysis can assist with understanding uncertainties. The Monte Carlo method provides insight into unpredictable, complex or interrelated risks, through establishing parameters and probability distributions, generating likelihood distributions of forecast conditions. Real Options Analysis is used in CBA to account for uncertainty within investment decisions, by placing a benefit on retaining flexibility in decision-making through delaying, changing scales, changing project types, abandoning and design amendments. Examples with relevance to resilience investments include 'delaying an investment until better information about demand becomes available, or building flexibility in design to allow an investment to be expanded or modified' (ATAP, 2020, p.5). Combining Monte Carlo with Real Options Analysis can be useful in unpredictable situations, helping projects adapt to future uncertainties by adjusting timing or scope.

Preparations for potential risks in non-linear systems, such as a city, require a shift from definitive prediction to probable outcomes (Burger et al., 2021), as the complexity and unpredictability weaken the effectiveness of both the prediction of extreme events and successful resilience strengthening interventions. Preparing adaptive resilience planning strategies that include attention to the precautionary principle, anticipatory action in preparation for and the mitigation of disaster risk, and adaptive governance can support the approach to deal with probable outcomes (Hewitt, 2013; Munene, 2018; Wu et al., 2023). Resilience planning should include different approaches to resilience, such as engineering, socio-ecological or adaptive and transformative resilience (see also Fien et al., 2026). In this context, strengthening urban resilience must also encompass the imperatives of Net-Zero policies and actions.

Resilience strategies and adaptive risk governance

Effective planning for urban resilience is context specific, and cities need to invest in resilience strategies that best suit current and anticipated shocks and the stressors that intensify their vulnerabilities. This requires building the capacities of all levels of government to collaborate with each other and with all community stakeholders to develop multi-sectoral and multi-scalar resilience plans. The cases of resilience planning under the 100 Resilience Cities movement and the UNDRR My City is Getting Ready (MCR2030) campaign are recommended for review.

One example of an approach to adaptive risk governance is anticipatory action planning. This approach involves developing a pre-planned and contextually relevant suite of resilience-building initiatives that enable individuals, communities, organisations, and governments to "act ahead of predicted hazardous events to prevent or reduce acute ... impacts before they fully unfold" (OCHA, n.d.). Anticipatory action plans are based upon multiple hazards and risks, adopt an area-based approach and seek to develop the adaptive capacities needed for systems resilience (Niekerk & Terblanché-Greeff, 2017; Scott, 2024).

Reducing exposure and drivers of vulnerability

Reducing risk includes reducing exposure to hazard risk, for example through land use planning decisions (e.g. relocation from a high-risk area) or through engineering works (e.g. levees). However, it also includes reducing vulnerability, for example through reducing socio-economic and political drivers of vulnerability in the context of vulnerability of people and groups; or in the context of vulnerability of infrastructure through engineering works. As vulnerabilities can lead to trigger points that catalyse and intensify cascading damage and loss, a key strategy is to reduce the stressors that cause systemic vulnerability. To be able to reduce vulnerability, it is

necessary to conceptualise vulnerability, which requires mapping exposure risk, social, economic and demographic dimensions. This can assist in understanding how vulnerability is experienced and what drivers of vulnerability are. Once the experiences and drivers are understood better, the sensitivities and vulnerabilities that intensify disaster risks can be mitigated. Examples of conceptualising vulnerability have been collected in Phase 2 of the project and are presented in the report on practices and processes (Nogueira de Moraes et al., 2026a) and also the Practical guidance tool (Module 4).

Social learning and formal inquiries

Social learning can also assist in understanding and developing approaches to resilience building in complex urban systems. Social learning builds on reflection on experiences of disasters at community and agency levels and the consolidation of the resulting knowledge, skills and values into new community-wide mental models of the relationships between human and natural systems and the adaptive capacity to apply various forms of agency to forge an active and increasingly resilient community (Zhang et al., 2019; Azad et al., 2021). This reflection can also inform better understanding of long-term societal challenges caused by disasters, such as reduced education and workforce participation, increased crime, and decreasing levels of physical and mental health, and potentially (resilience-building) activities to tackle these challenges.

Formal inquiries and royal commissions after disasters can serve a similar purpose by analysing where the system was not sufficiently prepared for a disaster and what resilience-building measures are necessary to avoid hazard impacts when the next hazard event occurs.

Research outputs as tools to enhance understanding and support resilience decision-making in complex urban systems

To support the consideration of the risk of cascading and compounding impacts, their impact on vulnerabilities and how to prioritise investment, the project has developed guidance documents and principles that aim to assist understanding of natural hazards and approaches to building resilience in complex urban systems: a Practical guidance tool for conceptual mapping of resilience and vulnerability in complex urban systems, principles for prioritising and influencing resilience investment and guidance on monitoring and evaluating resilience investments.

These tools hold the potential to support project development, capacity development, assessment of vulnerability and resilience, risk assessment, disaster adaptation planning and decision-making for resilience investment particularly in complex urban systems – as was discussed by participants in the workshops for the Practical Guidance Tool.

The Practical guidance tool for conceptual mapping of resilience and vulnerability assists in conceptualising vulnerability and resilience, as well as hazards, exposure and capacities and highlights ‘what we value’ as a crucial concept (see Appendix 1 for an overview of the Tool). It provides the conceptual basis for understanding the complexity of risks in urban areas, presenting a visual and textual conceptualisation of resilience and vulnerability, as well as a typology of disaster impacts and key terms for connecting urban complexity and risk assessment, such as feedback loops and thresholds.

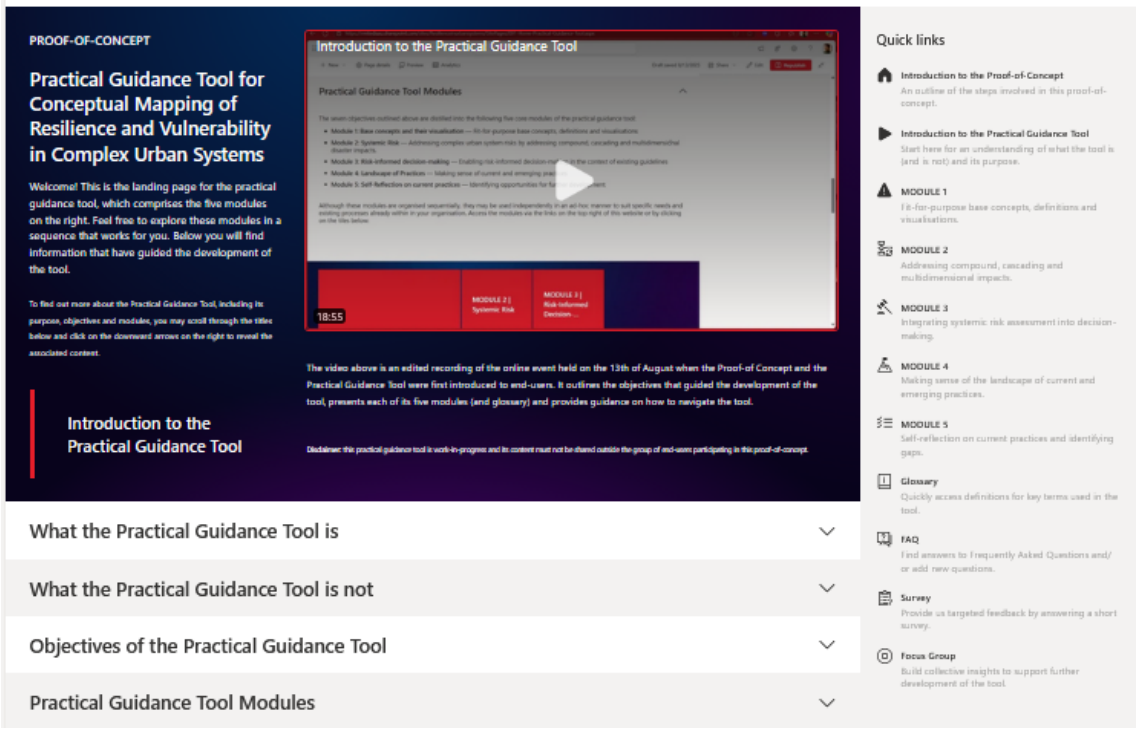
Organised around five modules and a glossary, the Practical guidance tool provides end-users with a flexible way to approach key concepts that support resilience, vulnerability and systemic risk assessments (see Figure 5). These include two sets of building blocks where key concepts are sequentially introduced to support assessments or resilience and vulnerability (module 1) and systemic risk assessment (module 2) as well as a text-based module that presents reflections on risk-informed decision-making which provides the context for the application of assessment findings (module 3). The Tool also presents a library of existing examples of conceptualisations and mapping of vulnerability and resilience with a focus on Australia (module 4). Finally, it

also provides opportunity for self-reflection of current practices (module 5). The Tool is supported by a Glossary and FAQs.

Although the modules are organised sequentially, they may be used independently in an ad hoc manner to suit specific needs and existing processes already within the end-user's organisation. As such, the Tool is not resource-intensive and can be used as required in the specific situation of the user.

The Tool was designed to provide a common platform for a wide audience -private-sector practitioners, government staff and community members – to understand systemic risk and its implications on lives, livelihoods and places where they live or help to manage. It is aimed at those involved in DRR and climate resilience in urban settings and aims to bring concepts of DRR approaches and public health and climate adaptation approaches together. While informed by academic research, this tool is not a scientific output and not a measurement, index or mapping tool; rather it translates research findings into practical guidance. The Tool can be accessed on the Natural Hazards Research Australia website: naturalhazards.com.au/practical-guidance-tool.

FIGURE 6: SCREENSHOT OF THE PRACTICAL GUIDANCE TOOL – PROOF-OF-CONCEPT VERSION



The **principles for prioritising and influencing resilience investment** (see Figure 6) provide a summary of insights from a document and interview analysis on resilience investment (Hosseinioon et al., 2026). They are envisaged to be used by applicants for resilience funding programs at all levels, by funders of these programs as well as other users. They are normative statements, designed to guide investment decisions by promoting holistic approaches that incorporate multidimensional risk analysis, prioritise vulnerable populations, encourage long-term planning and embed resilience considerations at every stage of development and policymaking. While not all principles may be achieved, the principles can have an 'educational' effect by providing an understanding of what resilience investment should and could strive for.

The Principles were developed as 'context-free' principles, that is, as broad statements applicable to different scales and situations. The overarching principles are specified further through statements ('processes'), to make them more tangible and applicable for users. Recommendations (Appendix 3) provide further detail for

policy and decision-making and activities for resilience investment, in addition to the provided principles and processes. The recommendations have a prescriptive nature and are used as an additional set of recommended principles for funding providers and applicants to enhance their projects towards fulfilling resilience goals. The principles are also accompanied by a checklist with more detailed questions for additional context and scales. Collectively, these actions are intended to elevate resilience investment practices, offering guidance for users on how to priorities and influence investments. Details for requesting the principles, recommendations and checklist documents can be found on the project's web page here: naturalhazards.com.au/research/research-projects/natural-hazards-and-resilience-complex-urban-systems.

FIGURE 7: PRINCIPLES FOR PRIORITISING AND INFLUENCING RESILIENCE INVESTMENT

Principles	Processes
Shift from a reactive to a proactive approach	Shift the focus of resilience investment from the response phase to preparedness, mitigation, adaptation, and transformation Adopt a systems approach. Incentivise preventative investments Enhance socio-spatial and economic justice Promote proactive planning for investment
Shift from a single hazard to a systemic risk approach	Adopt a systems approach Recognise the interconnected nature of risks Prioritise projects considering multidimensional and compound impacts Consider interactions between multiple hazards Move beyond assessing individual hazards Consider stress and deficiencies from damage and disruption Consider intensifying effects
Prioritise vulnerability and risk exposure	Consider vulnerability in the context of risk exposure Consider differences in risks of exposure Prioritise areas and groups at high-risk exposure
Prioritise long-term, sustainable solutions over short-term investment	Promote long-term planning and adaptability Shift towards sustainable investment Overcome traditional business practices
Embed resilience building in investment mechanisms and projects	Embed resilience investment in multiscale policymaking Build capacity for resilience investment Facilitate capacity building Embed resilience in general projects Leverage existing programs and services
Consider interdependencies across scales and sectors	Enhance coordination and relationships Foster a shared understanding of risks Pursue collaborative financing and funding Foster multisectoral and multiscale coordination Support community-led initiatives Ensure accountability
Prioritise investment in communities to create value and reduce negative effects	Emphasise long-term planning and adaptability Create value through resilience investment Empower communities for successful resilience delivery

Source: Hosseinioon et al., 2026

The guidance document on monitoring and evaluating resilience investments provides processes and questions that end-users can employ to undertake monitoring and evaluation of resilience investments and ensure learning from those investments. Monitoring and evaluation are pivotal processes for ensuring that resilience investments achieve their intended goals, learning outcomes and broader impacts across different scales and timelines. They provide a systematic approach to track outcomes, improve implementation, foster accountability and define future initiatives. The framework can be used in the context of the principles for prioritising and influencing resilience investment.

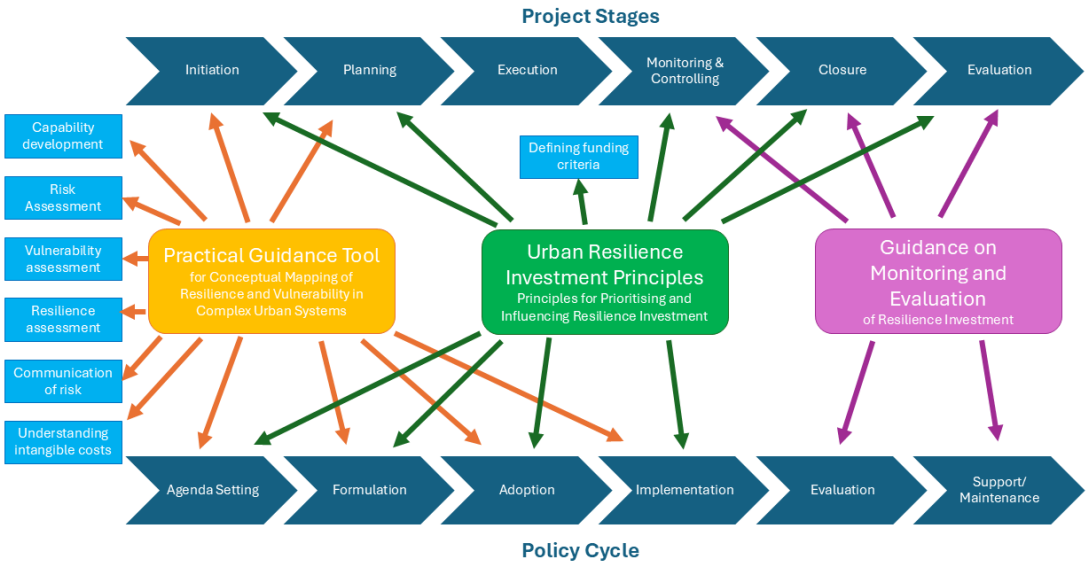
In the introduction, the document provides a brief overview of monitoring and evaluation and specific requirements and challenges in the context of resilience investment. Next, the document describes relevant tools for monitoring and evaluation. It then presents a framework with several elements (i.e. steps and tools) that can be utilised to monitor and evaluate resilience investment. These tools assist in assessing whether a project or initiative has achieved its resilience objectives as well as long-term returns and value across sectors. A brief overview of the content in the guidance document is provided in Appendix 4. The guidance document can be accessed here: naturalhazards.com.au/resources/publications/report/monitoring-and-evaluating-resilience-investments-frameworks-methods.

A planned output of this project are capability resources. These could take the form of short brochures or practice briefs which explain relevant concepts of resilience planning and disaster risk assessment. These items would be based on insights from Work Package 1 (see also Fien et al., 2026).

Potential uses and further development of the outputs

The potential uses of the produced outputs in the different stages of a project or policy development (darker blue) as well as for specific tasks (lighter blue) are presented in Figure 5. Specific tasks have partly been identified by research participants.

FIGURE 8: UTILISATION OPTIONS OF PROJECT OUTPUTS



While we have tested the Practical guidance tool with stakeholders, further (technological) development could be coupled with further testing and validation. For the proof-of-concept study the tool was published as a SharePoint website with invited access. However, to make it more accessible, it will be moved to a public website and has been modified to respond to feedback collected. While proof-of-concept participants

considered the tool robust and academically sound, they also stated that it could be made more practical and relatable to some of the intended audiences, for example through easier language, providing more examples and checklists to 'test' understanding and practices. We have modified the tool accordingly, but further testing is likely to improve the tool further and some larger changes were out of scope for this project. Related to this, participants assessed the tool as well-suited for training and capacity development, while the application to support the work of end-users needs to be brought out and communicated more clearly – a step which is also outside the current scope of the project.

Participants considered the 'landscape of current and emerging practices' (Module 4) valuable to those who are starting with vulnerability assessments and need to get a sense of what is out there and also those who already have experience but want to learn more about existing practices, processes and examples. It was flagged that it would be necessary to keep these examples and links up to date. A community of practice was suggested as a possibility which could provide new or updated examples. However, this would still need a type of custodian for the website of the tool. This is something that needs to be investigated further.

Further expansions of the Tool that can be investigated further in the context of new research or projects are: lists of existing indicators that can be used to assess vulnerability and resilience; expansion of the systemic risk building block, so it can provide guidance on how to conduct system mapping and systemic risk assessments, including detailed guidance on scenario-building and scenario plausibility; expansion of the module on integrating systemic risk assessment into decision-making to include practices on scenario planning and prioritisation of vulnerabilities that need to be addressed and how that feeds into decision-making, and guidance on the operationalisation of the concept of adaptation pathways, evolution of the self-reflection tool into a self-assessment tool to interrogate current and emerging practices against benchmarks/best practice.

As mentioned, the Resilience Investment Principles and guidance on monitoring and evaluation will be available via the project website and be used by practitioners. However, they could be tested and validated further to understand how they can be used and how they are useful to end-users.

The content for capability building resources holds large potential for increasing understanding and knowledge about a systems approach, transformative and adaptive resilience and compound and cascading disaster impacts in complex urban systems. A publication of the content as resources for end-users would support decision-making and resilience panning. This is a planned step that needs to be investigated further.

Conclusions

There is awareness in policy and practice that multi-hazard approaches to DRR and resilience building are necessary, particularly in complex urban systems. Multi-hazard approaches need to be capable of understanding and mitigating the ripple effects and cascading impacts of disasters across and between different urban systems and subsystems – making them preferably place-based approaches. Some observers additionally argue that a multi-risk approach would be preferable to avoid the focus on hazards and include a more comprehensive view on risks.

Disaster prevention or resilience-building measures have been identified as most cost-effective, as they have the potential to reduce the impact of a disaster, leading to less suffering and damage but also to lower costs of disaster response and recovery. Similarly, when looking at it from a systems perspective, this translates into the need to embed action on leverage points upstream in the dynamics of systems. As an example, planning strategies and building codes can be more comprehensive and better regulated and implemented to ensure that new urban developments are resilient to future extreme events from the beginning. Resilience-building strategies can also be integrated into post-disaster recovery programs by 'building back better', that is, building disaster prevention and preparedness into recovery activities. This can reduce systemic vulnerabilities and thus help to future-proof the resilience of social, economic, infrastructure and environmental systems. However, precaution is needed as 'maladaptation' may result if recovery strategies have not been carefully considered beforehand. Ultimately, prioritising investments that create value for communities—such as jobs, social capital and improved infrastructure—ensures that recovery, transition and development processes strengthen sustainable, well-adapted urban futures.

Resilience planning strategies for cities and towns can provide the necessary identification of resilience-building measures and development of a pre-planned and contextually relevant suite of resilience-building initiatives that enable individuals, communities, organisations and governments to act ahead and prevent or reduce impacts of hazardous events and stressors. However, equally important to having the discussion and developing resilience-building measures is the need for adequate funding (or an understanding of how to prioritise limited funds best), trained personnel and informed community members (showing a need for capability building resources) and necessary infrastructure (which is partly related to funding) to be able to develop and implement resilience-building strategies and DRR frameworks.

There is a need to understand compound and cascading disaster impacts and feedback loops of impacts of natural hazard events as well as responses to those events. While it is not possible to predict all impacts and feedback loops, it is possible to try to understand probable and potential impacts and to respond to those. Scenario planning is a useful tool in this regard and will need to be employed and developed further.

A barrier to developing joint strategies can be that language and terms may be used in slightly different ways between different sectors, organisations or strategies, which might mean that there is some misunderstanding or talking at cross-purposes between organisations or people. The Practical guidance tool aims to provide some broad conceptualisations of vulnerability and resilience as well as other notions to improve communication and to provide a common ground where differences can be reconciled, addressed or appropriately acknowledged. In this sense, the Practical guidance tool can also be used for developing resilience strategies, projects, business cases and grant applications and undertaking/preparing systemic risk assessment, assessment of vulnerability and resilience, building community profiles or hazard profiles and design of resilient building codes and land use considerations, as identified by users.

An idiosyncrasy of complex urban systems – apart from their complexity and interdependencies – is that residents are overall often less aware of natural hazard risk and trust more in immediate government support in comparison to residents of hazard-prone areas who tend to be more risk-aware and resilient in the sense that they understand that government support might not be available immediately – noting that this is a very generalising statement. This means that an investment in communication and awareness campaigns about risk

and community events and other approaches to include communities in place-based resilience building is money well spent. The 'What we value' building block of the Practical guidance tool was perceived by users as a good way to start a conversation with communities in relation to addressing heatwaves and climate risk and could also be used for other topic areas. Overall starting from ‘what we value’ is a helpful approach for multi-hazard and place-based approaches, and assists in clarifying what resilience and vulnerability means for an area or for a specific approach or strategy.

A further characteristic of complex urban systems is their complex governance situation. In Australia, major urban areas generally consist of a large number of councils (with the exception of Brisbane), which can impede development of city-wide strategies and the harmonisation of resilience investment. To develop place-based multi-hazard approaches and effective resilience investment, there is a need to collaborate on the city-regional level and develop a city-wide awareness of systemic risk and a city-wide approach. This is relevant for local (and state) government but also for residents, organisation and private businesses for collaboration and a shared knowledge base. Currently, if this city-wide cooperation is happening (largely in Sydney with Resilient Sydney) it is voluntary. To improve city-wide approaches there may need to be some sort of regulation for cooperation on city-wide risk assessments and also resilience investment decisions. Similarly, regulation on consideration of resilience in investment decisions for local government and private businesses might be necessary to improve approaches to and overall outcomes for resilience in, as currently the required resources and challenges of assessment mean that resilience and disaster risk is often not factored into investment decisions.

Further reading

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Utilisation outputs

Developed outputs

Practical guidance tool for Conceptual Mapping of Resilience and Vulnerability in Complex Urban Systems. naturalhazards.com.au/practical-guidance-tool-conceptual-mapping-resilience-and-vulnerability-complex-urban-systems

Principles for prioritising and influencing resilience investment (including Recommendations and Checklist)

Guidance: Monitoring and evaluating resilience investments: Frameworks, methods and tools

Hazard Note

Practice Note

Video outlining the purpose and application of the Practical guidance tool -

Training session on the Practical guidance tool

Planned outputs

Academic publications

Presentations delivered:

Natural hazards and resilience in complex urban systems. Natural Hazards Research Australia Research Forum. Adelaide. 19 June 2025.

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Reframing critical infrastructure: systemic risk assessment and Urban Blue-Green Infrastructure (UGBI) for climate resilience. State of Australasian Cities (SOAC) Conference. Brisbane. 11 December 2025.

Systemic risk assessment: Addressing compound, cascading and multidimensional disaster impacts for urban resilience action. State of Australasian Cities (SOAC) Conference. Brisbane. 11 December 2025.

Publications

Understanding cities as complex systems: Implications for urban resilience to hazards, risks and disasters Work Package 1 Report. Natural Hazards Research Australia.

Current (and emerging) practice in mapping vulnerabilities and resilience within urban systems. Work Package 2 Report. Natural Hazards Research Australia.

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Team members

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Jago is Professor of Urban Policy and works in the Research and Innovation Portfolio at RMIT University as the Director of the Urban Futures Enabling Impact Platform. Jago has an extensive record of research into urban problems addressing a wide array of housing, transport, urban planning, urban policy, governance, infrastructure, energy and spatial labour market questions. He has recently led an Australian Housing and Urban Research Institute (AHURI) project on housing, planning and disaster preparedness. Jago's research record includes more than 140 publications and has been awarded research funding from major scientific bodies including the Australian Research Council (ARC), AHURI, Natural Hazards Research Australia, Australian Urban Research Infrastructure Network (AURIN), and the EU Horizon scheme. He served as Director of the Urban Research Program at Griffith University (2011-2014) and the Centre for Urban Research at RMIT (2014-2023).

Dr Annette Kroen

Annette is a Senior Research Fellow in the Centre for Urban Research at RMIT University. She is an urban and regional planner with expertise in urban governance, resilience planning, integrated land use and transport planning, and policy analysis. She has worked on projects investigating housing policy, settlement planning, and disaster prevention, preparedness and response; resilience planning; social connectedness in communities on the urban fringe, benefit evaluation of investment in infrastructure in outer suburban growth areas; smart and sustainable cities; and National Urban Policy. She has also worked as a policy analyst with the Victorian State Government, and in private practice as a facilitator and consultant on a range of planning related projects.

Prof John Fien

John is Professor of Practice in the School of Architecture and Urban Design at RMIT University. With a focus on interdisciplinary research, previous positions have included Professor of Sustainability at RMIT University, Professor of Environmental Education at Griffith University, and Professor of Leadership at the Swinburne Leadership Institute. He applies his skills in systems thinking and community engagement to the development of adaptive capacities for climate and disaster resilience. He has completed research projects supported by the ARC and AHURI as well as consultancies for State and Australian governments and international agencies including UNESCO, UNEP, UNICEF, OECD, the World Bank, Qatar Foundation, the EU Horizon scheme and WWF-International. He has written, co-authored and edited several books including *Young People and the Environment, Growing Sustainable Communities, Ethical Cities,* and *Design for Fragility*.

Dr Leonardo Nogueira de Moraes

Leonardo is a Research Fellow in Disaster Resilience at RMIT University's Centre for Urban Research. He is part of the *Natural hazards and resilience in complex urban systems* project with his contribution focusing on assessing and mapping vulnerabilities and resilience within urban systems at local scales. His research program explores how formal and informal planning processes inform the building of resilience and vulnerability to disasters and climate change. Leonardo seeks to understand the roles of regulation, self-organisation and connectivity in resilience-building processes and global-local interplays from social-ecological and complex adaptive systems' perspectives. His emerging work looks at the roles of drone imagery and social media in supporting citizen science and understanding of climate change impacts as part of enabling adaptation through nature-based solutions.

Dr Solmaz Hosseinioon

Solmaz is a researcher, urban designer, planner and resilience expert. She is a Research Fellow at the Centre for Urban Research at RMIT University. Solmaz has an extensive research record addressing urban plans and regulations, resilience, sustainable development, heritage, placemaking, informality and disaster management. Working at the urban-policy-community interface, Solmaz has worked in the nexus of resilience, urban design and placemaking, adaptation capacity building, multi-hazards and climate change. In addition to her academic career, she has made significant contributions to raising knowledge and engagement in communities. Solmaz has designed and led workshops on urban resilience for professionals, academia and decision makers, held by public and private institutions, NGOs, UN-Habitat and other international organisations.

Dr Erica Kuligowski

Erica is an ARC Future Fellow and Principal Research Fellow in the Engineering School at RMIT University studying evacuation and emergency communications in hazard events. With a PhD in Sociology and Masters and Bachelors degrees in Fire Engineering, she has led post-disaster research studies of response and recovery in bushfires, floods, cyclones and severe weather events. Erica leads hazard-related research projects; for example, to examine community experiences in the 2022/2023 floods in Victoria and South Australia, to understand community comprehension and use of bushfire maps, and to study how residents and tourists make decisions about evacuation during bushfires in high-risk areas.

Dr Anthony Kent

Anthony is a researcher with the Centre for Urban Research at RMIT University. He is co-editor and chapter author of the recent Academic Press publication, *Smart Cities for Technological and Social Innovation: Case Studies, Current Trends, and Future Steps* and lead author of the chapter 'Planning for Resilience in Bandung: Case Studies of Local Disaster Management Strategies' which appears in *The Routledge Handbook of Urban Indonesia*. He is also Associate Editor of *Urban Policy and Research*, which is a leading urbanist journal in Australasia and Asia. Anthony is an economic geographer with a continuing focus on urban and regional settlement patterns, and he incorporates social, economic and environmental implications in his research and teaching.

Amanda Lamont

Amanda is founder of Nature Based Resilience. Previously, she worked in Dister Risk Management at Zoos Victoria, was Director Stakeholder Engagement & Projects at AIDR, and is the founder of the Australian Women in Emergencies Network. She has strong expertise in nature-based solutions and in gender, leadership and biodiversity issues in disaster risk management.

Dr Leila Irajifar

Leila is a Senior Lecturer and Program Manager for the Master of Disaster, Design, and Development (MoDDD) at RMIT School of Architecture and Urban Design. Her research and teaching focus on systemic design, disaster resilience, smart cities and digital solutions for urban resilience. During her PhD, she developed a disaster resilience model based on data collected after the 2011 Brisbane flood. Before academia, Leila worked in architecture and urban planning as a Building Information Modelling modeller and Spatial Analyst.

Dr Mittul Vahanvati

Mittul is a senior lecturer in the Sustainability and Urban Planning discipline at RMIT. Her research focuses on the complex relationship between housing recovery after disasters and community resilience, to uphold housing as a human right and enhance its resilience. Her research focuses on two aspects of housing recovery and community resilience: 1) bridging the short-term shelter needs with longer-term disaster resilience, and 2) negotiations between enabling recovery program design and governance by governments and grassroots community abilities for risk-informed decision-making. She employs collaborative methods of research, including co-design and knowledge co-production by engaging with various stakeholders from diverse cultural settings in Australasia and the Pacific. She engages with UN-bodies, national and local government as well as non-government organisations. Mittul has worked in architectural industry for over 8 years, in India, Switzerland and Australia. Her PhD focused on long-term impacts of owner-driven housing reconstruction programs and projects in India, in terms of community resilience. She is also a co-founder of a design + make social enterprise, Giant Grass. Mittul co-leads RMIT's Climate Change Transformations Research Group.

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Appendix 1: Practical guidance tool

The Practical guidance tool consists of five modules, plus a Glossary and FAQs. Although the modules are organised sequentially, they may be used independently in an ad hoc manner to suit specific needs and existing processes already within the end-user's organisation. The following gives an overview of the content.

Modules

Module 1: Base concepts and their visualisation — Vulnerability and Resilience

Building Blocks:

- What we value
- Hazards
- Exposure
- Vulnerability
- Capacities
- Resilience

Module 2: Addressing Compound, Cascading and Multidimensional Disaster Impacts in Urban Systemic Risk Assessment

Building Blocks:

- Disaster Impacts
- Feedback Loops
- Complex Impacts
- Thresholds
- Critical Infrastructure
- Systemic Risk

Module 3: Risk-informed decision-making – Enabling risk-informed decision-making in the context of existing guidelines

Module 3 is a text-based module that presents reflections on risk-informed decision-making. It highlights the need to address the collective nature of current, emerging and future riskscapes, but also the challenges inherent to integration of processes for building systemic resilience and addressing critical vulnerabilities.

Module 4: Landscape of Practices – Making sense of current and emerging practices

- Summary table of current and emerging practices which lists the practices identified during the research phase, providing links to their online source, a short description and an indication of the publisher and likely audience.
- Database of relevant sources: A repository that is designed as Microsoft Excel spreadsheet in which sources are classified according to themes of interest and levels of focus. Each level/scale is presented as a separate worksheet/tab.

Module 5: Self-Reflection on current practices — Identifying opportunities for further development

This module provides several questions to assist in self-reflection of current practices, and suggests relevant modules and building blocks to consider for each question.

Introduction to the Practical guidance tool

The website for the proof-of-concept study of the Practical guidance tool also provided an introduction to the proof-of-concept study and an introduction to the tool. The following gives a brief overview of the introduction to the tool.

What the Practical guidance tool is

This practical guidance tool is a resource made available to those involved in disaster risk reduction and climate resilience in urban settings. It supports the prioritisation of investment areas to strengthen the resilience of

complex urban systems to natural hazards and extreme weather events. The tool consists of five modules that practitioners can engage with either sequentially or independently, depending on their specific needs.

The tool provides practical guidance for understanding and addressing the complexities of urban systems in the context of a changing climate. It is intended to complement existing efforts by all working in disaster risk reduction, climate resilience and emergency management in major Australian urban areas.

What the Practical guidance tool is not

The Practical guidance tool is not a measurement, index or mapping tool. It is not prescriptive and should not be interpreted as investment advice for urban resilience. It does not aim to replace existing practice, nor is it designed for generating rankings of resilience and vulnerability.

Objectives of the Practical guidance tool

This Practical guidance tool was developed to achieve the following objectives:

- Promote a shared language and base conceptualisation of resilience and vulnerability that is multi-scalar and relevant to the diverse community of urban, climate- and disaster resilience stakeholders. This common language reconciles climate, disaster and urban resilience perspectives, supports a multi-hazard approach, recognises urban systems as complex (while identifying urban system functions that are valued), and explicitly considers cascading, compounding and multidimensional disaster impacts.
- Translate complex concepts into clear, concise and operational definitions to enable effective communication across sectors for the design and funding of local interventions that address systemic risk.
- Provide visualisations of core concepts, so they can be communicated more easily and used to support the assessment of systemic risk.
- Enable systemic risk assessment that explicitly accounts for cascading, compounding and multidimensional disaster impacts on Australian major urban areas.
- Support integration of systemic risk insights into decision-making, helping end-users embed risk awareness in policy, planning and investment processes.
- Offer a library of current practices for understanding, assessing and building resilience or addressing vulnerabilities, allowing users to reflect on their own practices, and identify opportunities for further development.
- Serve as a sounding board for evaluating existing tools and frameworks, ensuring they are fit for purpose and effective in promoting understanding of systemic risks (e.g. via checklists).

Limitations of the Practical guidance tool

This tool was designed to provide a common platform for a wide audience -private-sector practitioners, government staff and community members – to understand systemic risk and its implications on lives, livelihoods and places where they live or help to manage. While informed by academic research, this tool is not a scientific output; rather translates research findings into practical guidance.

As such, the proposed tool represents a research-supported design that is currently undergoing proof-of-concept validation. Actual use by practitioners (during the trial phase) may reveal that some components of the tool are more or less valuable than anticipated. Importantly, the tool does not introduce new practices; rather, it encourages users to self-reflect on existing practices, identify gaps and explore ways to make these practices fit for purpose in scenarios of increasing complexity.

Appendix 2: Principles for prioritising and influencing urban resilience investment

These principles and processes are intended to assist decision makers, grant applicants and fund holders with decisions about resilience investment.

Principles	Processes
Shift from a reactive to a proactive approach	Shift the focus of resilience investment from the response phase to preparedness, mitigation, adaptation, and transformation Adopt a systems approach. Incentivise preventative investments Enhance socio-spatial and economic justice Promote proactive planning for investment
Shift from a single hazard to a systemic risk approach	Adopt a systems approach Recognise the interconnected nature of risks Prioritise projects considering multidimensional and compound impacts Consider interactions between multiple hazards Move beyond assessing individual hazards Consider stress and deficiencies from damage and disruption Consider intensifying effects
Prioritise vulnerability and risk exposure	Consider vulnerability in the context of risk exposure Consider differences in risks of exposure Prioritise areas and groups at high-risk exposure
Prioritise long-term, sustainable solutions over short-term investment	Promote long-term planning and adaptability Shift towards sustainable investment Overcome traditional business practices
Embed resilience building in investment mechanisms and projects	Embed resilience investment in multiscale policymaking Build capacity for resilience investment Facilitate capacity building Embed resilience in general projects Leverage existing programs and services
Consider interdependencies across scales and sectors	Enhance coordination and relationships Foster a shared understanding of risks Pursue collaborative financing and funding Foster multisectoral and multiscale coordination Support community-led initiatives Ensure accountability
Prioritise investment in communities to create value and reduce negative effects	Emphasise long-term planning and adaptability Create value through resilience investment Empower communities for successful resilience delivery

Source: Hosseinioon et al. 2026

Appendix 3: Recommendations for prioritising and influencing urban resilience investment

Recommendations	Processes
Promote innovative methods for funding and investment	Consider innovative investment mechanisms Invest in advanced infrastructure Harness data and information Explore the use of smart city technologies Invest in innovative technologies
Encourage and facilitate public-public, public-private and private-private partnerships	Facilitate partnerships to leverage resources and expertise Promote collaborative financing Develop public-public partnerships Encourage collaborative private sector investment Leverage government policies and programs towards partnerships
Encourage and facilitate private sector and household investment for resilience by developing a market for resilience investment	Mobilise private capital Enhance individual-level involvement Encourage private sector support for communities Develop standardised methodologies for capturing and quantifying the value of resilience Promote private sector investment in resilience-building Develop a market for resilience investments Help businesses and individuals to invest in adaptation
Consider scenario planning for complex urban systems	Explore and evaluate various potential futures in decision-making Understand the range of possible outcomes Invest in adaptable systems and make informed decisions Understand the range of possible investment outcomes
Harness insurance mechanisms potential for resilience	Utilise risk-sharing and financial protection Acknowledge disaster risk in insurance premiums: Use innovative insurance models Use insurance products for resilience Address insurance protection gaps
Diversify funding mechanisms, models, resources and funds	Decentralise investment methods and funding sources Diversify assets, funding models, resources and beneficiaries Leverage national funding streams Incorporate financial resilience principles

Source: Hosseinioon et al. 2026

Appendix 4: Monitoring and evaluating resilience investments

The document 'Monitoring and evaluating resilience investments: Frameworks, methods and tools' provides processes and questions that end-users can employ to undertake monitoring and evaluation of resilience investments and ensure learning from those investments. As introduction, the document provides a brief overview of monitoring and evaluation, specific requirements and challenges in the context of resilience investment and relevant tools for monitoring and evaluation. These include CBA and associated methods, Resilience Return on Investment, Capability Maturity Models, Theory of Change and Logic Model. The document then presents a framework with several elements (i.e. steps and tools) that can be utilised to monitor and evaluate resilience investment. Figure 9 provides an overview of the elements. Figure 10 shows the monitoring and evaluation checklist for Element 5. The framework can be used in the context of the principles for prioritising and influencing resilience investment.

FIGURE 9: ELEMENTS OF THE EVALUATION AND MONITORING FRAMEWORK

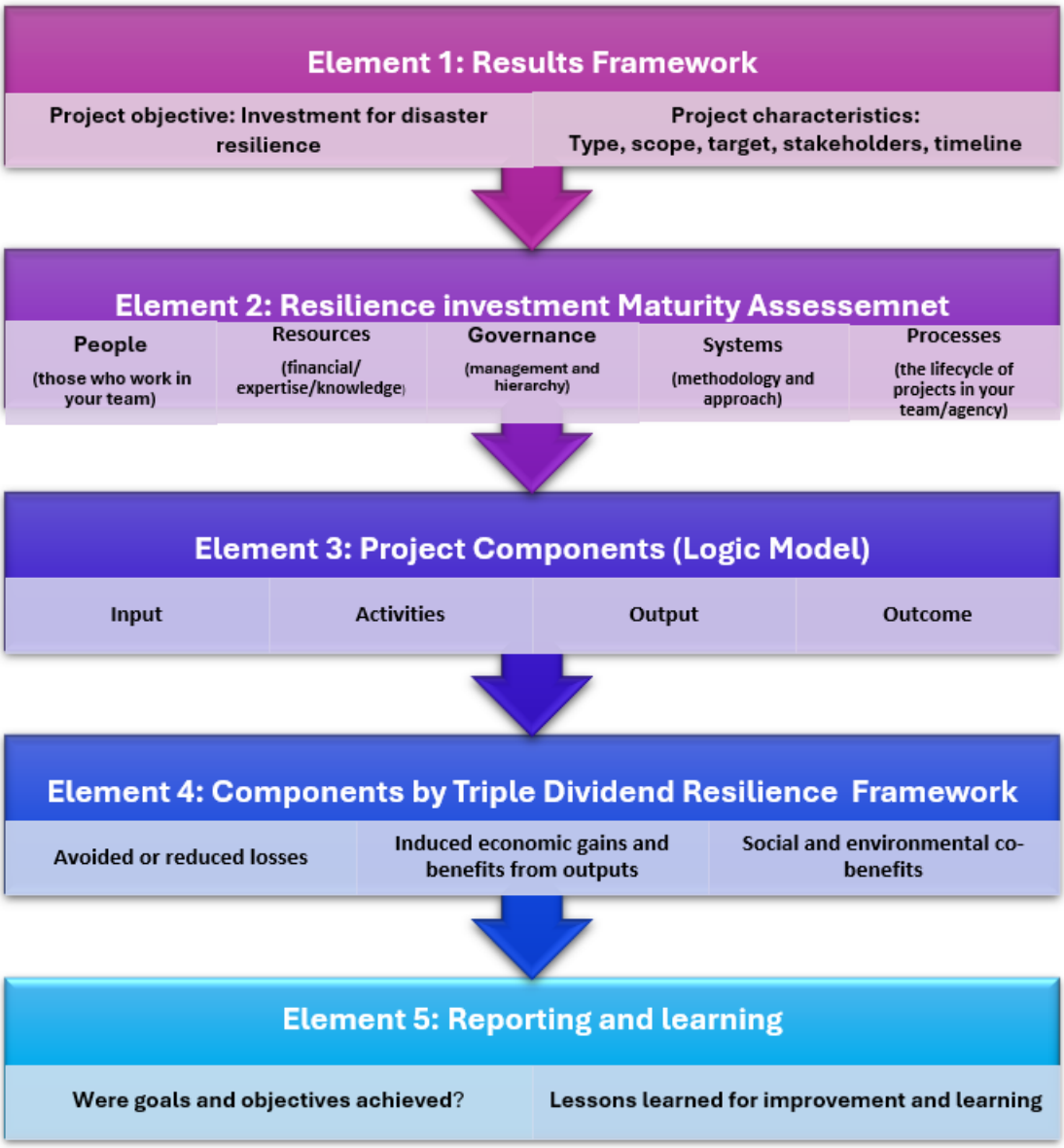

FIGURE 10: ELEMENT 5 MONITORING AND EVALUATION CHECKLIST

Goals and Objectives
Is there a clearly defined approach or need towards disaster resilience that the investment addresses?
Has the project been developed in a way to explain how the investment leads to resilience outcomes?
Is there a logic model showing inputs, activities, outputs, outcomes and impacts?
Strategic Alignment for Investing in Resilience
Does the project clearly define its nature, scale, alignment, source of funding, governance and stakeholders?
Are there strategic planning resources that can be referred to in order to strengthen alignment with national or local resilience strategies.
Identification and Addressing Gaps and Challenges for Investment
Has the project identified data/ implementation/governance gaps and challenges in the process of project investment?
How can gaps and challenges be addressed to proactively enhance project success?
Has the project engaged with community and data management experts to address identified challenges?
Planning & Integration
Has monitoring and evaluation been imbedded in the investment prospectus from the outset?
Has the project explored strategies to incorporate monitoring activities from the start to improve project outcomes?
Inputs and Activities
Are the inputs and resources (financial, human, technical) allocated sufficiently and appropriately towards resilience?
Are the planned activities and outputs aligned with the resilience goals?
Have outputs and outcomes achieved intended results?
Outputs
What products, services or infrastructure have been delivered?
Are outputs measurable and linked to the planned activities?
Have outputs reached the intended stakeholders or systems?
Outcomes
What short-term and medium-term changes have occurred because of the investment?
Are the outcomes aligned with resilience objectives (e.g., reduced vulnerability, improved adaptive capacity)?
Have any unintended outcomes emerged?
Impacts
What are the long-term tangible or intangible improvements that occurred (e.g., in community or system resilience)?
Are benefits monetary or non-monetary, and how are they valued?
Do benefits reflect equity, sustainability and social impact?
Indicators & Tools
Have output and outcome indicators relevant to the resilience aspects of the project been defined?
What types of data is needed to capture the full spectrum of project impacts? How could the data be collected?

Implementation & Tracking
Is there a regular schedule for data collection and progress tracking?
Are results of different data collections compared?
Reporting & Review
Have you designed an M&E process for producing periodic reports and updates?
Are reports internal or public?
Introducing Impact / Impact Assessment
Can you recognise the impacts of the project in enhancing resilience in different scales/aspects?
Can you introduce further activities to evaluate the impacts of the project?
Evaluation and Further Learning
Has an evaluation plan been developed with clear questions and methods?
Is the evaluation independent, objective and appropriately resourced?
Are counterfactuals or baseline scenarios considered?
Future Improvement & Learning
Do you integrate findings from previous projects to inform future resilience investments?

Appendix 5: Definitions

While exact definitions of some of these terms are open to (academic) argument here are definitions of relevant terms used in the report. Some of them refer to definitions in risk, hazard and disaster contexts, and definitions can be (slightly) different in other contexts as differences exist in interpretation between different disciplines and professional fields, and in different jurisdictions.

Adaptive capacity	The strengths and abilities of individuals and communities as well as natural and built environments and the systems and infrastructures that support them to withstand or adjust to hazard risks, take advantage of opportunities presented by a disaster, and/or respond to their consequences (Fien et al., 2026). In the context of climate change it has been defined as the degree to which people, places, institutions and sectors are able to adapt to climate change impacts. Adaptive capacity typically is indicated by socio-economic and environmental factors and local realities that enable a city or community to adjust its system in view of current and future risks. (UN-Habitat, 2014, p. 6).
Capacity	The combination of all the strengths, attributes and resources available within an organisation, community or society to manage and reduce disaster risks and strengthen resilience. Annotation: Capacity may include infrastructure, institutions, human knowledge and skills and collective attributes such as social relationships, leadership and management (UNDRR, 2017, n.p.).
Cascading disasters	Cascading disasters occur when the impacts of a disaster in one system or subsystem ripple outwards and impact on other interconnected systems as in a chain reaction. Cascading disaster events can be understood as having a connected cause, for example the impacts of the first disaster event can trigger a second disaster event. (Fien et al., 2026)
Complex urban system	Cities are complex systems because of the unpredictable results that emerge from the large number of human and non-human agents interacting within and between their systems and sub-systems. With open boundaries, multiple functions and no controlling laws, the interactions in complex systems result in non-linear rather than linear outcomes as systems and their components self-organise to adjust to the multiplicity of different states that the system can achieve (Fien et al., 2026).
Compound disaster	Compound disasters relate to occasions when multiple hazards or risks lead to more than one disaster impacting a region either at the same time or in close succession, potentially leading to amplified impacts. Definitions vary but broadly it can be said that compound disaster events have an independent cause but interacting impacts as they occur in the same (or a proximate) region and close in time to each other (Mocatto et al., 2024; Nemeth et al. 2024; Fien et al., 2026).
Coping capacity	The ability of people, organisations and systems, using available skills and resources, to manage adverse conditions, risk or disasters. The capacity to cope requires continuing awareness, resources and good management, both in normal times as well as during disasters or adverse conditions. Coping capacities contribute to the reduction of disaster risks (UNDRR, 2017, n.p.).
Disaster impact	The total effect, including negative effects (e.g., economic losses) and positive effects (e.g., economic gains), of a hazardous event or a disaster. The term includes economic, human and environmental impacts, and may include death, injuries, disease and other negative effects on human physical, mental and social well-being. (UNDRR, 2017, n.p.).

Disaster risk	The potential loss of life, injury or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity. Annotation: The definition of disaster risk reflects the concept of hazardous events and disasters as the outcome of continuously present conditions of risk. Disaster risk comprises different types of potential losses which are often difficult to quantify. Nevertheless, with knowledge of the prevailing hazards and the patterns of population and socioeconomic development, disaster risks can be assessed and mapped, in broad terms at least. (UNDRR, 2017, n.p.).
Engineering resilience	Engineering resilience is sought through material interventions that seek to make a system 'fail-safe'. It does this by increasing the resistance or absorbative capacity of a system to disturbance. It is often measured by the speed by which the system returns to stable state from a stressed state. The faster the system bounces back, the more resilient it is with an emphasis is on robustness and efficiency in returning to a pre-disturbance state. (Fien & Charlesworth, 2025).
Exposure	The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas. Annotation: Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability and capacity of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest. (UNDRR, 2017, n.p.).
Hazard	A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. A hazard is characterised by its location, intensity or magnitude, frequency and probability. Hazards may be natural (associated with natural processes and phenomena), anthropogenic (induced entirely or predominantly by human activities and choices) or socio-natural (a combination of natural and anthropogenic factors) in origin. (UNDRR, 2017, n.p.).
Multidimensional disasters	Multidimensional disaster events can be understood as highly interconnected events that lead to multidimensional impacts. The terms multidimensional hazards, risks and disasters are often used loosely as a synonym for situations where there are multiple hazards and risks, as in multi-hazard or multi-risk approaches to disaster risk management (Zobel & Baghersad, 2020), or in situations where multiple shocks and stressors intersect as in "multidimensional vulnerability" (da Silva et al., 2020). Multidimensional disaster events hold great potential to result in cascading disaster events and impacts.
Natural hazard	A natural process or phenomenon that may cause loss of life, injury or other adverse impacts, including on mental and physical health, property, the economy, communities and environmental assets. Natural hazards are driven primarily by weather and geology. (Australian Climate Service, 2025).
Resilience	The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management. (UNDDR, 2017, n.p.)
Sensitivity	The weaknesses or stressors of individuals and communities as well as the natural and built environments of a city that weaken their/its capacity to respond effectively to

	hazard risks or to withstand the damage and risk to life caused by a disaster. (Fien et al., 2026)
Shock	A shock is an acute natural and/or human-made event or process that can threaten major loss of life and/or damage to property, infrastructure and the natural environment, thus overwhelming the ability of urban systems to function and provide the basic services needed by all community sectors to continue to flourish. (Fien et al., 2026)
Social-ecological resilience	The capacity of coupled human and natural systems to absorb shocks, respond to the consequent changes by adapting (or reorganising) system elements, subsystems and their interconnections to retain essential functions without fundamentally altering its core identity. (Fien & Charlesworth, 2025)
Stressors	A stressor is a chronic condition or process in the socio-ecological systems of a city that weaken their capacity to provide the basic services required for natural systems, as well as social, economic and cultural life of all community sectors to flourish. As such, stressors increase the sensitivity – or propensity to damage and injuries – of a city to natural hazards. (Fien et al., 2026)
System	A system is an interdependent set of elements that are connected through a web of relationships. These elements can include living organisms (e.g., plants, animals and fungi) and physical entities (e.g., buildings, rocks and water), as well as immaterial social, political, economic and cultural institutions. Together, these components interact to produce a whole that is greater than the sum of its parts, like a forest or a city. Systems are surrounded and influenced by their environment, but have distinct boundaries, purpose and structure. (Fien et al., 2026)
Systemic risk	Systemic risk is associated with cascading impacts that spread within and across systems and sectors (e.g. ecosystems, health, infrastructure and the food sector) via the movements of people, goods, capital and information within and across boundaries (e.g. regions, countries and continents). (Sillmann et al., 2022)
Transformative resilience	Transformative resilience emphasises the capacity of a system to transform in response to crises or opportunities, leading to a new system patterns and processes that better address underlying vulnerabilities and promote long-term sustainability. Thus, it goes beyond adaptation and involves fundamentally changing the system to create new pathways and structures that are safer, and more sustainable and equitable. (Fien & Charlesworth, 2025, p. 51)
Urban resilience	The ability of an urban system and its socio-ecological elements and processes to resist, absorb, accommodate, adapt to, transform, and recover from the impacts of a hazard in a timely and efficient manner, including through the preservation or restoration of its essential basic structures and functions through disaster risk management. (Fien et al., 2026) (See Appendix 6 for a more detailed definition).
Vulnerability	The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards (UNDRR, 2017, n.p.). Also: The propensity or predisposition to be adversely affected by disaster risks brought on by persistent stressors and sensitivities, with the degree of vulnerability ameliorated or intensified by the relative capacity of infrastructure and communities to cope under intense shocks. (Fien et al., 2026)

Appendix 6: Urban resilience definition

A Working Definition of Urban Resilience

Urban resilience is considered the ability of a complex urban system[1] to maintain identity[2] and continuity while undergoing change in response to shock[3] and stress[4] disturbances. It relies on the system's capacity to absorb, accommodate, and adequately manage[5] such disturbances across temporal and spatial scales, including their cascading and compounding impacts, through due consideration of current and emerging riskscapes.

Urban resilience also presupposes the system's capacity:

- to re-organise, adapt and undergo transformation towards sustainability and climate responsibility in an efficient and timely manner
- to support, integrate and be informed by diverse and relevant knowledge systems that are critical to these tasks, and
- to retain or enhance valued critical system functions[6], structures[7] and feedbacks[8] that support essential social-ecological processes serving human and biodiverse needs in a social-environmentally equitable, culturally respectful and ethical way.

Notes

1 … and its constituent social-ecological and socio-technical networks

2 … place, culture, history and knowledge systems, etc.

3 … focus on natural hazards

4 … climate change, population growth, inequality, ongoing impacts of colonialism on First Nations people, etc.

5 … prevent, prepare for, respond to and recover from

6 … provision of livelihoods through specialisation, support of innovation, attending to key needs of its population, etc.

7 … institutional, such as democratic governance structures and physical, such as hard infrastructure and social structures

8 … innovation leading to specialisation and the provision of livelihoods

Appendix 7: Interview guide

Background questions

Participant workplace and professional experience details – length in current role, previous roles

Main current role and responsibilities

Multidimensional, compound and cascading disaster impacts in major urban areas

- What types of hazards are you considering in your work?
- Are these hazards and associated disaster impacts addressed in terms of being 'multidimensional', 'compounding', and/or 'cascading'?
- How do you experience the topic of 'multidimensional', 'compounding', and/or 'cascading' disaster impacts in your work? Are these terms and concepts used? Would you say there is a common understanding of what it is?
- What are some of the challenges in addressing these hazards in this way? How does your organisation overcome these challenges?
- To what extent are these types of impacts considered in resilience programs and projects? Could you give an example?

Practices for conceptualising and mapping vulnerabilities and resilience within urban systems

- How is resilience conceptually understood and mapped in your work?
- Does the concept of resilience involve understanding capacities? If so, what type of capacities are considered and how are these understood?
- How is vulnerability conceptually understood and mapped in your work?
- In relation to vulnerability, how are sensitivity and exposure considered?
- How is the relationship between resilience and vulnerability understood in your work or 'the relevant tool or project'?
- When it comes to ensuring the mapping of resilience and vulnerabilities can inform decision making, what are some of the challenges you face in the context of complex urban systems?
- As part of developing the tool/framework/index, were there any challenges associated with translating the concepts of resilience and vulnerability to different audiences? How were these addressed? Are there challenges that our project should be seeking to address as part of its contribution?
- As part of formulating strategies for resilience building, does your organisation attempt to map existing and emerging vulnerabilities?
- Can you describe what is spatially mapped and how this is done? What data is usually needed for conceptualising and mapping vulnerability and resilience?
- In addition to mapping, is there an attempt to measure key variables, including resilience, vulnerability and sensitivity, exposure to specific hazards and adaptive capacity or other capacities? If so, which are these variables and how are they measured?
- What are major challenges that your organisation and local governments are facing in relation to mapping and measuring these key variables? How are these being addressed/overcome?
- What are the most important learnings from these processes of mapping and measuring resilience and vulnerability in your municipality?
- Are there any specific best practice examples based on monitoring and evaluation that you could expand on?

Practices and processes used to prioritise, influence, and undertake urban resilience investments

- What are the main mechanisms for investments in the field of natural hazards and resilience in Australia/your organisation?
- Who are the main investors and key players in the field of investment for resilience in Australia? In what scale is most of the investment is done?
- Can you give an example of an urban resilience investment that you think worked well? Why did it work well? What were interesting results from this example?
- Are you aware of prioritisation mechanisms for resilience investment decisions? (e.g. for DRF, but maybe also for local or state government or private sector).
- Are you aware of how actors are trying to influence resilience investment decisions?
- What are the barriers for urban resilience investments? What are the enablers?
- Which stakeholders need to be involved? Who decides about the investment choices?
- Are you aware of evaluation and monitoring processes for resilience investment? For example, how was this done for the example mentioned?
- What needs to be done to ensure evaluation and monitoring? How can it be done?

Wrap-up

Do you have any further observation or comments?

Appendix 8: Questions of the first online survey

Introduction

1. In which type of organisation do you work? (Select all that apply)
    a) Commonwealth Government
    b) State Government
    c) Local Government
    d) Consultancy firm or planning/design/architecture practice
    e) NGO
    f) Professional representation
    g) Industry/sector representation
    h) Academia
    i) Other. Please specify: _____

2. In which area do you work? (Select all that apply)
    a) Emergency management / response agency/organisation
    b) Recovery/reconstruction agency/organisation
    c) DRR / resilience
    d) Climate change adaptation
    e) Urban and regional planning
    f) Infrastructure sector
    g) Other. Please specify: _____

Connection to urban resilience

3. What are the top 3 examples of where your organisation is involved in urban resilience?

Mapping of resilience and vulnerabilities

4. This research project investigates processes and practices of conceptual mapping of resilience and vulnerabilities to natural hazards. Has your organisation undertaken mapping of resilience and vulnerabilities or a similar exercise? (this process can refer to vulnerability of communities, certain population groups, infrastructure, certain geographical areas etc.)
    a) Yes
    b) No
    c) Unsure

5. If yes, how was the mapping or similar exercise undertaken? Please name any specific frameworks or approaches, or if available add a link to relevant documents. You can also upload documents (please feel free to forward the survey link to someone in your organisation who would be able to provide these details).

6. Are there any policies or guidelines that have guided the mapping or similar approach? Please name any relevant policies or guidelines, or if available add a link to relevant documents. You can also upload documents.

Resilience investment

7. This research project also investigates processes and practices of prioritising and influencing investment in urban resilience. Resilience investment in this case refers to investments that are made to enhance disaster resilience in an area or of a community, such as infrastructure investments as well as investments into community development and cohesion. Does your organisation undertake or support any specific investments into urban resilience?
    a) Yes
    b) No
    c) Unsure
8. If yes, what types of investments are these? Please name your top 3 types of investment. Please name your top 3 types of investment. If you aren't aware of the details, please leave the field empty, and feel free to forward the link to someone in your organisation who would be able to provide these details.
9. What processes does your organisation use to prioritise resilience investments? Please name any specific approaches, add links or documents or describe briefly how these decisions are made. For example, name the top 3 examples of where your organisations has prioritised investment. On the next page you can also upload a document if you like to. If you aren't aware of the details, please leave the field empty, and feel free to forward the survey link to someone in your organisation who would be able to provide the details.
10. Are there any policies or guidelines guiding the prioritisation of urban resilience investment? If so, please name any relevant references.
11. Has your organisation aimed to influence investment into resilience, that is, has the organisation aimed to convince other organisations to invest in certain resilience investments?
    a) Yes
    b) No
    c) Unsure
12. Please describe for what type of investment and how your organisation has aimed to influence resilience investments. Please name the most interesting or relevant examples.
13. Does your organisation have any specific processes to evaluate and/or monitor resilience investments? Please name any specific frameworks or describe briefly how evaluation or monitoring is organised.

Further research participation and comments

14. Are there specific examples of urban resilience projects, mapping, investments that you think would be useful to follow up in the project? If yes, please name the project, add a link or upload a document.
15. Would you be willing to take part in an interview or a focus group on urban resilience strategies, vulnerability and resilience mapping or resilience investment? Alternatively, could we contact you to potentially invite someone else in your organisation to an interview or focus group? Please select all relevant responses.
    a) Yes – urban resilience strategies
    b) Yes – vulnerability and resilience mapping
    c) Yes – resilience investment
    d) Yes – happy to assist in organising an interview or focus group participation with someone in my organisation
    e) No
16. If yes, please let us know how we can best contact you.
17. Do you have any further comments?

Appendix 9: Survey questions for proof-of-concept

Have you already explored the tool and do you feel ready to respond to this survey?

- Yes, I have explored the tool and I feel ready to respond to this survey.
- No, I have not explored the tool or do not feel ready to respond the survey (please go back to the Practical guidance tool and explore at least one of its modules).

Q1 Which modules of the tool did you explore? Tick all that apply.

- Module 1: Base concepts and their visualisation
- Module 2: Addressing Compound, Cascading and Multidimensional Disaster Impacts in Urban Systemic Risk Assessment
- Module 3: Risk-informed decision-making
- Module 4: Landscape of current and emerging practices
- Module 5: Self-reflection on current practices and identifying opportunities for action

Q2 In the context of your work setting and sector, please assess the modules you explored in relation to their usefulness:

Not at all useful; Limited usefulness; Somewhat useful; Useful; Very useful

Q3 The Practical guidance tool for systemic risk assessment comprises a set of five modules and a supporting glossary. Considering the tool's scope, which is to support the building of urban resilience in complex urban systems, do you see the need for additional topics/information/elements to be included in the tool? If so, what should be included?

Q4a Considering each module of the Practical guidance tool that you have explored, how would you rate their usability (in terms of ease of use) and utilisation potential? [to be responded to for each module that was explored]

Very difficult; Somewhat difficult; Neither difficult nor easy; Somewhat easy; Very easy

Q4b Have you used/plan to use the guidance in this module to support your work? (Utilisation Potential)

Yes, for sure; Yes, possibly; Not sure; No; Need to explore it further

Q5 Please rate the following aspects of the Practical guidance tool as a whole, on the following scale: Needs Significant Work, Needs Work, OK for a Proof-of-concept but can be improved, Very good but needs tailoring to our specific context, Excellent.

- Usefulness and relevance
- Ease of use/navigation
- Potential for utilisation
- Language
- Graphics

- Comprehensiveness
- Level of detail
- Integration between modules
- Fit for purpose

Q6 Please indicate your level of agreement with the following statements (which translate the objectives that guided the tool's design), on the following scale: strongly disagree, somewhat disagree, neither agree nor disagree, somewhat agree, strongly agree.

- The Practical guidance tool promotes a shared language and base conceptualisation of resilience and vulnerability that is multi-scalar and speaks to the diverse set of urban, climate and disaster resilience stakeholders.
- The Practical guidance tool translates complex concepts into clear and concise operational definitions that support the shared understanding of resilience and vulnerability and enable effective communication across sectors for addressing systemic risk.
- The Practical guidance tool helps me visualise base concepts, so these can be effectively communicated and used to support the assessment of systemic risk.
- The Practical guidance tool enables risk assessment that accounts for cascading, compound and multidimensional disaster impacts on Australian major urban areas.
- The Practical guidance tool helps me consider how systemic risk assessment can inform decision-making processes.
- The Practical guidance tool helps me identify and learn more about current practices in understanding, assessing and building resilience/addressing vulnerabilities, supporting self-reflection on my organisation's own practices.
- The Practical guidance tool can serve as a sounding board for the evaluation of existing tools and frameworks, so they are fit for purpose and effectively support the understanding of systemic risk to enable effective risk treatments.

Q7 Would you recommend this Practical guidance tool to a colleague working with risk assessment in Emergency/Disaster Management, Climate Resilience or connected sectors?

Yes; I am not sure. I need more time to explore the tool; No. Please explain why you have given this response

Q8 Please help us understand the context in which you have tested the tool by indicating your institutional setting(s):

Commonwealth Government / State Government / Local Government / Consultancy Firm or Planning, Design, Architecture Practice / NGO / Professional Representation / Industry or Sector Representation / Academia / Other, please specify

Q9 Please help us understand the context in which you have tested the tool by indicating your sector(s):

Emergency Management or Response Agency or Organisation / Recovery or Reconstruction Agency or Organisation / Disaster Risk Reduction or Resilience / Climate Change Adaptation / Urban and Regional Planning / Infrastructure Sector / Other, please specify

Q10 Do you have any further comments on the Draft Practical guidance tool for Systemic Risk Assessment?

Appendix 10: Survey questions for feedback on principles for resilience investment

Q1 After having read the principles, recommendations and the checklist, how would you rate their applicability to your work?

Very applicable / Somewhat applicable / A little applicable / Not applicable / Not sure

→ Why have you given this rating? (text question)

Q2 Is the division into principles, recommendations and a checklist useful for you? Would you prefer any additional sections or do you have any other suggestions?

Yes, the division into principles, recommendations and a checklist is useful.

No, I would prefer additional sections or a different division

→ Why have you given this response? (text question)

Q3 As explained, the principles are provided as 'context-free' principles. Is this approach useful for you?

Yes / No / Not sure

→ Please explain why you have given this answer (text question)

Q4 Based on your experience, would you suggest adding any topic areas to the principles?

Yes / No / Not sure

If yes, which topic areas do you think could be added? (text question)

Q5 Do you have any further comments on the principles, recommendations and checklist? (text question)

Q6.1 In which type of organisation do you work? (Select all that apply)

Commonwealth Government / State Government / Local Government / Consultancy Firm or Planning, Design, Architecture Practice / NGO / Professional Representation / Industry or Sector Representation / Academia / Other, please specify

Q6.2 In which area do you work? (Select all that apply)

Emergency Management or Response Agency or Organisation / Recovery or Reconstruction Agency or Organisation / Disaster Risk Reduction or Resilience / Climate Change Adaptation / Urban and Regional Planning / Infrastructure Sector / Other, please specify