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Resilience, Fragility, and Robustness: Cities and COVID-19[☆]

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ABSTRACT

The ongoing COVID-19 pandemic has had a devastating impact on cities around the world. In this paper, we analyse city fragility and resilience through the lens of the social compact framework. This framework enables an understanding of the interplay of agreements between citizens and city, state and national governments that exist within city systems. We examine three different case studies during the COVID-19 pandemic to understand instances of fragility in developed cities and how this fragility can affect a city's capability to respond to sudden disasters or emergencies. We identify the challenges and nuances that come with attempting to address urban fragility and improve city resilience, before finally presenting robustness as a way to conceptualise complex city systems and a means to thinking about more pro-active and adaptive policy.

1. Introduction

The COVID-19 pandemic has had a dramatic effect on the world over, putting immense strain on cities (Cheval et al. 2020; Sharifi & Khavarian-Garmsir, 2020). Response to the pandemic has been largely varied from country to country, state to state and even city to city depending on the alignment and power structure of nations governmental systems, and their pre-existing investments in resilience. Whilst the UK and Germany implemented nationwide lockdown to curb the spread of cases, countries like Sweden – who were considered amongst the most prepared for a pandemic (Cameron et al., 2019) - instead continued to allow residents to move freely (Bendix, 2021). Furthermore, in countries like Australia, case numbers and lockdown measures differ dramatically between state, as each is responsible for its own quarantine and prevention protocols, and lastly, in Italy, each individual regions investments in healthcare has seen widely varied outcomes for the respective area (Sanfelici, 2020).

Before the pandemic, cities were already investing significant efforts to improve their resilience in the face of rising urban populations (United Nations 2018) and increasing environmental challenges (Papa, Galderisi, Vigo Majello and Saretta, 2015). These globally recognised challenges saw the rise of programs such as the United Nations Sustainable Development Goals specific focus on making cities resilient (8), inclusive and sustainable. These programs aid cities in creating or aligning with different resilience standards, or for where to focus their investments in creating more resilient cities. In Indonesia, the development of guidelines for the implementation of a community-based landslide early warning system prevented one hundred households in Aceh

Besar from being destroyed during a 2015 landslide (Case Studies Standards).

Similarly, The Rockefeller Foundation's 100 resilient cities network - specifically developed to build resilience in 21st century cities (Spaans and Waterhout, Jan. 2017; Silva and Morera, 2014) – has seen an investment of 164 million dollars in attempts to build the capacity of cities to adapt to acute shocks. For example, Cape Town in South Africa developed a Water Resilience Task Team in attempts to deal with its worst drought in recorded history between 2015 and 2018 (Croese et al.). The city's recognition of the importance of resilience building efforts in supporting socio-economic vulnerabilities meant it's successful selection into the 100 resilient cities network. The selection enabled the appointment of a Chief Resilience Officer and the eventual development of a city wide Resilience Department, and it's now development of a bottom-up resilience strategy (Croese et al.).

Despite the significant efforts of cities to improve their resilience, the COVID-19 pandemic has damaged cities both socially and economically, exposing the underlying fragility of city systems and the sometimes uncooperative nature of governance processes. As the virus spread, healthcare systems were overwhelmed and governments struggled to communicate or initiate effective transmission mitigation policies (Sanfelici, 2020; Mareiniss, 2020; Binkin, Salmaso, Michieletto and Russo, 2020). Previous city efforts to improve resilience, such as large scale deployments of technologies to improve public transport efficiency (Desouza, Hunter, Jacob and Yigitcanlar, 2020) (Case Studies Standards) were under-utilised and ineffective as cities locked down and citizens stopped travelling. Instead, new technologies (e.g., mobile apps for checking into venues)

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had to be developed to aid in contact tracing or government health communication.

Unfortunately, whilst cities have made significant investments to become smarter and more resilient (Desouza, Hunter, Jacob and Yigitcanlar, 2020; Desouza and Flanery, Dec. 2013), large scale shocks require such robust, adaptable and unique solutions, that this focus may not be enough. In this paper, we introduce three concepts – resilience, fragility and robustness – to analyse the effects of the COVID-19 pandemic on modern cities. Whilst cities have invested significantly in improving resilience – that is the city’s ability to absorb, adapt and respond to changes – in some cases, they have not addressed the underlying fragility, such as systemic inequalities, which exist to the detriment of the city’s ability to function. In the event of the COVID-19 pandemic, this pre-existing fragility directly affects the city’s resilience by decreasing the city’s ability to absorb the unforeseen shock.

We introduce the concept of robustness to better explain how cities can improve resilience and decrease fragility. Robustness shifts the focus from cities as reactive and static systems and instead moves towards cities as dynamic, pro-active and predictive systems, not only capable of absorbing a shock, but capable of sense-making before a shock occurs and adapting and maintaining the same level of system functions.

Three case studies, New York, USA, Lombardy, Italy and Melbourne, Australia, are used to analyse the impact of COVID-19, the government response, the pre-existing fragility and the effects of the pandemic on future fragility. We analyse the cities as complex systems, identifying the government hierarchies they exist within and the impact these hierarchies had on their city resilience. Lastly, we present robustness and explore its possibilities for enabling more adaptive and predictive cities.

2. Background

2.1. City as a complex ecosystem

Cities are complex adaptive ecosystems that are both dynamic and self-organising (Desouza and Flanery, Dec. 2013). Complexity theory in the past four decades has demonstrated that cities are not dissimilar to organic and natural complex systems, in that while they are composed of some material components, organic components such as humans transform the simple system of a city into something more dynamic and complex (Portugali, 2016). Not only does the interaction between human components spark self-organisation and adaptability, but human components shape the physical components of a city too, as ideas and thoughts become roads, buildings and physical artifacts (Portugali, 2016). The complexity of this ecosystem has increased exponentially in the previous few decades as rapid urbanization processes have seen more than half the world move to cities (United Nations 2018) and the introduction of technologies for management and communication have created entirely new networks, interactions and systems. (Desouza, Hunter, Jacob and Yigitcanlar, 2020). Furthermore, understanding cities in this way has pushed more of a focus towards the importance of design and planning (Desouza and Flanery, Dec. 2013), which in turn has begun to involve a broader range of stakeholders in city processes, decentralising the approach and increasing the number and complexity of interactions that make up city life (Batty, 2007).

Understanding cities as complex adaptive systems allows for analysis of the dynamics of urban environments from the bottom up, as they emerge into patterns and are eventually articulated as networks (Desouza and Flanery, Dec. 2013; Batty, 2007). As we continue to understand cities as complex adaptive eco-systems, we move away from planning and design as purely technical activities and instead into planning as a means of negotiating, brokering and facilitating particular interactions (Batty and Marshall, 2012). This means of negotiation and facilitation comes with an acceptance of change and uncertainty inherent to complex adaptive systems (Desouza and Flanery, Dec. 2013), which develops into different strategies for creating more resilient cities. Through planning and design, the complexity of city systems can be managed in

such a way to increase resilience by preserving the interactions between actors and objects, and the networks that emerge as a result.

2.2. Resilience

Preserving the interactions within city systems has received a lot of attention in literature as the concept of resilience (Meerow, Newell and Stults, 2016; Martin-Breen and Anderies, 2011) (Desouza and Flanery, Dec. 2013; Carpenter, Walker, Anderies and Abel, 2001). Resilience can be understood in three parts – systemic integrity, coordination and self-improvement (Desouza and Flanery, Dec. 2013). Carpenter et al’s (Carpenter, Walker, Anderies and Abel, 2001) defines these as ‘the amount of disturbance a system can absorb while still remaining within the same state; the degree to which the system is capable of self-organization and the degree to which the system can build and increase its capacity for learning and adaptation’ (Carpenter, Walker, Anderies and Abel, 2001). We apply this three-tiered explanation of resilience to cities, explaining that in order to measure a city’s resilience we need to understand its ability to withstand shocks, coordinate a response and progress moving forward. City resilience often refers to a city’s ability to absorb, adapt and respond to changes within the urban system (Desouza and Flanery, Dec. 2013). Urban system resilience can be better conceptualised through components and stressors. Physical and social spheres house five main components – resources, processes, people, institutions and activities, which interact with each other on a daily basis to bring a city to life. These main components can be susceptible to natural, technological, economic and human stressors. Natural stressors are environmental disasters such as tsunamis; technological stressors can be complex technical system failures, economic stressors could be a decline in employment, and human stressors involve deliberate acts such as terrorism (Perrow, 2011, Wilson, 2011, Harrigan and Martin). In the case of COVID-19, the pandemic acted as an external stressor that had a flow-on effect on a number of city components, and contributed to new technological, economic and human stressors. For example, widespread lockdowns rendered many businesses (institutions) inoperable, leading to the economic stress of a decline in employment, a technological stress on government systems (processes) from demand for economic support, and in some cases, eventual human stress by way of protest in response to ongoing lockdowns (people).

Cities can use the different components, be that resources, processes or people, to influence the impact of the aforementioned stressors. Processes that enable a more educated workforce, will in turn improve social capital and enable people to act as a suppressor in the face of human or economic stressors. As a result, we improve the resilience of a city by improving its component’s ability to suppress the impact of stressors. One such example is Seoul in South Korea. Since 2014, South Korean cities have had on average 9.5 million CCTV cameras and more than 80% of the city’s vehicles have black boxes (Sonn and Lee, Sep. 2020). Utilising these resources, the South Korean government were able to better understand mobility patterns, in turn implementing more effective public testing sites and contact tracing (Sonn and Lee, Sep. 2020). As a result, South Korea sits at 50 deaths per million cases, as opposed to the United States with 2162 (United Nations Oct. 12, 2021). When planning cities, considering resilience through this framework allows for the design of processes that are capable of adapting and changing in response to significant shocks. However, whilst it is important to mitigate the effects of significant shocks on city systems, it is often not considered how underlying city fragility can greatly affect measures to improve resilience.

2.3. On Fragility

Fragility is often conceptualised in the analysis of failed states or governments with a focus on the uncertainty of economic, social, or military factors. Increasing risk factors such as economic inequality or weak community ties and demographic pressure are seen to be major contribut-

ing factors to the fragility of a state or government (Commins, 2011; Muggah, 2014). These failed states often demonstrate one or more of the above issues, and as a result research suggests understanding fragility across a spectrum of domains. Sekhar (Sekhar, 2010) categorizes these issues of fragility into three domains: economic, social, and political. In a failed state, we could see disparate or non-existent economic growth as an issue within the economic domain, severe ethnic divisions within the social domain, and a deterioration of public services within the political domain (Desouza and Selby). These issues are not separate of one another, and instead are more often interconnected. Aggregation of these risk factors puts continued stress on government administrations, increasing the difficulty for governments to maintain their social compacts and as a result greatly increasing the fragility of a city (Desouza and Selby).

Urban fragility should be distinguished from urban vulnerability. Vulnerability is often defined as a level of susceptibility to harm as a result of environmental and unavoidable threats (Selby and Desouza, Aug. 2019, Adger, 2006, Folke, Hahn, Olsson and Norberg, 2005), this is mostly in relation to urban resilience and the preparedness of a city to adapt to unavoidable shocks. We conceptualise fragility as a city's weakened capacity to govern and manage threats (Selby and Desouza, Aug. 2019). In the context of the pandemic, we could understand vulnerability as the unavoidable threat of the virus transmission before the declaration of the pandemic, and fragility as an administration's failure to mitigate this threat through appropriate lockdowns or an effective social safety net.

A city's fragility is often contributed to by state and federal powers, and so consideration of the larger government systems in place is equally important. Peterson's (Peterson, 2012) discussions around federalism highlight the fragmentation of resources in these systems which often contributes to potentially harmful or wasteful environments for city administrations. Understanding the relationship between federal and state powers is often viewed through a lens of autonomy at a state level where states are considered to be sovereign policy makers that enable a diffusion of power. Federal governments therefore exist in this relationship to protect the autonomous power of states. Competing federalism literature (Peterson, 2012, Bulman-Pozen and Gerken, 2008, Bowling and Pickerill, 2013), understands federalism in regard to the idea of cooperation, in that states should act as implementers of federal programs. As both Bulman-Pozen and Peterson point out however, the complexity of relationships within federalism often mean that states can be both a servant to a federal agenda, whilst resistive or challenging enough to be considered autonomous, a relationship referred to as unco-operative federalism (Peterson, 2012; Bulman-Pozen and Gerken, 2008). These relationships can also be influenced by partisan government systems and often become fragmented further between states who align with the federal party in power and those who don't (Bowling and Pickerill, 2013). This fragmentation often directly affects the implementation of policies between states (Bowling and Pickerill, 2013). To understand urban fragility, it's important to consider the government hierarchy that will inherently affect the policy in question. In this paper, we investigate fragility in a number of developed cities both pre and post the COVID-19 pandemic to understand the ways in which fragility may have affected the governments capabilities to respond in the face of crises, and the way government hierarchies can create and further fragility for local administrations.

Some form of fragility is unavoidable in cities. Governments do not have unlimited resources, and fractures in compacts are nuanced and difficult to identify. As such, we suggest a prioritisation of social compacts, similar to that of a hierarchy of needs (Maslow, 1943).

2.4. Social Compacts

We define social compacts as the implied agreements between government and individuals, such as the norms, traditions and laws that bind society. These compacts uphold the expectation that the govern-

ment will govern justly and that citizens will behave civilly (Selby and Desouza, Aug. 2019). By identifying and understanding these implied agreements, we can highlight the problems that should be addressed. This is made more apparent when a failure to uphold a compact occurs. If an implied agreement between government and citizens is the provision of public housing, a fracture may be a spike in homelessness. In developed cities, understanding social compacts is particularly useful as areas of fragility may not be so obviously apparent. An increasing number of fractures within social compacts, or in other words, ongoing failures to uphold agreements between governments and individuals, will lead to an increase in urban fragility.

Selby and Desouza (Selby and Desouza, Aug. 2019) segment social compacts into four different levels: fundamental, stability, integrity and prosperity. Governments should look to fulfill compacts beginning with the fundamental level.

Fundamental – This level includes compacts like housing, transport, and utilities. At a fundamental level, citizens should have access to appropriate housing and transport that enable them to survive and function.

Stability – This level includes compacts like provisions of public services. The city should be safe and predictable, and effective police, fire safety and public health should uphold this commitment.

Integrity – This level includes justice and law. A city government should act justly with a level of transparency as to imbue confidence in its citizens.

Prosperity – In this final level, there are implied agreements around economic policy and economic opportunity and targeted education. Governments may be responsible for increasing economic development for its citizens, be that through education that enables appropriate skills in today's economy or attracting jobs to the city.

Using this framework, we can analyse different city's levels of fragility and further identify cases where in the face of disaster, fragility may be exacerbated. However, it should be noted that these levels of fragility are not independent of each other, and so failures at higher levels of the framework may affect the agreements implied at a stability or fundamental level. Furthermore, addressing these social compacts increases in difficulty when we consider the nature of varying government hierarchies and the way in which policy is enacted. Whilst using the social compact framework helps to understand fragility, which in turn shapes the effectiveness of resilience measures, we suggest a final concept 'robustness' in order for cities to not only mitigate the effects of shocks, but to predict, adapt and learn from shocks whilst maintaining system functions.

2.5. Robustness

Whilst both resilience and fragility literature provide us with a useful framework for analysing the complex nature of developed cities in response to particular environmental challenges, we also require tools and frameworks that allow for more proactive and predictive thinking in order to address challenges not immediately present. Robustness can be understood as examining the ways systems can remain stable in the face of uncertainties and is often examined in management literature to understand risk mitigation and business continuity (Desouza and Xie, 2021). Robustness differs from resilience in that resilience will focus on a system's ability to return to a normal state in the face of crisis, whilst robustness will look for proactive and agile responses to the crisis, dynamically reconfiguring the system in the process (Desouza and Xie, 2021).

We define robustness as 'a property that allows a system to maintain its functions against perturbations in an environment' (Desouza and Xie, 2021). In this case, our systems are cities, which can be understood as a complex whole of interconnected individual parts. These systems are often viewed either as an instrument – a collection of processes that transform inputs into outputs (Xu and Mannor, 2012), or a self-organising autonomy where entities self-regulate for independent goals,

such as an economic free-market. The functions of these systems differ depending on our system perspective, where if instrumental, functions are properties of system behaviour, whilst if self-organising systems, the functions are emerging from complex interactions of entities. Perturbations can be understood as deviations from a system's normal operations that can affect its functions, and environments refer to the context that specifies guidelines for system operations (Desouza and Xie, 2021).

For example, if robustness is a property that allows a system to maintain its functions against perturbations in an environment, then we can also understand robustness as the property that allows complex cities to maintain their complex functions and services, regardless of the deviations that occur within the cities operative environments.

Robustness in literature is often examined in two different ways. Instrumental robustness explores how instruments – the collection of processes that transform inputs into outputs – can be applied to different contexts (Sussman, 2007). This type of robustness assumes that the system is not self-organising. Conversely, structural robustness instead focuses on ensuring the normal operation of core system functions in a self-organising autonomy (Fares, 2015). Therefore, this robustness focuses less on the re-application of instruments, and more on the avoidance of perturbations like uncertainty or disturbance. Both of these approaches consider the system to exist within a static environment. Desouza et al (Desouza and Xie, 2021), suggest a third type of robustness in cognitive robustness, which views the system as a self-organising autonomy that exists within a dynamic environment, and therefore is focused on how normal operations of the self-organising autonomy can be maintained within this dynamic context.

This conceptualisation of robustness is particularly useful for understanding the sense-making and environmental scanning capabilities of complex cities in reorganising or adapting before facing a crises. For cities to be robust, they must focus on developing cognitive robustness, employing mechanisms that allow for the adaptation of city functions in dynamic environments.

There are three layers of mechanisms that can be utilised to develop robustness – strategic, functional and infrastructure mechanisms. These mechanisms can be organised in a hierarchy of mechanisms that each support or enable each other, with strategic mechanisms such as persistence at the top, and infrastructure mechanisms such as distributed design at the bottom. Persistence is a strategic mechanism that can enable systems to counter perturbations without changing its operations, such as a back-up power system in the case of a blackout (Desouza and Xie, 2021). This strategic mechanism can be supported by a functional robustness mechanism such as redundancy, that provides a system with multiple pathways that it can switch between enabling persistence at a strategic level (Desouza and Xie, 2021; Kitano, 2007). Lastly, at an infrastructure mechanism level, we can enable robustness by adopting a distributed design mechanism. This mechanism enables modularization of components, in turn enabling redundancy at a functional mechanism level, and persistence at a strategic level.

In the case of city robustness, infrastructure mechanisms such as distributed design can help modularize different sections of a power grid, functional mechanisms such as redundancy can offer multiple methods of ensuring power to each section of the grid, and strategic mechanisms such as persistence can ensure that in the event of a power outage, the system can immediately switch to an alternative power source.

By adopting a complex adaptive system approach to analysing cities, we can understand the complex interactions of city actors and objects, be that between governments and citizens, citizens and infrastructure or humans and technologies. Analysing these complex systems in this way, we can further investigate the way a city has enabled resources, people and processes to improve resilience in the face of particular stressors, human, environmental or economic. Furthermore, using the social compact framework we can identify the complex interactions between citizens and governments that are failing to be upheld, and as a result increase the fragility of a city, and negatively affect its resilience. Lastly, we conceptualise robustness as a pro-active and predictive way for com-

Table 1

Summary of Concepts	
City as Complex Systems	A system of self-organising complex interactions between actors and objects
Resilience	Measures to preserve the interactions of actors and objects in the face of unforeseen shocks
Fragility	A weakened capacity for cities to govern and manage unforeseen shocks
Social Compacts	A framework for understanding the complex interactions, where they may fracture, and how this leads to fragility.
Robustness	
Cognitive City Robustness	A self-organising autonomy that exists within a dynamic environment
Infrastructure Mechanisms	Distributed design can help modularize different sections of a power grid
Functional Mechanisms	Redundancy can offer multiple methods on ensuring power to each section of the grid
Strategic Mechanisms	Persistence can ensure that in the event of a power outage, the system can switch to an alternative power source.

plex systems such as cities, to maintain their system functions in the face of extreme shocks and stressors (Table 1).

3. Methodology

We employed a case study research approach (Yin, 2009; Yin, 2015). Given the novelty of COVID—19 and its ongoing impact on our cities, we chose three global cities to analyse how resilience, fragility, and robustness played out. We collected and analysed data from news media, government reports, and other grey literature to develop our case profiles. Furthermore, it was important we also considered cities within their broader national contexts, and as such we have elected to review further literature discussing the government hierarchies that each city sits within. These countries all have varying government hierarchies and as a result represent different levels of authority for which to address social compacts. Whilst the levels of social compacts are often interconnected, so too are the levels of government that have the authority to address each implied agreement. Consider the stability level of social compacts (including agreements like the provisions of public services). In Italy, province, region and central governments each have their own law enforcement agencies, and as a citizen you may encounter either the national guard (Carabinieri), the civil national police (Polizia di Stato), the municipal police (Polizia Municipale) or the provincial police (Polizia Provinciale). The provision of each of these police forces is managed by a separate level of government. Therefore, the implied agreement between citizens and government regarding the provision of public services in Italy is a multi-tiered agreement between national and local stakeholders. If there was a fracture occurring in relation to this social compact, the government hierarchy must also be considered to appropriately identify and address where the fracture is occurring. Furthermore, government hierarchies can influence potential stressors which may impact city resilience. In the case of COVID-19, national government measures to respond to the virus had direct effects on the way in which cities could coordinate responses, or in some cases directly affected the city's structural integrity.

4. Case Studies

In order to provide context for the three case studies investigated, we first summarise the information in the below tables. These tables highlight the key case numbers, city populations and total COVID-19 deaths (Table 2).

Table 2

Cases	Population	Total Cases	Total Deaths
Melbourne, Australia	4,968,000	20,526	820
New York City, USA	18,823,000	934000	32,760
Lombardy, Italy	10,103,969	814000	33,081

This data was retrieved on 08/05/2021

4.1. Australia

The Australian government system is constantly adapting and re-evaluating the power between state and federal (national) governments. Since its federation in 1901, the structure of the Australian government has adapted from a largely state influenced decision-making process, to a more centralised growth of federal power (Brown, 2006). Regulation at a national level has developed to provide consistency for business and the economy, whilst state governments look to improve the delivery of social services (Twomey and Withers, 2007). As Brown discusses, this is further divided regionally into local city administrations although the majority of the power for local decisions resides with the state government. This tends to centralise policy and decision making in an efficient way, although reduces the effectiveness of local governments in addressing public dissatisfaction in their communities. When comparing social, political or economic factors, the majority of economic decisions are made at the federal level and social and political decisions at a state level, leaving the local administrations with little power over the decisions made regarding the pandemic, but with the difficult task of enforcing them.

4.1.1. Melbourne

Melbourne is considered one of the most liveable cities in the world and was awarded the world's top liveable city seven years in a row between 2010 and 2017 (World's 2nd most liveable city, 2021). This index awarded Melbourne perfect scores in the healthcare, education and infrastructure categories. Unfortunately, oftentimes the result of earning a top 'liveability' title is a strong focus on policy that will attract further investment or continued high ratings which increases city culture, events and a capital-centric vision of liveability (McCausland). Generally, this furthers inequality and unaffordability as the city grows in attractiveness. Melbourne housing prices increased 163% from 2000 to 2011 whilst the average wage only increased 57% (Goodman, 2018). Melbourne's focus on prosperity compacts has centralised 'high value' labour markets pushing lower income opportunities to the outer suburbs of cities and beginning a cycle of housing unaffordability proportionate to the opportunities of the inner city. As attractiveness grows, higher-income residents move closer to the city, pushing the housing price higher and focusing the attention of councils on improving such areas (Dodson and Berry, 2005). By prioritising the prosperity compacts, policy continues to favour attractiveness and fails to address the increasing housing unaffordability and insecurity of living for lower income households. Whilst this certainly represents a fracture in the fundamental level of compacts, it also welcomes fragility in regard to the disproportionate centralisation of economic opportunities which demonstrates the interconnected nature of the social compact hierarchy.

The COVID-19 pandemic was catastrophic for Melbourne city with the state of Victoria being responsible for almost 70% of the total reported cases within Australia, and Melbourne City responsible for the majority of those cases. The spike in cases forced the state government to enforce lockdowns, followed by the announcement of a large number of state supported funding initiatives. On March 15th, a \$100 million COVID-19 response package was announced aimed at boosting the health-systems capacity for dealing with the pandemic peak, and the next day the state government had announced a state of emergency. Over the next three months the state government would announce initiatives aimed at cushioning the blow of the pandemic such as \$500

million to help workers who had lost their jobs to find new opportunities, or \$8.8 million to build pop-up facilities capable of supporting more than 200 homeless (Safe Places For The Homeless). During the first lockdown, the federal government directed each state to introduce its own mandatory quarantine schemes for international travellers. The Victorian quarantine program suffered numerous breakdowns in communication, with staff failing to receive the proper infection control training, resulting in security services increasing rather than containing the spread of the virus (Mistakes in Victoria's). A second wave occurred in Melbourne lasting 139 days which was responsible for 18,000 cases and 800 deaths (Ten graphs that show). 99% of these cases could be traced back to three quarantine hotels organised by the Victorian quarantine program (Mistakes in Victoria's). A breakdown in different state departments attempting to implement a federally enforced program resulted in the closure of Melbourne city at a local level, damaging Melbourne's economy and its citizens. Unfortunately, the most vulnerable of Melbourne residents were hit the hardest as the higher-income jobs of the city were able to work from home whilst lower-income inner city hospitality suffered (Economic impacts of covid-19 on the city of Melbourne). Furthermore, whilst the Victorian Government did spend \$8.8 million on pop-up housing capable of housing 200 people, it is estimated there are 116000 homeless people in Victoria, 50% of which are either indigenous or international (Homelessness statistics, 2021).

Furthermore, Melbourne is home to a unique social housing situation built shortly after World War II, as the state government of the time looked to provide 80'000 units that would enable affordable housing for working class citizens. Policy over the remainder of the 21st century has seen a priority on private-home ownership that has left social housing in Melbourne at 3.0% of all dwellings, the lowest in the nation. As population and unaffordability has increased, these once spacious dwellings are now home to an average of 8 people per unit. During the pandemic, these commission towers experienced an outbreak of COVID-19 and were subject to targeted lockdowns. These lockdowns were due to start on the 5th of July, however the Victorian Premier announced the lockdown effectively immediately on the 4th, leaving residents with no chance to plan for food supplies or other living arrangements (RACGP - Melbourne public housing lockdown breached human rights: Ombudsman). Furthermore, many commission tower residents come from conflict-ridden developing nations, and so the immediacy of local police enforcement was found to be culturally insensitive and traumatic for residents (Melbourne's public housing tower residents file class). The provision of food during the lockdown was found to be of unsatisfactory standards and an investigation later found that residents waited more than a week to be allowed outside for fresh air. Inside one tower in North Melbourne, the outbreak grew to 311 cases (Covid-19 clusters and outbreaks | COVID-19). These lockdowns were later found to be a direct violation of human rights, due to their immediacy and the aggressive nature in which they were enforced (Ombudsman, 2020). At the time of writing, Melbourne has begun its third lockdown due to the recent outbreak of the Delta strain. Population data has shown that Victoria lost a net of 16'022 people during June-September of 2020, whilst Queensland's population grew by 8661 (Wright, 2021). Melbourne also lost its place as fastest growing capital to Brisbane (Towell and Wright, 2021).

A focus on economic opportunities and policy aimed at private home ownership in Melbourne has created a massive increase in housing unaffordability over the previous three decades. As a result, Melbourne city has the least amount of social housing in the country with the highest level of homelessness. The few over-crowded social housing complexes created unfortunately perfect circumstances for the COVID-19 disease to spread so rapidly, that the state government thought it was necessary to lockdown public housing in a way later to be deemed a violation of human rights. A failure of the fundamental compacts between citizens and governments has resulted in a costly, resource intensive situation for the state government and a traumatic lockdown for its already vulnerable citizens. To then consider the outbreaks that resulted from improper security training and the failure to maintain the stability compacts - that is

the city as a predictable place with effective public services - we can note that a breakdown at the two lower levels of compacts can be extremely costly to the cities fragility in the face of disaster.

4.2. USA

The American political structure is nuanced and decentralised in its policy arrangements and delineation of responsibilities. In some ways, it could be understood that state parties ultimately hold the most power, as it is generally unlikely that federal legislation will not be affected by state parties (Grodzins, 1960). For the most part, federal policy is subject to and enforced by the states and this mixture of legislation occurs across the economic and social spheres. Where financial aid may be delivered at a federal level, there is still a wide range of responsibilities handled by the state in terms of program definition and administration. This is furthered in the case of emergency response and financial aid. McDonald et al (McDonald, Goodman and Hatch, 2020) discuss the American emergency response system as bottom-up by design, intended to begin at a local level, with state and federal governments providing resources. Mallinson (Mallinson, 2020) also describes the power of state governments to defy, bargain or renegotiate federal policy as the state retains the power to provide public health and safety (Mallinson, 2020). Unfortunately, in the face of the COVID-19 pandemic, this complex inter-governmental relationship increased tensions and competition between different levels of government for authority and resources (McDonald, Goodman and Hatch, 2020).

4.2.1. New York

New York City has an unfortunately long history of natural disasters and public health emergencies. Events such as Hurricane Sandy, the devastating 9/11 attacks or previous public health emergencies such as the Cholera and Ebola outbreaks have all acted as unfortunate learning opportunities for the city's emergency response teams (Chokshi and Katz, 2020). Anecdotal evidence of numerous community driven acts of heroism - such as the firefighter's response during 9/11 (Carlin, Sep. 11, 2019) or the medical heroism of nurses and clinicians to treat trapped Queens residents in powerless apartments during Hurricane Sandy - paints an admirable picture of community efforts, but perhaps also of a fragile city with a lack of preparedness (Abramson and Redlener, 2012).

New York city is subject to large disparities in wealth equality, socio-economic status and mortality rates between suburbs. Large scale immigration during the 1970's and 1980's, followed by an economic boom in the 1990's (whilst not immediately tied to neighbourhood displacement (Freeman and Braconi, 2004)), is considered responsible for an extreme surge in housing unaffordability. Between the 1970's and 1990's the ethnic composition of New York City changed from 1/3rd non-white immigrant, to roughly 2/3rd (63%) and coincided with rapid economic growth and an unfortunately rapid increase in housing prices (Elmelech, 2004). Home ownership amongst these ethnic groups has been found to be as low as 5% (Elmelech, 2004) and rapid economic growth has been shown to disproportionately increase housing costs as a percentage of household income for ethnic populations (Elmelech, 2004). Unfortunately, lower socio-economic status and wealth inequality has been linked to higher mortality rates in a number of different cases. Rosenthal (Rosenthal, Kinney and Metzger, 2014), found that lower income areas, linked to lower quality housing face higher surface temperatures and increased mortality due to extreme temperatures such as heat-waves. An investigation into mortality rates and socio-economic status found that African Americans living in Harlem had a 50% higher mortality rate than that of African Americans anywhere else in the country (Anderson et al., 1997). Studies of mortality from HIV/AIDS, diabetes, and liver disease have all found increasing inequality between wealthy and poor New York City neighbourhoods (Karpati, Bassett and McCord, 2006). Furthermore, in 1990, the leading cause of death among young African American males was homicide (Sampson and Wilson, 2020). Inequalities within New York City are well

documented (Rosenthal, Kinney and Metzger, 2014, Anderson et al., 1997, Karpati, Bassett and McCord, 2006, Sampson and Wilson, 2020) and the COVID19 pandemic has exacerbated the city's fragility in a number of ways.

New York was one of the hardest hit urban centres in the United States. Between the first case in March and April 14, New York City had recorded the highest number of cases in the country and 106'763 people had tested positive to the virus (van Dorn, Cooney and Sabin, Apr. 2020). By mid-April, there were fears of city parks becoming temporary burial grounds (Gabbat, 2020) whilst 20% of the NYPD were out sick. During May, as the case numbers were starting to drop below 5000 a day, the tragic death of George Floyd sparked protests and eventual riots across the nation (Kerr, Apr. 05, 2020). However, fortunately due to the lockdown measures in place, through June cases continued to plateau, and Governor Cuomo would announce the re-opening plan for the city. Between this announcement and the end of the year, case numbers only increased from 225'000 to 250'000 roughly, until the Christmas period where cases spiked again (Kerr, Apr. 05, 2020). However, the vaccine announcement and transition of federal government has seen New York provide 1 million vaccine doses by January and the resurgence of the second wave has been minimised (Latest coronavirus updates in New York, 2021).

New York's response to COVID19 was similar to its previous responses to public health emergencies. A focus on public health and fundamental compacts meant that a number of measures were put in place to reduce the increase in cases and prioritise individual's health over economic outcomes. All New York City residents were eligible for three free meals a day at hundreds of sites across the city (Shahrigian and Sanders, Apr. 03, 2020) and 93 new enrichment centres were opened to ensure children of front-line workers would still receive education (Stack and Schweber, 2020). Oxiris Barbot (NYC Department of Health and Mental Hygiene commissioner) stated "Our primary focus at this moment has to be on keeping our city's communities safe. This means supporting the public hospitals with supplies; connecting underserved people to free access to care; and delivering health guidance through the trusted voices of community organizations" (van Dorn, Cooney and Sabin, Apr. 2020).

Whilst the public health response to COVID-19 prioritised citizens health and wellbeing over maintaining economic functions, the pre-existing systemic inequalities in New York were still exacerbated by the pandemic. This is first evidenced by the migration that occurred across New York City, where residents of Manhattan were substantially more likely to leave the city than those in Queens with a noticeable shift directly after the Mayor ordered his first lockdown on March 16 (Almagro, Coven, Gupta and Orane-Hutchinson, 2020). This has continued throughout the pandemic, as New York's domestic and international migration rate continues to drop, and it registers the second largest population loss in the country (Frey, 2021). In contrast, Almagro et al (Almagro, Coven, Gupta and Orane-Hutchinson, 2020) studied the GPS data of New York City residents during COVID-19 to find that poorer neighbourhoods exhibited more mobility during lockdowns within and outside of work hours and attributed this to the number of front-line workers living in low-income neighbourhoods and their access to delivery services or services that allowed them to shelter in place. These disparities are further confirmed by the testing results and the disproportionate number of front-line workers in lower socio-economic neighbourhoods. Borjas (Borjas, 2020) found that the probability of a positive result was far greater for persons living in poor neighbourhoods with large numbers of people residing together. Furthermore, these neighbourhoods were the least likely to get tested. Finally, at the peak of the pandemic it was found that 32% of COVID-19 deaths were African Americans despite only making up 13% of the population (Almagro, Coven, Gupta and Orane-Hutchinson, 2020).

The government hierarchy in the United States saw the state of New York with the power to enact lockdowns, but in dire need of extra resources to sustain their healthcare and support measures. Furthermore,

varying levels of information communicated via state and federal governments added to the confusion for citizens and damaged trust in policy that would mitigate transmission. At a federal level, the US surgeon general announced face masks as ineffective, before new evidence forced him to announce the opposite and President Trump suggested COVID-19 was like the flu and would be over in a matter of weeks (Balog-Way and Mccomas, 2020). Meanwhile, political agendas played into federal and state relations as states that voted for President Trump in 2016 received upwards of 10 times the amount of relief funds per patient that the state of New York did and the state received only fractions of personal protective equipment compared to its Trump-allied counterparts (van Dorn, Cooney and Sabin, Apr. 2020).

4.3. Italy

The Italian political hierarchy originated with a strong focus on local governments and largely placed cities as strong municipal structures evolving from a city-state based political system as early as the 12th century (Chittolini, 1989). These city-states began as city administrations that extended laws, fiscal and administrative rules to an entire territory. Over time these city-states exerted more influence over smaller neighbouring population centres - such as Florence's extension of control over Pistoia to Arezzo in the fourteenth century - and as a result more regional governance began to evolve. However, at the core of each of these regional expansions was a history of city-based governance and therefore cities largely maintained control over responsibilities across the region. In the 19th century all Italian territories became unified and in the early 20th century, a central government consolidated power (Ren, 2020). Italy's history of independent regions carries into its modern political structure with each region electing its own president, and each president responsible for responding to public emergencies (Ren, 2020). There is still a central government that is in charge of central systems such as civil defence, civil protection or fiscal policy and healthcare, but it should be noted that the large number of municipalities, cities, provinces, regions and territory administrations makes for a complex and multi-layered hierarchy of governance with a strong focus on regional autonomy. There are a total of 20 regional administrations and 107 provinces and metropolitan cities. Each regional administration has its own healthcare system (Berardi et al., 2020).

The complexity of this political structure increased tensions in the face of the COVID-19 pandemic. The complexity of a fragmented crisis response made for varying emergency responses between different regions as well as contrasting information spread across the country. This fragmentation was also highlighted in the disparity between regional healthcare policies and varying levels of enforcement at local and regional levels. To further add to the complexity, Italy is one of Europe's most populous nations with a total of 60 million people. The regions worst hit by the pandemic - Lombardy and Veneto - house 25% of that population.

4.3.1. Milan - Lombardy

Pre-existing fragility in Lombardy is for the most part, a shared fragility across both Italy and the European Union. Aging demographics have made for an ongoing challenge in the economy and healthcare as the numbers of elderly people begin to outweigh any other age group. However, Italy is particularly unique again because of its large number of regions and its focus on the cities within those regions. The increase in an aging population within Italy has correlated with a reduction of personnel in regional health programs (Binkin, Salmasso, Michieletto and Russo, 2020), and the regionalisation of healthcare has seen a divergence in approach between Lombardy and its neighbours. Before the pandemic and in partnership with the private sector, Lombardy had already implemented a more curative and patient based approach to healthcare, improving individual services greatly, but reducing community based health activities. Lombardy's increase

in public-private partnerships has seen a separation in management between different hospitals and networks as opposed to neighbouring region Veneto's local health units responsible for the majority of hospitals in the region (Silva and Morera, 2014). Two key metrics in comparison of the regions pre-pandemic, are the differences in public health prevention departments - Lombardy at 1 per 1.2 million citizens, and Veneto at 1 per 0.5 million (Binkin, Salmasso, Michieletto and Russo, 2020, Boldrini et al., 2021) - and home-care services, in which Lombardy serves 1.4 per 100,000 citizens, and Veneto at 3.5 per 100'000 citizens (Binkin, Salmasso, Michieletto and Russo, 2020). Lombardy's focus on individual patient care and private partnerships to improve these services positioned the region's system as a reactive and individualised healthcare system, reducing its ability to enact preventative and public measures in the face of the pandemic.

On February 20, Lombardy identified its first case of COVID-19 in Codogno (Malara, Mar. 25, 2020). After the national government was notified, a lockdown was enforced, contact tracing was introduced within the region, and testing began on symptomatic patients only. This lockdown was believed to have started an exodus of residents from Lombardy to other parts of Italy, although Beria et al's (Beria and Lunkar, Feb. 2021) study of mobility during the first wave found this to be untrue. Over the next month, the case numbers rose to 17'000 positive cases and 3500 deaths. The mortality rates of the virus in Lombardy were of the highest in the world, exceeding 20%, which has now been attributed to a lack of mass testing and testing solely focused on those with symptoms (Romagnani et al., 2020). In some cases, 43% of infected citizens have been asymptomatic (Romagnani et al., 2020). Not only was testing in Lombardy reduced to those showing symptoms, but a focus on patient centric care had created a process that often found citizens referred to hospitals, which overwhelmed hospital resources and spread the infection through over-worked healthcare workers. Lombardy was found to have 19 times higher infection rates among their health care workers than in the general population (Binkin, Salmasso, Michieletto and Russo, 2020). Lastly, while Veneto's focus on public health had enabled prompt community action, the silos of management in Lombardy created by public-private partnerships found public health testing or patient-monitoring centres were not available until cases had risen to upwards of 12'000 (Binkin, Salmasso, Michieletto and Russo, 2020).

As of this writing, Lombardy has had a total of 753'000 COVID-19 cases, with a second wave beginning in October, 2020 and the expectation of a third wave at the time of writing due to vaccination supply and quality concerns. Whilst initially, mobility was limited in and out of Lombardy, the region has since experienced a loss of 12'000 inhabitants to remote work (Mendoza, 2021). Many comparisons have been made between the regions of Lombardy and Veneto (Binkin, Salmasso, Michieletto and Russo, 2020; Ren, 2020; Berardi et al., 2020) due to the difference in regional healthcare policies and its effects on the outcomes of the pandemic in the region. Lombardy's privatised and patient centric healthcare system not only resulted in an overflow of hospitals and exhaustion of resources, but a disproportionate rate of mortality for those in lower socio-economic areas. A study on mortality rates in the Lombardy Region (Colombo, Alicandro and Vecchia, 2021), found that higher poverty suburbs had a mortality rate 2.7 times higher than the same month of the previous year.

5. Discussion

5.1. Resilience

We first discuss city resilience, exploring the previous investments and current measures put in place by cities to ensure resilience throughout the COVID-19 pandemic. Firstly, we can note an unfortunate correlation between increases in 'liveability' and increases in cost of living. Whilst liveability is more often a term used in the marketing of cities, it is clear that in most cities where liveability rankings have increased, subsequent population growth occurs along with an increase in housing

Table 3

City/Region	Resilience	Fragility	Robustness
Melbourne, Australia	Investments in Education, Infrastructure and Healthcare resulting in 'World's Most Liveable City' 7 years in a row	Lowest social housing in the country, highest housing unaffordability. Prioritised Prosperity through Centralised High Value labour markets.	Strategic – Super Position Functional – Redundancy Infrastructure – Modular Design
New York, USA	High quality Emergency Response department and large investments in support mechanisms for citizens in crisis	Constant immigration due to attractive employment opportunities and a focus on prosperity compacts. Fundamental compacts began to fail as unaffordability increases.	Strategic – Persistence Functional – Structural Infrastructure – Loop Design
Lombardy, Italy	Strong investments in patient centric healthcare improved individual healthcare services	Disproportionate amount of healthcare workers also primary care-givers in lower socio-economic areas. Over-crowded low income housing resulting in increased virus transmission.	Strategic – Persistence Functional – Degeneracy Infrastructure – Loop Design and Modular components

prices and cost of living (McCausland). Investments that increase liveability are often closely aligned with investments that would expectedly increase resilience, such as investments in education, infrastructure and healthcare. Whilst these investments do increase resilience for a portion of the population, they unfortunately increase fragility for another. Our social compact framework aims to contribute an understanding to the way in which this can occur and provide a better understanding for how the interplay of compacts can present a duality of increased resilience and fragility. Reflecting on this interplay can help ensure investments in resilience don't become siloed within their direct applicability without a consideration for the effects on other city issues. For example, strong investments in patient-centric healthcare in Lombardy can be seen to improve the resilience of the region's medical practices, however the specificity of this investment allowed for a continuous silo of process and practice that saw hospital management become largely separate from each other within the region, which in turn lowered the resilience of the community in dealing with the COVID-19 pandemic (Binkin, Salmaso, Michieletto and Russo, 2020). The complex nature of city resilience makes it difficult to understand the cause and effect of particular investments in resilience and we suggest further research is required to explore the effects of investments in resilience and their correlation to other points of fragility.

Secondly, we explore the resilience measures put in place by cities during COVID-19 and their effectiveness in allowing the city to absorb shocks, continue to function and improve moving forward. The strategy of lockdowns was employed in numerous cities across the globe, and whilst traditionally it is effective in limiting the flow of people and therefore the spread of the virus, this strategy had varying impacts. As discussed, the alignment of city policy with state and federal governments can add complications to the lockdown, especially in regard to its effectiveness in allowing the city to continue to function. Initial lockdowns in Australia were directly supported by national support funding, and at a state level, border closures were quickly put in place. This meant that for the most part, flow of people became quickly limited to cities rather than across states, and whilst economic activity slowed down, government financial aid supported the continuation of cities economically. Initially these cooperation's were effective in quickly mitigating the virus spread and demonstrated the effectiveness in these strategies to maintain resilience. However, as second and third waves of the virus emerge, these strategies diminish in effectiveness. Border closures at a state level can interrupt economic activity at a city level, and without the support of national financial aid, can have detrimental effects on city fragility. Therefore, it has become increasingly important for cities to develop city emergency management plans rather than rely on the cooperation of multi-tiered governments. This is particularly evident in the case of New York City, where existing emergency management plans were able to be implemented to continue the city-functions even as the pandemic was at its worst. Education for children of front-line workers and the three meals a day program are examples of emergency management plans that can enable a city's resilience regardless of the federal response. However, these plans are a reactive measure to avoid further

fragility in cities during crisis. It is important that we next explore the fragility in each city and the effects this had on city resilience before the crisis.

5.2. Fragility

Developed cities are fragile in a number of ways, and the COVID-19 pandemic significantly aggravated the existing fractures within cities. In each of the cases analysed, rapid population growth significantly affected housing prices in turn increasing unaffordability and making it more difficult for lower socio-economic citizens to afford a place to live that is sufficient for their needs. As a result, poorer communities often share housing amongst larger extensions of family and friends (Almagro, Coven, Gupta and Orane-Hutchinson, 2020). In all three cases, overcrowded housing was responsible for considerable transmission of the virus amongst poorer communities. In Melbourne, the average social housing dwelling is home to at least 8 people, and in Milan, a regional increase in salaries of 18% does not match the private rental market rise of 105% (Bricocoli and Cucca, 2016). Whilst this rise in real estate prices is often associated with a boom in economic activity, it disproportionately affects the already disadvantaged. Across the three cases, we can note a prioritisation of governments on prosperity compacts, resulting in a failure to uphold the fundamental compacts of housing for citizens. As economic activity is prioritised, public housing stock shrinks, as seen in Melbourne and Milan (Bricocoli and Cucca, 2016). Furthermore, this focus on prosperity compacts sees an increase in housing prices disproportionate to the perceived benefits of growth in wages, at 163% prices to 57% wages in Melbourne, and 105% prices to 18% wages in Milan (Bricocoli and Cucca, 2016). Often, the high value labour attracted through a focus on prosperity commitments is work that lower socio-economic families don't have the qualifications to participate in, further excluding them from the perceived benefits.

This underlying fragility is exposed in the face of the COVID-19 pandemic, as those who are fortunate enough to work from home can continue to operate, whilst those dependent on travel for work disproportionately felt the brunt of the infection and mortality rates (Almagro, Coven, Gupta and Orane-Hutchinson, 2020). In New York, front-line workers in lower socio-economic neighbourhoods were more likely to test positive for the virus, but simultaneously less likely to get tested, due to the need to continue work commitments or limited access to afford delivery services (Borjas, 2020). Resulting in increased mobility, increased transmission and unfortunately and increase in mortality rates. Similar patterns can be found in Barcelona where women under the age of 64 were the most likely to test positive to COVID-19 during its first wave. These numbers correlated with the disproportionate number of women working in care professions, and as a result were more exposed to the disease (Marí-Dell'Olmo et al., 2021). Furthermore, as experienced in an alarming number of cities, citizens living in lower socio-economic areas were more likely to transmit the disease through poor living conditions, a continued need for public transport, existing

chronic illnesses, or poor communication of information (Covid-19 in Spain; Papa et al., 2015).

These issues contribute to an increase in fragility in the current day due to a further exhaustion of resources for those in need, but even more so contribute to an ongoing fragility due to the effects of these issues on following generations. Again in Barcelona, the women working in care professions were often attempting to ensure their children's continued education in the limited time between shifts. In New York, enrichment centres were opened specifically to ensure children of front-line workers would still receive education. Whilst these measures in New York focused on stability compacts to decrease fragility, their reactive nature may only prevent further weakening of resilience in the city rather than pro-actively mitigate fragility. Of course this speaks to the difficulty that fragility brings in dealing with multiple compact fractures at the same time. Fundamental fractures trickle into stability, integrity and prosperity compacts for other generations. Housing fragility for families may affect their capacity to remain educated, or in some ways may affect their ability to act civilly.

Having said this, we can note that the cities that witnessed the least amount of fragility reactively prioritised a focus on fundamental and stability compacts. Through temporary unemployment relief, the three meals a day program (Shahrigian and Sanders, Apr. 03, 2020), the enrichment centres, or the early enforcement of lockdowns, cities that managed to prioritise the lower level compacts in the hierarchy experienced the least amount of continued fragility. This examination into city fragility and resilience across the three cases demonstrates how sometimes the mechanisms that make us resilient can also make us fragile.

5.3. Robustness

Attempts to ensure education and well-paid jobs in cities, whilst improving liveability in many ways, unfortunately also increases unaffordability which triggers failures in fundamental compacts and increases fragility. Cities need to move towards robustness as a way to not only ensure cities react sufficiently in the face of environmental shocks, but also to learn, adapt and create more resilient and dynamic processes in future. By understanding robustness across a three-tiered hierarchy of mechanisms, we highlight the ways in which each case study could employ a number of mechanisms to create more robust cities.

Melbourne's increasing prosperity unfortunately created a number of affordability issues and centralised a large majority of the workforce, increasing traffic congestion and rising housing prices in inner suburbs. Employing infrastructure mechanisms such as distributed design, we can begin to apply more modular approaches to housing and labour markets, looking at opportunities to decentralise. As a result, we avoid a singular place of high-value labour and concentration of higher wages, which results in increased unaffordability in living costs. The recent move to work-from-home for a lot of technology and high-value jobs points to the potential for a de-coupling of geography and economic opportunity, which could in turn shape the links between labour markets and unaffordability. From a more modular approach to markets, we support functional mechanisms such as redundancy, that allow a city to choose multiple pathways when facing obstacles. Without a singular place for value creation, we allow for city functions to choose alternative pathways for economic prosperity in the event of a particular module being affected. In dealing with COVID-19, this may have allowed for more nuanced lockdowns, and pre-covid would allow multiple options for citizens in terms of housing. Citizens may not be interested in their location relative to a central business district, if different modules of a city allow for different proportionate opportunities. This supports the final strategic mechanism of super-position, which looks at a city systems ability to adapt in an agile manner, sensing signals and reconfiguring quickly.

In New York, their unfortunate past experience with disaster created an extremely diligent emergency response system. However, with the use of an infrastructure mechanism such as loop-design, it could be better ensured that lessons learned from previous disasters were ad-

equately considered and used to improve future responses city-wide. Unfortunately, leaving emergency response in its own silo, meant that as a reactive measure it was successful (three meals a day), but as a pro-active measure, emergency response by definition, serves little purpose. With an infrastructure mechanism such as loop design, functional mechanisms such as structural stability would also be enabled. Structural stability can allow cities to have a system design that creates insensitivities to other perturbations. Rather than keeping silos in place, emergency response could communicate learnings across multiple departments increasing knowledge within the system, which would then create more capable systems in the face of perturbations. A more widespread knowledge basis in the face of emergencies could also allow for better support of the particular socio-economic areas most at risk. In turn, this supports strategic mechanisms such as persistence. Not dissimilar to Melbourne, a more nuanced emergency response may allow for more nuanced focus on particular areas. Through this, more large-scale lockdowns may not be necessary, allowing other parts of the city to continue to function whilst also allowing for a more focused response for those who need it most.

Lastly, Lombardy's strict focus on patient centric privatised healthcare provided improved services to a number of citizens in Milan, although unfortunately was unable to adapt in reaction to the COVID-19 pandemic. Whilst literature suggests this strong patient centric privatisation was the core problem for Lombardy during COVID-19 (Binkin, Salmaso, Michieletto and Russo, 2020; Berardi et al., 2020), implementation of a loop design infrastructure mechanism may have improved elements of the healthcare system more rapidly and allowed for more agile adaptation. Neighbouring region Veneto implemented more public health measures such as testing of citizens, symptomatic or not, to comparably more success, and perhaps with a well implemented loop design, Lombardy could have learned from there initial errors and adapted more quickly. The health departments of Lombardy were inherently more privatised and patient-centric, which resulted in greater silos between hospitals and clinics. As a result, transmission of information was slow and the majority of testing took place in major hospitals. Through the use of degeneracy as a functional mechanism health care systems could serve the same core functions, similar to Veneto, where testing took place at community and local clinics as well as hospitals. Sharing core healthcare functions more widely across healthcare facilities in Lombardy could help decentralise patients and mitigate virus transmission.

6. Conclusion

The COVID-19 pandemic has exacerbated urban fragility across cities. As the case studies have shown, failure to address fractures in social compacts can greatly affect disaster response capabilities. To progress towards more pro-active policy, the social compact framework looks to provide a prioritisation for addressing social compacts that will mitigate risk and fragility in the face of disasters. Of course, these issues are incredibly complex and often fractures appear subtly and not as the direct result of a single policy. Furthermore, these policies may be implemented at the state or federal level without significant input from the local administration. Therefore, when attempting to understand urban fragility in developed cities, we suggest a combination of the social compact framework with a consideration for the government hierarchies that are in place. In doing so, we can understand the layer of government that may have implemented the policy, the power structure for which local administrations are a part of and therefore the most appropriate response to mitigate the policy's effects on urban fragility.

Often, city investments in resilience can also result in increases in fragility. It is important to consider investments in resilience across the hierarchy of compacts to understand further how prosperity compacts may adversely affect fundamental or stability compacts. The complexity of this interplay can span generations of citizens. Future research is needed to understand the dynamics of fragility in our cities, especially

the most developed ones. Solving fragility in developed cities is critical given the critical role they play as economic, political, and cultural hubs of nations. Given that we are still going through the COVID-19 pandemic and some cities experiencing their second, or even, third wave, it is vital that we continue to monitor the situation to understand the nuances of urban fragility in the context of long-term pandemics. In understanding the nuance of fragility, it is also important to move towards more adaptable and pro-active city systems. This is where we suggest further exploration into robustness. Of course, more research is needed in this area as our preliminary analysis only briefly attempts to unpack how this framework may be utilised. More is required to explore the complexity of these issues and in many cases, further empirical work will help in aligning the framework with specific issues and potential actionable processes.

In conclusion, developed cities are complex systems with complex trade-offs between investments in resilience and increases in fragility. Understanding the government hierarchy that city administrations exist within can help to understand where policy decisions are made and the level of control a city has to implement fragility mitigation strategies. Furthermore, utilising the social compact framework can help to understand the different ways in which fragility can occur and the interplay between different city wide policy and arrangements. Lastly, whilst utilising the above frameworks to understand fragility, it is recommended that robustness be used to further mitigate fragility through the creation of more adaptive and robust processes and systems.

Conflict of interest

There are no declaration of interests required for this manuscript.

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