Resilience Hubs: Conceptualization, Transportation Needs, and Travel Behaviour

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science

in
Transportation Engineering

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Abstract

Over the last decades, cities have experienced an increase in the frequency and intensity of hazards due to unprecedented climate change. Consequently, cities need to develop strategies and infrastructure that mitigate the impacts of climate change and protect lives. An emerging idea to address this challenge is the development of community-centered resilience hubs. During disasters, these facilities act as evacuation shelters and resource centers. However, on a daily basis, they remain functional by providing services and supplies that meet the essential needs of the community. Most research and guidance for resilience hubs is theoretical without any empirical evidence. From a perspective of community needs, evidence remains scarce on what services, resources, and programming are ideal for resilience hubs and when they are most useful (i.e., during a disaster or normal conditions). Critically, the resilience hub field has not properly addressed the transportation needs of communities, creating a wide gap in knowing how people will travel to and from these hubs.

To address these gaps, I conducted a comprehensive literature analysis and an empirical study that used statistical tools and discrete choice models to understand transportation needs, travel behaviour, and hub location preferences. Data for the empirical studies came from a survey of Edmonton Metropolitan Area, Canada residents (n = 950) that was conducted between November 2022 and February 2023 via a panel of participants using Qualtrics.

The literature review which focused on resilience hub current definition, examples, and related concepts (e.g., evacuation shelters, community hubs, and mobility hubs), detected characteristics and needs for planning hubs. It also found that current resilience hub locations are not methodical or optimized. Additionally, I uncovered that current examples of resilience hubs fail to consider transportation needs, travel behaviour, or travel accessibility. Through statistical analysis, I found that residents prefer more localized resilience hubs within their communities and personal vehicle is the principal mode choice of travel to/from a hub during normal days and emergencies. However, a sizable number of respondents would walk, take public transit, or use shared mobility services, indicating the need for multi-modality planning and operations. Behavioural modeling results uncovered that household characteristics impact the willingness to use a resilience hub during normal days, while individual characteristics influence hub usage as a temporary shelter in a disaster. I also determined that some household and individual characteristics influenced mode choice for traveling to/from hubs, but that trip purpose (resilience hub usage) was largely insignificant. Altogether, the results point to a need to better integrate transportation design, planning, and operations into resilience hubs, including equity-centered strategies for those who would use hubs the most. Based on the results, I provide transportation recommendations for agencies and highlight future opportunities for strategic planning for community-centered resilience.

Keywords: Resilience hubs, disasters, community resilience, accessibility, equity, travel behaviour.

Preface

This thesis is an original work by Thayanne Gabryelle Medeiros Ciriaco. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "Evacuations and Resilience Hubs: Preparing Edmonton for Extreme Events and Climate Change", No. Pro00120602, 09/16/2022

Some of the work presented in this thesis has been accepted, published, or is under review in various journals related to Transportation Engineering.

Peer-reviewed Journal Published

1. **Ciriaco, T. G. M**., and Wong, S. D. (2022). Review of resilience hubs and associated transportation needs. *Transportation Research Interdisciplinary Perspectives*, *16*, 100697. https://doi.org/10.1016/j.trip.2022.100697

Peer-reviewed Journal under review

1. **Ciriaco, T. G. M**., and Wong, S. D. Travel Behaviour and Community Needs for Resilience Hubs.

Acknowledgments

There are people who make our journey more meaningful, for their company, support, and affection and because they make us better.

To my parents, Ediano and Ana Celme, my greatest examples of dedication, love, understanding, and family, I thank you for everything I am today: my character, my education, my essence, for always encouraging my dreams, and for all the opportunities you gave me to get here.

My special thanks to my brother Matheus, for all the words of encouragement, for your love, for the moments of immense joy, for the easy laugh, and for always being by my side.

To my dear grandmothers, Jandira (in memoriam) and Ana Maria (in memoriam), and to my grandfather Anthero (in memoriam), I thank them for the immense love, dedication, support, and unforgettable moments they gave me while they were present in my life.

To my great-grandmother Celme Farias Medeiros (in memoriam), an excellent writer and an example of dedication and brave woman in my family, I am deeply grateful for all the opportunities she gave me, which have been fundamental to my success. I appreciate all the love, affection, and wise words she dedicated to me.

I have neither words to describe what my family is to my life, nor thank them enough for everything they have done for me.

I thank God for everything I have achieved so far.

I am also grateful for my friendship with Narmeen, Veronica, Mohammad, and Jorge.

I am immensely grateful for the support and guidance from my advisor, Professor Stephen Wong. His dedication, advice, support, knowledge, and compassion were fundamental in making me a better researcher and helping me achieve my goals.

Finally, I would like to thank the City of Edmonton, Alberta Ecotrust Foundation, and Mitacs for proving funding support for this research.

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Chapter 1: Introduction

This chapter presents a concise background, provides the research motivation, objective, and research questions, and discusses the thesis structure.

1.1 Background and Motivation

Unprecedented changes in global climate have challenged communities around the world, with many facing more frequent and intense extreme weather events (Temmer et al., 2019). Some communities are also facing non-climate-related events that require emergency response, such as tornados, chemical/toxic accidents, and terrorist attacks. Consequently, many cities are rethinking their planning, design, and infrastructure to improve preparedness, response, and recovery. To assist communities in becoming more resilient, new ideas and tools need to ensure that residents both survive and thrive. However, as cities are complex and dynamic, resilience becomes intricate, interdisciplinary, and multilayered, which challenges jurisdictions' immediate response to events such as evacuating people, operating emergency shelters, and resources distribution chains (Twigg et al., 2011; Kohn et al., 2012; Wong et al., 2018; Lindell et al., 2019; Chen et al., 2020; Kotani et al., 2020; Wong, 2020; Kim et al., 2021; Nagarajan and Shaw, 2021; Wong et al., 2021). The response phase in disasters is usually enabled by transportation infrastructure and strategies that facilitate the movement of people and goods, such as evacuation plans, relief distribution, contraflow, and shelters.

In this context, one early and unique idea is to develop resilience hubs, which are localized physical spaces that aim to increase the community's resilience and preparedness, while also increasing social connection within the area (Baja, 2018; Kirwan et al., 2021; Sandoval, 2019). They function year-round, providing a range of services (e.g., social, recreational, and educational) that meets the community's daily needs. During a disaster, individuals receive assistance, resources, and temporary accommodation (Baja, 2018). Many cities, particularly in North America, are implementing or considering implementing resilience hubs to serve communities, prioritizing those most underserved and impacted by disasters. Despite some current examples and guidelines, the idea of resilience hubs has remained largely undefined and lacks information regarding characteristics, functions, transportation needs, and location. Within the transportation engineering field, little empirical evidence exists on: 1) communities' transportation needs to/from hubs; 2) where hubs should be located; and 3) how accessibility, mobility, or the overall transportation network should be integrated.

Given the only recent rise of resilience hubs in the past eight years, the concept has been minimally studied. This is particularly severe in the transportation engineering and planning fields, which have minimal research on the concept. From a practice-oriented perspective, there is also a lack of information and guidance related to transportation needs or even how transportation interacts and connects with resilience hubs. Since transportation systems enable travel to/from resilience hubs during disasters and normal conditions, these systems require an understanding and integration into resilience hub design/planning. Concurrently, data is not currently available on how people make choices about resilience hubs, what features they prefer, or where they would prioritize hub placement. This presents a critical gap for decision-makers, especially as design and planning strategies should be informed by community-centered evidence. Altogether, these gaps in both research and practice, coupled with a need for effective transportation responses in disasters, motivate this thesis. The thesis is also motivated by the pressing need to ensure equitable transportation and shelter for people in disasters and develop opportunities to create co-benefits that also focus on communities' everyday needs.

1.2 Research Objectives

The main objective of this research is to build a conceptual understanding of resilience hubs and their related transportation needs and empirically analyze people's needs and choices related to resilience hubs and travel behaviour. Gaps in research and practice motivated several research questions that were answered through this study to meet the main objective of the research:

1. What are resilience hubs, especially when considering other types of hubs or centres for disasters and everyday conditions?
2. How are resilience hubs currently being used and what are their functions?
3. What are the transportation needs and characteristics of resilience hubs?
4. How will people use resilience hubs in disasters and everyday conditions?
5. What types of transportation services and resources should be considered in resilience hub designs, planning, and operations?

6. What modes of transportation will be used by individuals to access a resilience hub in disasters and everyday conditions?

To answer these research questions, the study was divided into two phases. First, I conducted a comprehensive literature review that provides an early conceptual understating of resilience hubs and their related transportation needs, and can guide future pilots, programs, and design. The literature review answered the first three research questions and contributed to a new conceptual understanding and relation-building of resilience hubs and transportation. The second phase was conducted to address the last three research questions. During this phase, I surveyed 950 residents of the Edmonton Metropolitan Area in Alberta, Canada from September 2022 to February 2023. Subsequently, I used this data to apply simple descriptive statistics tools to understand individual and transportation preferences for resilience hubs. I then used discrete choice analysis (DCA) to identify factors that influence an individual's decision on using a resilience hub and to determine variables that impact mode choice of both disasters and normal conditions. This empirical contribution offers a clearer understanding of usage and transportation choices related to resilience hubs, which can be used to establish a clearer, scientific basis for hub design and operations.

1.3 Thesis Structure

This thesis is composed of four total chapters and is organized as follows. Chapter 1 provides background and research objectives related to the thesis. Chapter 2 (published in Transportation Research Interdisciplinary Perspective [TRIP]) presents the literature review on resilience hubs and transportation needs. Next, Chapter 3 (in preparation for journal submission) discusses the methods and results of my analysis of transportation needs, choices, and integration with resilience hubs. I end the thesis with Chapter 4 which presents the conclusions, several overarching recommendations, and future research directions.

Chapter 2: Review of Resilience Hubs and Associated Transportation Needs

2.1 Trend of Disasters and Community Resilience

Due to unprecedented changes in the global climate, many communities around the world are facing more frequent extreme weather events (e.g., floods, wildfires, heatwaves, and severe storms (Temmer et al., 2019)). Some cities are also susceptible to non-climate-related events that require an emergency response, such as earthquakes, tornadoes, volcanos, chemical/toxic accidents, and terrorist attacks. Consequently, many cities have been altering their planning, designs, and infrastructure to improve preparedness, response, and recovery in emergencies. The emerging concept of resilience – largely considered the capacity of people and cities to survive and adapt to hazards – has guided policymakers, professional practitioners, and researchers in recent decades (see Meerow et al. (2015), Meerow and Stults (2016), Keenan (2018) for more discussion). To help communities bounce back to their former state or even forward following disasters, new ideas and tools need to ensure that residents both survive and thrive. However, this type of resilience-building is intricate, interdisciplinary, and multi-layered, because cities are complex and dynamic systems. One area of resilience that continues to challenge many jurisdictions relates to immediate responses to an event such as evacuating people, operating shelters, and distributing resources (Twigg et al., 2011; Kohn et al., 2012; Wong et al., 2018; Lindell et al., 2019; Chen et al., 2020; Kotani et al., 2020; Wong, 2020; Kim et al., 2021; Nagarajan and Shaw, 2021; Wong et al., 2021). These responses in disasters are often facilitated by transportation infrastructure and specific strategies that prioritize the movement of people or goods (e.g., evacuation plans, transit-based evacuations, contraflow, relief distribution).

In this context of resilience and disaster response, one unique and emerging idea is to develop "resilience hubs" where people and resources could be gathered to increase safety and quality of life. Current resilience hubs have been developed at the local level through partnerships with existing organizations (e.g., community centers, recreation centers, non-governmental organizations, Red Cross, Urban Sustainability Directors Network [USDN]). Traditionally, they have been funded by governments, foundations, other non-governmental grants, and donations. For example, Vibrant Hawai'i, a community-based non-profit organization, opened community resilience hubs to provide resources to Hawai'i Island residents during the COVID-19 pandemic.

The establishment of these hubs was made possible through a $1.7 million (USD) award from the County of Hawaiʻi through an allocation from the U.S. Coronavirus Aid, Relief, and Economic Security Act (CARES) and an additional $171,000 (USD) provided by the Hawai'i County Council (Vibrant Hawai'i, 2020; Hawaii News Now, 2021). Alternatively, hubs have also been planned and funded by cities (e.g., City of Tallahassee (2022), Vancouver (2022a)).

Despite some early examples and planning around these hubs, the idea of resilience hubs remains largely undefined as a concept, lacking in characteristics or functions, and under-researched in terms of its connection to transportation and land use. This gap in research and practice motivated several research questions:

1) What are resilience hubs, especially when considering other types of hubs or centres for disasters and everyday conditions?
2) How are resilience hubs currently being used and what are their functions?
3) What are the transportation needs of resilience hubs?

To answer these research questions, this paper provides an early conceptual understanding of resilience hubs and their related transportation needs through a comprehensive literature review that can guide future pilots, programs, and designs. Through keyword searching of "resilience hubs" and related hubs (e.g., mobility hubs, evacuation shelters, community hubs) via Elsevier's Scopus, Web of Science, and Google Scholar, we identified the current state of the literature on the topic. A search of "resilience hubs" yielded a number of academic research articles and papers, which were supplemented by additional keyword searching for frameworks, reports, information available on trusted government websites, and white papers related to resilience hubs.

The earliest literature found for resilience hubs was 2016 so this paper provides literature between 2016 and September 2022 (current at the time of writing). For related hubs (e.g., mobility hubs, evacuation shelters, community hubs), the literature date range focused on the same date range to align with publications about resilience hubs and provide up-to-date information. Some relevant literature from periods before 2016 was also included in this review to supplement more recent information. In addition, we reviewed the literature from a transportation perspective to determine what mobility options, operations, and planning might be necessary to facilitate the movement of people and goods to/from the resilience hubs. This paper includes 56 academic papers from journals (including 11 from journals focused on transportation), 13 non-peer-reviewed academic sources (e.g., books, book chapters, conference papers, theses), 35 reports (including guidebooks, frameworks, and presentations), and 46 websites.

The paper is organized as follows. First, we present the concept of resilience hubs and include information about the placement of resilience hubs, function modes, and characteristics. Next, we provide background on preceding hubs to contextualize resilience hubs. We end the paper with a discussion of emerging needs, policy recommendations, and a conclusion.

2.2 Resilience Hubs

This section describes elements of resilience hubs. In the first subsection, the concept of resilience hubs is presented, followed by their elements.

2.2.1 Concept

Resilience hubs were first described by Baja (2016) and more formally defined by Baja (2018) in the report "Resilience Hubs: Shifting Power to Communities and Increasing Community Capacity" prepared for the Urban Sustainability Directors Network (USDN). Most of the studies about resilience hubs found in the literature review mention the concept of resilience hubs defined by Baja (2018) or present a very similar definition (Sandoval, 2019; Vibrant Hawai'i, 2019; Breton-Carbonneau and Griffiths, 2020; City of Houston, 2020; de Roode and Martinac, 2020; Lou, 2020; Resilience Hub Community Committee, 2020; Baltimore Office of Sustainability, 2021; Kirwan et al., 2021; Mardis et al., 2021). Generally, resilience hubs are community-serving physical spaces – a building and related infrastructure – created to support residents, coordinate communication and services, and provide resource distribution before, during, or after a disaster (Baja, 2018).

Aiming for various physical, ecological, and social goals, resilience hubs provide opportunities for communities by improving quality of life, increasing equity and mobility, reducing greenhouse gas emissions (GHGs), and providing more efficient emergency management and climate change mitigation (Baja, 2018). Kirwan et al. (2021) and Sandoval (2019) described how resilience hubs can be a promising mechanism to build neighborhood resilience to overcome these challenges. In addition, Baja (2022) highlighted that focusing resilient strategies on community necessities and self-determination can enhance social alliance and partnerships by supplying superior access to resources such as food, water, childcare, and the Internet. For instance, the Vibrant Hawai'i resilience hubs in the County of Hawai'i provide several key services, including access to laptops and Wi-Fi, programming, prepared meals, and food boxes. These services assisted 41,733 households and 108,214 individuals, of whom 38 % were under the age of 18 (Vibrant Hawai'i, 2020). They also offered safe learning spaces and connectivity for distance learning for children, which facilitated a safer return to school and work (Vibrant Hawai'i, 2020).

Regarding social alliances, research by Aldrich and Meyer (2015) on social capital and community resilience uncovered that policy responses for preparedness should go beyond physical infrastructures to include social infrastructures (e.g., social capital and social cohesion). For instance, social cohesion promotes a sense of inclusion for all members of a community, valuing the diversity of its residents, promoting equal access to opportunity for people of all backgrounds, and developing strong and positive relationships among residents (de Roode and Martinac, 2020). Resilience hubs have the potential to build this social cohesion through resource access (Baja, 2022).

2.2.1.1. Placement of Resilience Hubs

The placement of resilience hubs is critical to ensuring sufficient community trust and easy access (Baja, 2019). The initial criterium for hubs is the identification of existing well-known and well-utilized places, such as community centers, recreation facilities, libraries, universities, and/or government buildings that can be converted into a resilience hub. Key literature has also stressed that the hubs' locations should enable service to communities every day and specifically during disasters (Sandoval, 2019; Kirwan et al., 2021; Mardis et al., 2021). Research by Mazereeuw and Yarina (2017) in Japan and other Pacific countries demonstrated that combining disaster features with everyday amenities at community buildings improved hazard recovery. Moreover, mixed-use places were more likely to be known by the public and used in disasters (Mazereeuw and Yarina, 2017). Idziorek (2020) determined that public spaces should be sufficiently adapted to serve the community not only during disasters but also in daily conditions. Based on findings from Idziorek (2020) and Mazereeuw and Yarina (2017), selecting well-known and well-used places for resilience hubs could increase the likelihood that people will use them in times of disaster. While literature generally suggests places that have been pre-established (i.e., existing buildings), Baja (2022) noted that constructing new buildings may be an option for communities, especially if residents contribute to the site selection and design process.

Resilience hubs tend to be placed in urban areas to improve accessibility to resources, especially for underserved populations. For example, on Detroit's East side, the Bailey Park Neighborhood Development Corporation's Community Resilience Hub was created as a central access point for services and resources during regular days and emergencies (Sands, 2021). In 2020, the hub helped neighborhood residents through the distribution of fresh food (in partnership with Gleaners Community Food Bank) and personal protective equipment (PPE). A year later, the hub helped residents that were affected by floods from a large summer storm (Bailey Park Neighborhood Development Corporation, 2022). For suburban areas, the Millvale Food + Energy Hub in Millvale, Pennsylvania, a small suburb of Pittsburgh, distributed around three tons of fresh food in partnership with the USDA's Farm to Families program during the COVID-19 pandemic (Hussain and Zetkulic, 2021). Other urban and suburban resilience hubs have included Baltimore (Maryland), Tallahassee (Florida), Vancouver (British Columbia), Cambridge (Massachusetts), and Tempe (Arizona), to name a few.

Resilience hubs can also operate in rural areas. Mardis et al. (2021) described that in rural areas, public libraries are ideal locations for resilience hubs because they provide a variety of informational, educational, social, and personal services. Moreover, Bishop and Veil (2013) and McShane and Coffey (2022) highlighted that the staff and current functions of public libraries can help community residents in disaster response and recovery. For example, after a disaster, people can receive physical aid and/or shelter at public libraries, while librarians can assist residents by connecting them with emergency information, organizations that provide relief during disasters (e.g., Red Cross, food banks), and government services (Bishop and Veil, 2013; Mardis et al., 2021; McShane and Coffey, 2022). Regardless of geography, the effectiveness of resilience hubs depends on multiple community-oriented factors including: community co-development, individual knowledge of resources and services at a hub, trust in the hub and its staff, and the ability of resources to meet community needs during extreme events (Baja, 2018).

Regarding transportation and mobility, only Baja (2019) cited two transportation characteristics that should be considered for resilience hubs' site selection. The first focuses on placing a hub in areas that are walkable and easily accessed by pedestrians. Second, Baja (2019) recommended that hubs should be near evacuation routes or major roads. Beyond this planning guidance, the review did not uncover any other transportation considerations for hub placement.

2.2.1.2. Other Considerations for Resilience Hubs

In addition to placement, Sandoval (2019) described that the types and dimensions of disasters should play a central role in resilience hub design and operations. Hubs can also significantly differ based on the climate region, geographic characteristics, and cultural context (Sandoval, 2019). For example, a tsunami-prone community in Southeast Asia may require significantly different needs than a wildfire-prone community in North America. Breton-Carbonneau and Griffiths (2020) uncovered that some communities prioritized language support services as a crucial resource for resilience hubs in non-English speaking communities. Resilience hubs can also focus on internal resources. The Federal Emergency Management Agency (FEMA) in the U.S. determined that resilient communities should identify and leverage their own resources to recover from a disaster, rather than fully depend on external resources (FEMA, 2011). As an example of self-reliance, the resilience hub located at the Boyle Heights Arts Conservatory in Los Angeles (California) has a water capture and storage system and a renewable power system (solar + storage) (USDN, 2022a).

Beyond these considerations, it is difficult to define a resilience hub in a more concrete sense, because hubs can be uniquely designed to serve community needs. When locating and planning for resilience hubs, literature has found that planners should consider the needs of neighborhoods and design hubs based on surrounding land use (Baja, 2019; Georgetown Climate Center, 2022). Moreover, planning for resilience hubs can be seen as a dynamic and evolving process that changes depending on preparedness, response, and recovery activities specific to the community and its hazards (Small Planet Networks, 2022).

2.2.1.3. Resilience Hub Function Modes

Within the conceptual framing of resilience hubs, functionality was a common theme. Resilience hubs can operate in three modes (Baja, 2019; Resilience Hub Community Committee, 2020): (1) everyday or normal mode (non-disruption); (2) response or disruption mode (both short- and long-term disruption); and (3) recovery mode (post-disruption). For most days, resilience hubs function in normal mode, acting as reliable community places that offer a variety of community-determined services and programs such as access to health, food, water, Internet, childcare, and activities for seniors (Baja, 2019; Northampton Massachusetts, 2020). In the event of a disaster, hubs can transition from normal mode to response mode, reacting and responding to the disruption and improving operations to better meet the immediate needs of the community. After a disruption, they switch into recovery mode, serving as relief distribution centers.

During the response mode, which is activated when an emergency event occurs (i.e., either short- or long-term disruptions), resilience hubs can help reunite families, supply resources, share information, and provide medical support (Mazereeuw and Yarina, 2017). They can also be a gathering place where community members offer support and prioritize services to those most vulnerable (Baja, 2019). For longer-term disruption, hubs can also provide overnight accommodations for evacuees (similar to evacuation shelters). The demand for these accommodations will be dependent on the disaster, community demographics, and shelter characteristics (Das, 2018; Asgary and Azimi, 2019).

Similar factors will determine the duration that a hub will function in recovery mode. During this phase, the hub can remain a point for gathering that shares information and offers resources (Vancouver, 2022b). In addition, they can provide services that assist residents and local business owners to apply for government recovery assistance (Bishop and Veil, 2013).

2.2.2. Resilience Hub Elements

Moving from the concept and functionality of resilience hubs, Baja (2022) and Breton-Carbonneau and Griffiths (2020) describe five foundational elements of hubs:

(1) Services and Programming: offer services and programs that support community preparedness and response and improve their quality of life.
(2) Communications: provide accessible, reliable, and easily understood information in all three operation modes to increase community cohesion and connectivity.
(3) Building and Landscape: identify existing well-known and well-utilized buildings and strengthen them with the utilization of the surrounding landscape (e.g., water capture and reuse, air filtration, urban gardening) that can safeguard their function in disasters.
(4) Power Systems: provide uninterrupted power during a disaster using systems (e.g., solar panels, backup generators, batteries) that are aligned with resilience hubs' goals.
(5) Operations: have a capable team and processes to guarantee that the hub operates daily and can be a safe and accessible site for all residents of the service area.

Table 2.1 shows services, programs, and resources identified by the literature as elements/options that could be provided by a resilience hub. In addition, the table presents examples of these elements/options using known resilience hubs in North America that are currently functioning or are being designed. A simple search of resilience hubs as a keyword yielded 11 cities and 25 states with implemented or planned hubs. Cities tended to have more detailed information about implemented hubs. We note that this is not a complete list of examples of resilience hubs as the search focused more on readily available examples and not finding/analyzing all hubs, including some that may not have sufficient or searchable information.

Table 2.1 - Services, programs, and resources provided by current resilience hubs

Services, Programs, and Resources	**Description**	**Examples in Current Hubs**	**Sources**
Community emergency response training	Critical communication and information that help educate community members about hazards	Vancouver, BC; Tallahassee, FL; Hawaii; TX**; San Francisco, CA; Washington D.C.; Tempe, AZ; Los Angeles, CA; Cambridge, MA; Ontario, CA; AZ; CA; CO; GA; IA; IL; KS; KY; ME; MA; MI; MN; NC; NJ; NM; NY; OH; OR; RI; VA; VT; WI; Detroit, MI	(Neighborhood Empowerment Network, 2018; Vibrant Hawai'i, 2020, 2021; CREW, 2021; Higgins, 2021; Sands, 2021; City of Tallahassee, 2022; Oak Park Neighbourhood Centre, 2022; USDN, 2022a, 2022b, 2022c, 2022d; Vancouver, 2022a)
Heating and/or cooling	Heating on extreme cold days and/or cooling in heat waves	Vancouver, BC; Detroit, MI; San Francisco, CA	(Neighborhood Empowerment Network, 2018; Sands, 2021; Vancouver, 2022a)
Wi-Fi access	Free Wi-Fi access to the Internet and key communications	Vancouver, BC; Tallahassee, FL; Hawaii; Detroit, MI; Washington D.C.; Tempe, AZ	(Vibrant Hawai'i, 2020, 2021; Sands, 2021; City of Tallahassee, 2022; USDN, 2022c, 2022d; Vancouver, 2022a)
Food and water distribution	Food and water resources, which are offered daily or only during a disaster	Hawaii; TX*; Detroit, MI; Baltimore, MD; Millvale, PA; San Francisco, CA; Ann Arbor, MI; Ontario, CA; Tempe, AZ; Los Angeles, CA; Cambridge, MA	(Neighborhood Empowerment Network, 2018; Stanton, 2020; Vibrant Hawai'i, 2020, 2021; Baltimore Office of Sustainability, 2021; Higgins, 2021; Hussain and Zetkulic, 2021; Sands, 2021; Oak Park Neighbourhood Centre, 2022; USDN, 2022a, 2022b, 2022c)
Meal services	Daily meal distribution or selective meals during a disaster	Hawaii; TX*	(Vibrant Hawai'i, 2020, 2021; Higgins, 2021)

Health services/basic medical supplies	Medical services and care, dentists, and pharmacies	Tallahassee, FL; Detroit, MI; Tempe, AZ	(Sands, 2021; City of Tallahassee, 2022; USDN, 2022c)
Mental health experts	Mental health and wellbeing support programs	Tallahassee, FL; Washington D.C.; Tempe, AZ; Cambridge, MA	(City of Tallahassee, 2022; USDN, 2022b, 2022c, 2022d)
Showers and restrooms	Access to showers and restrooms	Vancouver, BC; TX*; Tempe, AZ	(Higgins, 2021; USDN, 2022c; Vancouver, 2022a)
Solar power	Power delivered to the hub via solar panels for improved resilience in disasters	Baltimore, MD*; Detroit, MI* Millvale, PA; Ann Arbor, MI; Washington D.C.; Tempe, AZ; Los Angeles, CA	(Stanton, 2020; Baltimore Office of Sustainability, 2021; Higgins, 2021; Hussain and Zetkulic, 2021; Sands, 2021; USDN, 2022a, 2022c, 2022d)
Information desk	Information about: (1) activities and services available daily and during disaster and (2) government programs aimed to assist the recovery of those affected by the disaster	Vancouver, BC; Hawaii; TX*; San Francisco, CA; Ontario, CA; AZ; CA; CO; GA; IA; IL; KS; KY; ME; MA; MI; MN; NC; NJ; NM; NY; OH; OR; RI; VA; VT; WI; Washington D.C.; Tempe, AZ; Los Angeles, CA	(Neighborhood Empowerment Network, 2018; Vibrant Hawai'i, 2020, 2021; CREW, 2021; Higgins, 2021; Oak Park Neighbourhood Centre, 2022; USDN, 2022a, 2022c, 2022d; Vancouver, 2022a)
Emergency communication system	Critical communication and information during a disruption phase	Washington D.C.; Tempe, AZ	(USDN, 2022c, 2022d)
Support for reuniting families	Reuniting place for families during a disaster	Vancouver, BC;	(Vancouver, 2022a)
Computers	Access to computers for communication and information	Vancouver, BC; Hawaii; Detroit, MI	(Vibrant Hawai'i, 2020, 2021; Sands, 2021; Vancouver, 2022a)
Fitness facilities	Gym, swimming pool, and sports courts	Vancouver, BC; Tallahassee, FL; Detroit, MI; Cambridge, MA	(Sands, 2021; City of Tallahassee, 2022; USDN, 2022b; Vancouver, 2022a)
Gathering places for group activities	Fitness center, squares, group activities, games, family breakfast/lunch/dinner, restaurants, and arenas	Vancouver, BC; Tallahassee, FL; Hawaii; TX*; Detroit, MI; Millvale, PA; San Francisco, CA; Ontario, CA; Washington D.C.; Cambridge, MA	(Neighborhood Empowerment Network, 2018; Vibrant Hawai'i, 2020, 2021; Higgins, 2021; Hussain and Zetkulic, 2021; Sands, 2021; City of Tallahassee, 2022; Oak Park Neighbourhood Centre, 2022; USDN, 2022b, 2022d; Vancouver, 2022a)
Community arts and culture	Music and art classes and expositions	Vancouver, BC; Tallahassee, FL; Hawaii; Detroit, MI; Ontario, CA; Washington D.C.; Los Angeles, CA; Cambridge, MA	(Vibrant Hawai'i, 2020, 2021; Sands, 2021; City of Tallahassee, 2022; Oak Park Neighbourhood Centre, 2022; USDN, 2022a, 2022b, 2022d; Vancouver, 2022a)

Coordinated childcare	Childcare services and pre-school	Vancouver, BC; Hawaii; Ontario, CA	(Vibrant Hawai'i, 2020, 2021; Sands, 2021; Oak Park Neighbourhood Centre, 2022; Vancouver, 2022a)
Older adult services and program	Yoga, meditation, sports, fitness facilities, group meetings, language classes, and technology classes for older adults	Vancouver, BC; Tallahassee, FL; San Francisco, CA; Ontario, CA	(Neighborhood Empowerment Network, 2018; City of Tallahassee, 2022; Oak Park Neighbourhood Centre, 2022; Vancouver, 2022a)
Youth and child programs	Children's before and/or after-school programs	Vancouver, BC; Tallahassee, FL; Detroit, MI; Ontario, CA; Los Angeles, CA; Cambridge, MA	(Sands, 2021; City of Tallahassee, 2022; Oak Park Neighbourhood Centre, 2022; USDN, 2022a, 2022b; Vancouver, 2022a)
Job training programs	Opportunities to learn additional skills for jobs and workforce development	Hawaii; Washington D.C.; Tempe, AZ; Los Angeles, CA; Cambridge, MA	(Vibrant Hawai'i, 2020, 2021; USDN, 2022a, 2022b, 2022c, 2022d)
Training on how to manage finances	Workshops about financial management	Hawaii; Washington D.C.	(Vibrant Hawai'i, 2020, 2021; USDN, 2022d)
Growth of fresh and local food	Place to grow and/or access fresh and local food	Vancouver, BC; Hawaii	(Vibrant Hawai'i, 2020, 2021; Vancouver, 2022a)
Horticulture courses	Courses related to growing food and plants	Vancouver, BC; Hawaii; Ontario, CA	(Vibrant Hawai'i, 2020, 2021; Oak Park Neighbourhood Centre, 2022; Vancouver, 2022a)
Cooking classes	Cooking classes for different age groups	Vancouver, BC	(Vancouver, 2022a)
*Geography has hubs only in the design phase. **Geography has hubs that are already opened *and* hubs that are in the design phase.			

From **Table 2.1**, the two most common services offered by the current hubs, especially in those located in libraries (e.g., (CREW, 2021)), are community emergency response training and an information desk. These services provide emergency preparedness opportunities and communicate key resources to residents. We noticed that among the resources provided, some (but not all) of the hubs provided food and water (Neighborhood Empowerment Network, 2018; Stanton, 2020; Vibrant Hawai'i, 2020, 2021; Baltimore Office of Sustainability, 2021; Higgins, 2021; Hussain and Zetkulic, 2021; Sands, 2021; Oak Park Neighbourhood Centre, 2022; USDN, 2022a, 2022b, 2022c). For example, 14 resilience hubs in Hawaii focused on food distribution (Vibrant Hawai'i, 2020) while none of the disaster support hubs in Vancouver reported this service (Vancouver, 2022a). This may be due to the different functionalities that were designed for these hubs and the needs of the community where they are located. This gap indicates that some hubs may not be able to meet basic needs during a disaster.

Other important resources during emergency situations include physical and mental health services and basic medical supplies. These resources were observed in the Bailey Park Neighborhood Development Corporation's Community Resilience Hub in Detroit, MI (Sands, 2021), the Smith-Williams Center in Tallahassee, FL (City of Tallahassee, 2022), the Resilience Incubators at F.H. Faunteroy in Washington D.C. (USDN, 2022d), the Envision Tempe Resilience Hub in Tempe, AZ (USDN, 2022c), and the Cambridge Community Center in Cambridge, MA (USDN, 2022b). However, we did not find substantial evidence of overnight accommodation needs such as beds/cots and showers. While these resources could be allocated quickly to hubs, a lack of information indicates that overnight shelter space or hygienic facilities are not a priority for current resilience hub design.

We also observed that a decent number of resilience hubs offered everyday services and programming (e.g., City of Tallahassee, (2022), Oak Park Neighbourhood Centre (2022), USDN, (2022b), and Vancouver (2022a)). Examples of services included children's before and/or after school programs, coordinated childcare, older adult services and programming, and community arts and culture. Some resilience hubs also offered general facilities for group meetings and gatherings (City of Tallahassee, 2022; Higgins, 2021; Hussain and Zetkulic, 2021; Neighborhood Empowerment Network, 2018; Oak Park Neighbourhood Centre, 2022; Sands, 2021; USDN, 2022b, 2022d; Vancouver, 2022a; Vibrant Hawai'i, 2020, 2021). A few hubs offered unique programs such as job training, cooking classes, financial courses, and horticulture courses (mostly in Hawaii, Washington D.C., Tempe, Los Angeles, Cambridge, and Vancouver). As mentioned previously, Internet access and space for distance learning for children were offered by resilience hubs in Hawai'i (Vibrant Hawai'i, 2020).

Table 2.1 is also informative about what resilience hubs do not provide. For example, language support services are a crucial resource for resilience hubs in communities that do not speak the official language of the country (Breton-Carbonneau and Griffiths, 2020). However, translation services were not found in the example hubs, which could produce inequitable outcomes for residents that do not speak the official local language. Critically, our review of resilience hub examples did not find any information related to transportation services. A wide range of transportation services (e.g., public transit, shared mobility, paratransit service, point-to-point transportation to/from key destinations) could be included as services or characteristics of a resilience hub. The lack of transportation examples indicates that while there may be the co-location of hubs and transportation, mobility services are not considered critical components of hubs in their current form. This also suggests that transportation – including connections to/from hubs – is not being considered as part of their functionality or usability.

2.3. Other Preceding Hubs

Before the concept of resilience hubs emerged, cities had adopted other types of hubs to achieve various societal goals. This section presents the types of hubs that are most correlated with the current concept of a resilience hub. These other hubs can help inform resilience hubs or be adapted to serve as resilience hubs.

2.3.1. Mobility Hubs

Mobility hubs, which can also be defined as intermodal terminals, are places where passengers can efficiently transfer between a variety of routes and modes of transportation (Anderson et al., 2017; Aono, 2019; CoMoUK, 2019; Henry and Marsh, 2008; Pitsiava-Latinopoulou and Iordanopoulos, 2012; Schemel et al., 2020). They are an opportunity to integrate various sustainable transport modes and increase a city's connectivity (Aono, 2019; Schemel et al., 2020). The type of mobility hub may vary from a single carshare space or connection between two modes to a concentration of multiple transportation modes (Anderson et al., 2017; Henry and Marsh, 2008; Schemel et al., 2020). This co-location of modes has several key benefits. First, mobility hubs can lower the cost and time of travel by enabling passengers to use a mode that suits each trip or trip segment (Henry and Marsh, 2008; Aono, 2019). Second, mobility hubs can reduce congestion by encouraging modes beyond auto travel (Pitsiava-Latinopoulou and Iordanopoulos, 2012; Portland Bureau of Transportation, 2018). Third, GHGs can be reduced since there are more active and clean transportation modes options (CoMoUK, 2019; Aydin et al., 2022). Finally, mobility hubs can increase transportation accessibility and equity (Henry and Marsh, 2008; Anderson et al., 2017; CoMoUK, 2019).

Regarding implementation, the construction of mobility hubs requires cooperation between local governments and transportation operators (National Commission on Intermodal Transportation, 1994; Aono, 2019). Some factors are considered essential to ensure the success of hubs (Aono, 2019; Bell, 2019; Pitsiava-Latinopoulou and Iordanopoulos, 2012). For example, mobility hubs need adequate accessibility for all users; reliable service from operators; safety and security across modes; a sense of place that values the community; and sufficient parking (if necessary). Moreover, mobility hubs can encompass some amenities which support passengers and transform the hubs from a place of transition to a destination (Schemel et al., 2020). Examples of these multi-use hubs can be found across Europe and North America (Arnold et al., 2022; Henry and Marsh, 2008; SmartHubs, 2022). Basic services that are offered by these multi-use mobility hubs include (but are not limited to): information desks, washrooms, storage lockers, mail/courier service, Wi-Fi, electric vehicle charging station, food courts, stores, gyms, and banks. Hubs can also function as transit-oriented developments (TODs) with residences and commercial space. Other co-located destinations can include supermarkets, stadiums, and medical facilities.

A mobility hub's location is usually determined by a city's land use, transportation network and demand, community demographics characteristics, and other local policies (Aono, 2019; CoMoUK, 2019; Metropolitan Transportation Commission, 2020; PBOT, 2020). Once new mobility hub facilities are needed, government agencies typically: (1) measure and model current travel demand, (2) analyze the current transportation network, (3) analyze the outcomes and select prioritized areas, (4) determine the type of mobility hubs, (5) choose potential sites, (6) evaluate candidates sites, and (7) select the best location based on several chosen factors (PBOT, 2020; Arlington, 2021; Arnold et al., 2022; Arseneault, 2022). Typically, cities prioritize existing sites that can be repurposed and redesigned. Most academic literature about the location selection of mobility hubs has focused on optimization methods, Geographic Information System (GIS) analysis, spatial analysis, and the analytic hierarchy process (Anderson et al., 2017; Guerreiro et al., 2018; Petrovic et al., 2019; Fazio et al., 2021; Aydin et al., 2022; Eren and Katanalp, 2022).

As mobility hubs continue to evolve, their design and functions can help inform the development of resilience hubs, in particular ensuring that people can travel to/from the hubs safely and efficiently in both disaster and everyday conditions. The placement of multiple modes can allow evacuees the ability to reach resources more quickly, and a centralized hub can also serve as a staging area or a primary drop point for key relief supplies. Consequently, a mobility-centered approach for resilience hubs can help produce co-benefits that can help meet community needs.

2.3.2. Community Hubs

Community hubs, whose precursors were early guilds, religious organizations, civic organizations, sporting clubs, and community houses (e.g., Chicago's Hull House) (McShane and Coffey, 2022), are sometimes called community centers, neighborhood associations/centers, and community leagues. They are multi-purpose institutions that provide central access to a variety of services (e.g., education, social, and health) in conjunction with more common cultural and recreational activities to increase community well-being (McShane and Coffey, 2022; Palumbo, 2016; Pitre, 2015). A key element of community hubs is their ability to create social infrastructure and networks, which can address vulnerabilities and better meet localized needs (McShane and Coffey, 2022). The process to select a place for a community hub usually begins with an identification of local needs. This is closely followed by a selection of areas that will be most impacted by their implementation and the development of partnerships within the community. Next, the organization that will implement the hub (e.g., local government, non-government organization, community-based organization) will identify potential locations that meet the community's needs and select the most appropriate site for the hub. These approximate steps are outlined in several practitioner guides (Government of South Australia, 2018; Queiser, 2019; Christopher Hellmundt Community and Culture, 2022; My Community Locality, 2022; Strathcona County, 2022). When identifying possible sites for community hubs, transportation options can be planned to increase equitable access to destinations (e.g., proximity to transit, access to parking, and proximity to pathways and cycle lanes) (Strathcona County, 2022). Many community hubs have been created at the local level through the repurposing of existing buildings (i.e., public spaces, semi-private, or private spaces). As an example of this overall process, the City of Edmonton has 161 community leagues that were established to meet residents' unique needs within individual neighborhoods (EFCL, 2022), displaying many of the characteristics and functions of community hubs.

Due to the increase in frequency and magnitude of climate change extreme events, community hubs have made some recent adaptations to prepare for the impact of disasters. Services such as emergency accommodations, information centers, community kitchens, and response and recovery services have been adopted by some community hubs (McShane and Coffey, 2022), which aligns with resilience hub objectives. The recent COVID-19 pandemic has also altered the role of community hubs. For example, the community hubs initiative in Calgary (Canada) reported a change in the services that their communities needed during the pandemic (United Way, 2021). Moreover, they noted that certain types of community hub support, such as basic needs (e.g., food hampers, meals, and hygiene items) faced an increase of over seven times (United Way, 2021). This switch from recreation and culture to key emergency response during the COVID-19 pandemic indicates a new shift in thinking that can extend to recovery and climate preparedness for resilience hubs.

Community hubs have been located in a variety of spaces and buildings including schools (Pitre, 2015; Grand Erie District School Board, 2022), libraries (Pitre, 2015; Ontario, 2017; First 5 El Dorado, 2022), older adult and senior care centers (Pitre, 2015; Primary Care Network, 2018), community health centers (Pitre, 2015; Ontario, 2017), and government buildings (Pitre, 2015). According to McShane and Coffey (2022), the placement of hubs is crucial as poor planning may result in the inappropriate placement of community hubs regarding accessibility and vulnerability. Hubs should be generally designed to meet the needs of the community through local services and resources. Guidance can be taken from McGee et al. (2021) on services for Indigenous communities in wildfire evacuations. Assistance during disasters for First Nations, Metis, and Inuit should offer foods that are part of the specific Indigenous culture, consider the financial needs of the population, and provide healthcare related to the health challenges that are predominant in those Indigenous communities (McGee et al., 2021).

Community hubs have a range of benefits. For example, they have been shown to: improve learning opportunities and well-being for students, enhance response to local needs, improve access to services, increase connectivity and social cohesion in the community, and allow neighbors to build a cooperative vision for the future of their community (Pitre, 2015; United Way, 2021). The community hubs initiative in Calgary cited that 40% of their hub activities involved collaborating with community partners, 84 % of residents felt a sense of community connectedness, and 92% of the volunteers felt connected to their hubs (United Way, 2021). These characteristics of community hubs – particularly related to social cohesion – can serve as key guidance for resilience hubs.

2.3.3. Evacuation Shelters

In the event of a disaster or emergency, evacuations that move people away from a hazard are common. To ensure that evacuees have a safe destination, evacuation shelters are often opened in nearby communities to the disaster (Sheu and Pan, 2014; Bayram and Yaman, 2018). The emergency shelter location is usually determined by deterministic facility location models that select sites to optimize specific selection parameters (Li et al., 2012; Xu et al., 2016; Boonmee et al., 2017; Zhao et al., 2017; Ma et al., 2019, 2022). For example, shelters are selected based on the hazard's potential impact, an appropriate travel distance, or a shelter's spatial coverage (Xu et al., 2016; Zhao et al., 2017). Shelters can also be located based on dynamic facility location models, where paraments such as traffic flow, time, and cost vary (Boonmee et al., 2017). Beyond optimization models, shelters are often planned and located based on convenience, availability, and accessibility. In particular, public and public-serving buildings – such as schools, universities, stadiums, libraries, leisure centers, and faith-based buildings – are chosen as evacuation shelters since they can often shelter significant numbers of people and provide sufficient resources for evacuees (ADA, 2007; Liu et al., 2011; Bashawri et al., 2014).

Evacuation shelters can be categorized into different types according to the period of time that people need to stay in the shelter from the commencement of the disaster event. Quarantelli (1995), Johnson (2007), Chou et al. (2013), and Felix et al. (2013) grouped them into four types of shelters: (1) emergency sheltering (i.e., short period of time during the emergency peak); (2) temporary sheltering (i.e., a few days/ weeks after the peak); (3) temporary housing (i.e., long term but not a final residence); and (4) permanent housing (i.e., existing, renovated, or rebuilt housing).

Depending on the disaster type, evacuation shelters can be planned for an open place (e.g., parks, playgrounds, squares, parking lots) or a safe indoor place (e.g., schools, churches, temples, libraries, recreation centers, government buildings). Indoor locations are the most common, as structures can protect people from multiple hazard risks. In evacuations, people seek shelter in a variety of places, most commonly a family member's or friend's residence or a hotel/motel (Lindell et al., 2019; Wong, 2020). In addition, some evacuees shelter at a second residence, inside their portable vehicle, or even with a peer-to-peer service (e.g., Airbnb), as described by Wong et al. (2020a). Evacuation shelters are predominantly public shelters where anyone may seek safety. These tend to be lower-used options, with literature indicating that 2% to 11% of evacuees go to public shelters (Cheng et al., 2011; Lindell, 2018; Smith and McCarty, 2009; Whitehead, 2003; Wilmot and Gudishala, 2013; Wong et al., 2018; Wong, 2020; Wu et al., 2012; Yin et al., 2014). These low numbers are partially a result of poor public perception of evacuation shelters. Wong et al. (2018) found that 31% of the people that did not evacuate from Hurricane Irma in 2018 cited their decision as partially not wanting to go to a public shelter. Evacuation shelters are often perceived as uncomfortable, unsafe, and lacking in necessary resources (Asgary and Azimi, 2019; McGee et al., 2021).

Despite this perception, evacuation shelters are critical in disasters, especially for those without reliable transportation or nearby social connections. Research has found that low-income residents often choose to not evacuate because of the cost and are more likely to use local and free public shelters if they do evacuate (Karaye et al., 2020; Perkins, 1996; Wong, 2020). Consequently, public shelters should provide free resources (e.g., food, water, personal hygiene facilities, healthcare) (Lindell et al., 2019), especially given that their users have less financial capability to buy essential items for survival. Many of these resources parallel functions for resilience hubs, which can help bolster outcomes in disasters by increasing the probability that people will use public shelters. To improve evacuation compliance and nudge non-evacuee behaviour, Wong et al. (2021) also recommended that jurisdictions should improve shelter conditions to make them safer and more comfortable for a variety of populations. Other pre-planned mechanisms can increase transportation reliability for carless individuals in evacuations. For example, city-assisted evacuation plans have established pickup locations and sufficient public transit to/from registration centers and shelters (City of New Orleans, 2022).

When considering transportation for evacuation shelters (and resilience hubs), a few other key transportation options exist to improve equity. Chen et al. (2020) cited that carpooling with neighbors was an effective solution that could reduce traffic congestion during the evacuation and assist older adults, people with mobility challenges, and low-income households. Moreover, Wong et al. (2020a) and Borowski and Stathopoulos (2020) identified that recent advancements in ridesourcing companies, such as Uber and Lyft, have made them a possible transportation alternative for evacuations, especially in small-scale evacuations. Wong et al. (2020a) describe the evolution of this shared resource opportunity provided by companies or residents (e.g., peer-to-peer). For example, Uber and Lyft have both developed initiatives that offer ride credits to/from evacuation shelters (Hawkins, 2018; Lyft, 2018).

Evacuation shelters are also undergoing a change in concept. According to Kotani et al. (2020), some shelters have poor accessibility and do not have sufficient capacity to assist everyone who needs to evacuate. Kotani et al. (2020) studied an alternative option of evacuation shelter in a case study in Kobe, Japan and demonstrated that shopping streets with disaster-proof buildings can be an evacuation shelter, offer food distribution, and improve accessibility. Moreover, Wong et al. (2020a) pointed out that peer-to-peer homesharing, such as through Airbnb's Open Homes Program, could improve the quality and quantity of shelters in an evacuation. Upwards of 29 % of respondents for a future wildfire evacuation (Wong et al., 2020b) and 19 % of respondents for a future hurricane evacuation (Wong et al., 2020a) were found to be extremely likely to share their home for free with another evacuee.

2.3.4. Other Disaster Response Centers

Mazereeuw and Yarina (2017) expanded the concept of evacuation shelters more broadly to consist of decentralized emergency preparedness hubs in open areas (Bosaikoen in Japanese), which are planned in collaboration and consultation with local partners and the surrounding community. These hubs function daily as parks/playgrounds and during/after an emergency as a reuniting location where people could access supplies and information. With the increase in the effects of climate change, studies have shown that excessive heat exposure can increase the risk of morbidity and mortality (Semenza et al., 1996; Curriero, 2002; Ostro et al., 2009; Vaneckova et al, 2010; Tobias et al., 2012; Berko et al., 2014; Berisha et al., 2017). To help prevent illness and death caused by extreme weather conditions, some governments and communities sponsor warming and cooling centers for at-risk communities during heat waves and extremely cold days (Toronto, 2017a, 2017b; California, 2021; City of Oshawa, 2021; Chicago, 2022; City of Edmonton, 2022; City of London, 2022; City of New York, 2022; City of Niagara Falls, 2022; City of St. Louis, 2022; Connecticut State, 2022; Vancouver, 2022c). These facilities are equipped with air-conditioning and/or heating, and they have also been used to provide water and medical support (Fraser Health Authority, 2021; New York State, 2022). Examples of places that have served as cooling/warming centers include libraries, community centers, schools, shopping malls, supermarkets, facilities that have indoor or outdoor swimming pools, and recreation centers. It is noteworthy that some of these locations are also identified as resilience hubs (Maricopa County, 2022; New York State, 2022).

Recent wildfires in California have prompted the utilization of other centers, such as clean air centers to escape the effects of smoke. For instance, recent American Rescue Plan Act funding has been used to develop clean air and cooling center by retrofitting schools' heating, ventilation, and cooling systems in the San Francisco Bay Area (Giarmoleo, 2021). These upgrades improve students' environment, while simultaneously creating a center that can be used by the community during smoke events.

Utilities in California have also implemented public safety power shutoff (PSPS) events by de-energizing parts of the electric grid to reduce wildfire risk. As part of these events, utilities have also activated over 500 fixed and mobile community resource centers since 2017 (Wong et al., 2022) that provide PSPS information, electronic charging, accessible restrooms and hand-washing stations, basic medical equipment charging, and key resources (e.g., water, snacks, Wi-Fi, personal protective equipment) (Pacific Gas and Electric Company, 2022; Southern California Edison, 2022; Wong et al., 2022). Additionally, the indoor centers offer air-conditioning or heating, seating, and ice (Pacific Gas and Electric Company, 2022).

2.4. Discussion And Policy Recommendations

Our literature review uncovered key concepts related to resilience hubs and associated hubs (e.g., mobility hubs, community hubs, evacuation shelters). We determined that resilience hubs remain an understudied idea, though elements of mobility hubs (e.g., transportation), community hubs (e.g., social infrastructure and cohesion), and evacuation shelters (e.g., disaster response) could inform the design and planning of resilience hubs. In this section, we discuss our observations from the review and recommendations for improved implementation.

2.4.1. Resilience Hubs as a Concept

One important observation from our literature review was that the functionality and characteristics of resilience hubs are generally well-known. The implementation of resilience hubs across multiple states and provinces in North America indicates a general understanding by jurisdictions of how hubs can be designed. The growing number of examples also suggests that jurisdictions are generally willing to plan and implement resilience hubs. However, it remains unclear the level at which jurisdictions are matching the needs of the community with the functionality of the hubs. While some jurisdictions do point to community input (Neighborhood Empowerment Network, 2018; Vibrant Hawai'i, 2020, 2021; Higgins, 2021; Hussain and Zetkulic, 2021; Sands, 2021; City of Tallahassee, 2022; USDN, 2022a, 2022b, 2022c, 2022d), the level of this input and the rigor of participation are not always clear. We recommend a small improvement in the planning process: the inclusion and transparent description of needs assessments of a community to determine what is most practical and critical for both everyday and disaster conditions.

Second, we found a strong amount of literature on the placement of resilience hubs within communities, including ideal facilities. Literature suggests that these facilities must be allocated in well-known and well-utilized existing places (Baja, 2019; Sandoval, 2019; Kirwan et al., 2021; Mardis et al., 2021), which can build social capital and reduce construction costs. At the same time, the review found that location siting is sometimes vaguely described in terms of key characteristics, appears unrelated to a city's evacuation plan, and lacks details on how the location can (or cannot) facilitate relief distribution. To overcome this gap, we recommend that resilience hubs should be planned ahead of time (similar to evacuation shelters) to ensure that they are included in an evacuation plan. The plan should include clear information on the location of the hubs, how resources will reach the hub, what entities will provide resources, and if pre-positioning will occur.

Though placement has been discussed, only a few empirically based studies on ideal locations for resilience hubs have been conducted, specifically based on important criteria. For instance, de Roode and Martinac (2020) and Kirwan et al. (2021) used hazard and sociodemographic variables to identify high-risk locations for resilience hubs in Maui, Hawaii and Ypsilanti, Michigan, respectively. However, research has not yet optimized the location of hubs based on a variety of factors nor have studies considered transportation networks, accessibility, or mobility equity. We recommend that surveys about travel behaviour and network analyses be conducted to better choose locations that can benefit community residents, especially those most vulnerable.

Fourth, despite the planning guidance for resilience hubs, literature and current examples have not offered metrics or key performance indicators. For example, most resilience hubs have not provided information on the number of people served or whom they serve. To prevent hubs from having the same problems perceived and real in public evacuation shelters, such as discomfort, low security, and a lack of necessary resources (Wong et al., 2018; Asgary and Azimi, 2019; McGee et al., 2021), we recommend that governments conduct an assessment of the number of people expected to use the hubs daily and during disasters to determine the amount of resources (e.g., meals, food, water, hygiene products, and beds) and the number of staff needed. Moreover, any evaluation of resilience hubs should provide a broad range of metrics related to equity, accessibility, and quality of life to indicate their effectiveness in meeting community needs.

Finally, we did not find any significant evidence that community hubs or mobility hubs have been informing the development of resilience hubs, beyond a few select examples (e.g., Cambridge Community Center (USDN, 2022b)). Indeed, the everyday benefits of community hubs and the accessibility benefits of mobility hubs could help guide planning such that resources and benefits are co-located. We also highlight here that resilience hubs will not encompass all the services offered by community centers or mobility hubs. Resilience hubs also serve different purposes and meet varying goals compared to community centers and mobility hubs. For instance, not all mobility hubs need to be resilience hubs. Mobility hubs serve a key goal of connecting people to mobility options, transportation modes, and destinations, while community centers aim to provide recreation, programming, and social connections. These goals partially align with resilience hubs, but the emphasis and vision are different. Indeed, resilience hubs are not a panacea. They can provide co-benefits alongside other forms of hubs, but they cannot (and should not) fulfill all a community's needs. While Baja (2018) discusses the importance of multiple functionalities of resilience hubs, the specific attributes of other hub examples, especially those related to transportation, remain largely absent from the literature and current resilience hubs in North America. We recommend that these hub concepts begin to be framed together as part of an ecosystem (in conjunction with evacuation shelters) in future discussions and policies for resilience hubs.

2.4.2. Transportation and Accessibility

One significant takeaway from the literature review was that transportation is rarely considered in the planning, design, or implementation of resilience hubs. While Baja (2019) briefly described two transportation elements for resilience hubs (i.e., centrally located for walkability and placement near evacuation routes or major roads), the discussion is limited to the phase of identifying and evaluating sites. Moreover, we were unable to find considerations of transportation or residents' mobility needs in current examples of resilience hubs. This presents a clear gap in research and practice, as people and resources must safely and effectively travel to/from resilience hubs. Within the planning phase of resilience hubs, we recommend that jurisdictions identify the transportation needs, responses, strategies, and resources to facilitate evacuations and relief distribution. For example, resilience hubs could promote accessible transportation by prioritizing public transit (Bish, 2011), integrate shared mobility for point-to-point transportation (Wong et al., 2020a), and enable cycling and walking as viable and safe modes of transportation (Chen et al., 2020).

Second, we found that the planning and implementation of resilience hubs have not yet considered everyday transportation needs, particularly of vulnerable populations. Without addressing accessibility to/ from hubs, jurisdictions may struggle to match services with populations who need resources the most (e.g., carless, transit-dependent, low-income), creating inequities related to climate and disaster preparedness. Reorienting a community's transportation systems to link resilience hubs with residents can serve to improve access under normal and disaster conditions. For example, public transit routes that incorporate resilience hubs can help people reach services and reduce the need for special bus operations in a disaster. Consequently, we recommend that resilience hubs lean on the design and implementation of mobility hubs (Schemel et al., 2020; Arnold et al., 2022), especially more recent versions that have also incorporated shared mobility services (e.g., bikeshare, scooter share) that have been shown to improve equitable outcomes (Anderson et al., 2017; Shaheen et al., 2017). Cues should also be taken for ensuring accessible and reliable transportation in disasters for individuals with disabilities (Renne et al., 2011).

Third, we observed that there is no information about how people should evacuate to resilience hubs and minimal integration of hubs into evacuation or emergency response planning. While some examples indicate usage during a disaster (e.g., Vancouver), elements are focused primarily on a gathering place in a disaster. This obscures the multiple steps that must be taken to evacuate people effectively and efficiently from a disaster (see Lindell et al. 2019 for extensive background on evacuations). It should also be noted that residents in an evacuation require information on where they can go, such as a list of evacuation shelters with pet policies, hygiene facilities, and capacities. In addition, residents need to know how they should get to a resilience hub (i.e., transportation mode) and if those options are available. These gaps require a broader focus on identifying residents' transportation needs and expected travel behaviour via surveys and other data collection tools. Using these data, we recommend that jurisdictions conduct simple transportation network analyses or more complex evacuation simulations to determine transportation responses and routes needed for the hub. Moreover, if the city already has an evacuation plan, we recommend stronger integration of resilience hubs and public-facing information such that hubs are well-defined, easy to understand, and well-known by residents.

Finally, the literature stressed that the resilience hubs' locations should provide sufficient services for disaster conditions (Sandoval, 2019; Kirwan et al., 2021; Mardis et al., 2021). However, key questions related to relief distribution (e.g., how supplies are distributed to hubs, if hubs can accept the supplies, who distributes the supplies) remain unanswered. Moreover, in some cases, the resilience hub may be unable to provide all necessary resources to residents, especially in the event of a major disaster. However, literature did not provide strategies to transport evacuees to other destinations, such as healthcare facilities, shopping facilities (e.g., for basic supplies), or government facilities (e.g., to receive recovery information and assistance). We recommend that resilience hubs consider relief distribution, supply chain procedures, and post-evacuation transportation (including reentry to affected areas) in their design and implementation. Current memorandum of understanding (MOUs) in emergency response plans, guidance from mobility hubs, and available reentry plans could be especially useful.

2.5. Takeaways

This literature review uncovered an early conceptual understanding of resilience hubs, a mechanism to co-locate resources for everyday and disaster conditions. Most existing literature focuses on explaining the resilience hub's concept, characteristics, and functionalities. We found multiple examples across North America where communities were receiving key services from resilience hubs for everyday and disaster conditions. Recent guidance for resilience hub design, placement, and services has focused on building a familiar, well-resourced, and flexible place for the local community. These spaces can help communities increase their resilience to climate change, while also building social cohesion and preparedness for a variety of emergencies. Moreover, resilience hubs are an opportunity to build additional social capital and community trust. However, to achieve this, a community will likely need to already possess some shared values, a sense of identity, trust, and cooperation. A community will also need a strong connection to a resilience hub's location and perceive the hub as safe. Otherwise, residents will likely not: 1) trust the hub, 2) know about its location, and/or 3) use it. Jurisdictions will likely need to develop community trust in advance and in tandem with resilience hubs to successfully grow social capital.

Despite the encouraging results, the design, planning, and implementation of resilience hubs have several key limitations related to transportation. First, guidance for integrating hubs within a community's transportation system has been minimal. Second, resilience hubs have not considered the everyday needs of vulnerable populations. Third, hubs have not been sufficiently integrated into evacuation or emergency response plans. Finally, transportation services and relief distribution during the recovery phase for evacuees have not been adequately described or planned.

Even though they cannot fulfill all the needs of a community, resilience hubs have a promising future. Opportunities exist to offer essential services for the community's needs during most times of the year, prepare the community for climate change and emergencies, and assist the community during major disasters (e.g., wildfires, hurricanes, earthquakes) or chronic disruptions (e.g., extreme heat, extreme cold, power outages, smoke events). The unique co-benefits of resilience hubs are within reach, but hubs remain a new and largely untested concept. Moreover, additional research is needed to consider the transportation components of hubs, including the travel needs of people to/from hubs during evacuations, the distribution of relief supplies, and the accessibility of hubs for vulnerable populations.

Chapter 3: Travel Behaviour and Community Needs for Resilience Hubs

3.1 Resilience Hubs Empirical Needs

In recent years, communities have been challenged by multiple disasters (climate and non-climate-related), requiring them to rethink their planning, design, and infrastructure to improve preparedness, response, and recovery. One key challenge is providing sufficient resources, shelter, and information to people affected by a disaster, which requires coordination and transportation access. In this context, one nascent idea is to create resilience hubs, which act as localized, physical places for people to receive assistance and temporary accommodations during disasters and provide a range of services during everyday conditions (Baja, 2018; Ciriaco and Wong, 2022). Resilience hubs aim to increase a community's resilience and preparedness, while also increasing social connection within the area (Baja, 2018; Ciriaco and Wong, 2022; Kirwan et al., 2021; Sandoval, 2019).

Multiple communities, particularly in the United States, are building or considering implementing resilience hubs to serve communities daily and during disasters (Higgins, 2021; USDN, 2022a, 2022b; Vibrant Hawaii, 2021, 2020). A literature review conducted by Ciriaco and Wong (2022) uncovered that the majority of existing research and practice has focused on resilience hub concepts, characteristics, and functionalities. At the same time, the review also determined that transportation is not being integrated or considered into resilience hub design or operations. For example, little evidence exists on how the communities' needs were assessed, how the hub location was determined, and if accessibility, mobility, or the overall transportation network were considered for the hubs. Consequently, a lack of empirical evidence exists on how resilience hubs might be designed to meet communities' needs and how individuals are going to travel to and from resilience hubs. This gap in research and practice motivated several research questions:

1. How will people use resilience hubs in disasters and everyday conditions?
2. What types of transportation services and resources should be considered in resilience hub designs, planning, and operations?
3. What modes of transportation will be used by individuals to access a resilience hub in disasters and everyday conditions?

To answer these questions, we surveyed 950 residents of the Edmonton Metropolitan Area in Alberta, Canada between September 2022 and February 2023. We first start this paper by briefly reviewing the literature on resilience hubs. We then explain the data collection and methodology, which leverages simple descriptive statistics and discrete choice modeling to identify resilience hub usage, transportation needs, and factors that influence the usage of resilience hubs and mode choice. After presenting the results of our analysis, we end the paper with discussions, policy recommendations, and a conclusion.

3.2 Resilience Hub Summary

Resilience hubs are community-serving facilities developed to support residents, by providing communication coordination, social support services and programs, and resource distribution before, during, or after a disaster (Baja, 2018; Ciriaco and Wong, 2022; Kirwan et al., 2021; Mardis et al., 2021; Sandoval, 2019; Vibrant Hawaii, 2019). Studies have revealed that these spaces encompass a variety of goals, such as improving residents' quality of life, increasing communities' preparedness for emergencies, providing climate change mitigation, and increasing social cohesion, equity, and mobility (Baja, 2018; Ciriaco and Wong, 2022; Kirwan et al., 2021; Sandoval, 2019). Additionally, literature suggests that resilience hubs may have three operational modes (Baja, 2019; Resilience Hub Community Committee, 2020): 1) normal mode; 2) response mode; and 3) recovery mode. Most of the year, resilience hubs operate in normal mode, switching to response mode when the community needs to react to a disruption. After the disruption, the operational mode transitions to recovery mode and converts back to the normal mode after the community has recovered.

Regarding placement, literature has found that location is a critical aspect of the resilience hub planning phase to ensure community trust and accessibility (Baja, 2019; Ciriaco and Wong, 2022; Sandoval, 2019). Thus, most literature suggests that existing well-known and well-utilized places (e.g., recreation centres, libraries, universities, government buildings) should be prioritized to be retrofitted (or newly built) as resilience hubs. Moreover, literature recommends that the selected locations should be able to serve the community year-round and support residents during a disaster (Kirwan et al., 2021; Mardis et al., 2021; Sandoval, 2019). The construction of a new building to serve as a resilience hub can also be an option, but it may require more financial investment.

As resilience hubs are designed to meet community needs, neighborhoods with different characteristics may have different hubs with varying characteristics. Moreover, hubs can differ based on the type and severity of disasters that impact communities, cultural contexts, and land use (Baja, 2019; Georgetown Climate Center, 2022; Sandoval, 2019). Although resilience hub design may be unique, literature pointed to key elements that should be considered (Baja, 2022; Breton-Carbonneau and Griffiths, 2020; Ciriaco and Wong, 2022). For instance, resilience hubs should offer services and programs that improve a community's resilience, preparedness, and quality of life. Hubs should also be located in a safe location (from the hazard) and provide reliable communication to increase response, preparedness, and community cohesion. More specific elements that have been provided by current existing resilience hubs can be found in Baja (2018), Baja (2019), and Ciriaco and Wong (2022).

Transportation services are essential to enable people and goods to reach resilience hubs during normal conditions and an emergency. Two transportation elements were cited by Baja (2019) to guide hub placement: 1) locating hubs near accessible pedestrian areas, and 2) placing hubs close to evacuation routes or major roads (Baja, 2019). Despite these two guidelines, the literature review on resilience hubs conducted by Ciriaco and Wong (2022) found that there is a lack of information, understanding, and analysis of how transportation services are being integrated into the functionality of resilience hubs. Moreover, we find a general disconnect between the transportation field to the resilience hub field, despite transportation's critical role in the success of hubs. To our knowledge, an empirical analysis of transportation needs, travel behaviour, and resilience usage (more broadly) has not yet been conducted in either field. As such, we conduct this analysis by using survey responses from community residents, which can be replicated across different geographies, hazard types, and contexts.

3.3 Methodology

In this section, we present the data collection method, descriptive statistics, and the discrete choice modeling methodology.

3.3.1 Data Collection

To conduct an empirical study focused on resilience hubs, we collected data for the Edmonton Metropolitan Area, Canada, which is one of the largest, northernmost regions in North America (populated with 1.4 million people). With a diversified economy and serving as the primary gateway to northern Canada, the Edmonton Metropolitan Area is a key region for Canadian and international business, education, and industry. While the Edmonton region does not have consistent or large-scale disasters, hazards including flooding, wildfires, smoke, tornados, blizzards, and extreme cold can still cause significant and region-wide disruptions. Edmonton also has a significant number of industrial activities (especially related to oil and gas) and logistics via major highways and railways, which increases vulnerability related to hazardous materials, chemical spills, and industrial fires.

Our data collection in the Edmonton Metropolitan Area was conducted from September 2022 to February 2023 through convenience and market research panel samples. The convenience survey was distributed online with the help of local agencies and organizations such as community leagues, the City of Edmonton, and the Edmonton Food Bank. Organizations shared the survey link via social media, websites, newsletters, and other digital platforms. The convenience survey gathered 162 total viable responses after removing people outside of the metropolitan area. Respondents were incentivized with the opportunity to win one of the ten $100 (Canadian dollar) gift cards. To increase the sample size, a market research panel was conducted by Qualtrics, who contacted people living in the Edmonton Metropolitan Area to fill out the survey. Respondents were provided an incentive to participate through a rewards program. The panel gathered 944 responses.

Both surveys were carried out via the Qualtrics survey platform, and the questionnaire was designed to ask about individuals'/households' sociodemographic characteristics, their evacuation behaviours, and opinions about resilience hubs. Data cleaning was conducted to remove uncompleted responses, fast responses (≤ 3min), patterned/inconsistent responses, and responses that provide a location outside the Edmonton Metropolitan Area. The final sample consisted of 950 respondents.

3.3.2 Descriptive Statistics and Discrete Choice Analysis

Descriptive statistics were conducted to understand the residents' needs and travel behaviour. Statistics were developed for resilience hub placement and transportation needs. We also asked a question about where respondents would place a resilience hub. We used this proposed hub location and the respondent's residential location to calculate the Euclidian distance (via a Python code), which we then broke down by mode choice. To better understand individuals' willingness to use a resilience hub within their neighbourhood, we developed three binary logit models. For the analysis, we divided the decision to use the hub into a binary variable, with choice one being very or somewhat likely to use a resilience hub and choice two being all other options. We first added all independent sociodemographic variables that were not correlated to each other (correlation coefficients under 0.3), variables related to travel behaviour, and trust and compassion variables. After this, we followed guidance from (Ben-Akiva and Lerman, 1985) in variable selection for factors that were behavioural relevant, statistically significant, or met a priori expectations. We note that we retained some statistically insignificant variables due to their behavioural relevance and because we opted for decreased model bias (rather than high efficiency). The models developed for the 950 respondents were:

- Use of resilience hub during normal conditions;
- Use of resilience hub as a temporary shelter during a disaster; and
- Use of resilience hub as a place to gather critical resources during a disaster.

In addition, we developed two multinomial logit (MNL) models to assess mode choice to reach resilience hubs during normal conditions and emergencies. The mode choices were clustered as personal vehicles, public transit, sharing mobilities, and active modes. For multinomial models, we excluded those that did not select one of the available mode choices. This changed our sample size, particularly for mode choice during an emergency. Our models use a sample of 856 observations for normal conditions and 492 observations for emergencies. We believe that the reduction in observations for emergency conditions was due to the similarity in questions, leading people to skip the emergency question. We followed the same approach as the binary logit models related to correlation removal, variable section, and model finalization.

We used the Python package Biogeme 3.11 (Bierlaire, 2023) to develop the binary and multinomial logit models. As a limitation, we note that we decided on simpler models as they are behaviourally consistent, parsimonious, and easy to interpret for government agencies, policymakers, and decision-makers. Future research can use the same dataset for other modeling analyses, including testing other discrete choice modeling forms and hypotheses.

3.4 Results

This section presents the characteristics of respondents, descriptive statistics analysis of resilience hubs, and results from the binary and multinomial logit models for the decision to use resilience hubs and mode choice.

3.4.1 Characteristics of Respondents

We found that despite sampling bias due to data collection methodology, key demographic characteristics are similar to the 2021 Canadian census results for Edmonton Metropolitan Area (Statistics Canada, 2023). For instance, the average age of the sample is 38 years, and the census indicated 38.8 years. Additionally, 28.3% of the respondents are visible minorities (following the Employment Equity Act specification), while the census had 33%. In both, households have an average of three people. Although the survey collected household income in 2021 and the census collected household income in 2020, both show similar distribution, though our sample had a larger proportion of residents making $100,000 and over (in Canadian dollars). According to our survey and census data, most individuals are employed (78.9% and 60.0%, respectively), which indicates an undersampling of students, retirees, and unemployed individuals. Our survey was 54.5% women and 43.2% men, a slight oversampling of women compared to the 2021 Census.

Furthermore, the survey found that almost 95% of the respondents have at least one automobile in their household and 71% have at least one bicycle, which aligns with the general transportation patterns of auto-centric Edmonton. In addition, most households have access to an Internet connection (98%). Regarding the level of education, 71.8% of respondents had completed a college/diploma, bachelor’s, graduate or professional degree, or doctorate.

3.4.2 Descriptive Statistics

We first asked respondents if they had heard about resilience hubs before and asked them to select characteristics that would best describe a resilience hub. We found that most respondents had never heard about resilience hubs (**Figure 3.1**). For characteristics, hubs were often described to provide emergency sheltering, be a community-serving physical space, offer response services during disasters, and be a central location to access a variety of services (see **Figure 3.2**). We noted that these characteristics align with the description of resilience hub found in the literature (e.g., Baja (2018), Ciriaco and Wong (2022)). Regarding locations for a resilience hub (**Figure 3.3**), participants were very or somewhat satisfied if resilience hubs were located at a variety of different places, especially in community centers (recreation centers), schools/universities, libraries, and community leagues.

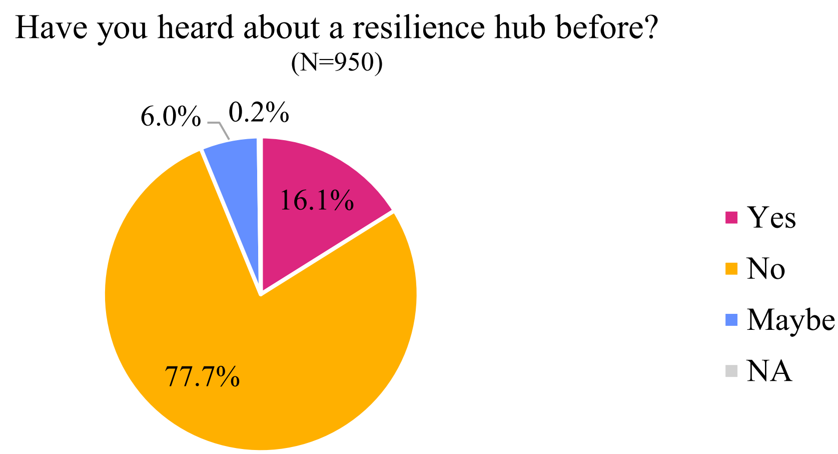

Figure 3.1 - Previous knowledge about resilience hub

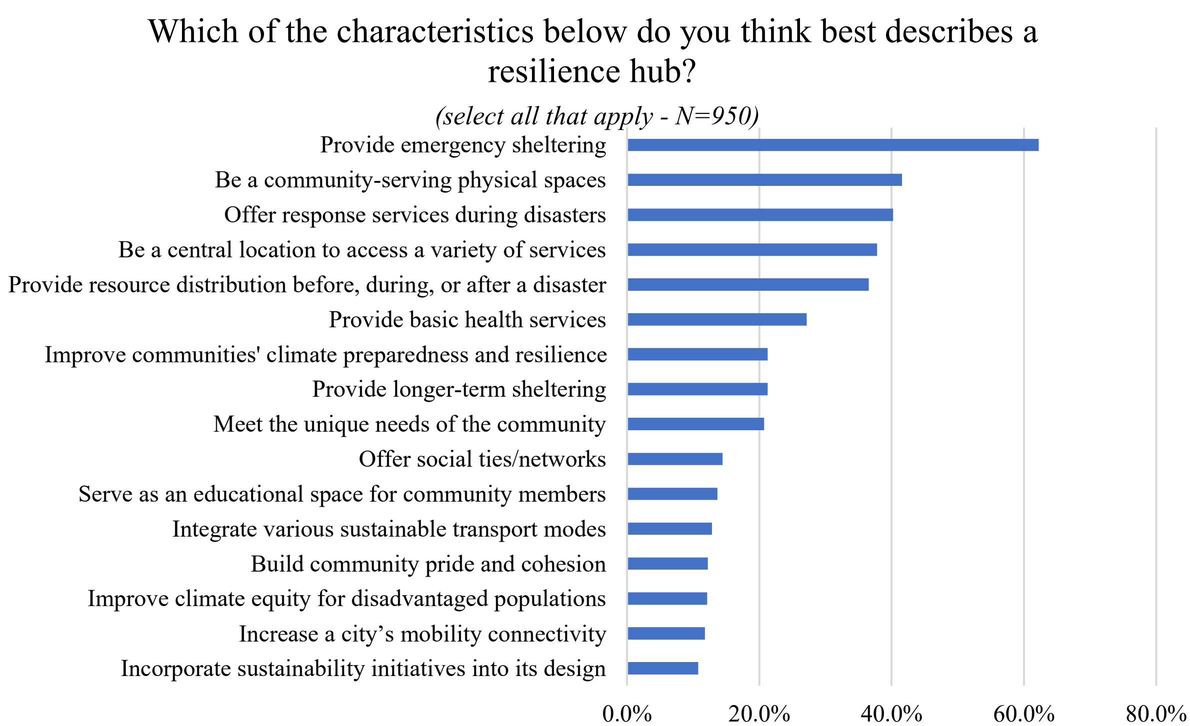

Figure 3.2 - Characteristics that individuals believe that best describe a resilience hub

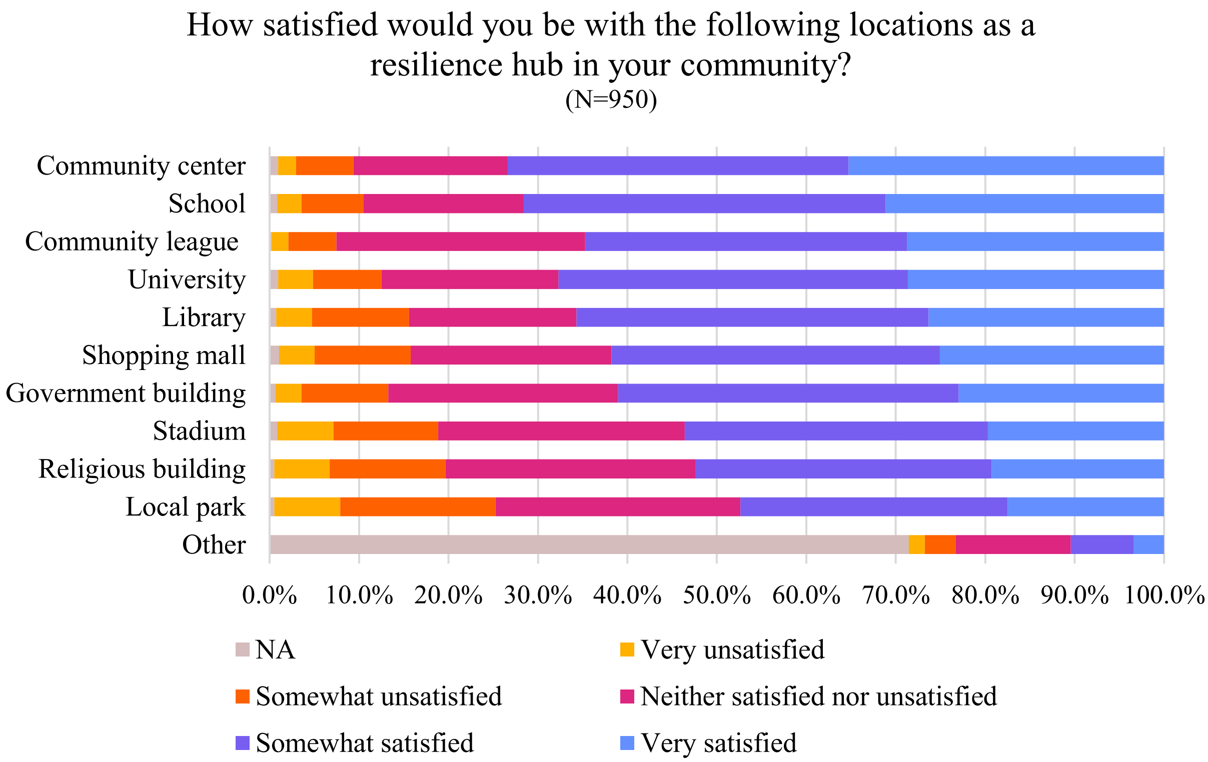

Figure 3.3 - Preferred places to locate a resilience hub

More than half of respondents stated that resilience hubs would be very or mostly important for their community. Further, individuals stated that resilience hubs would very likely or somewhat likely help their community to be more resilient (64.5%), meet the needs of their neighbours on a daily basis (56.0%), and increase social cohesion in their communities (58.6%). Regarding how individuals intended to use the resilience hub (**Figure 3.4**), 41.4% and 61.2% are very or somewhat likely to use it during normal conditions and as a temporary evacuation shelter, respectively. Additionally, during a disaster, individuals would be very or somewhat likely to gather information about the disaster (69.8%) and gather critical resources (63.9%) at the resilience hub. The results also suggest that they are more likely (very/somewhat) to volunteer at a resilience hub during relief efforts (60.2%) than during normal conditions (44.4%).

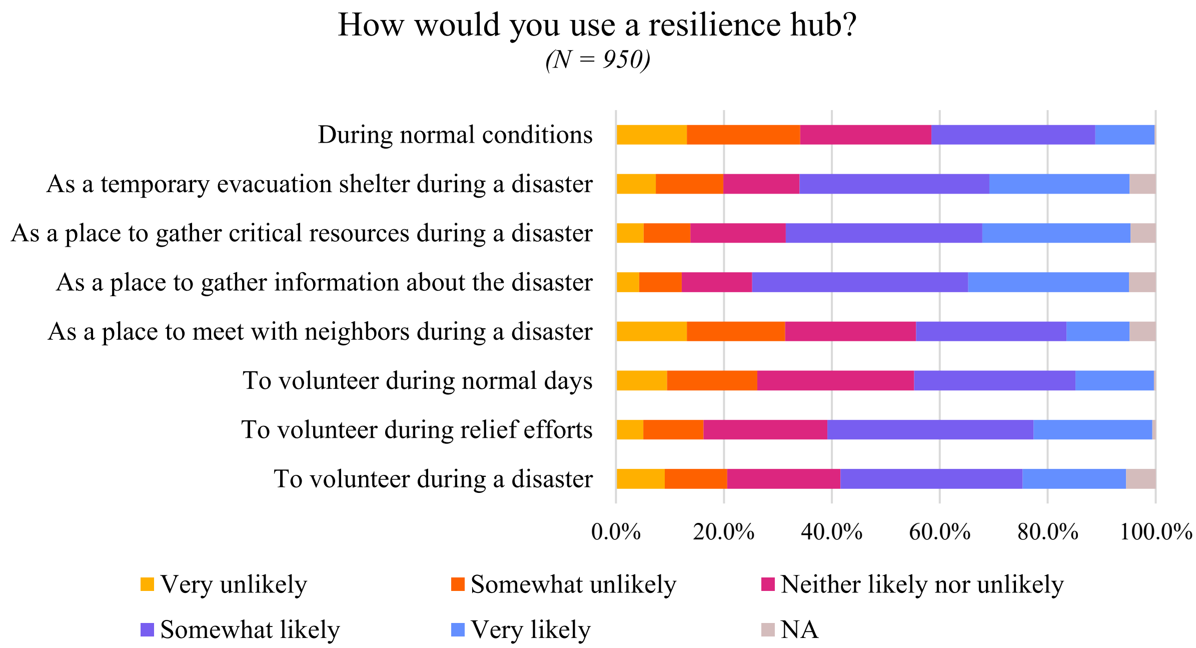

Figure 3.4 - Resilience hub usage

Respondents also indicated preferences for transportation services that should be provided by resilience hubs (**Figure 3.5**) and their primary mode choice to go to a resilience hub (**Table 3.2**). Accessible infrastructure for individuals with disabilities was the most prevalent service among transportation services. This service was even more important for older adults and people with disabilities, with 82.1% of older adults and 76.7% of people with disabilities indicating it as very/mostly important. As seen in Figure 5, car parking and public transit connection services had similar preferences. However, as noted in Table 1, personal vehicles would be used by a larger percentage of the respondents (70.7% under normal circumstances and 79.0% during an emergency). Within the general population, 8.1% would use public transit (e.g., bus, rail, microtransit) to reach a hub during normal days, while 27.3 % of carless individuals would use it. Moreover, transit connections were the second most important transportation service indicated by carless people. **Figure 3.5** also shows that individuals considered providing heated bus stop more important than bike sharing and bike parking services. Likewise, more people cited parking for electric vehicles as a very or mostly important service than services related to bicycles. The auto-centric design of the Edmonton Metropolitan Region may be affecting this prioritization.

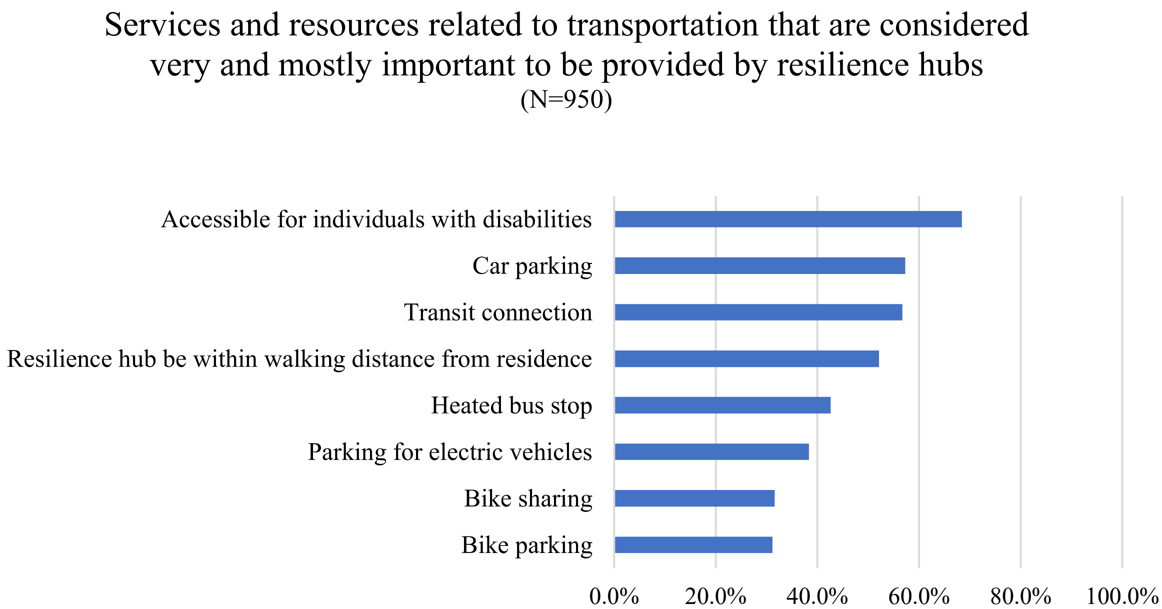

Figure 3.5 - Transportation services

Table 3.2 - Transportation mode choice and resilience hub distance

Distance between resilience hub and residence		
	Median (km)	**Sample size**
	1.7	779
Distance between residence and resilience hub by mode choice during normal condition		
	Median (km)	**Sample size**
Personal vehicle	2.0	512
Public Transit (Bus, rail, microtransit)	2.5	57
Walk	0.6	113
Sharing mobility (Carpool, ridesource, carsharing, rental)	1.9	34
Others (motorcycle, bike, recreational vehicle)	5.2	6
Percentage of modal choice		
	Normal condition	**Emergency condition**
Personal vehicle	70.7%	79.0%
Public Transit (Bus, rail, microtransit)	8.1%	4.0%
Walk	14.8%	8.5%
Sharing mobility (Carpool, ridesource, carsharing, rental)	5.7%	6.5%
Others (motorcycle, bike, recreational vehicle)	0.7%	2.0%
Sample size	*860*	*496*

As seen in **Figure 3.5**, individuals indicated that it is very or mostly important that resilience hubs be within walking distance from their residences. Moreover, walking was the second preferred mode choice to reach a hub during normal conditions or disasters (**Table 3.2**). Surprisingly, walking was the first transportation mode choice for carless individuals during normal conditions (38.6%)

or emergencies (48.0%). In addition, it had almost the same relevance as personal vehicles for older adults during normal conditions, with 51.6% choosing a personal vehicle and 44.7% choosing walking.

Regarding the distance between respondents' residences and locations selected to place a resilience hub, the median distance was 1.7 km, revealing a preference for closer locations. The median distance is smaller for people who would walk to a resilience hub, with the median being 0.6 km. An interesting finding is that those who would use public transit would be willing to travel slightly greater distances than those who would use a personal vehicle – 2.5 km and 2.0 km, respectively.

3.4.3 Behavioural Modeling

We next present results from three binary logit models that were developed to determine the factors that influence individuals' choices related to resilience hub usage. **Table 3.3** presents the associated coefficients, signs, p-values, and significance levels in each of these models. Since the decision to not use a resilience hub is the base choice, a positive coefficient indicates that the variable increases the likelihood to use a resilience hub under certain circumstances, while a negative coefficient denotes that the variable decreases the likelihood.

The first model explored the decision of whether or not to use a resilience hub during normal conditions. As seen in **Table 3.3**, all coefficients of this model are positive, indicating that all variables included in the model increase the likelihood to use a hub during normal conditions. The results show that those that are part of a community organization are more likely to use a resilience hub during normal conditions. Households with two or more members and households that had an income under $50,000 in 2021 are significantly more likely to use a resilience hub during normal conditions. Additionally, those that believe that a resilience hub would help increase social cohesion in their neighbourhoods are considerably more likely to use the hub than those who did not have this opinion.

Table 3.3 - Binary Logit Models

Binary Logit Models
Choice 1: Neither likely nor unlikely, somewhat unlikely, very unlikely to use – Base
Choice 2: Somewhat likely, very likely to use

	Binary Logit Model 1			***Binary Logit Model 2***			***Binary Logit Model 3***		
	Use a resilience hub during normal condition			**Use a resilience hub during a disaster as a temporary shelter**			**Use a resilience hub during a disaster as a place to gather critical resource**		
Variable	*Estim. coef.*	*p-value*		*Estim. coef.*	*p-value*		*Estim. coef.*	*p-value*	
Constant	-1.73	0.000	**	-1.34	0.006	**	-1.61	0.003	**
Household Characteristics									
Household with 2+ people	0.63	0.000	**	------	------		-0.12	0.455	
Household income less than CAD 50,000 (in 2021)	0.66	0.000	**	------	------		------	------	
Household has at least one child	------	------		0.30	0.036	*	------	------	
Individual Characteristics									
Individual is employed full time or part-time	------	------		-0.44	0.015	*	-0.43	0.032	*
Individual is a visible minority	------	------		0.38	0.015	*	------	------	
Individual with a disability	------	------		0.53	0.002	**	0.42	0.021	*
Age under 35 years	------	------		------	------		-0.43	0.003	**
Woman	------	------		------	------		0.36	0.017	*
Access to Internet at home	------	------		1.06	0.025	*	1.42	0.003	**
Part of a community organization/group, not including a Community League	0.41	0.007	**	------	------		------	------	
Use active mode (walk or bike) to go to a resilience hub during an evacuation	------	------		------	------		-0.86	0.010	*
Trust and compassion									
One of the activities that provide me with the most meaning in my life is helping others in the world when they need help (very and somewhat true)	------	------		------	------		0.59	0.000	**
It is possible to trust most people	------	------		------	------		0.46	0.002	**
My neighbors would help me in an emergency/disaster	------	------		0.46	0.002	**	0.31	0.040	*
Resilience hub									
A resilience hub would help increase social cohesion in my neighborhood	1.18	0.000	**	0.87	0.000	**	0.86	0.000	**
Number of observations	950			950			950		
ρ2 (fit)	0.11			0.11			0.16		
ρ2 (adjusted fit)	0.10			0.09			0.14		
Final Log-Likelihood	-588.22			-589.37			-553.26		

* 95% significance **99% significance

The second model determines if individuals are likely to use a resilience hub as a shelter during a disaster. This model included several variables related to individual characteristics, showing that visible minorities and individuals that have a disability are more likely to use resilience hubs as a temporary shelter during a disaster. On the other hand, those employed full-time or part-time are less likely to use resilience hubs as a temporary shelter. For household characteristics, we found that households with children are more likely to use a resilience hub as a shelter during an emergency. Results also found that individuals who stated that their neighbours would help them during a disaster or emergency are more likely to use resilience hubs during a disaster. Additionally, those that believe that a resilience hub would increase social cohesion in their neighbourhood are highly more likely to use hubs as a shelter.

During a disaster, streets can be impacted and consequently closed, impeding the flow of resources and making it important to understand who will use a resilience hub to gather critical resources during an emergency. The third model was developed to determine variables that influence the decision to use a resilience hub as a place to gather critical resources in a disaster. The results found that individuals employed full-time or part-time and young adults (35 years and under) are less likely to use a hub as a place to gather critical resources during a disaster. Conversely, women and individuals with a disability are more likely to use the hub. Moreover, those who would use an active mode (walk or bike) to reach a hub during an evacuation are significantly less likely to use a hub to gather critical resources. Regarding trust and compassion variables, individuals with a strong compassion for others (in the form of helping others), those who mentioned that is possible to trust most people, and those who indicated that their neighbours would help them during an emergency or disaster are more likely to use a resilience hub as a place to gather critical resources.

An interesting finding is that all models had the variable "believe that a resilience hub would help increase social cohesion in my neighbourhood" and it is significant and positive, indicating that these individuals are more likely to use a resilience hub. We also note that variables related to household characteristics have more influence on the willingness to use a hub during normal conditions than the willingness to use a hub as a temporary shelter. Moreover, variables related to individual characteristics have more influence on willingness to use a resilience hub as shelter than during normal days.

Besides the binary models, we developed multinomial logit models to understand individuals' primary mode choice to go to a resilience hub within their community during normal days and emergencies. **Table 3.4** and **Table 3.5** show the results of the normal conditions and emergency models, respectively. In both models, the base choice is public transit. Thus, a positive coefficient indicates that the variable increases the likelihood to use a certain mode of transportation in comparison with public transit, while a negative coefficient denotes that the variable decreases the likelihood.

Based on the constants in **Table 3.4**, individuals show some preference for using personal vehicles or active modes to reach a resilience hub during normal conditions when compared to public transit. Regarding household characteristics that influence mode choice, we found that households with more than two people are less likely to use sharing mobility and active mode when compared to public transit. However, if the household has at least one child or one older adult, the individual is more likely to use a sharing mobility mode than public transit.

Women are more likely to use personal vehicles or active modes compared to public transit. Individuals that are young adults (under 35) and those employed full-time or part-time are less likely to use active modes to go to a hub during normal conditions. Individuals that live in their current residence for more than ten years are more likely to use personal vehicles when compared to public transit. This may be due to the availability of vehicles and bicycles at home. Those that own their residence are less likely to use sharing mobility.

In testing variables related to how people would use a resilience hub, we found largely insignificant results. However, we found that people who are very or somewhat likely to volunteer at a resilience hub during normal conditions are less likely to use active modes. The results indicate further exploration in resilience usage (i.e., trip purpose) is needed within this context.

Table 3.4 - Multinomial Logit Model – Mode Choice Normal Conditions

Choice 1: Personal vehicle (one or more vehicles)
Choice 2: Public transit (bus, rail, microtransit) - **Base**
Choice 3: Sharing mobility (carpool, ridesource, carsharing, rental)
Choice 4: Active mode (walk, bike)

Variable	Personal vehicle			Sharing mobility			Active mode		
	Estm. Coef.	*p-value*		*Estm. Coef.*	*p-value*		*Estm. Coef.*	*p-value*	
Constant	1.753	0.000	**	-0.213	0.494		1.427	0.000	**
Household characteristics									
Household with 2+ people	------	------		-1.374	0.001	**	-0.680	0.001	**
Household has at least one child	------	------		1.374	0.001	**	------	------	
Household has at least one older adult (65+)	------	------		0.758	0.036	*	------	------	
Individual characteristics									
Woman	0.461	0.024	*	------	------		0.907	0.001	**
Indigenous (i.e., First Nations, Métis, Inuit)	------	------		------	------		-0.783	0.063	
Age under 35 years	------	------		------	------		-0.594	0.007	**
Individual is employed full-time or part-time	------	------		------	------		-0.664	0.003	**
Long-time resident (10+ years)	0.786	0.013	*	------	------		0.721	0.053	
Homeowner	------	------		-0.939	0.002	**	------	------	
Resilience hub									
Use a resilience hub during normal conditions (very or somewhat likely)	0.097	0.592		0.619	0.072		------	------	
Volunteer at a resilience hub during normal conditions (very or somewhat likely)	------	------		------	------		-0.642	0.003	**
Number of observations	856								
ρ2 (fit)	0.40								
ρ2 (adjusted fit)	0.38								
Final Log-Likelihood	-714.70								

* 95% significance **99% significance

During an emergency (**Table 3.5**), the constant parameters indicate that individuals are more likely to use a personal vehicle or active mode to reach a resilience hub when compared to public transit. Households that have more than three automobiles are more likely to use a personal vehicle than public transit. They are also less likely to use sharing mobility or active modes in comparison to public transit. Households that have more than two individuals are more likely to use a personal vehicle in comparison to public transit.

Similar to normal conditions, young adults are less likely to use active modes to go to a resilience hub during an emergency. Individuals that have a disability are less likely to use sharing mobility than public transit. Additionally, individuals that own their residence are more likely to use personal vehicles.

Individuals who stated that are very or mostly prepared for an evacuation are less likely to use an active mode to reach a resilience hub during an emergency. Those that feel very or somewhat comfortable using a resilience hub as a shelter during a disaster are less likely to use a sharing mobility when compared to public transit. Moreover, individuals that are very or somewhat likely to use a resilience hub as a place to gather critical resources during a disaster are less likely to use an active mode. While those that are very or somewhat likely to volunteer at a resilience hub are more likely to use sharing mobilities than public transit.

Table 3.5 - Multinomial Logit Model – Mode Choice Emergency Conditions

Choice 1: Personal vehicle (one or more vehicles)
Choice 2: Public transit (bus, train, microtransit) - **Base**
Choice 3: Sharing mobility (carpool, ridesource, carsharing, rental)
Choice 4: Active mode (walk, bike)

	Personal vehicle			**Sharing mobility**			**Active mode**		
Variable	*Estm. Coef*	*p-value*		*Estm. Coef*	*p-value*		*Estm. Coef*	*p-value*	
Constant	2.076	0.000	**	0.196	0.722		1.757	0.000	**
Household characteristics									
Household with 2+ people	0.756	0.009	**	0.819	0.094		------	------	
Households with 3+ automobiles	6.572	0.000	**	-1.108	0.019	*	-1.861	0.000	**
Household with 1+ bike	------	------		------	------		0.538	0.121	
Individual characteristics									
Indigenous (i.e., First Nations, Métis, Inuit)	------	------		------	------		-0.931	0.170	
Age under 35 years	------	------		------	------		-1.496	0.000	**
Woman	------	------		-0.466	0.204		------	------	
Individual with a disability	------	------		-1.236	0.034	*	------	------	
Visible minority	------	------		-0.615	0.172		------	------	
Homeowner	0.547	0.029	*	------	------		------	------	
Preparedness for an emergency									
Prepared for an evacuation (very or mostly)	------	------		------	------		-1.155	0.030	*
My household will be impacted by a disaster in the next 5 years (very or somewhat likely)	------	------		0.595	0.132		------	------	
Resilience hub									
Feel comfortable using a resilience hub as shelter (very and somewhat)	------	------		-0.841	0.049	*	------	------	
Use a resilience hub as a place to gather critical resources during a disaster (very or somewhat likely)	------	------		------	------		-0.783	0.016	*
Volunteer at a resilience hub (very or somewhat likely)	0.297	0.297		1.123	0.024	*	------	------	
Number of observations	492								
ρ2 (fit)	0.53								
ρ2 (adjusted fit)	0.50								
Final Log-Likelihood	-319.46								

* 95% significance **99% significance

3.5 Discussion and Recommendations

In this section, we leverage the results from the descriptive statistics and the discrete choice analysis to provide practice-ready policy recommendations for transportation agencies and other government entities. In summary, our modeling and descriptive statistics approach found that:

- Household characteristics influenced resilience hub usage, more so for normal conditions than as a temporary shelter. The reverse was true for individual characteristics.
- Variables related to how people would use a resilience hub were largely insignificant in mode choice.
- Trust and compassion variables had a positive impact on using a hub during a disaster, either as a temporary shelter or as a place to gather critical resources.
- Individuals that are part of a community organization, households with three or more people, and lower-income households are more likely to use a resilience hub during normal conditions.
- Walking was the second most chosen transportation mode to travel to/from a resilience hub during both normal conditions and a disaster. However, individuals using active transportation to travel to/from a hub during an emergency are less likely to use it as a place to gather critical resources.
- Mode choice variables were largely insignificant in the binary models related to hub usage during normal conditions and as a temporary shelter. However, automobile ownership impacts the mode choice decision to travel to/from a hub during emergencies.
- Distance-based results indicate a strong preference by residents for highly localized resilience hubs, mostly for those who would walk to a hub.

We developed several recommendations related to resilience hub location, usage, and access focusing on the more detailed results. We recognize that resilience hubs are a very recent concept that lacks empirical resources regarding usage and effectiveness, and we highlight that many of these recommendations require additional research to evaluate their effectiveness. The recommendations are compiled in **Table 3.6**, which also provides empirical evidence from our research, some discussions, and supporting literature. The supporting literature is composed primarily of practical implementation guidance, which our research bolsters through our empirical analysis.

Table 3.6 - Recommendations from Descriptive and Modelling Results

<table>
<tr><th colspan="4">Resilience hub services and usage</th></tr>
<tr><th>Recommendation</th><th>Evidence</th><th>Discussion</th><th>Support</th></tr>
<tr><td>Publicly share accessible emergency response and evacuation plans with residents</td><td rowspan="3">61.2% indicated that they were very or somewhat likely to use a resilience hub as a temporary shelter during a disaster.

69.8% indicated that they are very or somewhat likely to go to a resilience hub during a disaster to gather information about the disaster.

63.9% indicated that they were very or somewhat likely to go to a resilience hub during a disaster to gather critical resources.

62.2% described resilience hubs as a place that provides emergency sheltering, 40.2% as a place that offers response services during disasters, and 36.5% as a place that provides resource distribution before, during, or after a disaster.

Visible minorities and individuals with disabilities were very or somewhat likely to use a resilience hub as a temporary shelter (Binary Model 2)</td><td rowspan="3">Many survey participants indicated that they were very or somewhat likely to use a resilience hub as a temporary shelter or would go there to gather services and resources during a disaster. However, less than a quarter said that they were very or mostly prepared for an evacuation. Consequently, individuals should be aware of how to evacuate to a resilience hub during an emergency. They should also be informed about mode choice options that will be available to travel to a resilience hub during a disaster. A list of resilience hubs, the area served by them, and transit services available should be open access to residents. Importantly, resilience hub management and operation teams should also be prepared to support individuals with disabilities.</td><td>(Sandoval, 2019)</td></tr>
<tr><td>Provide emergency shelter facilities in resilience hubs.</td><td>(Ciriaco and Wong, 2022; Mardis et al., 2021; Sandoval, 2019)</td></tr>
<tr><td>Educate the community on the risk of climate change and how to be prepared</td><td>(Baja, 2022; Kirwan et al., 2021; Sandoval, 2019)</td></tr>
<tr><td>Increase social cohesion within the community</td><td>“Believe that a resilience hub would help increase social cohesion in my neighbourhood” was a significant positive variable presented in all binary models.

Individuals who stated that their neighbours would help them during a disaster or emergency are more likely to use resilience hubs during a disaster (Binary Model 2 and Model 3)</td><td>All binary models about resilience hub usage showed that individuals that believe that a resilience hub would help increase social cohesion in their neighbourhood were more likely to use a resilience hub during normal conditions, as a temporary shelter during a disaster, or as a place to gather critical resources during a disaster. Therefore, strategies might be adopted to increase social cohesion in a community. For example, communities could have more social neighbourhood events, expand volunteer networks, increase civic pride, or develop community leagues (such as those in Edmonton). In addition, community centers and community leagues could provide more information about their services and events to engage their community, and jurisdictions could provide support and/or incentives to community centers.</td><td>(de Roode and Martinac, 2020)</td></tr>
</table>

<table>
<tr><th colspan="4">Resilience hub placement and accessibility</th></tr>
<tr><th>Recommendation</th><th>Evidence</th><th>Discussion</th><th>Support</th></tr>
<tr><td>Place resilience hubs in neighborhoods to localize resources, meet community needs, and increase usage</td><td>The median distance between residences and resilience hubs was 1.7 km.

The median distance by mode of transportation ranged between 0.6 km and 5.2 km.

Those that will walk to a resilience hub during normal conditions indicated a median distance of 0.6 km.</td><td>Individuals revealed a preference to have a resilience hub close to their residences. It aligns with the guidance present in the current literature. Thus, resilience hubs should be located in places within a more localized community, rather than selective points across a large city.
By placing a resilience hub within the community, governments can:
1) provide resources to assist the neighbourhood to be more resilient and prepared to recover from a disaster;
2) benefit underserved communities that rely on community assistance;
3) strengthen community cohesion;
4) increase accessibility, especially for carless, low-income individuals, and older adults;
5) encourage regular usage.</td><td>(Baja, 2018, 2019; Ciriaco and Wong, 2022; Kirwan et al., 2021)</td></tr>
<tr><td>Transform existing local/community buildings (e.g., recreation centres, community leagues, libraries, and government buildings) that already meet some goals of resilience hubs through retrofits</td><td>35.3% would be very satisfied and 38.1% somewhat satisfied with community centers being resilience hubs.

28.7% would be very satisfied and 36.0% somewhat satisfied with community leagues being resilience hubs.

26.3% would be very satisfied and 39.4% somewhat satisfied with libraries being resilience hubs.</td><td>Preceding literature has indicated community centers, libraries, and recreation facilities could be retrofitted into resilience hubs. Our study emphasizes that most people would be very or somewhat satisfied with these places. By selecting an existing well-known and well-utilized location for retrofit, communities can encourage their usage during a disaster. Rather than building new, retrofits can be effective in reducing overall costs. For any new buildings, resilience hub characteristics should be embedded in the design. It should be noted that schools and universities were mentioned by participants to serve as a resilience hub, but these facilities might not be usable during school hours and days.</td><td>(Asgary and Azimi, 2019; Baja, 2018, 2019; Kirwan et al., 2021; Kotani et al., 2020; Mardis et al., 2021; McGee et al., 2021; Sandoval, 2019)</td></tr>
<tr><td>Design resilience hub design with accessibility and mobility considerations</td><td rowspan="2">69.4% indicated accessibility for individuals with a disability as a very or mostly important service to be provided by a resilience hub.

82.1% of older adults selected accessibility for individuals with a disability as a very or mostly important service.

76.7% of people with a disability selected accessibility for individuals with a disability as a very or mostly important service.</td><td rowspan="2">The survey confirmed recommendations, provided by previous literature, on locating a resilience hub in an accessible pedestrian area and close to evacuation routes. People were concerned about accessibility and mobility, especially for older adults, people with disabilities, and carless. We recommend that the jurisdiction should assess community accessibility needs, implement Universal Design principles, and provide infrastructure that accommodates these groups’ needs.</td><td>(Baja, 2019; Ciriaco and Wong, 2022)</td></tr>
<tr><td>Focus mobility planning of hubs to meet underserved populations, especially older adults, people with disabilities, and carless</td><td>------</td></tr>
</table>

	76.6% of carless residents selected accessibility for individuals with a disability as a very or mostly important service.		
Facilitate walking to hubs through pedestrian-friendly infrastructure	Walking was the second most popular mode of transportation to travel to a resilience hub during normal conditions (14.8%) and during an emergency (8.5%). 44.7% of older adults and 38.6% of carless individuals selected walking as their primary mode choice during normal conditions. Forty-eight percent of carless individuals indicated that they would walk to reach a resilience hub during an emergency. Women are more likely to walk to a resilience hub during normal conditions than use public transit (Multinomial logit model – normal conditions)	After personal vehicle, walking was the most relevant primary mode choice. When planning a resilience hub, jurisdictions should select areas where sidewalks are well structured and safe, and crosswalks are well signalized. Wide sidewalks with easy-to-use curb cuts (or continuous sidewalks) can accommodate wheelchair users. If a hub location does not meet these conditions, governments should plan infrastructure improvements to redesign and improve sidewalks and crosswalks.	(Baja, 2019)
Locate a resilience hub near public transit and/or redesign routes to increase the frequency	56.7% indicated transit connection as a very or mostly important service to be provided by a resilience hub. Public transit was the third most selected mode choice to reach a resilience hub during normal conditions. 27.3% of carless individuals and 10.9% of people with disability would use public transit to go to a resilience hub during normal conditions. 16% of carless and 6.4% of people with disability would use public transit to go to a resilience hub during an emergency. Young adults are more likely to use public transit than active modes in both conditions – normal and emergency (Multinomial logit models)	Public transit is important to increase equity in accessibility and mobility. Although the percentage of people in the general population indicating that would use public transit during normal days (8.1%) and during an emergency (4.0%) was small, this mode was more important for underserved populations such as carless and people with disability. Therefore, efficient transit connections for resilience hub users should be a priority in design and location considerations. Route redesigns may be necessary to enhance transit connections and increase frequency.	(Sandoval, 2019)
Pre-plan how critical resources will reach resilience hubs,	63.9% indicated that they were very or somewhat likely to go to a resilience hub during a disaster to gather critical resources.	Within the planning phase of resilience hubs, jurisdictions should assess transportation routes and strategies to guarantee that critical resources would	(Ciriaco and Wong, 2022)

including sharing information with the public in real-time	61.2% indicated that they were very or somewhat likely to use a resilience hub as a temporary shelter during a disaster. Women and individuals with a disability were more likely to use the hub as a place to gather critical resources during a disaster. (Binary Model 2) Individuals were less likely to use active modes to gather critical resources at resilience hubs during disasters when compared to public transit (Multinomial logit model emergency condition)	reach the hub during an emergency. In this way, resilience hubs can help facilitate relief distribution. Moreover, resilience hub relief resources should prioritize the needs of the community. Therefore, jurisdictions should assess community needs and determine how residents will know what resources are available.	

3.6 Limitations

Despite important insights related to resilience hubs usage and transportation needs, my research has several limitations associated with the data collection and methodology. First, both the convenience survey and panel survey may be biased since respondents self-select into the study. Second, the online survey may have excluded those without access to the Internet or knowledge of how to use a computer or smartphone. Regarding methodology, I note that I used simple binary and multinomial logit models (which limits our behavioural conclusions) and that other discrete choice models could be tested. Fourth, I recognize that the way we split categorical variables may miss certain behaviours, especially where there was high heterogeneity in the population. Fifth, our model related to mode choice during an emergency had a small sample size which may have affected the significance of variables. Finally, my research focuses on the case of the Edmonton Metropolitan Area, and future work will be needed to determine external validity and community context in other places in North America and globally.

3.7 Takeaways

In this study, we presented a comprehensive analysis of resilience hub usage, location, accessibility needs, and people's behaviour. We used descriptive statistics to understand individuals' needs and opinions related to the resilience hub. Subsequently, we developed three binary logit models for the willingness to use or not a resilience hub during normal conditions and a disaster. Finally, we developed two multinomial logit models to assess individuals' mode choices to reach a resilience hub during normal conditions and an emergency. All methodologies used data collected from individuals that reside in the Edmonton Metropolitan Area (n=950).

We found that individuals prefer to have a resilience hub within their neighbourhood, and most of them will use a personal vehicle to reach a hub during normal days or an emergency. However, walking was the second most chosen mode, and it was the primary option for carless individuals. Respondents also indicated that accessibility was a very or mostly important element of resilience hubs. Moreover, respondents would be very or somewhat satisfied with placing a resilience hub in community centers, community leagues, and other public buildings. They are more likely to use a resilience hub during an emergency than during normal conditions.

Binary models showed that during normal condition usage, individuals' willingness to use a hub is heavily influenced by household characteristics, while using it as shelter is influenced by individual characteristics. There was relative inconsistency in significant variables across the three usages (i.e., in normal conditions, as a shelter, for critical resources). Despite this, several unique variables were found to be significant for some of the models. For example, high levels of trust and compassion increase the likelihood of using the hub to find critical resources. People that believe that their neighbour would help them during a disaster are more likely to use a resilience hub during normal conditions. In addition, those that believe that a resilience hub would help increase social cohesion in their neighbourhood are more likely to use a hub during normal days and a disaster.

Multinomial logit models revealed that households that have more than two individuals are more likely to use sharing mobility than public transit during an emergency. During normal days, larger households are more likely to use public transit than shared mobility. This shows that mode choice can differ depending on the context. Thus, it is important to assess transportation needs in different scenarios and plan a hub that meets both needs. We also found that young adults are more likely to use public transit than active modes in both scenarios (emergency and normal conditions). Moreover, in both conditions, a variety of variables related to household characteristics and individuals' characteristics influenced mode choice. We also note that resilience hub usage (i.e., trip purpose) generally does not influence mode choice.

Future studies are needed to determine if residents in other cities have similar behaviour related to resilience hubs. However, this study is a steppingstone for resilience hub planning and design, as it provides empirical results and recommendations that guide agencies to better plan resilience hubs. Moreover, the study uncovered key transportation elements that should be considered when planning a resilience hub.

Chapter 4: Conclusion

This thesis explored a unique new concept of resilience hubs that is understudied and has significant gaps associated with transportation needs, design, and location. The thesis focuses on answering, through a conceptual framework and an empirical analysis, how resilience hubs might be designed to meet communities' needs and how individuals are likely to travel to and from resilience hubs. To explore these topics, I conducted an extensive literature review on resilience hubs and collected and analyzed survey data from residents of the Edmonton Metropolitan Area in Alberta. Below I present the key takeaways of the thesis, main policy recommendations, and future research directions.

4.1 Key Takeaways

Each thesis chapter presents a unique understanding of resilience hubs. With its conceptual and empirical contributions, this thesis takes an important step in broadening resilience hub research to consider communities' needs, desires, and transportation accessibility. The second chapter uncovered an early conceptual understanding of resilience hubs, showing that most existing literature focuses on explaining the concept, characteristics, and functionalities of resilience hubs. Moreover, I found that resilience hubs can help increase community resilience to climate change, while also building social cohesion and preparedness for a variety of emergencies. However, transportation is rarely considered in these resilience hubs, which severely limits their usefulness. This is especially problematic for people without reliable, safe, or affordable access to transportation for traveling to/from these hubs. I conclude that the transportation engineering and planning fields require data-driven studies on how to best integrate transportation strategies with resilience hubs, especially in establishing co-benefits.

The third chapter presented a comprehensive analysis of resilience hub usage, location, accessibility needs, and people's behaviour. By applying descriptive statistics, I found that individuals preferred to have a resilience hub close to their residence at the neighborhood level. Moreover, most people in the Edmonton area would use a personal vehicle to travel to/from a resilience hub during normal days and emergencies. However, I determined that walking was the second most chosen mode to travel to/from a hub in both scenarios, indicating a strong need for pedestrian-friendly infrastructure and locations. I also found that individuals were more likely to use a hub during emergencies than during normal conditions. Through discrete choice analysis, I found that individuals' willingness to use a hub during normal conditions was heavily influenced by household characteristics while using a hub during a disaster as shelter was influenced by individual characteristics. Interestingly, high levels of trust and compassion increased the likelihood of using the hub to find critical resources. Regarding transportation mode choice, multinomial models determined that in both conditions (normal days and disasters), a variety of variables related to household characteristics and individuals' characteristics influenced mode choice. However, I found that resilience hub usage variables (i.e., trip purpose) generally do not influence mode choice.

4.2 Policy Recommendations

In this section, I provide several key recommendations for resilience hubs that were derived from the research results (from Chapters 2 and 3). These overarching strategies can help guide jurisdictions broadly in resilience hub design, though more community-centered analyses will be necessary to incorporate the local context and needs.

Recommendation 1: Jurisdictions should assess community needs to determine the most practical and critical resources and transportation services for both everyday and disaster conditions.

> Evidence: It remains unclear, from current examples, the level at which jurisdictions are meeting community or transportation needs through resilience hub services.

Recommendation 2: Resilience hubs should be included in cities' evacuation plans and include clear information on how resources, especially relief resources, will reach the hub.

> Evidence: Current examples were missing of how resilience hubs are encompassed in cities' evacuation plans. Additionally, 63.9% of respondents indicated that they were very/somewhat likely to go to a resilience hub during a disaster to gather critical resources, and 61.2% were very/somewhat likely to use a resilience hub as a temporary shelter during a disaster.

Recommendation 3: Jurisdictions should identify community transportation needs to ensure easy and accessible travel to/from resilience hubs in both normal and disaster conditions.

> Evidence: Individuals and resources must reach a resilience hub effectively and safely. However, current literature and examples of existing resilience hubs do not clearly inform considerations of transportation needs or residents' accessibility and mobility needs.

Recommendation 4: A resilience hub should be placed within neighborhoods and transit networks to localize resources, increase usage, and better meet residents' needs.

> Evidence: Individuals indicated a preference to have a resilience hub close to their residence, especially those who would not be driving. A significant portion of the sample preferred to walk, take transit, or use shared mobility to travel to/from hubs. In addition, community needs may differ depending on the local environment and individual choices, as identified through the discrete choice modeling.

Recommendation 5: Jurisdictions should prioritize retrofits of existing buildings within the community that already provide services and resources that meet some goals of resilience hubs.

> Evidence: Individuals indicated that they were very or somewhat satisfied with community centers, community leagues, libraries, and schools/universities as locations for resilience hubs. Moreover, preceding literature found that existing buildings are already well-trusted in the community.

Recommendation 6: Hubs should include accessible features in resilience hub design and facilitate walking to hubs.

> Evidence: Most individuals indicated that accessibility for individuals with a disability is a very/mostly important design feature of a resilience hub. Within the general sample, walking was the second most popular mode choice to travel to/from a resilience hub in both conditions (normal and disaster), and it was the first option for carless individuals.

Recommendation 7: Jurisdictions should consider building social cohesion within the community to increase willingness to use a resilience hub in both normal and emergency conditions.

> Evidence: In binary models focused on trip purpose, the variables related to social cohesion, trust, and compassion were often significant and positive, indicating that these variables

would increase resilience hub usage during normal days, and during a disaster as a temporary shelter, or as a place to gather critical resources.

4.3 Future Research Directions

Although resilience hubs cannot fulfill *all* community needs, they demonstrate an opportunity to co-locate essential services that meet the community's needs most of the year, prepare residents for climate change and emergencies, and help people during disasters. Resilience hubs remain a newly and largely untested concept that needs additional research. First, my results are based in the Edmonton Metropolitan Area, a mid-sized North American city. Future studies are needed to determine if results apply to other cities in North America and the world more widely, especially in light of cultural and hazard differences. Second, several methods related to resilience hub location could be further expanded, such as conducting location optimization to provide better transportation and network recommendations. Third, the discrete choice models — while highly valuable for decision-makers — could be explored further, especially in the development of joint discrete choice models or alternative decision-rules for behaviour (e.g., regret minimization, emotion-based modeling).

This research could also be expanded in several other important directions related to surveying, sampling, and analysis. For example, future work can place a higher priority on underserved populations, especially in the identification of similarities and disparities among underserved groups who are mostly likely to use hubs. Additionally, future studies can be done to determine the effect of individuals' previous and expected hazard experiences on their preferences related to resilience hub location, characteristics, and transportation needs. With opportunities for future research, this thesis is a key first step that developed a conceptual understanding of transportation and the resilience hub and presented early empirical results that can better guide jurisdictions for resilience hub planning, design, and transportation.

References

ADA (2007) *ADA Checklist for Emergency Shelters*. Available at: https://www.ada.gov/pcatoolkit/chap7shelterchk.htm (Accessed: 21 September 2022).

Aldrich, D.P. and Meyer, M.A. (2015) 'Social Capital and Community Resilience', *American Behavioral Scientist*, 59(2), pp. 254–269. Available at: https://doi.org/10.1177/0002764214550299.

Anderson, K., Blanchard, S. D., Cheah, D. and D. Levitt. (2017) 'Incorporating Equity and Resiliency in Municipal Transportation Planning: Case Study of Mobility Hubs in Oakland, California', *Transportation Research Record*, 2653(1), pp. 65–74. Available at: https://doi.org/10.3141/2653-08.

Aono, S. (2019) *Identifying Best Practices for Mobility Hubs*. UBC Sustainability Scholar, p. 72. Available at: https://sustain.ubc.ca/sites/default/files/Sustainability%20Scholars/2018_Sustainability_Scholars/Reports/2018-71%20Identifying%20Best%20Practices%20for%20Mobility%20Hubs_Aono.pdf.

Arlington (2021) 'Arlington County Mobility Hubs Guidebook and Pilot Concept Design'. Available at: https://www.mwcog.org/assets/1/6/TLC_FY21_-_Arlington_County_Micro-Mobility_Transit_Hub_Prototype.pdf (Accessed: 21 September 2022).

Arnold, T., Frost, M., Timmis, A., Dale, S. and Ison, S. (2022) 'Mobility hubs: review and future research direction', in *Transportation Research Board 101st Annual Meeting*. *Transportation Research Board 101st Annual Meeting*, Washington D.C., USA. Available at: https://hdl.handle.net/2134/17516522.v1.

Arseneault, D. (2022) 'Mobility Hubs: Lessons Learned from Early Adopters'. Available at: https://doi.org/10.17610/T6N31C.

Asgary, A. and Azimi, N. (2019) 'Choice of emergency shelter: valuing key attributes of emergency shelters', *International Journal of Disaster Resilience in the Built Environment*, 10(2/3), pp. 130–150. Available at: https://doi.org/10.1108/IJDRBE-10-2018-0044.

Aydin, N., Seker, S. and Özkan, B. (2022) 'Planning Location of Mobility Hub for Sustainable Urban Mobility', *Sustainable Cities and Society*, 81, p. 103843. Available at: https://doi.org/10.1016/j.scs.2022.103843.

Bailey Park Neighborhood Development Corporation (2022) *Our Impacts*, *Bailey Park NDC*. Available at: https://www.baileyparkndc.org/our-impacts.html (Accessed: 21 September 2022).

Baja, K. (2016) 'Climate resiliency: A unique multi-hazard mitigation approach', *Journal of Business Continuity & Emergency Planning*, 9(4), pp. 304–316.

Baja, K. (2018) 'RESILIENCE HUBS Shifting Power to Communities and Increasing Community Capacity'. USDN. Available at: https://www.usdn.org/uploads/cms/documents/usdn_resiliencehubs_2018.pdf.

Baja, K. (2019) 'Guide to Developing Resilience Hubs'. USDN. Available at: http://resilience-hub.org/wp-content/uploads/2019/10/USDN_ResilienceHubsGuidance-1.pdf (Accessed: 09 February 2022).

Baja, K. (2022) 'Resilience Hubs: Shifting Power to Communities through Action', in *Climate Adaptation and Resilience Across Scales: From Buildings to Cities*. 1st edn. New York: Nicholas B. Rajkovich and Seth H. Holmes, pp. 89–109. Available at: https://doi.org/10.4324/9781003030720.

Baltimore Office of Sustainability (2021) 'The Baltimore City Community Resiliency Hub Program | Baltimore Office of Sustainability', 26 April. Available at: https://www.baltimoresustainability.org/baltimore-resiliency-hub-program/ (Accessed: 23 March 2022).

Bashawri, A., Garrity, S. and Moodley, K. (2014) 'An Overview of the Design of Disaster Relief Shelters', *Procedia Economics and Finance*, 18, pp. 924–931. Available at: https://doi.org/10.1016/S2212-5671(14)01019-3.

Bayram, V. and Yaman, H. (2018) 'Shelter Location and Evacuation Route Assignment Under Uncertainty: A Benders Decomposition Approach', *Transportation Science*, 52(2), pp. 416–436. Available at: https://doi.org/10.1287/trsc.2017.0762.

Bell, D. (2019) 'Intermodal Mobility Hubs and User Needs', *Social Sciences*, 8(2), p. 65. Available at: https://doi.org/10.3390/socsci8020065.

Ben-Akiva, M. E., & Lerman, S. R. (1985). *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press

Berisha, V. *et al.* (2017) 'Assessing Adaptation Strategies for Extreme Heat: A Public Health Evaluation of Cooling Centers in Maricopa County, Arizona', *Weather, Climate, and Society*, 9(1), pp. 71–80. Available at: https://doi.org/10.1175/WCAS-D-16-0033.1.

Berko, J., Ingram, D., Saha, S. and Parker, J. (2014) *Deaths Attributed to Heat, Cold, and Other Weather Events in the United States, 2006–2010*. National health statistics reports 76. Hyattsville, MD: National Center for Health Statistics, p. 16. Available at: https://www.cdc.gov/nchs/data/nhsr/nhsr076.pdf.

Bierlaire, M. (2023). *Estimating discrete choice models with BIOGEME*. Biogeme. https://biogeme.epfl.ch/index.html

Bish, D.R. (2011) 'Planning for a bus-based evacuation', *OR Spectrum*, 33(3), pp. 629–654. Available at: https://doi.org/10.1007/s00291-011-0256-1.

Bishop, B.W. and Veil, S.R. (2013) 'Public Libraries as Post-Crisis Information Hubs', *Public Library Quarterly*, 32(1), pp. 33–45. Available at: https://doi.org/10.1080/01616846.2013.760390.

Boonmee, C., Arimura, M. and Asada, T. (2017) 'Facility location optimization model for emergency humanitarian logistics', *International Journal of Disaster Risk Reduction*, 24, pp. 485–498. Available at: https://doi.org/10.1016/j.ijdrr.2017.01.017.

Borowski, E. and Stathopoulos, A. (2020) 'On-demand ridesourcing for urban emergency evacuation events: An exploration of message content, emotionality, and intersectionality', *International Journal of Disaster Risk Reduction*, 44, p. 101406. Available at: https://doi.org/10.1016/j.ijdrr.2019.101406.

Breton-Carbonneau, A. and Griffiths, A. (2020) *Resilience-Hubs_final-report_English.pdf*. City of Medford. Available at: https://www.medfordma.org/wp-content/uploads/2020/09/Resilience-Hubs_final-report_English.pdf (Accessed: 22 March 2022).

California (2021) *Cooling Centers*. Available at: https://www.cpuc.ca.gov/consumer-support/cooling-centers (Accessed: 4 April 2022).

Chen, C. *et al.* (2020) ‘Households’ Intended Evacuation Transportation Behavior in Response to Earthquake and Tsunami Hazard in a Cascadia Subduction Zone City’, *Transportation Research Record: Journal of the Transportation Research Board*, 2674(7), pp. 99–114. Available at: https://doi.org/10.1177/0361198120920873.

Cheng, G., Wilmot, C.G. and Baker, E.J. (2011) ‘Dynamic Gravity Model for Hurricane Evacuation Planning’, *Transportation Research Record*, 2234(1), pp. 125–134. Available at: https://doi.org/10.3141/2234-14.

Chicago (2022) *Cooling Areas*. Available at: https://www.chicago.gov/content/city/en/depts/fss/provdrs/serv/svcs/dfss_cooling_centers.html (Accessed: 4 April 2022).

Chou, J.-S., Ou, Y.-C., Cheng, M.-Y., Cheng, M.-Y. and Lee, C.-M. (2013) ‘Emergency shelter capacity estimation by earthquake damage analysis’, *Natural Hazards*, 65(3), pp. 2031–2061. Available at: https://doi.org/10.1007/s11069-012-0461-5.

Christopher Hellmundt Community and Culture (2022) ‘Process Review: Community Hub Model’. City of Ryde. Available at: https://www.ryde.nsw.gov.au/files/assets/public/community/community-hubs/community-hubs-model-the-seven-stages-of-creating-community-hubs.pdf (Accessed: 21 September 2022).

Ciriaco, T. G. M., & Wong, S. D. (2022). Review of resilience hubs and associated transportation needs. *Transportation Research Interdisciplinary Perspectives*, 16, 100697. https://doi.org/10.1016/j.trip.2022.100697

City of Edmonton (2022) *Extreme Weather Response | City of Edmonton*. Available at: https://www.edmonton.ca/programs_services/emergency_preparedness/extreme-weather (Accessed: 4 April 2022).

City of Houston (2020) *Resilient Houston*. Available at: https://www.houstontx.gov/mayor/Resilient-Houston-20200518-single-page.pdf (Accessed: 23 March 2022).

City of London (2022) *Warming centres | City of London*. Available at: https://london.ca/warming-centres (Accessed: 4 April 2022).

City of New Orleans (2022) *Hurricanes & Tropical Weather Hurricane - NOLA Ready*, *NOLA READY THE CITY OF NEW ORLEANS*. Available at: https://ready.nola.gov/plan/hurricane/ (Accessed: 27 April 2022).

City of New York (2022) *Cooling Centers · NYC311*. Available at: https://portal.311.nyc.gov/article/?kanumber=KA-02663 (Accessed: 4 April 2022).

City of Niagara Falls (2022) *Extreme Heat Relief | City of Niagara Falls, Canada - City of Niagara Falls*, *City of Niagara Falls Website*. Available at: https://niagarafalls.ca/living/severe-weather/extreme-heat-relief.aspx (Accessed: 4 April 2022).

City of Oshawa (2021) *Cooling Centres*. Communications. Available at: https://www.oshawa.ca/en/residents/cooling-centres.asp (Accessed: 4 April 2022).

City of St. Louis (2022) *Cooling Centers in the St. Louis Area*, *stlouis-mo.gov*. Available at: https://www.stlouis-mo.gov/live-work/summer/cooling-centers.cfm (Accessed: 4 April 2022).

City of Tallahassee (2022) *Resilience Hubs*. Available at: https://www.talgov.com/ (Accessed: 23 March 2022).

CoMoUK (2019) 'Mobility Hubs Guidance'. Available at: https://como.org.uk/wp-content/uploads/2019/10/Mobility-Hub-Guide-241019-final.pdf.

Connecticut State (2022) *Extreme Heat and Cooling Centers*, *CT.gov - Connecticut's Official State Website*. Available at: https://portal.ct.gov/DEMHS/Emergency-Management/Resources-For-Individuals/Summer-Weather-Awareness/Extreme-Heat-and-Cooling-Centers (Accessed: 25 April 2022).

CREW (2021) *What Is A Climate Resilience Hub?*, *CREW*. Available at: https://www.climatecrew.org/resilience_hubs (Accessed: 23 March 2022).

Curriero, F.C. (2002) 'Temperature and Mortality in 11 Cities of the Eastern United States', *American Journal of Epidemiology*, 155(1), pp. 80–87. Available at: https://doi.org/10.1093/aje/155.1.80.

Das, R. (2018) 'Disaster preparedness for better response: Logistics perspectives', *International Journal of Disaster Risk Reduction*, 31, pp. 153–159. Available at: https://doi.org/10.1016/j.ijdrr.2018.05.005.

de Roode, A.F. and Martinac, I. (2020) ‘Resilience hubs: a Maui case study to inform strategies for upscaling to resilience hub networks across coastal, remote, and island communities’, *IOP Conference Series: Earth and Environmental Science*, 588(5), p. 052050. Available at: https://doi.org/10.1088/1755-1315/588/5/052050.

EFCL (2022) ‘What is a Community League?’, *Edmonton Federation of Community Leagues*. Available at: https://efcl.org/about/ (Accessed: 17 September 2022).

Eren, E. and Katanalp, B.Y.˘git (2022) ‘Fuzzy-based GIS approach with new MCDM method for bike-sharing station site selection according to land-use types | Elsevier Enhanced Reader’, *Sustainable Cities and Society* [Preprint]. Available at: https://doi.org/10.1016/j.scs.2021.103434.

Fazio, M., Giuffrida, N., Le Pira, M., Inturri, G. and Ignaccolo, M. (2021) ‘Planning Suitable Transport Networks for E-Scooters to Foster Micromobility Spreading’, *Sustainability*, 13(20), p. 11422. Available at: https://doi.org/10.3390/su132011422.

Félix, D., Branco, J.M. and Feio, A. (2013) ‘Temporary housing after disasters: A state of the art survey’, *Habitat International*, 40, pp. 136–141. Available at: https://doi.org/10.1016/j.habitatint.2013.03.006.

FEMA (2011) ‘A Whole Community Approach to Emergency Management: Principles, Themes, and Pathways for Action’. Available at: https://www.fema.gov/sites/default/files/2020-07/whole_community_dec2011__2.pdf.

First 5 El Dorado (2022) *El Dorado | Community Hubs | California*, *EDC Community Hubs*. Available at: https://www.eldoradocommunityhubs.com (Accessed: 21 March 2022).

Fraser Health Authority (2021) *Municipal cooling centres*. Available at: https://www.fraserhealth.ca/health-topics-a-to-z/sun-safety/cooling-centres (Accessed: 4 April 2022).

Georgetown Climate Center (2022) *Equitable Adaptation Legal & Policy Toolkit » Supporting the Development of Resilience Hubs - Georgetown Climate Center*, *georgetownclimatecenter.org*. Available at: https://www.georgetownclimate.org/adaptation/toolkits/equitable-adaptation-toolkit/supporting-the-development-of-resilience-hubs-a.html (Accessed: 28 February 2022).

Giarmoleo, J. (2021) *EPA to Help Schools in Bay Area Create Cleaner Air and Cooling Centers*. Available at: https://www.epa.gov/newsreleases/epa-help-schools-bay-area-create-cleaner-air-and-cooling-centers (Accessed: 29 April 2022).

Government of South Australia (2018) ‘How Toplanfora Community Recreation and Sports Hub -Guide’. Government of South Australia - Office for Recreation, sport and Racing. Available at: https://www.orsr.sa.gov.au/places-and-spaces/documents/Community_Rec_Sports_Hubs.pdf (Accessed: 21 September 2022).

Grand Erie District School Board (2022) *Neighbourhood Hub at Major Ballachey Public School Opens: Grand Erie District School Board*. Available at: https://granderie.ca/board/community/newsroom/feature-stories/2015-16/neighbourhood-hub-major-ballachey-public-school-opens (Accessed: 21 March 2022).

Guerreiro, T. de C.M., Providelo, J.K., Pitombo, C.S., Ramos, R.A.R. and Rodrigues da Silva, A.N. (2018) ‘Data-mining, GIS and multicriteria analysis in a comprehensive method for bicycle network planning and design’, *International Journal of Sustainable Transportation* [Preprint]. Available at: https://doi.org/10.1080/15568318.2017.1342156.

Hawaii News Now (2021) *Big Island initiative creates community hubs to support residents during COVID*, *hawaii news now*. Available at: https://www.hawaiinewsnow.com/2021/03/04/big-island-initiative-works-create-community-hubs-support-residents-during-covid/ (Accessed: 10 April 2022).

Hawkins, A.J. (2018) *Uber is overhauling the way it responds to emergencies and natural disasters*, *The Verge*. Available at: https://www.theverge.com/2018/9/25/17897836/uber-disaster-response-hurricane-price-cap (Accessed: 25 April 2022).

Henry, L. and Marsh, D.L. (2008) ‘Intermodal Surface Public Transport Hubs: Harnessing Synergy for Success in America’s Urban and Intercity Travel’. *2008 American Public Transportation Association Bus and Paratransit Conference*, Austin, Tex. Available at: https://www.vtpi.org/henry_marsh.pdf.

Higgins, W. (2021) *Resilience hub initiative continues to evolve*, *Austin Monitor*. Available at: https://www.austinmonitor.com/stories/2021/11/resilience-hub-initiative-continues-to-evolve/ (Accessed: 23 March 2022).

Hussain, Z. and Zetkulic, A. (2021) *Protecting and Empowering Communities during Disasters*, *RMI*. Available at: https://rmi.org/community-resilience-hubs/ (Accessed: 23 March 2022).

Idziorek, K. (2020) *Op-Ed: Preparing for the Next Disaster: Looking Beyond COVID-19 Toward Multi-Hazard Approaches to Transportation Planning*. Available at: https://www.enotrans.org/article/op-ed-preparing-for-the-next-disaster-looking-beyond-covid-19-toward-multi-hazard-approaches-to-transportation-planning/ (Accessed: 29 March 2022).

Johnson, C. (2007) 'Strategic planning for post-disaster temporary housing', *Disasters*, 31(4), pp. 435–458. Available at: https://doi.org/10.1111/j.1467-7717.2007.01018.x.

Karaye, I.M., Thompson, C., Perez-Patron, M., Taylor, N. and Horney, J.A. (2020) 'Estimating Evacuation Shelter Deficits in the Houston–Galveston Metropolitan Area', *Risk Analysis*, 40(5), pp. 1079–1091. Available at: https://doi.org/10.1111/risa.13448.

Keenan, J.M. (2018) 'Types and forms of resilience in local planning in the U.S.: Who does what?', *Environmental Science & Policy*, 88, pp. 116–123. Available at: https://doi.org/10.1016/j.envsci.2018.06.015.

Kim, M., Kim, K. and Kim, E. (2021) 'Problems and Implications of Shelter Planning Focusing on Habitability: A Case Study of a Temporary Disaster Shelter after the Pohang Earthquake in South Korea', *International Journal of Environmental Research and Public Health*, 18(6), p. 2868. Available at: https://doi.org/10.3390/ijerph18062868.

Kirwan, D., Faber, G., Porter, P. and McCarty, T. (2021) *A Framework for Implementing Resilience Hubs in Ypsilanti, Michigan*. Seas - School for Environment and Sustainability - University of Michigan, p. 84. Available at: https://deepblue.lib.umich.edu/handle/2027.42/167216 (Accessed: 20 February 2022).

Kohn, S., Eaton, J.L., Feroz, S., Bainbridge, A.A., Hoolachan, J. and Barnett, D.J. (2012) 'Personal Disaster Preparedness: An Integrative Review of the Literature', *Disaster Medicine and Public Health Preparedness*, 6(3), pp. 217–231. Available at: https://doi.org/10.1001/dmp.2012.47.

Kotani, H., Yokomatsu, M. and Ito, H. (2020) 'Potential of a shopping street to serve as a food distribution center and an evacuation shelter during disasters: Case study of Kobe, Japan', *International Journal of Disaster Risk Reduction*, 44, p. 101286. Available at: https://doi.org/10.1016/j.ijdrr.2019.101286.

Li, A.C.Y., Nozick, L., Xu, N. and Davidson, R. (2012) 'Shelter location and transportation planning under hurricane conditions', *Transportation Research Part E: Logistics and Transportation Review*, 48(4), pp. 715–729. Available at: https://doi.org/10.1016/j.tre.2011.12.004.

Lindell, M.K. (2018) 'Communicating Imminent Risk', in H. Rodríguez, W. Donner, and J.E. Trainor (eds) *Handbook of Disaster Research*. Cham: Springer International Publishing (Handbooks of Sociology and Social Research), pp. 449–477. Available at: https://doi.org/10.1007/978-3-319-63254-4_22.

Lindell, M.K., Murray-Tuite, P., Wolshon, B. and Baker, E.J. (2019) *Large-Scale Evacuation - The Analysis, Modeling, and Management of Emergency Relocation from Hazardous Areas*. 1st edn.

Liu, Q., Ruan, X. and Shi, P. (2011) 'Selection of emergency shelter sites for seismic disasters in mountainous regions: Lessons from the 2008 Wenchuan Ms 8.0 Earthquake, China', *Journal of Asian Earth Sciences*, 40(4), pp. 926–934. Available at: https://doi.org/10.1016/j.jseaes.2010.07.014.

Lou, Z. (2020) *Resilience Before Disaster*, p. 49. Available at: https://apen4ej.org/resilience-before-disaster/.

Lyft (2018) *Expanding 'Wheels for All' to Help Those in Need**, *Lyft Blog*. Available at: https://www.lyft.com/blog/posts/expanding-relief-rides-program (Accessed: 25 April 2022).

Ma, Y., Liu, B., Zhang, K. and Yang, Y. (2022) 'Incorporating multi-criteria suitability evaluation into multi-objective location–allocation optimization comparison for earthquake emergency shelters', *Geomatics, Natural Hazards and Risk*, 13(1), pp. 2333–2355. Available at: https://doi.org/10.1080/19475705.2022.2118623.

Ma, Y., Xu, W., Qin, L. and Zhao, X. (2019) 'Site Selection Models in Natural Disaster Shelters: A Review', *Sustainability*, 11(2), p. 399. Available at: https://doi.org/10.3390/su11020399.

Mardis, M.A., Jones, F.R., Ozguven, E.E., Horner, M., Piekalkiewicz, E., Pickett, S., Mathias, J. and Leon, J.D. (2021) '*Rural Resiliency Hubs: An Integrated, Community-Centered Approach to*

Addressing the Resiliency Divide through Rural Public Libraries', in. Available at: https://scholarcommons.sc.edu/cgi/viewcontent.cgi?date=1636425784&article=1046&context=newlibrarianshipsymposia&preview_mode= (Accessed: 22 March 2022).

Maricopa County (2022) *Cooling Stations & Water Donation Sites*. Available at: https://www.maricopa.gov/2461/Cooling-Stations-Water-Donation (Accessed: 25 April 2022).

Mazereeuw, M. and Yarina, E. (2017) 'Emergency Preparedness Hub: Designing Decentralized Systems for Disaster Resilience', *Journal of Architectural Education*, 71(1), pp. 65–72. Available at: https://doi.org/10.1080/10464883.2017.1260928.

McGee, T.K., Christianson, A.C., and First Nations Wildfire Evacuation Partnership (2021) *First Nations Wildfire Evacuations A Guide for Communities and External Agencies*. University of British Columbia Press.

McShane, I. and Coffey, B. (2022) 'Rethinking community hubs: community facilities as critical infrastructure', *Current Opinion in Environmental Sustainability*, 54, p. 101149. Available at: https://doi.org/10.1016/j.cosust.2022.101149.

Meerow, S. and Stults, M. (2016) 'Comparing Conceptualizations of Urban Climate Resilience in Theory and Practice', *Sustainability*, 8(7), p. 701. Available at: https://doi.org/10.3390/su8070701.

Meerow, S., Newell, J.P. and Stults, M. (2015) 'Defining urban resilience: A review', *Landscape and Urban Planning*, 147, pp. 38–49. Available at: https://doi.org/10.1016/j.landurbplan.2015.11.011.

Metropolitan Transportation Commission (2020) 'Mobility Hub Advisory Services - Siting Criteria, Screening Methodology, and Prioritization'. Nelson\Nygaard Consulting Associates, Inc.

My Community Locality (2022) 'Community Hubs: How to set up, run and sustain a community hub to transform local service provision'. Available at: https://www.salfordcvs.co.uk/sites/salfordcvs.co.uk/files/Community-Hubs-FINAL.pdf (Accessed: 21 September 2022).

Nagarajan, M. and Shaw, D. (2021) 'A behavioural simulation study of allocating evacuees to public emergency shelters', *International Journal of Disaster Risk Reduction*, 55, p. 102083. Available at: https://doi.org/10.1016/j.ijdrr.2021.102083.

National Commission on Intermodal Transportation (1994) *Toward a National Intermodal Transportation System – Final Report*. Washington, D.C: National Commission on Intermodal Transportation. Available at: https://ntlrepository.blob.core.windows.net/docs/325TAN.html (Accessed: 21 February 2022).

Neighborhood Empowerment Network (2018) *Empowered Communities Program*, *empowersf.org*. Available at: https://www.empowersf.org/ecp-communities/ (Accessed: 23 March 2022).

New York State (2022) *Frequently Asked Questions About Cooling Centers*. Available at: https://www.health.ny.gov/environmental/weather/cooling/ccfaq.htm (Accessed: 4 April 2022).

Northampton Massachusetts (2020) *Community Resilience Hub | Northampton, MA - Official Website*. Available at: https://www.northamptonma.gov/2166/Community-Resilience-Hub (Accessed: 22 March 2022).

Oak Park Neighbourhood Centre (2022) *Oak Park Neighbourhood Centre » Programs*. Available at: https://opnc.ca/programs-b/ (Accessed: 23 March 2022).

Ontario (2017) *Archived - Two-Year Progress Report on Community Hubs in Ontario: A Strategic Framework and Action Plan*, *ontario.ca*. Available at: http://www.ontario.ca/page/two-year-progress-report-community-hubs-ontario-strategic-framework-and-action-plan (Accessed: 26 February 2022).

Ostro, B.D., Roth, L.A., Green, R.S. and Basu, R. (2009) 'Estimating the mortality effect of the July 2006 California heat wave', *Environmental Research*, 109(5), pp. 614–619. Available at: https://doi.org/10.1016/j.envres.2009.03.010.

Pacific Gas and Electric Company (2022) *Find support resources during a PSPS*. Available at: https://www.pge.com/en_US/residential/outages/public-safety-power-shuttoff/psps-support.page (Accessed: 28 April 2022).

Palumbo, D. (2016) *NEIGHBOURHOOD RESILIENCE AND COMMUNITY HUBS IN ONTARIO*. Master of Planning. Ryerson University. Available at: https://rshare.library.ryerson.ca/articles/thesis/Neighbourhood_Resilience_and_Community_Hubs_in_Ontario/14665506.

PBOT (2020) *Mobility Hub Typology Study*, p. 28. Available at: https://altago.com/wp-content/uploads/PBOT-Mobility-Hub-Typology_June2020.pdf

Perkins, J.B. (1996) *Shaken awake!: Estimates of uninhabitable dwelling units and peak shelter populations in future earthquakes affecting the San Francisco Bay region.* Oakland, CA: Association of Bay Area Governments.

Petrović, M., Mlinarić, T.J. and Šemanjski, I. (2019) ‘Location Planning Approach for Intermodal Terminals in Urban and Suburban Rail Transport’, *Promet - Traffic&Transportation*, 31(1), pp. 101–111. Available at: https://doi.org/10.7307/ptt.v31i1.3034.

Pitre, K. (2015) *Community Hubs in Ontario: A Strategic Framework and Action Plan*. Ontario, Canada: Premier’s Community Hubs Framework Advisory Group. Available at: https://docs.ontario.ca/documents/4815/community-hubs-a-strategic-framework-and-action.pdf (Accessed: 24 February 2022).

Pitsiava-Latinopoulou, M. and Iordanopoulos, P. (2012) ‘Intermodal Passengers Terminals: Design Standards for Better Level of Service’, *Procedia - Social and Behavioral Sciences*, 48, pp. 3297–3306. Available at: https://doi.org/10.1016/j.sbspro.2012.06.1295.

Portland Bureau of Transportation (2018) *2018 E-Scooter Findings Report*, *Portland.gov*. Available at: https://www.portland.gov/transportation/escooterpdx/2018-e-scooter-findings-report (Accessed: 23 April 2022).

Primary Care Network (2018) *Seniors’ Community Hub*, *Edmonton Oliver PCN*. Available at: https://www.eopcn.ca/services/seniors-community-hub/ (Accessed: 21 March 2022).

Quarantelli, E.L. (1995) ‘Patterns of sheltering and housing in US disasters’, *Disaster Prevention and Management: An International Journal*, 4(3), pp. 43–53. Available at: https://doi.org/10.1108/09653569510088069.

Queiser, S. (2019) *How to Hub: Community Hub Development Toolkit: a Practical Guide to Support Residents in Navigating the Initial Stages of a Community Hub Initiative*. Toronto, ON, CA: Social Planning Toronto.

Renne, J.L., Sanchez, T.W. and Litman, T. (2011) ‘Carless and Special Needs Evacuation Planning: A Literature Review’, *Journal of Planning Literature*, 26(4), pp. 420–431. Available at: https://doi.org/10.1177/0885412211412315.

Resilience Hub Community Committee (2020) *Ward 7 Resilience Hub Proposal*. Available at: https://faunteroycenter.org/wp-content/uploads/2021/02/RHCC-Report-Year-1.pdf (Accessed: 23 March 2022).

Sandoval, S. (2019) *Resilience Hubs in Austin, Texas: Developing Equitable Climate Infrastructure*, p. 48.

Sands, D. (2021) *Climate resilience hubs finding a foothold on Detroit's East Side, helping residents face disasters*, *Metromode*. Available at: https://www.secondwavemedia.com/metromode/features/ClimateResiliencyHubs.aspx (Accessed: 23 March 2022).

Schemel, S., Niedenhoff, C., Ranft, G., Schnurr, M. and Sobiech, C. (2020) *Mobility Hubs of The Future: Towards A New Mobility Behaviour*. ARUP and RISE. Available at: https://www.ri.se/sites/default/files/2020-12/RISE-Arup_Mobility_hubs_report_FINAL.pdf (Accessed: 21 March 2022).

Semenza, J. C., Rubin, C.H., Falter, K. H., Selanikio, J. D., Flanders, W. D., Howe, H. L. and Wilhelm, J. L. (1996) 'Heat-Related Deaths during the July 1995 Heat Wave in Chicago', *New England Journal of Medicine*, 335(2), pp. 84–90. Available at: https://doi.org/10.1056/NEJM199607113350203.

Shaheen, S., Bell, C., Cohen, A. and Yelchuru, B. (2017) *Travel Behavior: Shared Mobility and Transportation Equity*. PL-18-007, p. 66. Available at: https://www.fhwa.dot.gov/policy/otps/shared_use_mobility_equity_final.pdf (Accessed: 29 April 2022).

Sheu, J.-B. and Pan, C. (2014) 'A method for designing centralized emergency supply network to respond to large-scale natural disasters', *Transportation Research Part B: Methodological*, 67, pp. 284–305. Available at: https://doi.org/10.1016/j.trb.2014.05.011.

Small Planet Networks (2022) *Community Resilience*. Available at: https://www.smallplanetworks.com/Community-Resilience.php (Accessed: 8 February 2022).

SmartHubs (2022) *Mobility Hubs*. Available at: https://data.smartmobilityhubs.eu/wiki/Main_Page (Accessed: 21 March 2022).

Smith, S.K. and McCarty, C. (2009) 'Fleeing the storm(s): an examination of evacuation behavior during Florida's 2004 hurricane season', *Demography*, 46(1), pp. 127–145. Available at: https://doi.org/10.1353/dem.0.0048.

Southern California Edison (2022) *Power Outage Awareness Map*, *SCE*. Available at: https://www.sce.com/outage-center/check-outage-status (Accessed: 28 April 2022).

Stanton, R. (2020) *Ann Arbor celebrates launch of city's first solar-powered 'resilience hub'*, *mlive*. Available at: https://www.mlive.com/news/ann-arbor/2020/09/ann-arbor-celebrates-launch-of-citys-first-solar-powered-resilience-hub.html (Accessed: 23 March 2022).

Statistics Canada. (2023). *Census Profile. 2021 Census of Population.* https://www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/index.cfm?Lang=E

Strathcona County (2022) 'Strathcona County Community Hub Study'. Available at: https://strathconacablob.blob.core.windows.net/files/files/fcs-strathcona-county-community-hub-study-final-report.pdf (Accessed: 21 September 2022).

Temmer, J., Smith, R. and Terton, A. (2019) *Building a Climate-Resilient City: Disaster preparedness and emergency management*, p. 12. Available at: https://www.iisd.org/publications/brief/building-climate-resilient-city-disaster-preparedness-and-emergency-management.

Tobias, A., Armstrong, B., Zuza, I., Gasparrini, A., Linares, C. and Diaz, J. (2012) 'Mortality on extreme heat days using official thresholds in Spain: a multi-city time series analysis', *BMC Public Health*, 12(1), p. 133. Available at: https://doi.org/10.1186/1471-2458-12-133.

Toronto, C. of (2017a) *Cool Spaces Near You*, *City of Toronto*. City of Toronto. Available at: https://www.toronto.ca/community-people/health-wellness-care/health-programs-advice/hot-weather/cool-spaces-near-you/ (Accessed: 4 April 2022).

Toronto, C. of (2017b) *Homeless Help*, *City of Toronto*. City of Toronto. Available at: https://www.toronto.ca/community-people/housing-shelter/homeless-help/ (Accessed: 4 April 2022).

Twigg, J., Kett, M., Bottomley, H., Tan, L.T. and Nasreddin, H. (2011) 'Disability and public shelter in emergencies', *Environmental Hazards*, 10(3–4), pp. 248–261. Available at: https://doi.org/10.1080/17477891.2011.594492.

United Way (2021) *2020 Community Hubs Annual Report*. United Way Calgary and Area, p. 26. Available at: https://calgaryunitedway.org/impact/communities/community-hubs/ (Accessed: 21 March 2022).

USDN (2022a) *Boyle Heights Arts Conservatory*. USDN, p. 4. Available at: http://resilience-hub.org/wp-content/uploads/2022/09/USDN_Progress-_BoyleHeights.pdf (Accessed: 10 September 2022).

USDN (2022b) *Cambridge Community Center*. USDN, p. 4. Available at: http://resilience-hub.org/wp-content/uploads/2022/07/USDN_Progress-_CambridgeCommunityCenter.pdf (Accessed: 10 September 2022).

USDN (2022c) *Envision Tempe Resilience Hub*. USDN, p. 4. Available at: http://resilience-hub.org/wp-content/uploads/2022/07/USDN_Progress-_Tembe_Feb2022.pdf (Accessed: 10 September 2022).

USDN (2022d) *Resilience Incubators at F.H. Faunteroy*. USDN, p. 3. Available at: http://resilience-hub.org/wp-content/uploads/2022/09/USDN_Progress-_Faunteroy_Sept2022.pdf (Accessed: 10 September 2022).

Vancouver, C. of (2022a) *Community centres*. Available at: https://vancouver.ca/parks-recreation-culture/community-and-cultural-centres.aspx (Accessed: 4 April 2022).

Vancouver, C. of (2022b) *Disaster support hubs*. Available at: https://vancouver.ca/home-property-development/disaster-support-hubs.aspx (Accessed: 17 January 2022).

Vancouver, C. of (2022c) *Stay safe in the summer heat*. Available at: https://vancouver.ca/people-programs/hot-weather.aspx (Accessed: 4 April 2022).

Vaneckova, P., Beggs, P.J. and Jacobson, C.R. (2010) ‘Spatial analysis of heat-related mortality among the elderly between 1993 and 2004 in Sydney, Australia’, *Social Science & Medicine*, 70(2), pp. 293–304. Available at: https://doi.org/10.1016/j.socscimed.2009.09.058.

Vibrant Hawai'i (2019) *Resilience Hubs*, *Vibrant Hawai'i*. Available at: https://www.vibranthawaii.org/hubs (Accessed: 22 March 2022).

Vibrant Hawai'i (2020) *2020 Hubs Final Report*. Available at: https://www.vibranthawaii.org/_files/ugd/fb5ef8_832bf02d4e61442aa0a80a34d9ef1e01.pdf (Accessed: 22 March 2022).

Vibrant Hawai'i (2021) *Hubs 2.0 Final Report*, p. 24. Available at: https://www.vibranthawaii.org/_files/ugd/fb5ef8_c2dd42a7025c4a5cb5a61a822ee7f8a0.pdf. (Accessed: 22 March 2022).

Whitehead, J.C. (2003) ‘One million dollars per mile? The opportunity costs of Hurricane evacuation’, *Ocean & Coastal Management*, 46(11–12), pp. 1069–1083. Available at: https://doi.org/10.1016/j.ocecoaman.2003.11.001.

Wilmot, C.G. and Gudishala, R. (2013) *Development of a time-dependent hurricane evacuation model for the New Orleans area.* FHWA/LA.12/494. Available at: https://rosap.ntl.bts.gov/view/dot/25769 (Accessed: 21 March 2022).

Wong, S., Broader, J., Cohen, A. and Shaheen, S. (2021) ‘Double the Trouble: A Playbook for COVID-19 and Evacuations’. Available at: https://doi.org/10.7922/G2TT4P8D.

Wong, S., Shaheen, S. and Walker, J. (2018) ‘Understanding Evacuee Behavior: A Case Study of Hurricane Irma’. Available at: https://doi.org/10.7922/G2FJ2F00.

Wong, S.D. (2020) *Compliance, Congestion, and Social Equity: Tackling Critical Evacuation Challenges through the Sharing Economy, Joint Choice Modeling, and Regret Minimization*. UC Berkeley. Available at: https://escholarship.org/uc/item/6z43s8qx.

Wong, S.D., Broader, J.C. and Shaheen, S.A. (2022) ‘Power Trips: Early Understanding of Preparedness and Travel Behavior During California Public Safety Power Shutoff Events’, *Transportation Research Record*, p. 03611981221078569. Available at: https://doi.org/10.1177/03611981221078569.

Wong, S.D., Walker, J.L. and Shaheen, S.A. (2020a) ‘Bridging the gap between evacuations and the sharing economy’, *Transportation* [Preprint]. Available at: https://doi.org/10.1007/s11116-020-10101-3.

Wong, S.D., Walker, J.L. and Shaheen, S.A. (2020b) ‘Trust and compassion in willingness to share mobility and sheltering resources in evacuations: A case study of the 2017 and 2018

California Wildfires', *International Journal of Disaster Risk Reduction*, p. 101900. Available at: https://doi.org/10.1016/j.ijdrr.2020.101900.

Wu, H.-C., Lindell, M.K. and Prater, C.S. (2012) 'Logistics of hurricane evacuation in Hurricanes Katrina and Rita', *Transportation Research Part F: Traffic Psychology and Behaviour*, 15(4), pp. 445–461. Available at: https://doi.org/10.1016/j.trf.2012.03.005.

Xu, J., Yin, X., Chen, D., An, J. and Nie, G. (2016) 'Multi-criteria location model of earthquake evacuation shelters to aid in urban planning', *International Journal of Disaster Risk Reduction*, 20, pp. 51–62. Available at: https://doi.org/10.1016/j.ijdrr.2016.10.009.

Yin, W., Murray-Tuite, P. and Gladwin, H. (2014) 'Statistical Analysis of the Number of Household Vehicles Used for Hurricane Ivan Evacuation', *Journal of Transportation Engineering*, 140(12), p. 04014060. Available at: https://doi.org/10.1061/(ASCE)TE.1943-5436.0000713.

Zhao, L., Li, H., Sun, Y., Huang, R., Hu, Q., Wang, J. and Gao, F. (2017) 'Planning Emergency Shelters for Urban Disaster Resilience: An Integrated Location-Allocation Modeling Approach', *Sustainability*, 9(11), p. 2098. Available at: https://doi.org/10.3390/su9112098.