Attaining climate justice through the adaptation of urban form to climate change: flood risks in Toronto

by

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Author’s Declaration

This thesis consists of material all of which I authored or co-authored: see the Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

This dissertation consists of five chapters. Chapters 2, 3, and 4 are three manuscripts, co-authored by my advisor, Dr. Luna Khirfan. My advisor offered intellectual insight, feedback, and editorial changes. Additionally, the dissertation has two other chapters −Chapters 1 (Introduction) and Chapter 2 (Conclusion) – of which I am the sole author.

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Abstract

Empirical evidence points out that entrenched cost-benefit rationales behind urban form adaptations to climate change unequally exacerbate vulnerabilities and hazard exposures, engendering risk inequalities and triggering climate injustice. Specifically, adaptive interventions for managing climate change-induced floods, whether through green and blue infrastructure (GBI), land use planning, or urban design, prioritize the protection of high-value urban assets while excluding vulnerable groups. To redress climate injustice, some have called for the consideration of the three pillars of justice: distributive justice, i.e., the just spatial distribution of adaptation responses; procedural justice, i.e., the equality of decision-making processes; and recognitional justice, i.e., the legitimization of marginalized groups. To assess the extent of these pillars' integration in the scholarship (theoretically and empirically), this dissertation conducted a systematic review of 136 peer-reviewed papers on urban climate justice vis-à-vis adaptation. The findings reveal a lack of theoretical and empirical connections between the three-pillared justice framework and climate adaptive interventions in urban form.

The dissertation's theoretical framework overcomes these omissions by using different theories/concepts in the literature as nexuses connecting climate justice pillars with urban form. It capitalizes on interconnections distributive justice has with differential vulnerabilities, flood exposures, and the adaptive capacity of urban form to identify areas that unequally experience flood risks and need to be prioritized in adaptation. It, furthermore, combined the three-pillared justice framework with epistemic justice and local experiential knowledge concept to explore how flood-adaptive GBI planning can address the root causes of vulnerabilities, hence facilitating justice-oriented transformative adaptation. Accordingly, the research developed a multi-criteria model including indicators and variables for measuring the spatial distribution of social vulnerabilities, exposure, and the adaptive capacity of urban form, whereby it proposes pathways for justice-oriented transformative adaptation of high-risk priority areas through GBI planning.

The dissertation focuses on Toronto in Ontario, Canada, to test the theoretical framework, which can be applied in any city. The study in Toronto asks: "who" is unequally at-risk of flooding events, "where" are they located, "why" they are unequally vulnerable, and "how" we can engage the high-risk community in adaptive GBI planning to promote justice-oriented

transformative adaptation. The methodology started with operationalizing the spatial multi-criteria model through weighted overlay analysis using ArcGIS and an online survey of 120 Toronto-based flooding experts, which yielded the identification of four priority neighborhoods at a disproportionate risk of floods. Focusing on one of the high-risk priority neighborhoods, Thorncliffe Park, I conducted 20 semi-structured interviews with flooding experts and local leaders and an online survey of residents to investigate whether the local experiential knowledge of residents has been recognized in adaptive GBI planning decisions. I furthermore performed an online participatory-mapping activity in this neighborhood during which participants marked, on the neighborhood map, locations that require GBI for socio-cultural benefits. I overlaid the resulting participatory maps with land uses' run-off coefficients to propose sites for allocating GBI for both socio-cultural benefits and run-off management.

The findings show the effectiveness of the theoretical framework in identifying priority neighborhoods and developing place-based adaptation solutions inside and outside Canada. All four high-risk neighborhoods are inner-city tower communities with old infrastructure and dense low-income, racialized, and migrant populations, typical tower blocks built after the second World War in several cities across North America and Europe. The findings in Thorncliffe Park, as the priority neighborhood, unveil the exclusion of residents from flood-adaptive GBI planning despite their vulnerabilities and exposure. This exclusion, as results indicate, is rooted in technocratic processes based on technical knowledge and cost-benefit rationales. The findings show four epistemic barriers that need to be addressed to facilitate climate justice in adaptation interventions within Thorncliffe Park: lack of social networks, citizenship rights, climate awareness opportunities, and communicational tools. The results also show that the industrial uses around the railway and residential-commercial sites around Overlea Boulevard in this neighborhood are in dire need of GBI for managing run-offs and socio-cultural benefits. I propose adopting inclusive processes to allocate small-scale adaptive GBI in these locations. Building on the findings, the dissertation proposes future theoretical and empirical studies to complement this study by proposing how to design GBI and other urban form adaptive interventions by changing the layout patterns, orientation, and geometry of streets, buildings, and blocks in the high-risk disenfranchised communities to advance climate justice. At the center of this proposition are developing new theories to expand the climate justice triad and devising new forms of inclusive and collaborative design.

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Last, many thanks to my husband, Alireza. He has faced the front line of my frustrations throughout my studies and has always reciprocated love, patience, and understanding.

Dedication

To Alireza, my husband and my best friend, who has always been a constant source of support and encouragement.

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Chapter 1
Introduction

1.1 Research context

Variations in precipitation patterns due to climate change, combined with increased urbanization, environmental degradation, and the insufficient capacity of urban drainage infrastructure, have turned floods into one of the 21st century frequent and intense climate extreme events within cities (Hadi Pour et al., 2020; Miller & Hutchins, 2017). Yet, disenfranchised groups unequally experience higher risks of loss/injury from these flooding events due to their embedded vulnerabilities, exposures, and low adaptive capacity (Mohtat & Khirfan, 2022; Shi et al., 2016). Evidence of these flood risk inequalities abounds globally. In the US, empirical studies in Miami, New York, and New Orleans show that immigrants, low-income, and racial groups have faced power outages after extreme precipitations and ensuing flooding events more than the affluents because they mostly reside in low-lying lands and flood zones (Herreros-Cantis et al., 2020; Islam & Winkel, 2017; Mitsova et al., 2018). In Germany, financial damages from flooding events impact the welfare of low-income households more than others because they lose a higher proportion of their limited assets compared to middle- and high-income individuals (Osberghaus, 2021). In Bangkok, Thailand, the insufficient adaptive capacity of low-income slum communities due to their limited flood-protective infrastructure, proximity to precarious sites, inadequate financial resources, poor quality of settlements, and lack of access to citizenship rights led to a high rate of mortalities in the face of inland flooding events of October 2011 (Marks, 2015).

Additionally, attempts to manage urban floods through climate change adaptation might exacerbate risk inequalities and trigger climate justice challenges. In recent decades, applying climate change adaptation as an urban development agenda to protect urban economies and valuable urban assets against climatic hazards like flooding events has led to technocratic solutions based on scientific knowledge, cost-benefit rationales, and functional efficiency (Connolly, 2019; Long & Rice, 2019). Among these technical solutions are strategic interventions in urban form through land use planning, green and blue infrastructure (GBI) projects, and urban design measures to incorporate flood adaptive amenities, such as linear parks, greenbelts, and recreational uses, in abandoned sites, industrial zones, and floodplains (Anguelovski et al., 2020; Mohtat & Khirfan, 2021). Despite their benefits, these adaptive urban

form interventions support city-branding strategies to attract real-estate and tourism investments and raise land values without bearing climate justice concerns in mind. Housing unaffordability, climate gentrification, land expropriation, and forced relocation are examples of the exclusionary outcomes and costs adaptive urban form interventions impose on vulnerable groups, exacerbating their vulnerability and exposure to climatic events (Amorim-Maia et al., 2022; Shi, 2020a).

Climate justice scholarship, such as (Schlosberg & Collins, 2014) and (Schlosberg, 2001), propose integrating the three interrelated pillars of climate justice, namely, distributive, procedural, and recognitional justice, to avoid the exclusionary outcomes. **Distributive justice** concerns the equity of outcomes, whereby resources are distributed equally across space and time to maximize benefits to the most disadvantaged (Rawls, 1971; Shi et al., 2016). Distributive justice is rooted in "social structures" and "institutional contexts" (Young, 2011, p. 29). Accordingly, it is complemented by **procedural** and **recognitional justice**. The former pertains to equal access to democratic decision-making processes such as participation, while the latter refers to the legitimization of different racial, ethnical, and gender identities and the historical patterns of oppression and domination that have excluded them from political decisions (Schlosberg, 2001; Young, 2011).

Particularly, emerging studies have highlighted the role of this three-pillared justice framework in shifting technocratic adaptation responses, which entrench business-as-usual urban development patterns, to integrate structural and root causes of risk inequalities (Schlosberg et al., 2017). Accordingly, these three pillars can facilitate justice-oriented transformative adaptation (Bahadur & Tanner, 2014; Lamb & Khirfan, 2022; Ziervogel et al., 2022), referring to "deliberately and fundamentally changing systems to achieve more just and equitable adaptation outcomes" (Shi & Moser, 2021).

Despite these benefits, there is a lack of empirical studies that deploy the three-pillared justice framework to assess adaptation responses (Mohtat & Khirfan, 2021) and to facilitate transformative adaptation (Lamb & Khirfan, 2022) within the urban form. Specifically, of the three pillars, recognitional justice has grabbed the fewest attention in the urban climate change adaptation literature (Chu & Michael, 2019; Mohtat & Khirfan, 2021). These deficits are rooted in the newness of theoretical and empirical debates on urban form/design (Dhar & Khirfan,

2017a), climate justice (Bulkeley et al., 2014; Mohtat & Khirfan, 2021; Steele et al., 2015), and justice-oriented transformative adaptation (Pelling et al., 2015). Considering the historical dearth of synthesis between theories on urban form with social justice theories and inclusive planning frameworks, the urban form debates in the literature have overemphasized normative suggestions/critiques when discussing climate justice without proposing methodologies on "how" to advance it. While there is limited evidence on the applications of GIS, surveys, and interviews on assessing land use planning and GBI in terms of climate justice, there is a complete absence of studies that investigate "how" urban design interventions in the orientation, size, geometry, and layout patterns of streets, buildings, and blocks can impact the three-pillared justice framework (Mohtat & Khirfan, 2021).

This dissertation expands on other urban planning theories to investigate how the three-pillared justice framework can prevent flood risk inequities, facilitating transformative adaptation. It capitalizes on a part of the framework (Dhar & Khirfan, 2017a) proposed for measuring the adaptive capacity of urban form through land uses and town plans (the patterns of street networks, building footprints, and urban blocks). My purpose is to investigate associations among the spatial distribution of urban form adaptation interventions, differential vulnerabilities, and hazard exposures (the three drivers of risks) to find the patterns of flood risk inequities; hence locations need to be prioritized for a distributive just allocation of adaptive interventions within the urban form.

The study furthermore draws on the concept of epistemic injustice, in reference to the systematic exclusion of " … someone in their capacity as a knower" due to their social status (Byskov, 2021; Fricker, 2007, p. 1). Focusing on flood-adaptive GBI interventions in urban form, this study uses the epistemic justice concept to explain structural inequities and power asymmetries that have shaped the hegemony of technical knowledge over socially embedded context-specific knowledge (local experiential knowledge). This concept can guide policymakers on how to empower at-risk disenfranchised groups to fairly include their diverse voices in the design and the spatial distribution of GBI adaptation interventions. Hence, it can facilitate transformative adaptation through advancing procedural, recognitional, and distributive justice.

1.2 The research objective and questions

The overarching objective of this research is to develop theories and methodologies for advancing climate justice in urban form adaptation. Building on this objective, the research follows three main questions:

1. To what extent and how does urban form adaptation literature discuss climate justice?
2. How can priority areas be identified for the just distribution of adaptive interventions within the urban form?
3. How can we engage the priority communities in adaptive GBI planning to promote just transformative adaptation?

1.3 The case study

This research's case study is Toronto, the capital city of Ontario and Canada's economic and trading hub (Mohtat & Khirfan, 2022). With a population of more than 2.7 million people (Statistics Canada, 2021) and an area of 633.5 km^2, this city is the most populated city in Canada and the fourth large city in North Canada (City of Toronto, 2020c; Mohtat & Khirfan, 2022). As a major destination for immigrants, Toronto is the most diverse Canadian city. More than 50% of its population are visible minorities, and its residents speak over 200 languages (City of Toronto, 2016).

The city's location in the Lake Ontario Watershed and its exposure to the moist air masses have led to several flooding events. Hurricane Hazel in October 1954 led to 210 mm of rainwater over two days, which resulted in the loss of 81 lives and $25 million in damage. In August 1976, two major storms caused 75 mm of precipitation during two days, engendering $100 million in damage to major infrastructure, such as bridges. In August 2005, 153mm of precipitation in three hours triggered a 100-year flooding event, which left 10,000 people without power and caused $500 million in insured damage. Last, in July 2013, Toronto witnessed the most expensive flooding disaster, with more than $850 million in damage. This severe flooding caused a power outage for 300,000 Torontonians, disrupting air travel and public transportation (Nirupama et al., 2014; Rincón et al., 2018; TRCA, 2021). Feltmate and Thistlethwaite (2012) also noted that this city's extreme precipitation events have increased due to climate change. From 1996 to 2011, Toronto witnessed two 10-year and six 50-year

precipitation events. This increased precipitation, combined with the increased urbanization in the last decades, has raised the intensity and frequency of flooding events in this city (Feng et al., 2021).

Simultaneously, there is evidence of increased social inequities across the lines of race and income during the last 50 years with the increase in diversity. From 1990 to 2015, income segregation has risen 56% across the neighborhoods, showing that there are now more low- and high-income neighborhoods and fewer middle-income neighborhoods. Low-income neighborhoods' populations are mostly non-white communities and newly-arrived immigrants who lack access to affordable housing and decision-making processes. Of the three low-income families, one lives in tower buildings older than 35 years with unreliable infrastructure, exacerbating their vulnerability to different hazards, including flooding events (City of Toronto, 2020c).

The rise of flooding events and social vulnerabilities have posed a risk of loss and damage for individuals and properties. That is why the City of Toronto partners with different governmental, non-governmental, and private organizations to develop policies and strategies to reduce the risk of flooding. "Ahead of the Storm: Preparing Toronto for Climate Change" is the first Toronto's climate adaptation strategy, which includes actions for protection against floods and emergency management (City of Toronto, 2008).

Following this strategy, the City had a year-long collaboration with 18 stakeholders representing City divisions, academic institutions, agencies, governmental organizations, and private sectors to develop the Flood Resilient Toronto charter (City of Toronto, 2019b) as part of Toronto's First Resilient Strategy (City of Toronto, 2020c). The charter has gathered and updated existing flood mitigation plans such as Basement Flooding Protection and Wet Weather Flow Master Plan and Management Guidelines while scaling up ongoing GBI projects to integrate climate resilience into flood management. (City of Toronto, 2019b). At the center of this charter is developing a city-wide flood risk mapping tool based on the social cost-benefit analysis. The tool includes social vulnerability, critical infrastructure, and physical flooding hazard indicators to identify, rank, and prioritize neighborhoods for risk reduction measures to decrease the vulnerability of equity-seeking disadvantaged groups while enhancing their flood risk awareness

1.4 Research design

Research design entails "plans and … procedures for research that span the decisions from broad assumptions to the detailed methods of data collection and analysis" (W. Creswell, 2009, p. 3). This study builds its research design on the components proposed by Groat and Wang (2013, p. 10): systems of inquiry, school of thoughts, strategies, and tactics – see Dhar (2016) on the application of this framework. Systems of inquiry refer to the ontological and epistemological assumptions and paradigms that build the general philosophical direction of the research regarding the nature of reality and the ways the researcher can capture it. School of thoughts pertains to the broad theoretical perspectives that can shape the research questions. Strategies define the general research plan and structure. Tactics relate to detailed techniques for data gathering and analysis (W. Creswell, 2009). Dhar (2016) refer to systems of inquiry and school of thoughts as the broad philosophical research foundations that can direct strategies and tactics.

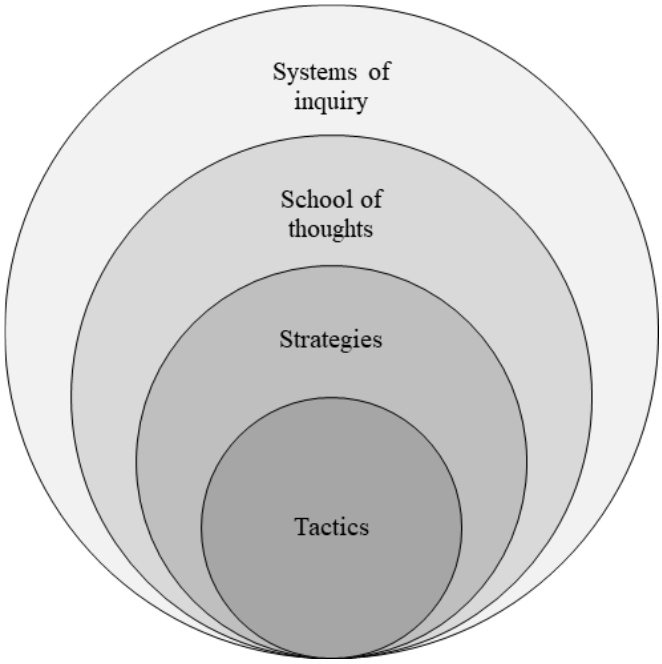

Figure 1. Research design components − adopted from Groat and Wang (2013, p. 10)

1.4.1 Systems of inquiry and school of thought

The types of methods the researchers choose for their studies are deeply rooted in their ontological and epistemological assumptions regarding the world. These assumptions in interdisciplinary fields like urban planning and social science span a wide variety of paradigms from the subjective perspectives centered on plural personal interpretations to the objective systems of inquiry based on singular concrete facts (Groat & Wang, 2013; Morgan & Smircich, 1980). Building on previous subjective-objective epistemological models such as W. Creswell (2009) and Morgan and Smircich (1980), Groat and Wang (2013, p. 76) proposed a continuum consisting of three ontological/epistemological positions from the "positivism/post-positivism" on one end, to "intersubjective" in the middle, to "constructivism" at the other end (Table 1).

The ontological and epistemological position of this study lies in exploring place-specific flood risk inequalities, social vulnerabilities, and individuals' multiple preferences regarding adaptation options. The existing theoretical debates on climate justice emphasize the need for inclusive adaptation responses that recognize different identities and prioritize socio-economically vulnerable groups instead of purely-technical and top-down processes that are based on single-viewed scientific assumptions. The general assumptions of this study regarding the nature of reality involve identifying "who" should be prioritized in adaptation responses and "how" to include diverse needs and perspectives of prioritized groups to advance climate justice. Accordingly, the paradigm that affected my ontological and epistemological assumptions centers on the constructivism worldview (Table 1).

While the ontological assumptions behind the positivism paradigm emphasize one externally-driven singular reality, the constructivism paradigm underscores relational ontology based on a variety of realities (Denzin & Lincoln, 2011). Climate justice scholarship relates the exclusionary outcomes of adaptive urban form interventions to the application of adaptation planning as an urban development agenda, based on the naïve and apolitical individualistic and positivist views of technical elites (Anguelovski et al., 2020). To avoid exclusionary outcomes, emerging studies emphasize the transformation of adaptation knowledge systems to integrate plural context-specific lived experiences by the social construction of adaptation knowledge (Ziervogel et al., 2022). These situation-based and context-specific worldviews regarding the

nature of just climate adaptation affect the ontological and epistemological assumptions of this study to tackle a constructivist paradigm.

Additionally, climate justice scholarship underscores the co-creation of expert-driven and socially-situated knowledge as a way to both respond to the climate crisis and address the structural inequities. This co-creation of knowledge can also empower vulnerable groups to assert their needs and impact decisions that shape entitlements (Ziervogel et al., 2022), hence addressing power asymmetric patterns. Such assumptions are in line with the constructivist epistemological assumptions that question the validity of scientific knowledge for reflecting the multiple realties of the world. These assumptions, at the same time, emphasize the co-production of knowledge by researchers and individuals who experience a phenomenon as a way to switch power to impacted communities (Denzin & Lincoln, 2011).

Table 1. Research paradigm continuum proposed by Groat and Wang (2013, p. 76)

	Objective ⟷ Subjective				
	Positivism/Post-positivism		Intersubjective	Constructivism/Radical constructivism	
Ontology	Assumes objective reality	External reality revealed probabilistically	Diverse realities situated in socio-cultural context	Multiple constructed realities	Knowledge perpetually provisional
Epistemology	Knower distinct from the object of inquiry	Knowing through distance from the object	Knowledge framed by understanding socio-cultural engagement	Knowledge co-constructed with participants	Knowledge perpetually provisional

As Groat and Wang (2013) propose, the next step after identifying the system of inquiry is deciding about the school of thoughts, or the overarching theoretical lens guiding the general ideas of the study. It is widely discussed that the relationship between research and theory obeys an inductive-deductive dichotomy (Swaffield & Deming, 2011; W. Creswell, 2009). The inductive approach generates theories based on empirical observations and interpretations while the deductive approach tests existing theories through evaluation and experimentation. There is a third approach between the inductive-deductive duality, called the reflexive approach. A reflexive strategy, also called abduction, requires the researcher to shift back and forth between existing theories and empirical evidence to revisit theoretical debates while proposing new ways

of investigating and questioning (Swaffield & Deming, 2011). In this study, developing the theoretical framework is the result of a back-and-forth process mainly between existing theoretical interconnections climate justice pillars have with urban form adaptation and empirical evidence on risk inequities, differential vulnerabilities, and technocratic adaptation. Hence, this study capitalizes on a reflexive approach to both build theories and test them in Toronto as the case study.

Accordingly, the broad philosophical research foundations of this study are built upon a constructivism paradigm that adheres to multiple subjective realities and knowledge co-production while tackling a reflexive approach for generating and testing theories (Figure 2).

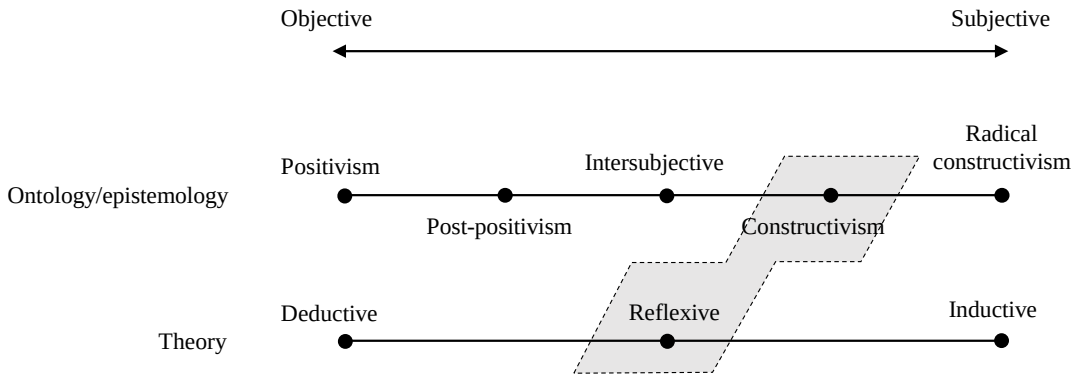

Figure 2. The philosophical research foundation

1.4.2 Strategies and tactics

Climate change adaptation is a local phenomenon; hence its outcomes in terms of justice are perceived locally. Climate justice scholarship proposes climate adaptation measures, including adaptive interventions within the urban form, to include lived experiences and socially-constructed context-specific conditions that vulnerable groups face to avoid exclusionary outcomes. The importance of including plural realities embedded in the social context is also reflected in the constructivist paradigm of this research that requires the researcher to involve in the subject matter to co-produce knowledge with the society instead of being an external investigator. Considering these theoretical debates and epistemological positions, this study tackles a case study approach.

Yin (2009, p. 18) defines a case study research strategy as "an empirical inquiry that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident". A case study is a prevalent approach in urban planning and social science research disciplines, which provides a multifaceted and deep understanding of a phenomenon within a real-life context. Contrary to experimental studies, which deliberately control events to test a hypothesis, case study research responds to "why", "what", and "how" questions without manipulating and controlling the conditions (Crowe et al., 2011; Groat & Wang, 2013).

Building on a case study strategy, this study deeply investigates: What areas should be prioritized in flood-adaptive interventions within the urban form and why? and how should GBI be designed in priority areas to promote just transformative adaptation? To answer these questions, I adopted a single case study approach in Toronto. My reasons for focusing on a single case instead of multiple case studies are two-fold.

First, Toronto faces a critical condition in terms of flood risk due to the raised precipitation rates, rapid urban developments, and more importantly, increased social vulnerabilities due to the increased racial and income segregation (City of Toronto, 2020c; Mohtat & Khirfan, 2022). These conditions make it a critical case for testing the climate justice three-pillared framework. Second, Toronto is a typical multicultural North American city in terms of urban development patterns and the characteristics of racially-segregated neighborhoods (Qadeer, 2016). Accordingly, my findings include general insights applicable to other similar cases. These reasons are in-line with two of Yin's (2009, p. 41) proposed rationales for single case study research, those are being a "critical case" for testing theories and being a "representative or typical case". The latter point also sheds light on the fact that the study's proposed theoretical frameworks are generalizable and applicable to cities beyond Toronto and Canada. In other words, the case study strategy is instrumental (which utilizes a specific case to gain insights regarding a broader issue) instead of intrinsic (which investigates a case as a unique phenomenon) – see Stake (1995) for instrumental and intrinsic case studies.

Additionally, the case study strategy in this research includes all three categories of descriptive, exploratory, and explanatory proposed by Yin (2009) to answer the research questions. I explore specific communities that differentially experience flood risks in Toronto and describe their

everyday struggle for meeting basic needs and their preferences regarding adaptive GBI planning in their neighborhood. At the same time, I operationalize the three-pillared justice framework in a high-risk community to explain the causal patterns that have produced risk inequalities and differential vulnerabilities.

As Yin (2009) proposes, the case study strategy usually relies on multiple sources of evidence. That is why this study deployed a combination of different qualitative and quantitative methods and tactics. The method started with developing a multicriteria model, applicable in any city, that includes indicators and variables for measuring the risk drivers of flood hazard exposure, social vulnerabilities, and the adaptive capacity of urban form (in terms of land uses and town plans). I developed a survey that asked 120 Toronto-based flooding experts to weigh the importance of risk drivers of our multicriteria model and their associated indicators in triggering flood risks in Toronto. I then overlaid the values of the risk drivers and their indicators in ArcGIS, using the experts' assigned weights, to produce a map highlighting the high-risk neighborhoods (in terms of floods) that should be prioritized in future adaptive interventions within Toronto's urban form. Henceforth, I call these neighborhoods "the priority neighborhoods".

The combined method adopted several tactics in one of the priority neighborhoods (Thorncliffe Park). I first conducted semi-structured online interviews with six Toronto-based flooding experts and 14 local neighborhood leaders to unravel if the local knowledge of residents in the priority neighborhood is recognized in previous decisions on adaptive GBI. At the same time, I did an online component using Qualtrics for the priority neighborhood residents, consisting of 199 surveys and 120 participatory mapping activities. The survey gathers local knowledge of neighborhood residents on floods and GBI while the participatory mapping activities ask participants to select on the neighborhood map areas that require GBI for socio-cultural benefits.

Once I completed the participatory component, I did a spatial analysis, using the land-use data prepared by the City of Toronto (2020f) and run-off coefficients proposed by Thompson (2006), to produce a map showing the exposure of different neighborhood spaces to surface run-offs. I then overlayed this run-off map with the map produced by local participants as the result of the participatory mapping activity to create a final map that shows spaces requiring GBI for both run-off management and socio-cultural benefits.

Last, I reviewed relevant policies and programs, including the Toronto First Resilient Strategy (City of Toronto, 2020c), the Flood Resilient Toronto charter (City of Toronto, 2019b), and the Sustainable Neighborhood Action Plan (SNAP) by Toronto and Region Conservation Authorities (TRCA, 2022). The purpose of this review was to support findings in previous stages.

1.4.3 Trustworthiness

I have focused on the four quality standards Guba (1981) proposes for studies with subjective paradigms to ensure the trustworthiness of this research design: credibility, transferability, dependability, and confirmability (Table 2). **Credibility** assures the truthfulness, or the "truth value", of the findings. To demonstrate credibility, Guba (1981, p. 80) and proposes "triangulation" (the use of multiple data sources) and "member checks" (checking findings and interpretations with participants). Accordingly, I have used a combination of data collection techniques (e.g., interviews, surveys, and participatory mapping) while double-checking the main findings of the spatial analysis, surveys, and participatory mapping activities with the local and expert interviewee participants to assure credibility of the research.

Transferability, or generalizability in the objective paradigm, shows to what extent the findings apply to other situations. Guba (1981, p. 80) proposes qualitative researchers provide a detailed and "thick description" of the phenomenon to establish transferability. This research facilitates transferability judgments through a detailed description of the research setting to make sure that other researchers can assess the extent to which my findings apply to their study.
Dependability, which is about the reliability and consistency of finding, assure that repeating the research under the same conditions yield the same findings. To advance dependability, Guba (1981, p. 80) proposes the adoption of an "audit trail", in reference to the detailed documentation of all the processes of data collection, analysis, and interpretation. This study provides a rich description of different research tactics, including spatial analysis, interviews, and surveys, among others.

Last, **confirmability**, or the neutrality of the research, ensures that the researchers' probable biases do not affect interpretations and findings. Data triangulation and reflexibility (see subsection 1.5.1 and the previous paragraph), which both are addressed in this study, can assure confirmability (Guba, 1981, p. 81).

Table 2. Guba's (1981, p. 80 & 81) quality standards and how they are addressed in this study

Quality standards	Criteria for meeting quality standards	How the study meets the quality standards using the proposed criteria
Credibility	"Data triangulation" and "member checks"	Using a combination of data collection techniques and double-checking the findings with participants
Transferability	"Thick description"	A detailed description of the research setting
Dependability	"Audit trail"	Detailed documentation of all the processes of data collection, analysis, and interpretation
Confirmability	"Data triangulation" and "reflexibility"	Using a combination of data collection techniques and shifting back and forth between the findings and theories

1.5 The research Process and structure

The research starts with defining a research problem through a comprehensive review of peer-reviewed literature connecting the climate justice three-pillared framework with urban form adaptation. The review facilitates the identification of empirical and theoretical gaps and trends in the literature. The proposed research design addresses the gaps in the literature by proposing a theoretical framework, which can be operationalized through a conceptual framework with measurable variables and a combined methodology consisting of spatial analysis, surveys, interviews, participatory mapping activities, and policy reviews. This proposed research design, specifically, underscores how one can assess urban form adaptation in terms of climate justice and how urban form adaptation can advance justice-oriented transformative adaptation. Building on the findings, the research yields recommendations for justice-oriented transformative adaptation within the urban form, which are generalizable to any city.

This dissertation follows a manuscript-based format, presenting the above-mentioned processes in three stand-alone manuscripts that either are published or submitted to academic journals. The first manuscript systematically reviews the relevant literature while the second and third operationalizes the theoretical framework in Toronto as the case study. Figure 3 shows how the research process connects to the three manuscripts and research questions while Table 3 entails the list of the manuscript and the conferences and journals they are presented and published/submitted. Figure 4 also shows how each manuscript responds to the dissertation's general objectives.

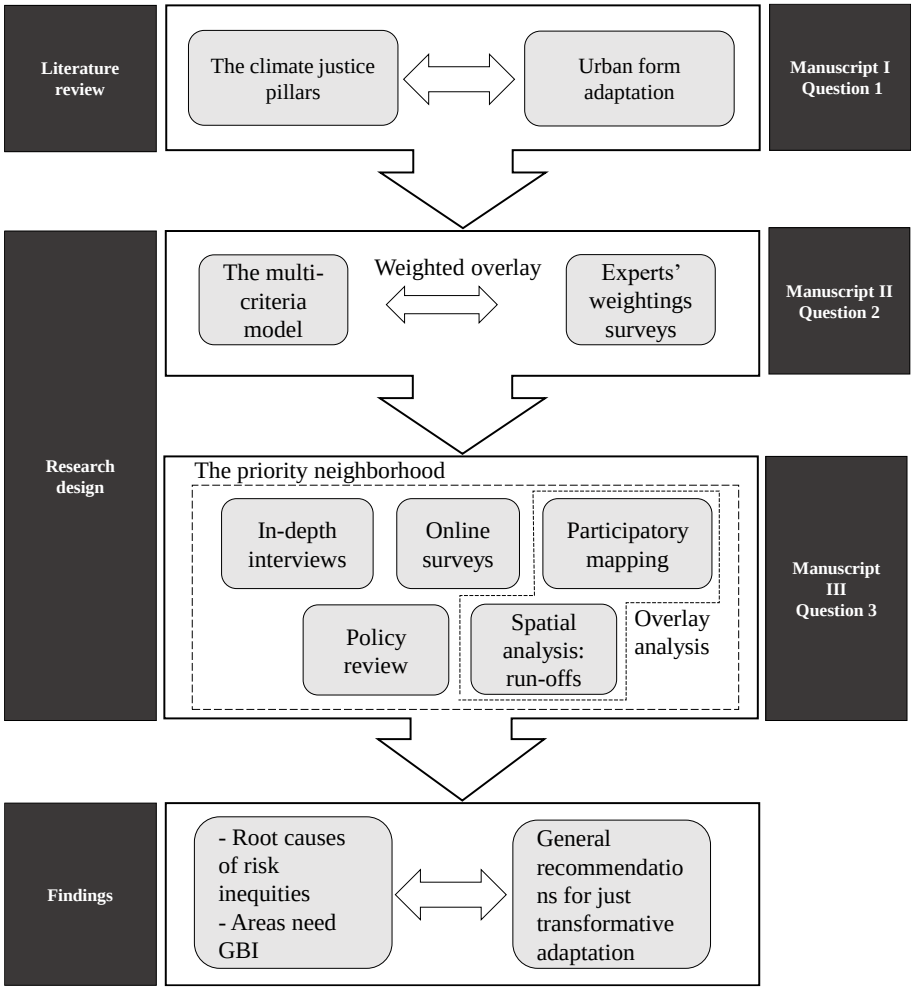

Figure 3. The research process

Table 3. List of manuscripts in this dissertation

Manuscripts	Conference presentations	Journals	
		Journal titles	Status
I. The climate justice pillars vis-`a-vis urban form adaptation to climate change: A review	N/A	Urban Climate	Published
II. Distributive Justice and Urban Form Adaptation to Flooding Risks: Spatial Analysis to Identify Toronto's Priority Neighborhoods	- The International Seminar on Urban Form (2021), South Lake City, USA. - Canadian Association of Geographers (2021), Prince George, Canada.	Frontiers in Sustainable Cities	Published
III. Justice-oriented transformative adaptation to urban floods through green-blue infrastructure planning: Thorncliffe Park, Toronto	- Smart and Sustainable Planning for Cities and Regions (2022), Bolzano, Italy. - The Association of Collegiate Schools of Planning (2022), Toronto, Canada.	Landscape and Urban Planning	Submitted

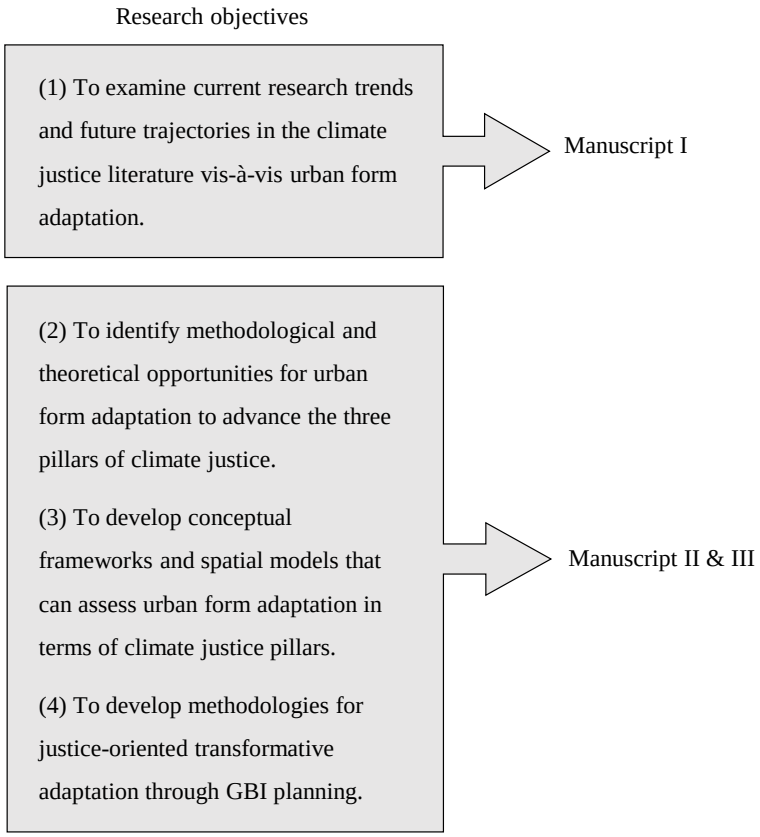

Figure 4. The three manuscripts and the general research objectives they assess

1.6 Dissertation outline

In addition to this introduction chapter (Chapter 1), this dissertation has four other chapters:

- **Chapter 2 (Manuscript I)** reviews peer-reviewed literature on climate justice and adaptation in urban scales to identify how existing studies discuss the climate justice three-pillared framework with regards to urban form adaptation. The results reveal five major omissions: a deficit of empirical applications of climate justice pillars in assessing urban form adaptation; an overemphasis of the literature on normative suggestions/critiques; a dearth of urban design discussions on climate justice; a lack of discussions on recognitional justice; and last, a dearth of studies investigating the justice outcomes of urban form adaptation across multiple spatial/temporal scales.

- **Chapter 3 (Manuscript II)** draws on the interconnections distributive justice has with flood risk drivers of exposures, social vulnerabilities, and the adaptive capacity of urban form to develop a multi-criteria model that assesses "where" the high-risk priority areas are located and "how" urban form adaptation can advance climate justice in the priority areas. The study tests the model in Toronto using ArcGIS, where experts weighted the impact of risk drivers on flood risks in Toronto. Building on the findings, this research proposes future studies, specifically in North America and Europe, to prioritize tower communities with aging infrastructure in adaptive interventions within the urban form.
- **Chapter 4 (Manuscript III)** builds on the interconnections the three-pillared justice framework has with epistemic justice and local experiential knowledge to explore "how" and "why" flood-adaptive GBI planning can exclude vulnerable communities and "how" it can facilitate justice-oriented transformative adaptation. The study focuses on one of the priority neighborhoods (Thorncliffe Park), identified in Manuscript II, as the case study. The methodology includes in-depth interviews, online surveys, online participatory mapping activities, spatial analysis of surface run-offs, and policy reviews. The results show four epistemic barriers that should be addressed for recognizing the residents of deteriorating tower communities in adaptive GBI planning.
- **Chapter 5 (Conclusion)** synthesizes the three manuscripts to demonstrate how this dissertation responds to the research objectives and questions. This chapter describes the research contributions to theory, methodology, and practice while proposing directions for future research based on the limitations.

Chapter 2

Manuscript I: The climate justice pillars vis-à-vis urban form adaptation to climate change: A review

(Published in *Urban Climate*)

Abstract

Indications point to exacerbated socio-economic inequalities and/or the emergence of new ones from climate-adaptive interventions in urban form, such as green and blue infrastructure (GBI), adaptive land uses, and urban design measures. We combine a systematic review and content analysis to review 136 peer-reviewed articles (published between 2008 and 2020) on urban climate justice in adaptation in order to: (1) review the emergence of the discourse on climate justice's pillars (i.e., distributive, procedural, and recognitional justice) vis-à-vis urban climate adaptation; (2) investigate the correlations between climate justice and the adaptive urban form interventions (GBI, adaptive land uses, and urban design measures); and (3) identify the spatial and scalar connections between the climate justice pillars and the adaptive urban form interventions. The findings reveal several trends, including: a deficit of empirical studies that deploy the climate justice pillars for assessing adaptive urban form interventions; an overemphasis on normative suggestions and/or critiques without clarifying "how" to advance climate justice; a dearth of urban design discussions on climate justice; a particular lack of connections between recognitional justice and urban form; and last, a dearth of studies that investigate the justice outcomes of adaptive urban form interventions across multiple spatial and temporal scales.

Keywords: climate justice; climate change adaptation; adaptive urban form interventions; green and blue infrastructure; adaptive urban design measures; adaptive land uses

2.1 Introduction

There are indications that the spatial distribution of climatic risks within cities remains unequal because the vulnerability and exposure of different societal groups to climatic hazards vary based on their socio-economic composition and spatial distribution. Several studies − see: Romero-Lankao and Gnatz (2019), Miller (2020), and Moser and Stein (2011) − argue that

societal groups with high levels of vulnerability and exposure also maintain low levels of adaptive capacities due to embedded patterns of privilege in adaptation responses.

This study investigates the paradoxical outcomes for disadvantaged societal groups of the three most recommended adaptive interventions for urban form, namely: (1) green and blue infrastructure (GBI) that incorporates ecosystem services in urban form to regulate climatic hazards (Coutts et al., 2012; Depietri et al., 2012); (2) adaptive land uses through its triad of protect (against hazards), retreat (from hazards), and/or accommodate (hazards) interventions (Bijlsma, 1997; Scott et al., 2016); and (3) urban design adaptive measures that mitigate climatic hazards through design interventions in the urban landscape (e.g., the street networks and the three-dimensional built-form) (Dhar & Khirfan, 2017b; Holt et al., 2015; Shashua-Bar et al., 2009). Empirical evidence points to the fact that these interventions, despite their adaptation benefits, ensue in unequal outcomes, such as prioritizing the more valuable assets of affluent groups (e.g., high-end real estate) and/or justifying the interests of elite groups (e.g., economic development) (Anguelovski et al., 2019b; Garcia-Lamarca et al., 2021; Kabisch et al., 2016; Long & Rice, 2019; Tan et al., 2015).

To address these inequalities and simultaneously ensure that climate adaptive interventions are implemented, there is a need to balance the three pillars of climate justice (Schlosberg (2001), namely: the distributive justice (i.e., the equity of outcomes through an equitable distribution of adaptive interventions), the procedural justice (i.e., the fairness of planning processes in terms of engagement and inclusiveness), and the recognitional justice (i.e., processes that proactively recognize and tackle rooted inequities) (Chu & Michael, 2019; Miller, 2020; van den Berg & Keenan, 2019). However, the connections between these pillars and urban climate change adaptation, particularly with regard to adaptation interventions in urban form, remain unexplored in the literature. This deficit may be influenced by the relative nascence of the urban climate justice discourse (Bulkeley et al., 2014; Steele et al., 2015), and also that of climate change adaptation through urban form (Dhar & Khirfan, 2017a; Dhar & Khirfan, 2017b). Accordingly, we use the three pillars of climate justice in combination with the adaptive urban form interventions as a theoretical framework for analyzing the literature. Building on this framework, this literature review's three objectives are: (1) to review the emergence of the discourse on climate justice's three pillars vis-à-vis urban climate adaptation; (2) to investigate the correlations between the climate justice discourse and the three urban form adaptation

interventions (GBI, adaptive land uses, and urban design measures); and (3) to identify the spatial and scalar connections between the three pillars of climate justice and the three urban form adaptive interventions. For these objectives, we adopt the methodology developed by (Khirfan et al., 2020) that combines a systematic review and a content analysis of all the English-language peer-reviewed papers published until 2020 that discuss justice in urban climate change adaptation.

The results reveal five major omissions in the literature that warrant further investigation, hence providing direction for future research, namely: (1) The literature's overemphasis on normative suggestions and or critiques without mentioning "how" adaptive urban form interventions may advance climate justice; (2) a deficit in empirical studies that integrate the climate justice pillars in the assessment of adaptive urban form interventions whether before, during, or after their implementation; (3) a dearth in the urban design discussions that tackle climate justice; (4) a failure to establish theoretical and empirical connections between recognitional justice and urban form; and (5) a lack of empirical studies on the multi-scalar dimensions of climate justice as they relate to urban form.

2.2 The theoretical framing

2.2.1 Urban climate justice in adaptation

Justice concerns in urban climate adaptation (henceforth adaptation) ensue from the urgency behind adapting cities, as major engines of global economic development, to climate change (Long & Rice, 2019). Consequently, mainstream climate adaptation policies, in the absence of power balance checks and political representation, either entrench the political-economic patterns of privilege in allocating adaptive resources or use adaptation as a justification for economic development. Such policies further exacerbate the vulnerability and exposure (to hazards) of the already marginalized and disadvantaged and exclude them from the benefits of adaptation while burdening them with its costs (Borie et al., 2019; Bulkeley, 2010; Chu et al., 2017; Hughes, 2013; Long & Rice, 2019; Steele et al., 2012; Tan et al., 2015; Woroniecki et al., 2019). An example of these are adaptive policies that concentrate climate adaptive interventions such as GBI and public services in "exclusive enclaves" for the affluent while excluding marginalized groups from these interventions' benefits of such (Anguelovski et al., 2019b;

Thomas & Warner, 2019, p. 4). Several social justice scholars, including Schlosberg (2001), Fraser (2009), and Young (2011), argue that the unjust outcomes of responses to climate change, such as adaptation, ensue from the absence of at least one of the three inter-connected pillars of justice.

The first distributive justice pillar is concerned the fairness of the outcomes. Building on Rawls (1971) classic definition of justice as the distribution of goods so that they benefit the disadvantaged the most, distributive justice has since expanded to include diverse temporal, spatial, scalar, and topical dimensions. In adaptation, distributive justice pertains to the fair spatial and temporal distribution of the material and social advantages and disadvantages of adaptation responses among urban communities regardless of their diverse socio-economic conditions, adaptive capacity, and political voice (Bulkeley et al., 2014; Chu & Michael, 2019; Eizenberg & Jabareen, 2017).

The second procedural justice pillar relates to the fairness of processes, procedures, and regulations that govern decision-making (Adger, 2006a; Romero-Lankao & Gnatz, 2019). In adaptation, procedural justice relates to the fair inclusion of different needs, values, and interests in climate adaptation-related decision-making processes so that different voices are heard in the allocation and distribution of adaptive resources (Chu & Michael, 2019). This fair inclusion in political processes is rooted in equity in the access to democratic decision-making processes, such as participation, deliberation, and negotiation, among others (Fraser, 2009; Schlosberg, 2001; Young, 2011).

The third recognitional justice pillar tackles the social, political, and economic differences that shape unjust decision-making processes and outcomes, hence, complements the other two pillars of climate justice (Bulkeley et al., 2014; Fraser, 2009; Miller, 2020). Recognitional justice refers to the equal legitimization of all racial, ethnic, gender, cultural, and social identities in adaptation processes and its outcomes. This warrants the identification of historical processes during which patterns of inequality, operation, segregation, vulnerability, and privilege have been and continue to be produced within cities (Chu & Michael, 2019; Miller, 2020; van den Berg & Keenan, 2019).

2.2.2 Adaptive interventions in urban form

The study of urban form, also known as urban morphology, based on the historic-geographical approach, refers to the physical shape of the built-environment and the socio-economic functions and uses (Conzen, 1960; Kropf, 2009). Accordingly, and as proposed by Conzen (1960), urban form consists of three components: the town-plan, the three-dimensional built-form , and the patterns of land and building uses, where town-plan itself incorporates the streets and their networks, the patterns of building footprints, and the patterns of blocks and plots.

Urban form impacts local climate. It is possible to create microclimates, change wind speeds, and control outdoor temperature through the urban form. Urban form has, therefore, been deployed to create urban spaces that are consonant with human health and bodily rhythms (e.g., temperature regulation, natural rhythms, and sensory inputs) (Kleerekoper et al., 2012; Lynch, 1984; Pattacini, 2012). The increase in the frequency of climate-change related severe events and their ensuing hazards (such as storm surges and heat waves) warrant the deployment of urban form as a means of adaptation, whereby adaptation refers to the "The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects" (Noble et al., 2014, p. 838).

This study, specifically, focuses on three interrelated interventions that have highly been used and recommended for the adaptation of urban form (i.e., i.e., the town-plan, land and building uses, and the three-dimensional built form) to climate change due to their flexibility, multi-functionality, and reliability, namely: green and blue infrastructure (GBI), adaptive land uses, and adaptive urban design measures[1]. We have pre-categorized and pre-selected these three interventions based on our review of emerging studies on urban form adaptation to climate change, including, among others: Bijlsma (1997); Lennon et al. (2014); Holt et al. (2015); Berke

[1] In addition to these three urban form interventions, grey infrastructure has also been mentioned by the current studies on urban form adaptation to climate change. Since grey infrastructure was highly criticized due to its lack of flexibility and adaptability to the future change (Depietri & McPhearson, 2017), we opted to exclude it from this study and to include only the interventions that are associated with positive outcomes.

and Stevens (2016); Depietri et al. (2016); Dhar and Khirfan (2017b); Roggema (2014); Sharifi (2019b), Sharifi (2019c), Sharifi (2019a); Li et al. (2020).

Green and blue infrastructure (GBI) refers to an interlinked network of natural ecosystems (e.g., forests, parks, cultivated lands, street trees, wetlands, streams, and lakes) and/or semi-natural ecosystems (e.g., green roofs and urban water features) that when integrated within urban form provide ecosystem services beneficial to humans (Bolund & Hunhammar, 1999; Childers et al., 2015; PLennon et al., 2014). These multifunctional ecosystem services include regulating, supporting, provisioning, and cultural services. Sharifi (2019a) renders ecosystems an encompassing approach for urban climate adaptation (Childers et al., 2015; Depietri & McPhearson, 2017). For example, cultivated lands regulate heat waves through shading and evapotranspiration, support biodiversity through restoring wildlife habitats and nutrition/water cycle, provide food security through crop production, and elevate socio-cultural resilience through social cohesion and educational opportunities (Ahern et al., 2014; Demuzere et al., 2014).

Adaptive land uses relate to specific activities, functions, and arrangements that are conducted in and/or defined for specific urban lands so as to facilitate urban adaptation to climate change and its associated impacts (Anguelovski et al., 2016; Berke & Stevens, 2016; IPCC, 2000). Generally, there are three types of climate adaptive interventions through land use: protect, accommodate, and retreat (Bijlsma, 1997; Butler et al., 2016; Macintosh, 2013). Protecting hazard prone urban spaces against climatic hazards occurs through designating land uses for infrastructure networks (e.g., sea-walls, dikes, and levees against sea-level rise and storm surge) (Lyles et al., 2018) or for natural buffers (e.g., berms against heat and pollution) (Larsen, 2015). Accommodation entails allowing climatic hazards to take their course with minimal impact on human safety and property damage through, for example, recreational land uses adjacent to rivers to temporarily accommodate floods (Doberstein et al., 2019). Last, retreat land uses strategies entail the relocation of urban structures and infrastructure from hazard-prone to safe locations and includes the resettlement of vulnerable populations (King et al., 2016; Scott & Lennon, 2020).

Last, urban design adaptive measures include any morphological, spatial, and/or landscape ecological interventions and/or their associated regulations that enhance urban form’s adaptive

capacity (Dhar & Khirfan, 2017b; Feliciotti et al., 2017; Pattacini, 2012). Morphological and spatial interventions entail changes to the size, area, geometry, orientation, and density of street networks, urban blocks, building footprints, and urban infrastructure as well as changes to the building materials, urban canyon ratio, and geometry of the three-dimensional built forms (Johansson, 2006; Kleerekoper et al., 2012; Norton et al., 2015; Shashua-Bar et al., 2009). They also include modifications to the spatial organization and layout pattern of urban form (streets, blocks, and buildings), such as through polyvalency, heterogeneity, and connectivity in order to increase urban form's ability to absorb shocks, recover from disruptions, and maintain ecosystem services (Cadenasso et al., 2013; Dhar & Khirfan, 2017b; Sharifi, 2019a). Landscape ecological interventions align with GBI through designs that increase ecosystems in the urban landscape and, consequently, their services (Steiner, 2011). For example, water-sensitive urban designs improve thermal comfort, harvest rainwater, manage stormwater runoff, and reuse greywater (Coutts et al., 2012).

2.3 The theoretical framework

The increased implementation of GBI, land use interventions and urban design measures as critical adaptive solutions in the prevalent neoliberal and socially unjust urban contexts has raised serious concerns regarding climate justice in academic and policy arenas (Chu & Michael, 2019; Long & Rice, 2019; Smit et al., 2001). From debates on the impacts of such urban form interventions on increased land values and rents and the ensuing climate gentrification (Anguelovski et al., 2019b; Keenan et al., 2018), to exacerbating disadvantaged groups' vulnerability (Berke & Stevens, 2016; Juhola, 2016), to the displacement of the economically and socially disadvantaged (Brown et al., 2012; Padawangi, 2012) – these concerns have become more frequent in the academic literature over the last decade.

To delve deeper into these connections between the adaptation of urban form to climate change and climate justice, we conduct a review of the literature framed around the three pillars of climate justice (i.e., distributive, procedural, and recognitional) (see Figure 5). Some studies have used the spatial distribution patterns of GBI (Shih & Mabon, 2018), adaptive land uses (Anguelovski et al., 2016), and adaptive urban design measures (Wilson et al., 2008) as spatial yardsticks for assessing climate justice especially, the procedural and recognitional justice in adaptation decisions. Building on these theoretical/ empirical links, the proposed framework

indicates that just adaptation to climate change manifests in urban form through an equitable spatial distribution of GBI, adaptive land uses, and adaptive urban design measures. Such an equitable distribution is rooted in inclusive and participatory decision-making processes that (i.e., procedural justice) that simultaneously legitimize and recognize the needs of those at higher risk[2] from climate change-related hazards (i.e., recognitional justice) (see Figure 5).

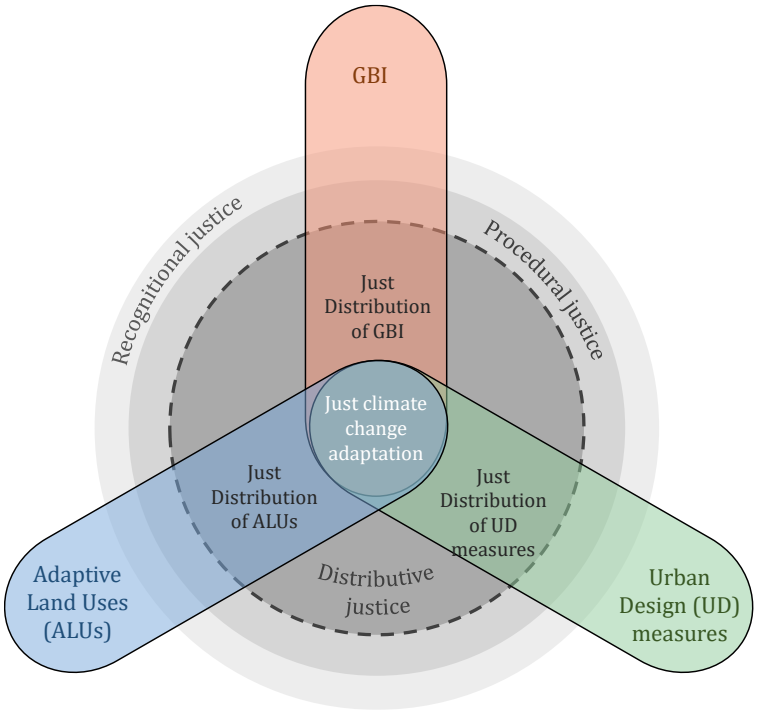

Figure 5. A framework for just adaptation of urban form to climate change

2.4 The methodology

Building on the proposed framework, this literature review follows three objectives: (1) to review the emergence of the discourse on climate justice's three pillars vis-à-vis urban climate adaptation; (2) to investigate the correlations between the climate justice discourse and the three adaptive urban form interventions (GBI, adaptive land uses, and urban design measures); and (3) to identify the spatial and scalar connections between the three pillars of climate justice and the three urban form adaptive interventions. We adapt to the purposes of this study Khirfan et al.

[2] Climate change related risk ensues from high exposure to climatic hazards, increased vulnerability, and decreased adaptive capacity (Carter et al., 2015).

(2020) methodology that combines systematic literature review and content analysis. Such a combination facilitates an accurate, replicable, and biased-free approach to review the majority of the existing sources on a specific topic, and also, to categorize the sources' contents − see Petticrew and Roberts (2006) on systematic review and Elo and Kyngäs (2008) on content analysis.

Our review, as per Khirfan et al. (2020), follows six stages: (1) Determining the research questions; (2) Defining the literature search rules (i.e., the search keywords and the databases) and searching; (3) Identifying the inclusion/exclusion criteria and screening the literature search results accordingly; (4) Deciding on the data that will be extracted (i.e., data types) and collecting the data; (5) Organizing and categorizing the data; and last, (6) Synthesizing and reporting.

The research questions, detailed in Table 4, ensued from the three aforementioned objectives. Using four search engines − Google Scholar, Primo, Scopus, and Web of Science- we conducted the literature search between March and December 2019 for the following combinations of keywords and Boolean operators: "climate change adaptation" AND "urban" AND "justice" OR "equity" OR "equality" OR "fairness". We screened the search results to include only English-language peer-reviewed papers that discuss justice in relation to climate change adaptation at various urban scales (starting from the metropolitan to smaller urban scales). Our search continued until we could no longer find new articles. This search yielded a total of 136 peer-reviewed papers published from 2008 until the end of 2020.

Table 4. The literature review objectives and their associated questions as well as the types of data extracted, and the ensuing categories identified.

Literature review objectives	Questions associated with each objective	The extracted data (data types)	The ensuing categories (with examples)
(1) to review the emergence of the discourse on climate justice's three pillars vis-à-vis urban climate adaptation	When did climate justice and its pillars emerge in the literature? and how has the number of publications change over time?	Publication year	N/A
	How does the literature discuss each of the climate justice pillars? How frequently is each pillar discussed?	The climate justice pillars that are addressed	1. Distributive justice − e.g., Friend and Moench (2013); Barnes (2015); Jenerette et al. (2011) 2. Procedural justice − e.g., Turhan and Armiero (2019); Douglas et al. (2012)

			3. Recognitional justice − e.g., Chu and Michael (2019); Reckien and Petkova (2019)
	What planning topics have the debates on climate justice focused on?	The discussed Planning topics	1. Urban politics and governance – e.g., Bulkeley (2010); Borie et al. (2019); Ziegler et al. (2019) 2. Urban form and physical planning − e.g., Padawangi (2012); Jabeen (2014) 3. Urban risk management − e.g., Doberstein et al. (2019); Graham et al. (2016); Shi (2020a) 4. Natural resources and ecosystem management − e.g., Shih and Mabon (2018); Mahlanza et al. (2016); Leichenko (2011) 5. Urban economy − e.g., Brown et al. (2012); Kuhl et al. (2014); Hughes (2015) 6. Public health − e.g., Bautista et al. (2015); Ebi (2009); Friel et al. (2011)
(2) to investigate the correlations between the climate justice discourse and the three adaptive urban form interventions (GBI, adaptive land uses, and urban design measures)	How do the climate justice debates discuss the adaptive urban form interventions?	The adaptive urban form interventions that are discussed in the literature	1. GBI − e.g., Ambrey et al. (2017); Kabisch et al. (2016); Chu et al. (2017); Anguelovski et al. (2020) 2. Adaptive land uses − e.g., Anguelovski et al. (2016); Kashem et al. (2016); Macintosh (2013) 3. adaptive Urban design measures − e.g., Vargo et al. (2016); Wilson et al. (2008)
(3) to identify the spatial and scalar connections between the three pillars of climate justice and the three adaptive urban form interventions	How, and how frequently, do discussions on each of the climate justice pillars discuss adaptive interventions in urban form? Specifically, do the literature sources advocate for the adaptive interventions to advance climate justice? Or do they criticize the adaptive interventions through the lens of the three pillars?	Any criticisms, suggestions, and /or employment of the adaptive interventions	1. Criticisms − e.g., Steele et al. (2015); Ranganathan and Bratman (2019); Markanday et al. (2019) 2. Suggestions − e.g., Meyer et al. (2018); Shi (2019); Hurlimann et al. (2014) 3. Applications − e.g., Mabon and Shih (2018)
	What spatial scales have the debates on climate justice and urban form focused on?	The tackled spatial scales from the metropolitan to the finer urban grain	1. Micro − e.g., Byrne et al. (2016); Meyer et al. (2018); Mahlanza et al. (2016) 2. Meso − e.g., Anguelovski et al. (2018); Michael et al. (2019); Garschagen et al. (2018) 3. Macro − e.g., Archer and Dodman (2015); Dilling et al. (2019); Aylett (2010)

To answer these research questions, we collected six types of data from each paper, namely: (a) the publication year; (b) the tackled climate justice pillars; (c) the addressed planning topics; (d)

the discussed adaptive urban form interventions; (e) any criticisms, suggestions, and/or employments of the adaptive interventions; and (f) the tackled spatial scales (see Table 4).

Publication years were first collected and recorded in a master spreadsheet. While reading each paper, we color-coded all the phrases on climate justice pillar(s) with three different colors, each indicating one pillar (Figure 6). Since the climate justice pillars are implicitly discussed in several papers, we highlighted all the relevant phrases regardless of whether they use direct terminology (i.e., distributive, procedural, and/or recognitional justice) or implicitly refer to their meanings/definitions. After entering the pillars that each paper is addressing in the master spreadsheet, we re-read the highlighted sections to inductively develop categories for the planning topics and the spatial scales, and to extract the type of adaptive interventions and whether they are suggested, criticized, and/or employed (see Khirfan et al. (2020) on content analysis). Once all categories were generated and transferred to the master spreadsheet, we used Microsoft Excel software to synthesize, correlate, and overlay the data by producing multiple bar charts.

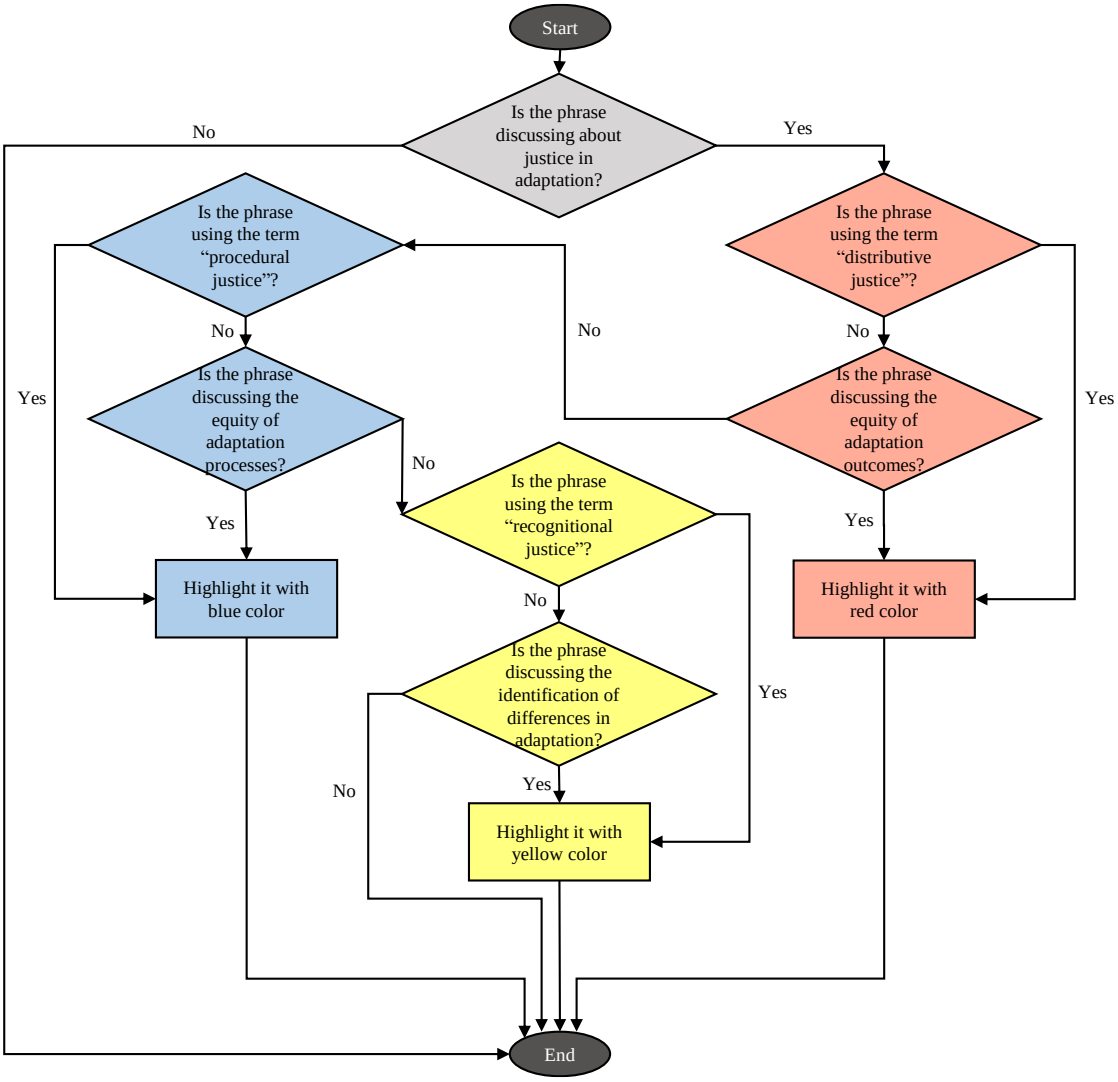

Figure 6. The color coding and data extraction process of the three climate justice pillars from the literature

2.5 The results

2.5.1 The emergence of climate justice and its pillars in urban climate adaptation

The analysis confirms the relative nascence of justice discussions in the urban climate change adaptation literature. This finding is in line with Steele et al. (2015) claim that climate justice emerged in urban literature in the early 21st century. Surely, general discussions of climate

justice in adaptation had appeared since the early 2000s (Adger, 2001, 2006a; Dow et al., 2006; Thomas & Twyman, 2005); however, it was only in 2008 that such discussions specifically focused on the urban context through two peer-reviewed papers (Figure 7), one of which investigated the design of public urban spaces for thermal comfort vis-à-vis socio-economic disparities (Wilson et al., 2008) while the other examined the role of local governance in advancing justice in adaptation (Dodman & Satterthwaite, 2008). Shortly after, from only two publications on justice in adaptation in 2010, there was a notable increase to eight in 2011. This increase may be attributed to Bulkeley (2010) review on urban climate governance that highlighted the need for empirical investigations of the outcomes of climate governance on social and environmental justice (Figure 7).

The analysis in Figure 7 and 4 also reveals that, as early as 2008, the discussions addressed all three climate justice pillars, albeit with unequal attention. In this respect, procedural and the distributive justice have been tackled the most (in 92 and 96 of the 136 articles respectively), while recognitional justice received significantly less attention (discussed in only 48 of the 136 articles). Looking at the discussions over time, it appears that distributive justice had received most of the early attention between 2008 and 2013 (in 21 of the 26 articles published during that period), but a shift occurred between 2013 and 2019 when the debates centered mostly on the procedural justice (in 58 of the 80 articles published during that time). It is highly likely that this increase may be attributed to four notable publications from 2013 on procedural justice in urban climate governance: Castán Broto and Bulkeley (2013), Shi et al. (2016), Bulkeley et al. (2013), and Castán Broto et al. (2013), consecutively cited by 831, 271, 192, and 40 subsequent sources. It was not until 2019 that the recognitional justice discussions witnessed a relatively marked increase, with 11 and 18 articles, respectively in 2019 and 2020 (Figure 7).

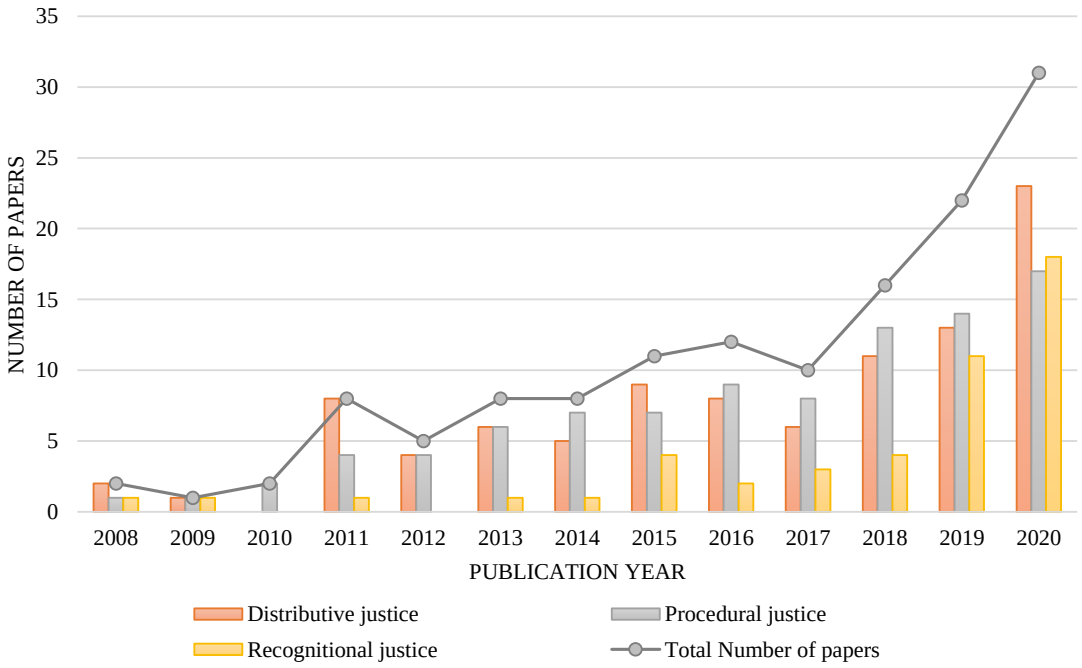

Figure 7. The number of publications per year that discuss the three pillars of climate justice whereby each paper may focus on one or more pillar

Our analysis of the literature's contents reveals that the discussions of the climate justice pillars span six different planning topics, namely: "urban politics and governance", "urban form and physical planning", "urban risk management", "Natural resources and ecosystem management", "urban economy", and "urban public health" (Table 4 and Figure 8). The most discussed topic across the board is "urban politics and governance" as follows: in 58 of the 96 articles on distributive justice, in 75 of the 92 articles on procedural justice, and in 37 of the 48 articles on recognitional justice. In contrast, "urban public health" is the least discussed in only 7 of the 96 on distributive justice, in 4 of the 92 on procedural justice, and in only 2 of the 48 articles on recognitional justice. More importantly, "urban form and physical planning" (which emerged at the outset in climate justice literature – see: Wilson et al. 2008) is the second most discussed topic, appearing in 53 of the 96 articles on distributive justice, in 36 of the 92 articles on procedural justice, and in 17 of the 48 articles on recognitional justice. This topic includes all

the sources discussing the three adaptive interventions in urban form (i.e., GBI[3], adaptive land uses, and urban design adaptive measures). This article, henceforth, investigates the articles of this topic to find spatial and scaler connections between adaptive urban form interventions and climate justice.

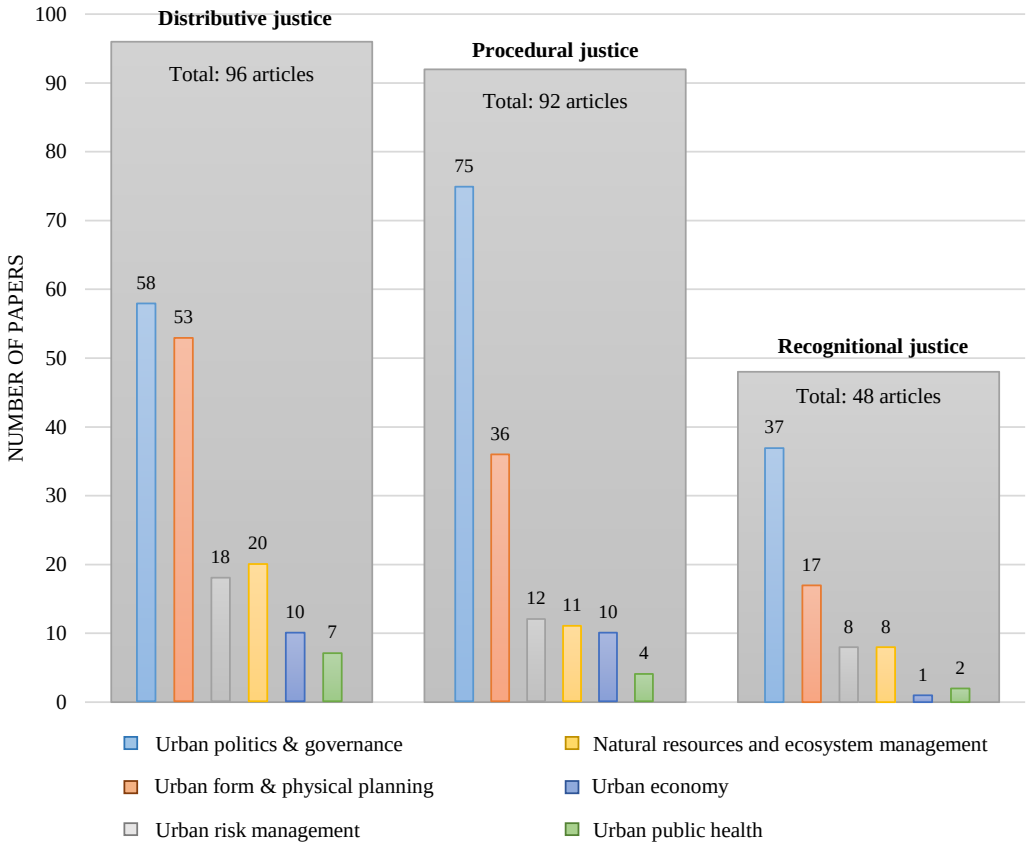

Figure 8. The frequency of sources addressing climate justice pillars and their associated planning topics (note that each paper might tackle more than one climate justice pillar and planning topics)

[3] While some of the literature sources straddle both the "Natural resources and ecosystem management" topic and GBI, in our analysis we distinguish between them. In this article, the reference to GBI includes the literature sources that discuss green/blue infrastructure specifically with regards to urban form as extracted from the content analysis while "Natural resources and ecosystem management" is more encompassing and includes all the literature sources that discuss natural resources and ecosystems in general.

2.5.2 The spatial and scalar connections between the three climate justice pillars and adaptive urban form interventions

Of the 62 articles on the "urban form and physical planning" topic, 43 discuss GBI, 32 discuss adaptive land uses, and only 6 discuss urban design adaptive measures − keeping in mind that each article may tackle more than one adaptive intervention.

2.5.2.1 Spatial connections

Our investigation reveals that the majority of the discussions in these 62 articles on the urban form relate to distributive justice (Figure 8 and Figure 9). Of the 62 articles, only eight empirically apply the climate justice pillars to adaptive urban form interventions, namely: Anguelovski et al. (2019b); Anguelovski et al. (2016); Henrique and Tschakert (2019); Shih and Mabon (2018); Mabon (2020); Hughes (2020); Choi et al. (2020); La Rosa and Pappalardo (2020). These articles, which are all authored by scholars based in the Global North, assess, through the lens of climate justice pillars, projects, plans, and/or policies on GBI and adaptive land uses in cities in both the Global North (e.g., Boston, Detroit and Avola) and the Global South (Medellin, Taipei, and Durban). The methods used to evaluate the justness of adaptation in the Global South case studies are primarily stakeholder interviews/surveys which, in the Global North case studies, are supplemented by spatial analysis probably attributed to the ease of access to spatial data.

Examples of these articles include: Henrique and Tschakert (2019), who integrate the three-pillared justice framework in the surveys of local communities in Sao Paulo (Brazil) to assess the implementation of flood adaptive land uses; Anguelovski et al. (2019b), who assess, through the lens of the climate justice pillars, the conditions before, during, and after the implementation a greenbelt project in Medellin (Colombia) using interviews with local experts; La Rosa and Pappalardo (2020) who investigate, through spatial analysis of Avola (Italy), connections between the performance of implemented sustainable drainage systems for reducing flood hazards and the social groups benefitting from them. Interestingly though, there are only two articles (out of eight) that investigate the how climate justice pillars were considered in land use and GBI projects/plans before implementation. The first of these papers, authored by Shih and Mabon (2018), evaluates, through experts' interviews, an adaptive land use project in the most vulnerable areas of Durban (South Africa). The other, authored by Hughes (2020), confirms,

through interviews with decision-makers and through policy reviews, that legacy cities in the USA (i.e., Detroit, Ohio, Michigan, and Cleveland) considered the connections between the implementation of GBI strategies and climate justice. While these studies highlighted the positive aspects of justice in adaptation initiatives, other studies were more critical.

In fact, most articles (46 of the 62 on urban form and distributive justice) criticize the adverse climate justice outcomes of the three adaptive urban form interventions while only a few (eight of the 62 articles) propose these adaptive urban form interventions as a way for advancing climate justice (Figure 9). Over the next paragraphs we discuss these critiques of, and proposals for, the adaptive urban form interventions through the lens of each climate justice pillar.

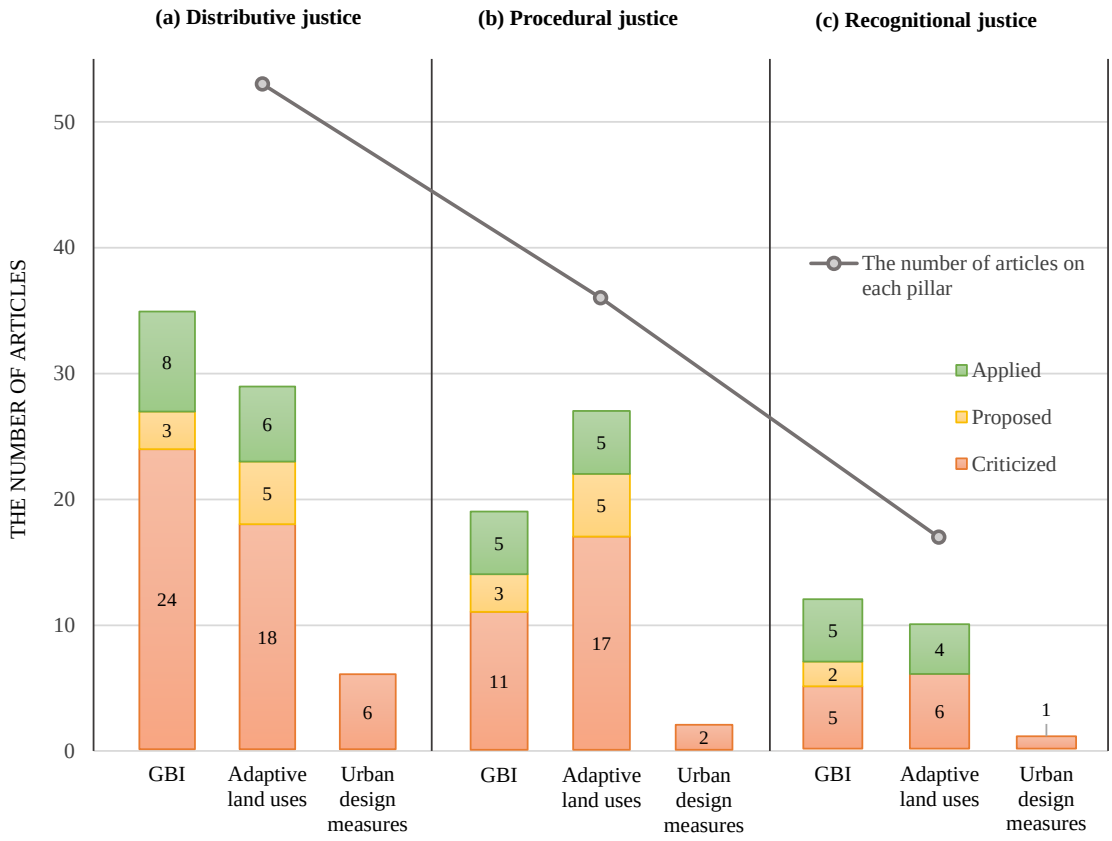

Figure 9. The frequency of the articles that discuss the adaptive urban form interventions vis-à-vis: (a) Distributive justice; (b) Procedural justice; and (c) Recognitional justice (note that each article may focus on multiple urban form interventions and climate justice pillars)

Of the 62 articles, 53 connect the adaptive interventions to distributive justice (refer to Figure 8 and Figure 9, part (a)). Of these 53 articles, seven very briefly suggest GBI and adaptive land uses as means for advancing distributive justice − see for example: Hetz and Bruns (2014), Shi (2019), and (Porter et al., 2020). Furthermore, of these 53 articles, 38 criticize the adaptive interventions in terms of their exclusionary spatial outcomes and their imposition of costs. Specifically, the exclusionary outcomes are rooted in, among other issues, the uneven spatial distribution of adaptive interventions in high-value real estate and central urban districts, while investment in crowded high-density, low-value real estate, and marginalized urban districts remains minimal or non-existent (Anguelovski et al., 2020; Dodman et al., 2019; Friel et al., 2011; Mitchell & Chakraborty, 2018; Romero-Lankao, 2012; Tubridy, 2020). As for the costs, they include climate gentrification, hazard redistribution, and relocation. Climate gentrification ensues from adaptive interventions that increase the real estate values and rents, which consequently, displaces the economically disadvantages groups in society − see, for example: Shokry et al. (2020); Anguelovski et al. (2019b); Brink et al. (2016). Hazard redistribution happens when providing adaptive interventions in privileged spaces relocates climatic hazards to vulnerable areas, such as when flood protective interventions in higher altitude areas directs runoff to low-lying areas − see, for example: Thomas and Warner (2019); Romero-Lankao (2012); Ajibade (2019). Relocation occurs when the disadvantaged groups are forcefully relocated to provide space for adaptive urban form interventions, such as for creating flood-buffer land uses that relocate the inhabitants of urban informal settlements to new sites with limited livelihood opportunities − see, for example: Hetz and Bruns (2014); Doberstein et al. (2019).

Of the 62 articles that discuss urban form, 36 establish connections with procedural justice (see Figure 9 and Figure 9 part (b)). Among these 36 articles, only seven propose that GBI and adaptive land uses should consider the socio-climate justice dimensions of adaptation by using inclusive and collaborative planning processes, such as through participation and engagement of diverse stakeholders, community-based adaptation, and the integration of local ecological knowledge − Hurlimann et al. (2014); Hetz and Bruns (2014); Shi et al. (2016); Ziervogel et al. (2017); Meyer et al. (2018); see: Shi (2019); Porter et al. (2020). These, and other sources, recommend combining such inclusive processes with spatial analytical tools (such as GIS) to identify the social groups most in need of adaptation interventions based on justice concerns (Li

et al., 2020; Shih & Mabon, 2018; Shokry et al., 2020). Conversely, of the 36 articles, 23 criticize how dominant technocratic top-down approaches of governance lead to unfairness in the allocation of adaptive interventions because they entrench the privilege patterns of political-economy and political-ecology (Anguelovski et al., 2020; Bautista et al., 2015; McManus et al., 2014; Tubridy, 2020). The critics, furthermore, indicate that even when inclusive processes are adopted in adaptive interventions, these processes might be dominated by the highly educated and socio-economically affluent who have the time and resources to participate while excluding the less educated, lower income, and marginalized groups (Anguelovski et al., 2020; Chu & Michael, 2019). Expert-led or exclusionary processes lead to discriminatory land use and GBI policies such as those that promote large-scale visible ecological amenities for the purpose of economic development and/or those that create exclusive enclaves for the affluent (Mabon, 2020; Tubridy, 2020). In the cases that policies themselves are not discriminatory, they might be selectively implemented, such as through preventing the economically disadvantaged from building in flood-prone areas while allowing developers to build luxury complexes in the same places (Ajibade, 2019; Meerow & Mitchell, 2017).

Last, 17 of the 62 articles that discuss urban form describe the recognitional justice aspects of adaptive interventions (see Figure 9, part (c)). Of these 17 articles, two propose GBI to address the immediate needs of marginalized groups along with their other adaptation needs without creating new vulnerabilities, such as through community gardens in small-sized green spaces and in abandoned urban spaces that alleviate poverty, produce food, diversify livelihoods, empower vulnerable groups, and promote a sense of place (Porter et al., 2020; Shi, 2020a). Yet, 10 of the 17 articles critique these adaptive interventions centering their critiques on the dominant neo-liberal adaptation policies that entrench the structural patterns of inequality and social vulnerabilities by ignoring the root causes that have historically created subordination, dominance, segregation, and stigmatization (Anguelovski et al., 2020; Eizenberg & Jabareen, 2017; Kashem et al., 2016; Ranganathan & Bratman, 2019; Ziervogel, 2020). The policies ensue in the invisibility of disadvantaged groups in adaptive interventions, which leads to their lack of representation and the misrecognition of their long-term needs, their shifting preferences, and the spaces of their everyday life (Chu & Michael, 2019; Eriksen et al., 2011; Hobbie & Grimm, 2020; Hughes, 2013).

2.5.2.2 Scalar connections

Our analysis unveils that the pillars of climate justice tackle the adaptive urban form interventions at three different spatial scales (Figure 6) that start with the neighbourhood (see for example: Jabeen (2014) and Meyer et al. (2018)), cover multiple neighborhoods (see: Hetz and Bruns (2014) and Hurlimann et al. (2014)), and span an entire city or metropolitan region (see: Sperling et al. (2016) and Tan et al. (2015)). We dub these the micro, meso, and macro scales respectively.

Our analysis of the articles' contents reveals that each climate justice pillar interprets these spatial scales differently. Distributive justice addresses the spatial scales across which the adaptive urban form interventions are spatially distributed, such as Mitchell and Chakraborty (2015) that investigates inequality in heat exposure at the macro (city) scale through the unjust spatial distribution of GBI. Procedural justice considers the various governance levels (scales) through which decisions on adaptive urban form interventions are made. For example, Chu (2018) evaluates the fairness of decisions that are made by local community organizations for infrastructure provision (i.e., at the meso scale). Last, recognitional justice argues that the scales across which people and their associated urban spaces are recognized in adaptation decisions and/or their outcomes. For instance, Anguelovski et al. (2019b) argue that the economically disadvantaged in several neighborhoods adjacent to Medellín's greenbelt (i.e., meso scale) were misrecognized in the decision-making process.

Furthermore, our results reveal that 36 of the 62 articles that connect urban form and the three pillars focus on the macro scale. In contrast, only eight of the 62 articles tackle the micro scale – notably, these articles only discuss the distributive justice (see Figure 6). It seems also that, for the most part, each article exclusively focuses on just one spatial scale. Indeed, only four of the 62 articles explore more than one spatial scale. For example, Mitchell and Chakraborty (2015) and Doberstein et al. (2019) combine the macro and micro scales while Friel et al. (2011) and Lioubimtseva and da Cunha (2020) combine the meso and micro scales.

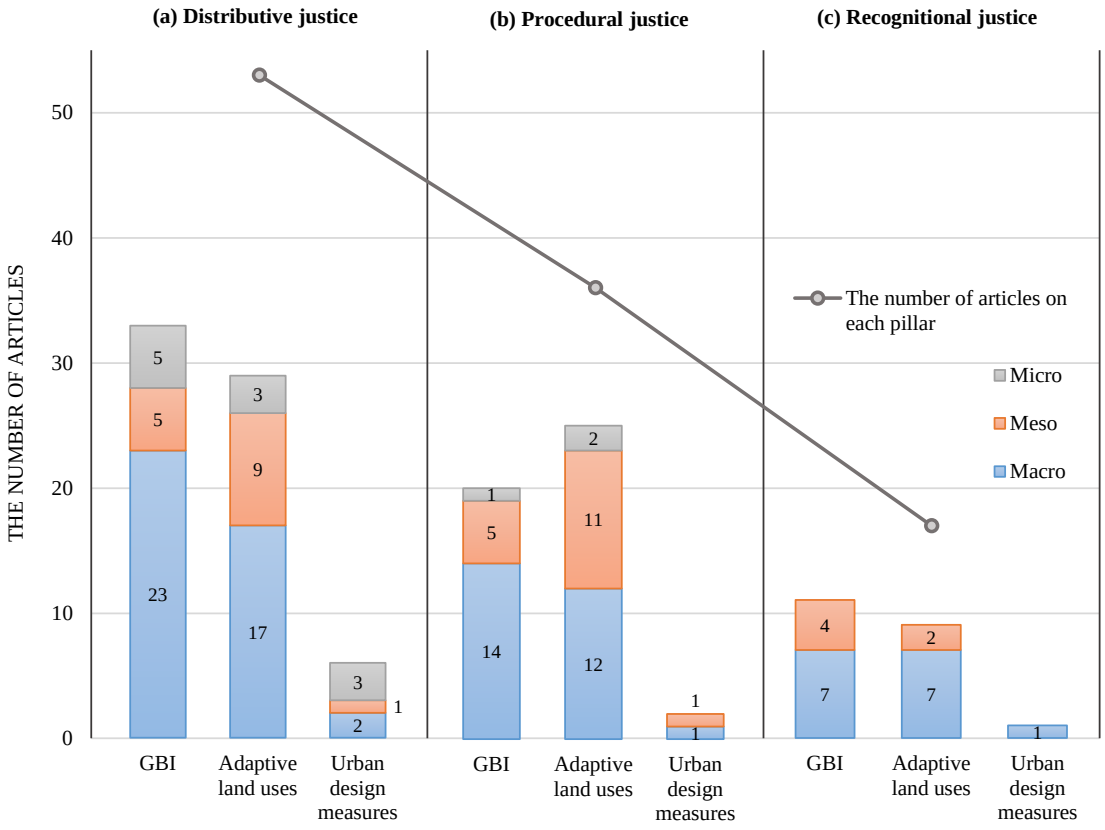

Figure 10. Climate justice debates over the adaptive urban form interventions at multiple spatial scales

2.6 Discussion

The results confirm the growing attention, since 2008, paid in the peer-reviewed literature to the justice outcomes of adaptation (Figure 7). Among the different planning topics discussed in relation to the justice outcomes of adaptation, “urban politics and governance” has received the most attention (discussed in 83 of the 136 articles included in this study). This might be attributed to the increased attention to urban governance in adaptation studies and practices during the last two decades (Bulkeley, 2010; Dhar & Khirfan, 2017a).

More importantly, the results reveal that the physical configuration of cities and urban form are central to the debates on climate change adaptation and climate justice (Figure 8). Indeed, 62 of 136 articles included in this study discuss the connections between the adaptive urban form interventions and climate justice whether briefly, such as: Meyer et al. (2018) and Dilling et al.

(2019), or in detail, such as: Mabon and Shih (2018), Ambrey et al. (2017), and Shi (2020b). This finding, however, does not necessarily indicate that sufficient attention has been paid to the connections between the adaptive urban form interventions and the pillars of climate justice. In this respect, we identify, based on our findings, five major omissions that need to be addressed in future studies.

Firstly, there is a lack of empirical studies that actually deploy the three pillars of climate justice as a basis either to assess the just adaptation of urban form to climate change or to propose ways to achieve just urban form adaptation. To illustrate, only eight articles use the three-pillared justice framework to assess adaptive interventions in urban form (e.g., through surveys, interviews, and spatial analysis) before, during, and/or after their implementation – see: Anguelovski et al. (2019b), Henrique and Tschakert (2019), La Rosa and Pappalardo (2020), Choi et al. (2020), Hughes (2020), and Mabon (2020) on assessments post-implementation, and Anguelovski et al. (2016) and Shih and Mabon (2018) on the assessment before, during, and after implementation; Of these articles, only two confirm that climate justice pillars were considered in adaptive interventions pre-implementation through the use of GIS for the identification of most vulnerable urban areas (see: Shih and Mabon 2018) and through policy tools (see: Shih and Mabon 2018 and Hughes 2020).

Such a deficit of empirical studies might be rooted in theoretical and methodological barriers. Historically, except for a few normative theories of urban form such as Kevin Lynch (1984) Good City Form, there has been a dearth of meaningful engagement and/or amalgamation between theoretical debates on urban form in general, and that of social justice. Considering the nascence of the empirical and theoretical discussions that connect adaptation urban form and urban climate justice, it seems that there is a need for sound theorical frameworks that enable empirical studies to deploy the pillars of climate justice. Other studies' findings confirm this − see: Dhar and Khirfan (2017a), Tubridy (2020), and Anguelovski et al. (2020). Moreover, the scarcity and/or limited access to spatial data, especially in cities in the Global South, presents a methodological barrier for deploying spatial analysis for the assessment of urban form interventions through the lens of the climate justice pillars. Indeed, the two articles (out of eight) that apply spatial analysis to the study of adaptation vis-à-vis the justice pillars actually focus on Global North case studies – see: Choi et al. (2020) on 12 cities in USA and La Rosa and Pappalardo (2020) on Avola (Italy). Living in urban informality and the ensuing informal status

that comes with it, combined with communication barriers that rooted in their historical exclusion from education, also might create other methodological barriers for climate justice researchers when conducting surveys and/or interviews (Chu & Michael, 2019; Fricker, 2007; Padawangi, 2012).

Secondly, and because of the lack of empirical studies, the literature's discussions on adaptive urban form interventions vis-à-vis climate justice fall mostly in the realm of normative suggestions and/or critiques, which center dominantly on the lack of social considerations and technocratic approaches of governance. Accordingly, the literature's discussions on urban form highlight the significance of climate justice but without developing appropriate methodologies for the assessment of adaptive urban form interventions nor clarifying "how" to advance it (Figure 9).

Thirdly, of the three urban form interventions for climate adaptation, there is a dearth of studies that connect adaptive urban design measures and climate justice's three pillars (see Figure 9 and 6), confirmed by Shi et al. (2016). To clarify, only six articles of the 62 on urban form are discussing urban design adaptive measures with regards to their climate justice outcomes – see: Vargo et al. (2016), Byrne et al. (2016), Wilson et al. (2008), Shi et al. (2016), Jabeen (2014), Tubridy (2020). These articles, except Shi et al. (2016) and Jabeen (2014), are project-based studies that briefly criticize the inaccessibility of urban design measures, such as the open spaces, high-albedo materials, street trees, and green space standards, to the racially and economically disadvantaged groups. Like the other urban form interventions, such criticisms center on the purely technical approaches of design and implementation (Byrne et al., 2016; Vargo et al., 2016; Wilson et al., 2008) as well as on the unequal participatory processes (Tubridy, 2020). Despite the strengths of such studies, it is not still obvious under which urban design morphological and spatial conditions (including size, geometry, orientation, and layout patterns of blocks, buildings and streets), would distributive, procedural, and recognitional equities be advanced or threatened. Such a dearth might be due to the fact that the growing debates on adaptation have rarely focused on urban design (Dhar & Khirfan, 2017a). In addition, the limited number of researchers who focus on adaptation through urban design – see: Lennon et al. (2014), Dhar and Khirfan (2017b), and Sharifi (2019b) – barely approach socio-climate justice issues. More importantly, design practitioners generally lag behind the progress in the theories on collaborative and participatory planning and, particularly, in the theories on

socio-climate justice, which indicates a division between theory and practice (Shi et al., 2016). It seems that there is a need for more interactions among the researchers who theorize climate justice, the researchers who, based on empirical studies, propose urban design solutions for adaptation, and urban designer practitioners who implement adaptation interventions.

Fourthly, despite the fact that the recognitional justice appeared since the emergence of the literature in 2008 (Figure 7), there remains a dearth in the studies on recognitional justice, in general, and on its connections with urban form, in particular (only 17 papers connect recognitional justice to urban form adaptation to climate change). Such a deficit might be the result of the relative newness of theoretical debates on recognitional justice. As discussed by Schlosberg (2001) and Young (2011), most social justice theorists such as Rawls (1958) consider social goods as static phenomena, ignoring, in the spatial distribution of public goods, the role of social status and differences, which is rooted in structural domination and oppression.

Lastly, there is a lack of attempts, in the literature, to examine the justice outcomes of adaptive urban form interventions across multiple spatial scales. This finding is proved by only four papers that focus on more than one spatial scale. However, adaptive urban form interventions at one scale may have cascading effects on climate justice at other scales (Blok, 2020; Leichenko, 2011). For example, the allocation of GBI across a metropolitan area, may lead to climate gentrification at the neighborhood scale.

2.7 Conclusion

Through a combined methodology (systematic literature review and content analysis), this study reviewed 136 English-language peer-reviewed articles, published between 2008 and the end of 2020, that discuss justice in urban climate change adaptation. This literature review specifically followed three purposes: (1) to review the emergence of the discourse on climate justice's three pillars vis-à-vis urban climate adaptation ; (2) to investigate the correlations between the climate justice discourse and the three adaptive urban form interventions (GBI, adaptive land uses, and urban design measures); (3) to identify the spatial and scalar connections between the three pillars of climate justice and the three adaptive urban form interventions.

The results reveal that the first discussions of climate justice's three pillars in the peer-reviewed literature on urban climate adaptation emerged in 2008 and spans six planning topics, of which "urban politics and governance" is tackled the most. The results, moreover, show that the

articles tackle at least one climate justice pillar, and also, there are 62 papers that discuss the adaptive urban form interventions. An overlay of the discussions of the climate justice pillars and of the adaptive urban form interventions reveals five major omissions in the literature, namely: a lack of empirical studies that deploy climate justice pillars vis-à-vis discussions and assessments of adaptive urban form interventions whether before, during, and after their implementation; an overemphasis of normative suggestions and/or critiques –i.e., underscoring the need for climate justice without clarifying "how" to advance it through urban form and how to assess urban form adaptations through its lens; a lack of urban design discussions on climate justice; a dearth of studies that connect the recognitional justice to urban form; and last, a deficit of studies that delve into the multi-scalar dimensions of climate justice in adaptive urban form interventions. To address these gaps, we recommend future empirical and theoretical researchers and urban design practitioners to incorporate the climate justice pillars in connection to urban form.

Specifically, we propose that future theoretical studies should establish sound theoretical connections between the three-pillared justice framework and climate change adaptation through urban form and urban design. Central to this connection should be the impact of adaptive urban design morphological and spatial interventions (e.g., through changing the size, geometry, orientation, and layout patterns of the streets and their networks, the buildings and their footprints, and the blocks and plots as well as changing the land and building uses, and the three-dimensional built-form) and their relevant procedures (e.g., technocratic versus inclusive) on distributive, procedural, and recognitional justices/injustices.

We, furthermore, recommend that empirical studies should operationalize and apply the climate justice pillars as a means for advancing climate justice in urban form through developing appropriate methodologies (e.g., spatial analysis, GIS, and on-site measurements). In cities in the Global South, we propose that the barriers associated with the scarcity of spatial data should be tackled through the labor intensive, yet effective, digitization of aerial photographs and satellite images (using tools such as ArcGIS), in situ measurements, and participatory and interactive GIS (which also are inclusive of the local spatial knowledge of different social groups). Such methodologies need to take into account the temporal and scalar dimensions of adaptive interventions by continuously assessing them before, during, and after implementation and through considering their multi-scalar and cascading climate justice consequences.

Last, we stress the need for stronger interactions and knowledge exchange between urban design practitioners and scholars who theorize and/or conduct empirical research on climate justice and urban form adaptation for the purpose of advancing fair (i.e., procedural justice) and inclusive (i.e., recognitional justice) adaptive design processes that achieve just spatial outcomes (i.e., distributive justice).

Chapter 3

Manuscript II: Distributive justice and urban form adaptation to flooding risks: spatial analysis to identify Toronto's priority neighborhoods

(Published in Frontiers in Sustainable Cities)

Abstract

Empirical evidence points out that urban form adaptation to climate-induced flooding events − through interventions in land uses and town plans (i.e., street networks, building footprints, and urban blocks) − might exacerbate vulnerabilities and exposures, engendering risk inequalities and climate injustice. We develop a multicriteria model that draws on distributive justice's interconnections with the risk drivers of social vulnerabilities, flood hazard exposures, and the adaptive capacity of urban form (through land uses and town plans). The model assesses "who" is unequally at-risk to flooding events, hence, should be prioritized in adaptation responses; "where" are the high-risk priority areas located; and "how" can urban form adaptive interventions advance climate justice in the priority areas. We test the model in Toronto, Ontario, Canada, where there are indications of increased rainfall events and disparities in social vulnerabilities. Our methodology started with surveying Toronto-based flooding experts who assigned weights to the risk drivers based on their importance. Using ArcGIS, we then mapped and overlayed the risk drivers' values in all the neighborhoods across the city based on the experts' assigned weights. Accordingly, we identified four high-risk tower communities with old infrastructure and vulnerable populations as the priority neighborhoods for adaptation interventions within the urban form. These four neighborhoods are typical of inner-city tower blocks built in the 20th century across North America, Europe, and Asia based on modern architectural ideas. Considering the lifespan of these blocks, this study calls for future studies to investigate how these types of neighborhoods can be adapted to climate change to advance climate justice.

Keywords: climate justice, urban form adaptation, distributive justice, Toronto, spatial analysis, flood risks

3.1 Introduction

The risks to lives, livelihoods, and property from climate change-related hazards, including floods from extreme rainfall events, is not equal, ensuing from the triad of: spatially differentiated patterns of social- and climate-related vulnerabilities, exposure to hazards, and adaptive capacity where adaptive capacity refers to the ability to cope (Carter et al., 2015; Thomas & Warner, 2019). Empirical evidence shows that the urban form of socially and climatically vulnerable neighbourhoods with high exposure to flooding often maintains low adaptive capacity that renders marginalized groups unable to cope with flood hazards (Anguelovski et al., 2016; Michael et al., 2019). For instance, there is evidence that low-income neighbourhoods contain a higher percentage of impervious surfaces than affluent neighbourhoods due to a lack of green spaces (Bautista et al., 2015; Garcia-Lamarca et al., 2021), leading to their inadequate adaptive capacity.

These risk inequities are rooted in the uneven patterns of urban development based on economic rationales that have long prioritized infrastructure investments in high-value real estate, leading to decades of disinvestments in hazard-exposed and impoverished yet vulnerable neighbourhoods (Herreros-Cantis et al., 2020). The prevalence of climate change further extended the rationales underlying inequities, hence, exacerbated vulnerabilities and exposures through land use planning (Anguelovski et al., 2016), and we argue the town plans' design, where the town plan is defined as the streets and their networks and the arrangements of the building footprints and urban blocks (Conzen, 1960). Henceforth, urban form refers to land uses and the town plan − two of the three Conzen's (1960) urban morphology components. For example, when retreat is adopted as a land use adaptation measure for flood-prone areas, it often entails the forced relocation of marginalized communities to sites far away from their social networks and livelihoods, hence worsening their vulnerabilities (Henrique & Tschakert, 2019).

Despite such unequal outcomes, there is a deficit of empirical studies that propose methodologies to measure how the adaptive capacity (or adaptation) of urban form is connected to the differential vulnerabilities (i.e., different sensitivities to risks), exposures, and risk inequities (Mohtat & Khirfan, 2021). This deficit is attributed to the nascence of theoretical studies that connect urban form with adaptation and adaptive capacity in general (Dhar &

Khirfan, 2017b; Sharifi, 2019c), and with climate justice in particular (Mohtat & Khirfan, 2021).

To identify how adaptation interventions can be distributed to avoid flood risk inequities, hence advance climate justice, this study draws on Rawl's (1971) distributive justice, referring to the just spatial distribution of resources to maximize benefits to the disadvantaged. We operationalize Dhar & Khirfan's (2017b) framework for measuring urban form's adaptive capacity to investigate the spatial distribution of adaptation interventions, hence urban form's adaptive capacity, and explore this adaptive capacity's connections to differential vulnerabilities and hazard exposures. Accordingly, we develop a multicriteria model that includes indicators and variables to identify the spatial distribution patterns of risk drivers: social vulnerabilities, flood hazard exposures, and areas with a low adaptive capacity of urban form. Our model assesses specifically "who" are unequally at-risk to flooding events, hence should be prioritized for adaptation interventions; "where" are the high-risk priority areas located; and "how" urban form adaptive interventions may advance climate justice in these priority areas.

We test this model, which can be applied in any city within Canada and beyond, in Toronto, Ontario, Canada, where there are indications of increased frequency and intensity of flood events combined with the disparities in social vulnerabilies (Feltmate & Thistlethwaite, 2012; Rincón et al., 2018). We aim to identify how social vulnerabilities, flood exposures, and adaptation interventions within the urban form are distributed in Toronto? Based on this, which neighbourhoods are experiencing the highest risks of floods and need to be prioritized in adaptation? And how can we identify these priority neighbourhoods?

To answer these queries, we developed a survey that asked Toronto-based flooding experts to weigh the importance of risk drivers of our multicriteria model and their associated indicators in triggering flood risks in Toronto. We then overlaid the values of the risk drivers and their indicators in ArcGIS, using the experts' assigned weights. The results reveal that flood risks are disproportionately distributed in four tower neighbourhoods with old infrastructure, where low-income, racialized, and migrant populations concentrate, namely: Thorncliffe Park, Flemingdon Park, North St. James Town, and Black Creek.

3.2 From differential vulnerabilities to climate justice in urban form adaptation to flooding risks

Vulnerability, or people's susceptibility to being adversely affected by shocks, stresses, and hazards (Adger, 2006b; Gallopín, 2006), is not equal but differential. Differential vulnerability entails that some social groups undergo greater human, livelihood, and financial losses due to their exposure to stresses and lack of coping capacity (Suarez, 2002; Thomas et al., 2019). Evidence on differential vulnerabilities abounds globally: from the proximity of racial neighbourhoods to contaminated sites and the ensuing negative impacts on the health of their residents in the USA, to the lack of low-income communities' access to potable water and sanitary services, hence, their sensitivity to droughts in the Philippines (Bautista et al., 2015; Porio et al., 2019). Differential vulnerabilities are rooted in the historical capitalist processes of urban development and their embedded domination and oppression patterns that shape inequity in the spatial distribution of urban assets (e.g., housing, land, green space, and infrastructure) and entitlements among socially different groups, whether across income, race, gender, or ethnicity, among others (Michael et al., 2019; Ribot, 2014; Sen, 1982). With the emergence of climate change as an urban crisis, the historical disinvestments in disenfranchised neighbourhoods and the systematic exclusions of the disadvantaged from power structures place vulnerable groups in unsafe living conditions, exacerbating their vulnerabilities and exposures to different hazards, including flooding events (Blaikie et al., 2005; Michael et al., 2019). Additionally, efforts to mitigate climatic hazards, such as through adaptation, align with the uneven historical mechanisms of urban development, prioritizing the protection of urban economies over climate justice through selective investment in vital urban infrastructure and wealth reproduction systems (Long & Rice, 2019, 2020).

3.2.1 Flood risks and climate justice challenges

Changing precipitation rates combined with the increase in the density of urban impervious surfaces, old and overburdened drainage systems, and urban population, particularly in low-lying areas, intensify the risk of loss of lives and livelihoods and damage to properties and infrastructure from rainfall run-off and river flooding events (Faccini et al., 2018; O'Donnell & Thorne, 2020; Sohn et al., 2020). Yet, individuals experience these flood risks differentially, depending on three context-specific risk drivers: social vulnerabilities, low adaptive capacity,

and exposure to flooding hazards. In fact, empirical evidence indicates that social vulnerabilities are associated with inequities in flood hazard exposures and access to adaptive capacity, triggering inequities in the spatial distribution of risks across the lines of race, income, and ethnicity, among others (Herreros-Cantis et al., 2020; Islam & Winkel, 2017; Suarez, 2002).

The uneven processes of urban development have forced marginalized groups with economically precarious and socially unstable conditions to live in deteriorating settlements, prone to power outages and infrastructure failures in the face of hazards (Graham et al., 2016; Walker & Burningham, 2011). Many of these settlements are located in low real estate value and precarious sites, like low-lying areas, floodplains, and industrial zones with impervious surfaces, which increase their exposure to flooding events. The lack of land tenure rights and informality in the Global South and discriminatory policies and zoning laws based on market rules in the Global North have led, over time, to the systematic disinvestment in these vulnerable and flood-prone neighbourhoods (Borie et al., 2019; Chakraborty et al., 2014; Michael et al., 2019). Among the residents of these neighbourhoods are new immigrants with language and employment barriers who lack community connections and citizenship entitlements, including election rights, to influence the formal urban governance structures and local decision-makers; hence, they are often excluded from flood awareness, warning, and management programs (Dodman et al., 2019; Donner & Rodríguez, 2008; Turhan & Armiero, 2019). Additionally, the employment of these vulnerable groups in low-paying service jobs, their everyday struggles for basic needs like food, and their lack of housing ownership render them financially unable to adopt flood protective behavior, such as buying insurance and retrofitting their flimsy settlements (Anguelovski et al., 2020; Herreros-Cantis et al., 2020; Ziervogel, 2020).

With their lack of preparedness, disenfranchised and marginalized vulnerable groups are more at risk of losing life, assets, and income due to flood hazards than the affluent groups in society (Collins et al., 2018; Kim et al., 2018). In addition, they have fewer opportunities for recovery, reconstruction, and relief due to their lack of access to personal wealth and timely and adequate assistance programs such as loans and emergency services (Graham et al., 2016; Rufat et al., 2015; Thomas & Warner, 2019). Hence, their frequent experience of risks worsens their existing vulnerabilities, reproduces new ones, and reduces their capacity to cope with future hazards.

3.2.2 Climate justice challenges in urban form adaptation

Climate change adaptation refers to "the process of adjustment to actual or expected climate and its effects … to moderate or avoid harm or exploit beneficial opportunities" while adaptive capacity is the ability of humans, institutions, and systems to adapt to climatic effects (IPCC, 2014, p. 5). Urban form adaptation entails physical interventions in the built environment and functions to minimize risks by improving the adaptive capacity of urban form to reduce vulnerabilities and exposures, thereby coping with, surviving, and recovering from hazards (Dhar & Khirfan, 2017b). Specifically, improving the adaptive capacity of town plans and land uses can enhance urban form's flexibility to absorb unknown climatic events with uncertain patterns, such as flooding ensuing from extreme precipitations. This improved adaptive capacity can ensure that the urban form maintains its functions and structure, contributing to urban form resilience (Dhar & Khirfan, 2017b; Khirfan & El-Shayeb, 2020).

Khirfan and El-Shayeb (2020) connect urban form adaptation and resilience by drawing on Meerow et al. (2016, p. 39) definition of resilience: "the ability of an urban system-and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity". Accordingly, adaptation (and adaptive capacity) is among the three pathways to resilience, along with persistence and transformation. Framing urban form adaptation under the umbrella of resilient planning has rendered resilience central to flood adaptation policies and projects to enhance the flexibility and adaptability of urban forms to increased rainfall events (Graham et al., 2016; Lennon, 2015; Shi, 2020a; Shokry et al., 2020). This is evident in the shift in land use policies to integrate large-scale green projects that absorb and dissipate rainwater run-off (Anguelovski et al., 2019a; Shi, 2020a) and urban design interventions that incorporate resilient water-sensitive infrastructure in town plans to infiltrate, harvest, and convey rainwater (Matos Silva & Costa, 2016; Watson & Adams, 2010).

Despite its benefits for urban form adaptation to climate change-induced floods, resilient planning risks ignoring the underlying causes behind risk inequities and differences in adaptive capacity, perpetuating the historic uneven processes of urban development (Meerow et al., 2019). In particular, the application of resilience planning as a development agenda in the last

decades has capitalized on branding cities as climate- and flood-adaptive sites to encourage investments by the tourism industry, real-estate developers, and the new sustainability class (Anguelovski et al., 2020; Connolly, 2019; Garcia-Lamarca et al., 2021). The exclusionary controls over the types and locations of investments can exacerbate vulnerabilities, whether through increased land values/rents and ensuing climate gentrification (Chu et al., 2017; Shi, 2020a) or through the forced relocation of marginalized groups to clear space for large-scale projects (Henrique & Tschakert, 2019). Accordingly, enhancing urban form resilience through flood-adaptive land use planning and town plan design risks excluding vulnerable neighbourhoods that already lack sufficient adaptive capacity (Anguelovski et al., 2016).

3.3 Theoretical framing: how to combine urban form adaptation with distributive justice

To investigate how the adaptive capacity of urban form is connected to differential vulnerabilities and exposures to floods, and how urban form adaptation responses should be distributed to advance climate justice, the theoretical framework of this study combines Dhar and Khirfan's (2017b) urban design resilient index (UDRI) and the notion of distributive justice.

3.3.1 The UDRI framework

We draw on Dhar and Khirfan's (2017b) UDRI framework to assess and compare the adaptive capacity of urban form in different urban neighbourhoods to identify the disadvantaged ones whose adaptive capacity is also low. We focus on this framework because it is clear, comprehensive, and generalizable; it is also applicable to (Conzen, 1960). urban form components, particularly land uses and town plans. The framework includes seven concepts that impact the resilience, hence the adaptive capacity, of urban form across functional, spatial, physical, and temporal dimensions; they are: harmony with nature, polyvalency, heterogeneity, connectivity, indeterminacy, latency, and modularity (refer to Table 5 for definitions).

While Dhar and Khirfan (2017b) developed their UDRI framework for measuring the resilience of urban form at the neighbourhood scale, this study applies it at the urban scale − that is, for the entire city. To facilitate this, we draw on only four of the seven concepts in the UDRI, namely: harmony with nature, polyvalency, heterogeneity, and connectivity, for which we found empirical evidence of their application at the city scale (see Table 5). Furthermore, we added a

fifth concept, flexibility, due to the numerous theoretical and empirical debates regarding its application in assessing the general resilience of urban form at the city scale (Freire & Monteiro, 2020; Roggema, 2014; Sharifi, 2019a), particularly with regards to flooding events (Sharifi, 2019c).

While Dhar and Khirfan (2017b) apply their resilient concepts to all the three of Conzen's (1960) urban form components (i.e., land uses, town plans, and three-dimensional built form), we apply the five concepts only to land uses and town plans. Our reason for this is the lack of data and empirical evidence that facilitate measuring the adaptive capacity of the three-dimensional (3D) urban form elements to flood risks at the city scale.

Accordingly, beginning with land uses, we consider that their adaptive capacity can be enhanced through the configurational characteristics of **harmony with nature**, **heterogeneity**, and **polyvalency**. Land uses in **harmony with nature** have a minimal impact on the natural environment and can mitigate climatic hazards by strengthening ecosystem functions. One of the prevalent ways to enhance harmony with nature through land uses for adaptation to flooding is by integrating green and blue infrastructure (GBI). GBI refers to an interconnected network of natural (e.g., lakes, streams, and parks) and semi-natural ecosystems (e.g., community gardens and green roofs) that benefit humans through providing ecosystem services (Bolund & Hunhammar, 1999; Mohtat & Khirfan, 2021). GBI can mimic natural hydrological processes such as infiltration, evapotranspiration, retention, detention, and slow flow (Liu et al., 2019) that collectively promote nature-based solutions for adaptation (IPCC, 2022). Therefore, several studies have introduced GBI as a decentralized approach for managing the excess rainwater and regulating flooding, which can supplement the centralized urban drainage grey infrastructure (Abebe et al., 2018; Li et al., 2020). **Heterogeneous** land uses, through the variation of their types over a spatial unit, facilitate the spread and dissipation of hazards across space. For instance, urban forms that include a rich combination of land use kinds with different porosity (e.g., open spaces, industrial uses, green spaces, and residential uses) are better able to dissipate rainwater run-off (Cadenasso et al., 2013; Dhar & Khirfan, 2017b; Zhou et al., 2017). **Polyvalent** land uses allow a change in functions without significant physical changes to accommodate hazards (Dhar & Khirfan, 2017b). For example, recreational spaces adjacent to rivers can become spaces that temporarily accommodate floods (Macintosh, 2013).

As for town plans, we consider that their adaptive capacity increases when they are **flexible** and **connected**. **Flexibility** refers to the urban form's ability to integrate future changes and interventions for adaptation; hence, it bears some similarities with Dhar and Khirfan's (2017b) latency and indeterminacy concepts (Table 5). **Flexibility** and **connectivity** often go hand in hand. **Flexible** town plans facilitate accommodating adaptive interventions and incorporating land modification regulations. For example, integrating green spaces, in fined-grained urban blocks is easier and more cost-effective than in large-grained ones with little connectivity (Salat, 2017; Sharifi, 2019a, 2019c). **Connectivity** enhances the town plans' permeability by increasing the contact between blocks with streets. It, therefore, accelerates access to buildings and emergency management in the advent of intense rainfall events leading to run-off flooding (Sharifi, 2019b; Sharifi & Yamagata, 2014).

Table 5. The UDRI framework adapted from Dhar and Khirfan (2017b, p. 83 & 84) and the concepts from this framework that this study uses.

The UDRI framework (Dhar & Khirfan, 2017b)			Evidence on how to apply concepts to:					The concepts used in our theoretical framework		
			Urban form application						Urban form application	
Concepts	Definition	Examples	Town plans	Land uses	3D built form	City-wide scales	Sources	Concepts	Town plans	Land uses
Harmony with nature	The organization of urban form to minimize impacts on the environment while strengthening natural ecosystems to absorb risks.	GBI and natural elements that can minimize urban imperviousness.	✓	✓	✓	✓	(Li et al., 2020; Meerow & Newell, 2017)	Harmony with nature		✓
Polyvalency	The ability of urban form to serve diverse functions during and after disasters.	Multi-purpose open spaces that can provide space for temporary shelters after a disaster.	✓	✓	✓	✓	(Roggema, 2014; Sharifi, 2019a)	Polyvalency		✓

Heterogeneity	The separation of urban form components to dissipate risks.	A mixture of different land cover types across a spatial unit that can spread out run-offs.	✓	✓	✓	✓	(Cadenasso et al., 2013; Zhou et al., 2017)	Heterogeneity		✓
Connectivity	The ability of urban form components to hierarchically be connected to facilitate emergency management	Well-connected street networks that facilitate emergency rescue.	✓	✓	✓	✓	(Sharifi & Yamagata, 2014)	Connectivity	✓	
Indeterminacy	Urban form organization, including determined and non-determined morphological elements, which leaves a variety of possibilities to cope with unknown functional, spatial, and environmental changes.	Vacant spaces that accidentally are created from intersections among street networks can be used to function as bioswales.	✓	✓	✓		Not found	Flexibility* (the additional concept)	✓	
Latency	Design opportunities that enable urban form to accommodate different uses to cope with uncertainty.	Adequate spaces adjacent the streets that can be used as a shelter.	✓	✓	✓		Not found			
Modularity	A modular urban form can group and control different parts, facilitating modifying the parts affected by a shock without affecting others.	Modular-shaped housing units, which facilitate their retrofit after disasters.	✓	✓	✓		Not found			

3.3.2 Distributive justice

Distributive justice refers to the just spatial/temporal distribution of resources to maximize benefits to the most vulnerable (Adger, 2006a; Rawls, 1971; Shi et al., 2016). Building on Rawls (1971) liberty and maximization rules, distributive justice gives those with the greatest needs the right to equal access to resources and the priority in their spatial allocation (Adger, 2006a; Sen, 1992). We draw on the distributive justice notion to identify how different the neighbourhoods' urban forms are shaped in terms of the five resilience concepts, how social vulnerabilities and exposures are distributed, hence how we can remedy flood risk inequities.

Accordingly, our theoretical framework indicates that the residents of neighbourhoods at a high risk of floods are most in need of adaptation, deserving to be prioritized in the decision around adaptive urban form interventions.

3.3.3 Theoretical framework

Our theoretical framework connects these disparate notions whereby the identification of high-risk neighbourhoods ensues from the simultaneous presence of four flood risk drivers: (1) exposures to flooding hazards; (2) social vulnerabilities; (3) low adaptive capacity of land uses; and (4) low adaptive capacity of town plans. Drawing on our interpretation from the UDRI framework, we assess the adaptive capacity of land uses based on their degree of harmony with nature, heterogeneity, and polyvalency while evaluating the adaptive capacity of town plans in terms of their connectivity and flexibility.

3.4 Methodology

To operationalize our theoretical framework, our methodology starts with developing a conceptual framework that includes indicators and variables for measuring the four flood risk drivers (hereafter, we dub this conceptual framework "the multicriteria model"). We then conduct overlay analysis in ArcGIS using the experts' assigned weights.

3.4.1 Conceptual framework: our proposed multicriteria model (MM)

Several studies propose multicriteria models (MM) to identify the spatial distribution of flood risks and their drivers, hence the priority areas for adaptation responses. In most existing studies, MMs include physical factors that cause flood hazards and exposures, such as slope, elevation, rainfall, and soil types (Lin et al., 2019; Ogato et al., 2020). However, less attention is paid to the unequal spatial distribution of adaptation interventions, hence differences in the adaptive capacities of land uses and town plans across neighbourhoods and their connections to differential vulnerabilities and exposures. The few empirical studies that connect urban form adaptation with differential vulnerabilities and flood exposures also consider the unequal access of vulnerable groups to GBI so as to identify priority areas for just adaptative interventions– see Meerow and Newell (2017) and Li et al. (2020). However, they overlook frameworks like the UDRI that take into account the configurational characteristics of resilient urban form

Thus, we operationalize our theoretical framework to address this deficit by proposing a MM whose indicators and variables tackle the spatial distribution of four co-existing risk drivers: (1) flood hazard exposures; (2) social vulnerabilities; (3) low adaptive capacity of land uses (due to a lack of harmony with nature, heterogeneity, and polyvalency); (4) low adaptive capacity of town plans (due to a lack of flexibility and connectivity) – see Figure 11 and Table 6. Our MM, in total, includes 38 variables, which measure 15 indicators per neighbourhood as the unit of analysis, whereby the City of Toronto has defined the neighbourhood's boundaries since the 1990s to facilitate collecting data, planning, and analysis[4] (City of Toronto, 2019a). All the variables are mapped in ArcGIS. We normalize the variables' values from zero to ten (using linear scale transformation) to make them comparable to and combinable with each other (Li et al., 2020; Lin et al., 2019; Meerow & Newell, 2017). We calculate the average of variable values to map each indicator. The following sections explain in detail each risk driver's indicators and variables and the data sources.

[4] The City of Toronto consists of 25 wards and 140 neighborhoods. While each ward includes a number of neighborhoods, it is essential to underscore that, in some cases, the ward boundaries do not always align with their associated neighborhoods.

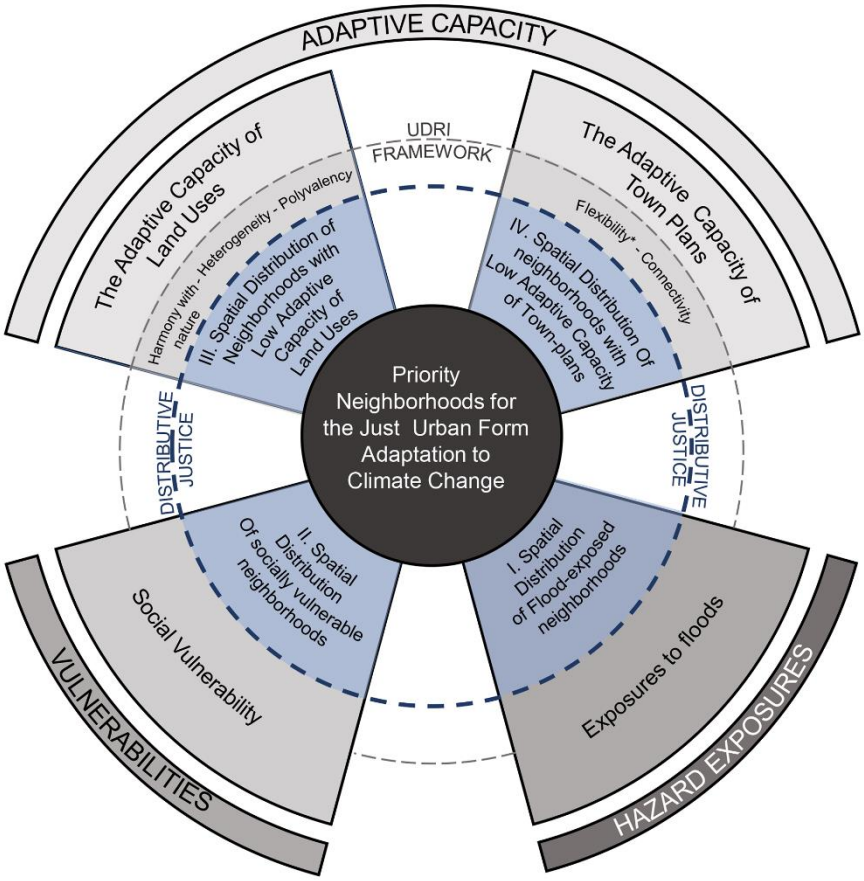

Figure 11. The theoretical framework. *Flexibility is not included in the UDRI framework.

Table 6. The multicriteria model including the major risk drivers and their associated indicators and variables. *Flexibility is the additional fifth concept of our theoretical framework.

risk drivers	Indicators	Variables (per neighbourhood)	(+) or (−) relationship with risks	Data sources
I. exposure to flood hazards	Proximity to floodplains	The percentage of lands covered by floodplains	+	(TRCA, 2020b)
	Run-off coefficients	The Run-off coefficients of land use categories (Table 7)	+	(City of Toronto, 2020f)
II. social vulnerabilities	Age	The percentage of people who are 19 years old and under	+	(City of Toronto, 2019a)
		The percentage of 65 years old and above population	+	
	Gender	The percentage of females (15 years old and above) who participate in the labor force a	+	
		The percentage of female people	+	
	Wealth	The percentage of the low-income population	+	
		The percentage of households spending 30% and more of their income on shelter costs	+	
		The percentage of Renter households	+	
	Ethnicity, race, and immigration status	The percentage of visible minorities b	+	
		The percentage of the population with the first generation c status	+	
		The percentage of people with aboriginal identity d	+	
		The percentage of recent immigrants (those who have obtained their landed immigrant or permanent resident statuses between 2011 and 2016)	+	
		The percentage of people with no knowledge of official language (English or French).	+	
	Employment status	The percentage of male people who are not in the labor force e	+	
		The percentage of **unemployed** [f] individuals	+	
	Family structure	The percentage of **single-parent** families	+	
		The percentage of **Couple census families** with three children and more	+	
		The percentage of persons living **alone**	+	
	Education	The percentage of people (25 to 64 years old) who have **no certificate, diploma, or degree** (including high school diploma)	+	

		The percentage of people (25 to 64 years old) whose highest degree is a secondary (high) school diploma or equivalency certificate.	+	
III. The adaptive capacity of town plans	Built-environment conditions	The percentage of households living in homes with need for **major repair**	+	
		The percentage of households with **more than one person** per room	+	
		The percentage of Labour Force (above 15) whose main mode of **commute** to work is **public transportation** [g]	+	
		The percentage of **movers** (people who have lived in another area and have moved here since 2015 or less)	+	
		The percentage occupied private dwellings built **before** the **1980s** [h]	+	
		Population density	+	
	Flexibility	The average size of blocks	+	(City of Toronto, 2020b)
		The average size of building footprints	+	(City of Toronto, 2020a)
	Connectivity	The average density of street networks' intersections	−	(City of Toronto, 2020b)
IV. The adaptive capacity of land uses	Harmony with nature	The percentage of lands allocated to **green spaces**	−	(City of Toronto, 2020f)
		and blue spaces	−	
		The density of **street trees** per square meter	−	
	Polyvalency	The percentage of lands covered by **open spaces**	−	
		The percentage of lands covered by **mixed land uses**	−	

The heterogeneity of land uses	Total number of land use patches		–
	The number of different patches (patch richness)		–
	The average frequency of different patch types	The number of **Commercial** patches	–
		The number of **Commercial Residential** patches	–
		The number of Commercial Residential Employment patches	–
		The number of **Residential** patches	–
		The number of **Open Space** patches	–
		The number of **Institutional** patches	–
		The number of **Employment Industrial** patches	–
		The number of Utility and Transportation patches	–

[a] Structural gender inequality causes female workers to suffer more than their male counterparts from unstable working conditions and low income (Kalev and Deutsch, 2018), reducing their access to assets to cope with risks.

[b] Visible minority refers to "persons, other than Aboriginal peoples, who are non-Caucasian in race or non-white in color" (Chakraborty et al.,2020, p. 4).

[c] First generation refers to "persons born outside Canada. For the most part, these are now, or once were, immigrants to Canada" (Chakraborty et al.,2020, p. 4).

[d] Aboriginal identity relates to "persons who are First Nations (North American Indian), Métis or Inuk (Inuit) or those who are Registered or Treaty Indians or those who have membership in a First Nation or Indian band" (Chakraborty et al.,2020, p. 4).

[e] Male not in the labor force refers to male persons "who are unwilling or unable to offer or supply labor services under conditions existing in their labor markets (including persons who were full-time students currently attending school)" (Statistics Canada, 2008). Many cultures consider males as the main persons who financially support families.

Therefore, this variable can indicate the unfavourable financial condition of households, which reduces their access to adaptive resources.

[f] Unemployed persons are those "without work, are available for work and are actively seeking work" (Statistics Canada, 2008).

[g] Flooding events can damage public transportation infrastructure (such as subways), leading to the closure of public transit systems and delays (Nirupama et al,. 2014) and adversely affecting those who depend on them.

[h] The Canadian building codes before the 1980s were not strict enough to include emergency conditions (Archer, 2003).

3.4.1.1 Exposure to flood hazards

To identify the exposure of each neighbourhood to flood hazards, our MM proposes two indicators: “proximity to flood plains” (Chakraborty et al., 2014; Lyu et al., 2016) and “run-off coefficients” (Li et al., 2020; Meerow & Newell, 2017; Thompson, 2006). We measure the proximity to floodplains by calculating the percentage of land covered by floodplains in each neighbourhood using the Floodplain Mapping Index data (TRCA, 2020b) and the Intersect Analysis tool in ArcGIS. We estimate the average Run-off coefficients for each neighbourhood, using Thompson's (2006) rational method (see also Li et al. (2020)). We first estimate the average area of lands covered by land use categories in the rational approach, using the land use data (City of Toronto, 2020f) and the Intersect Analysis tool in ArcGIS (Table 7). We then multiply the percentage values with their relevant coefficient amount to calculate the average estimated amount for each neighbourhood.

Table 7. The run-off coefficients (Thompson (2006), and Li et al. (2020))

Land use categories	**Coefficient**
Utility and transportation	0.85
Industrial	0.8
Multi-family and apartment residential	0.65
Commercial	0.6
Institutional	0.6
Single family residential	0.4
Open spaces	0.2

3.4.1.2 Social vulnerabilities

We adopt Chakraborty et al.'s (2020) social vulnerability index to measure the vulnerability of Canadians to floods. Chakraborty et al. (2020) developed this index's indicators and variables based on theoretical debates, policy documents, and Canadians' demographic characteristics across census tracts. They used several statistical approaches to assure the index's generalizability, validity, and replicability. Hence, it is reliable enough to represent Canadians' socioeconomic characteristics, making it an appropriate tool for measuring social vulnerabilities across Toronto in this study. Accordingly, we consider “age”, “gender”, “wealth”, “ethnicity, race, and immigration status”, “employment status”, “family structure”, “education”, and “built-environment conditions” as social vulnerability indicators (see the full list of indicators and variables in Table 6). We extract all the variable values from the Neighbourhood Profiles, which the City of Toronto has built based on the 2016 census data (City of Toronto, 2019a).

3.4.1.3 The adaptive capacity of land uses

As our theoretical framework indicates (Table 6), when it comes to assessing the adaptive land uses, this study draws on the three indicators of “harmony with nature”, “polyvalency”, and “heterogeneity” (Table 6).

Dhar and Khirfan (2017b) have proposed that the larger the amounts of land covered by natural porous surfaces, such as GBI, the higher harmony with nature of land uses. Thus, we consider the percentage of land covered by green and blue spaces and the density of street trees to measure the harmony with nature and the adaptive capacity of land uses.

To measure heterogeneity, or the spatial differentiation of land uses, we calculate the values of variables proposed by Cadenasso et al. (2013) per neighbourhood. These variables include: (1) the number of land use patches; (2) patch richness, in reference to the number of different land use patches such as commercial, residential, and institutional; (3) the frequency of different patch types, referring to the number of times each land use patch appears in the urban landscape (Table 6). Note that the more the variables' values, the higher the urban form's ability to spread and mitigate climatic hazards like floods.

Several studies have referred to open spaces and mixed-use developments as polyvalent (or multifunctional) land uses that can accommodate floods and provide space for erecting

emergency shelters (Macintosh, 2013; Roggema, 2014; Sharifi, 2019a). Therefore, we consider the percentage of areas covered by these land use types per neighbourhood as variables to measure polyvalency.

For all the indicators, we use the Zoning By-Law data provided by the City of Toronto (2020f). We use the Intersect Analysis and Summary Statistics tools in ArcGIS to map all the indicators. In addition, the Dissolve and Merge tools in ArcGIS are used for analysing the third indicator.

3.4.1.4 The adaptive capacity of town plans

Building on our theoretical framework, we draw on two indicators of "flexibility" and "connectivity" (Table 6) to measure the adaptive capacity of town plans.

Sharifi (2019a) and Salat (2017) proposed that fine-grained blocks and building footprints are more flexible than large-grained blocks to accommodate changes, such as through small-scale adaptive interventions for incremental adaptation at a lower cost. Furthermore, they can accelerate emergency responses in the advent of flooding disasters by providing opportunities for multi-use developments and enhancing access points at street edges. Thus, we compare the flexibility of town plans in different neighbourhoods by calculating the average size of their blocks and building footprints, whereby the smaller the size, the higher the flexibility.

Dhar and Khirfan (2017b), Feliciotti et al. (2016), and Sharifi and Yamagata (2014) argue that the connectivity of town plans promotes the accessibility of blocks and buildings through street networks, thus facilitating evacuation planning, emergency search, and rescue activities in the advent of flooding disasters. As Feliciotti et al. (2016) proposed, the higher the number of three- and four-way intersections, the higher the connectivity. Therefore, we use the average density of street networks' intersections per neighbourhood as the variable for measuring the connectivity of town plans; in other words, the higher the density, the higher the connectivity.

For both indicators, we use the data provided by the (City of Toronto, 2020b, 2020d). Furthermore, we use ArcGIS for the Intersect Analysis and Summary Statistics tools to produce the indicators' maps (Table 6).

3.4.2 Weighted overlay analysis through ArcGIS

Since risks result from intersections among multiple drivers with unequal importance, the existing GIS-based multicriteria approaches on flood risk mapping often involve weighted overlay analysis. Qualitative and mixed-method research studies like this one often use experts' judgments for weightings such as through different approaches of rating and ranking – see: Li et al. (2020), Rincón et al. (2018), Meerow and Newell (2017). This weighting approach facilitates quantifying immeasurable data and responds to the challenges of data scarcity (Lin et al., 2019; Wang et al., 2011).

For this study, we conducted an online survey (using Qualtrics) to seek the experts' opinions regarding the weights of flood risk drivers (Figure 11) and their associated indicators (Table 6). Our survey population comprised Toronto-based planning experts who have experience in at least one of the fields of urban flood management, climate change adaptation, and/or adaptive urban form. We found these experts through a systematic search on Google, LinkedIn, and LinkedIn Premium. Our search yielded 392 relevant experts, working variously in four academic, 13 non-governmental, 27 governmental, and 44 private organizations. We shared the survey link with these experts through email and/or LinkedIn messaging from April to the end of June 2021. The survey eventually yielded 120 responses (31% response rate).

To ask the survey participants to weigh the flood risk drivers, we draw on the Analytic Hierarchy Process (AHP), which is a rational, accurate, cost-effective, and easy-to-use approach for measuring the importance of immeasurable elements through pair-wise comparisons (Lin et al., 2019). First proposed by Saaty (1990) for quantifying the weights of decision criteria, AHP became a popular approach for subjective evaluation of flood risk drivers in GIS overlay analysis – see: Ogato et al. (2020); Lin et al. (2019); Li et al. (2020). Building on this approach, we asked the expert participants to pair-wisely compare the relative importance of the four risk drivers regarding the exacerbation of flood risks in Toronto with a scale that ranges from 1 (equal importance) to 9 (extremely more important) – see Saaty (1990) and Figure 12.

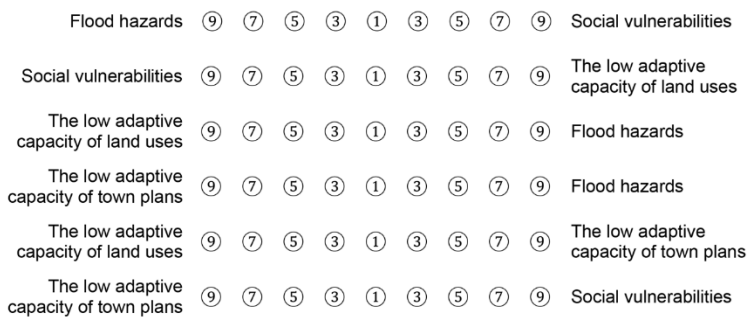

Figure 12. Concepts' weightings through AHP approach

To interpret the data, we create a pair-wise comparison matrix (i.e., $[\mathbf{C}]$) for each participant based on the fundamental AHP scale suggested by Saaty (1990):

$$[\mathbf{C}] = \begin{bmatrix} 1 & c_{12} & c_{13} & c_{14} \\ c_{21} & 1 & c_{23} & c_{24} \\ c_{31} & c_{32} & 1 & c_{34} \\ c_{41} & c_{42} & c_{43} & 1 \end{bmatrix} \quad ; \quad c_{ij}c_{ji} = 1 \tag{1}$$

where c_{ij} represents the scale preferred by participants for the importance of concept i over the concept j. We then divide the components of the pair-wise comparison matrix $[\mathbf{C}]$ by the summation of each column to calculate the normalized matrix $[\mathbf{M}]$:

$$[\mathbf{M}] = m_{ij} = \frac{c_{ij}}{\sum_{k=1}^{4} c_{kj}} \tag{2}$$

where m_{ij} is the component of the normalized matrix. We eventually obtain the weight of the i^{th} concept ($1 \leq i \leq 4$) as the average of each row in the normalized matrix:

$$W_i = \frac{1}{4}\sum_{j=1}^{4} m_{ij} \tag{3}$$

To evaluate the consistency of the survey responses, the Consistency Index ($C.I.$) is calculated as follows:

$$C.I. = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

where λ_{max} is the maximum eigen value of the pair-wise comparison matrix $[\mathbf{C}]$ and n is the number of concepts that are compared (i.e., $n = 4$). According to Saaty (1990), a consistent

matrix has a Consistency Index of less than 10% of the Consistency Ratio ($C.R.$) ; where the value of the $C.R.$ for a matrix with the size of four is proposed to be 0.9 by Saaty (1990). Considering these consistency criteria, we filter the responses and calculate the weight of concepts corresponding to each participant. The final weights of concepts are the average of weights obtained for each participant.

While AHP approach is reliable for weighting the four risk drivers, it may become a lengthy task for weighting the 16 indicators due to a large number of pair-wise comparisons (Li et al., 2020). Accordingly, we measure the weights of indicators through direct rating (DR) where expert participants assigned a weight (from 0 to 10) to the impact of indicators on each risk driver – see Yang et al. (2011) and Bottomley and Doyle (2001) on DR. The final weight of each indicator is the average of weights assigned by all the participants.

Using the weights assigned by the experts, we began our overlay analysis in two steps: overlaying the indicator maps to map their associated concepts and overlaying the risk drivers' maps to draw the final flood risk map. We used the Union Analysis tool and the weighted sum average function in ArcGIS to complete the weighted overlay analysis for both steps. Note that all the concepts and the final risk map values are normalized from 0 to 10, using linear scale transformation (see Figure 13).

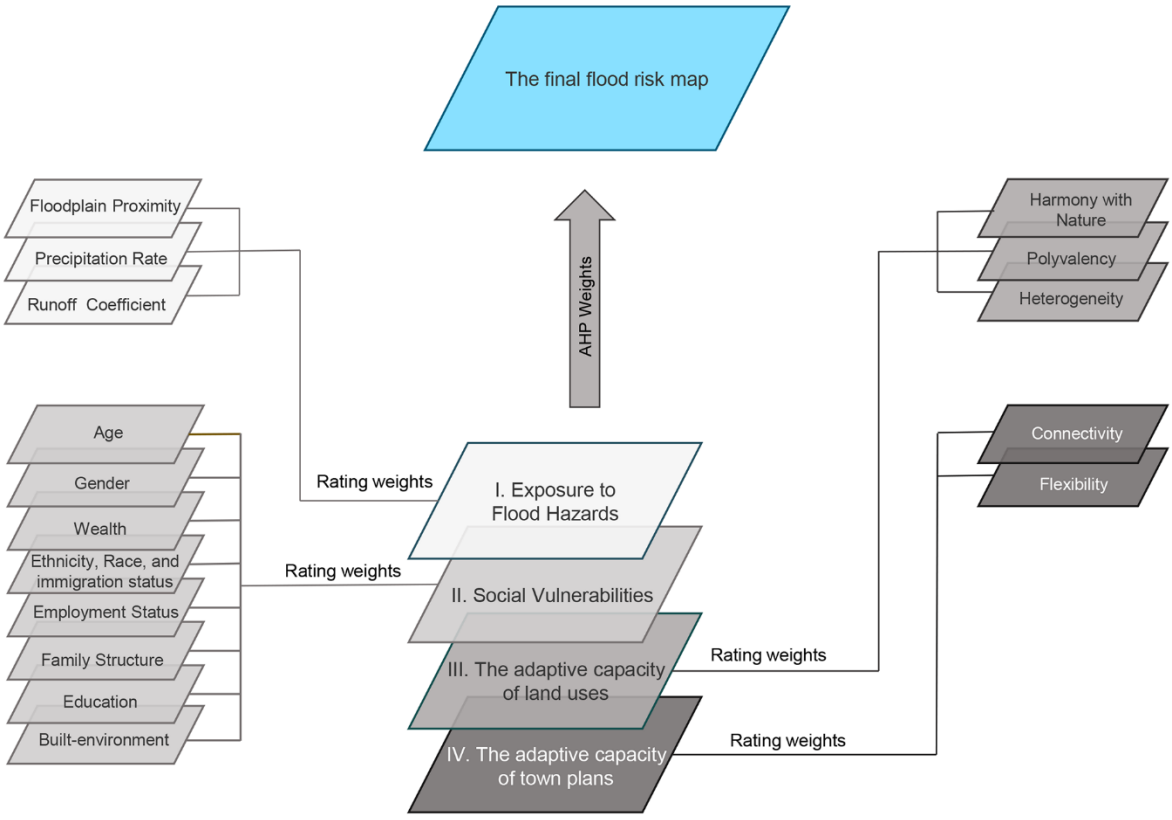

Figure 13. A schematic diagram showing the overlay analysis process

3.5 The case study: Toronto

Toronto is Ontario's capital and Canada's foremost economic hub. Toronto spreads over 633.5 km^2, and its population totals 2.73 million (in 2016), 50% of which are visible minorities, which makes it the most populous city in Canada and one of the most multicultural cities in the world (Filion et al., 2015; Statistics Canada, 2017). The city's location within the Lake Ontario Watershed and its exposure to moist air masses and high precipitation rates have caused several historical flooding events that caused a loss of lives and damages to properties and infrastructure in 1878, 1954 (after Hurricane Hazel), 1976, 2005, and 2013 (Nirupama et al., 2014; Rincón et al., 2018; TRCA, 2021).

More importantly, there is evidence of increased precipitation rates due to global climate change in this city. Feltmate and Thistlethwaite (2012) mentioned that six 50-year and two 10-year precipitation events had been recorded during just 15 years – from 1996 to 2011. Over the last

decade, governmental, non-governmental, academic, and private organizations at the different municipal, regional, and provincial levels have developed stormwater management plans, policies, and/or strategies to promote climate change adaptation (Henstra et al., 2020). In Toronto, the City'sWater Division oversees developing policies and implementing strategies for stormwater management and climate change adaptation. After the approval of the Climate Change Action Plan in 2007, the City of Toronto published its first climate adaptation strategies, including actions on flood protection and emergency management, in a document titled "Ahead of the Storm: Preparing Toronto for Climate Change" (City of Toronto, 2008). Following this document, the City continues to work on its first Resilience Strategy, which includes 50 major plans, including the Basement Flooding Protection Program and Wet Weather Flow Master Plan and Management Guidelines (City of Toronto, 2017, 2020c).

The City of Toronto collaborates with other organizations as well. Vertically, it works with regional and provincial governmental organizations such as the Toronto and Region Conservation Authority (TRCA). Being one of the 36 conservation authorities in Ontario, the TRCA receives funds from municipalities to offer them information on flood mapping, educational workshops, awareness programs, and low impact development (LID) design guidelines (CVC & TRCA, 2010; Henstra & Thistlethwaite, 2017; TRCA, 2020a, 2020b). At the provincial level, the City receives advice from the Ministry of Environment, Conservation, and Parks (MECP), and the Ministry of Environment and Climate Change (MECC), among others (City of Toronto, 2020c; Henstra et al., 2020). Horizontally, non-governmental organizations (e.g., Toronto Environmental Alliance), private firms (e.g., Metrolinx), and academic institutions (e.g., Intact Center for Climate Change Adaptation) assist the City of Toronto in conducting feasibility assessment projects and developing strategies and standards (City of Toronto, 2020c; Metrolinx, 2018).

3.6 Results: how are flood risks distributed?

3.6.1 Mapping the risk drivers

3.6.1.1 Exposure to flood hazards

In terms of exposure to flood hazards, the survey results show that the average weights of proximity to flood plains and run-off coefficients are 0.47and 0.53 (Figure 14A). Accordingly,

experts believe that the run-off coefficient has a slightly higher impact on exposure to flood hazards in Toronto than proximity to flood plains. When we overlay the indicator values in ArcGIS, using their assigned weights, the results show that Flemingdon Park neighbourhood, followed by West Humber-Clairsville, and Morningside, are the most exposed to flood hazards (Figure 15A and Table 8A).

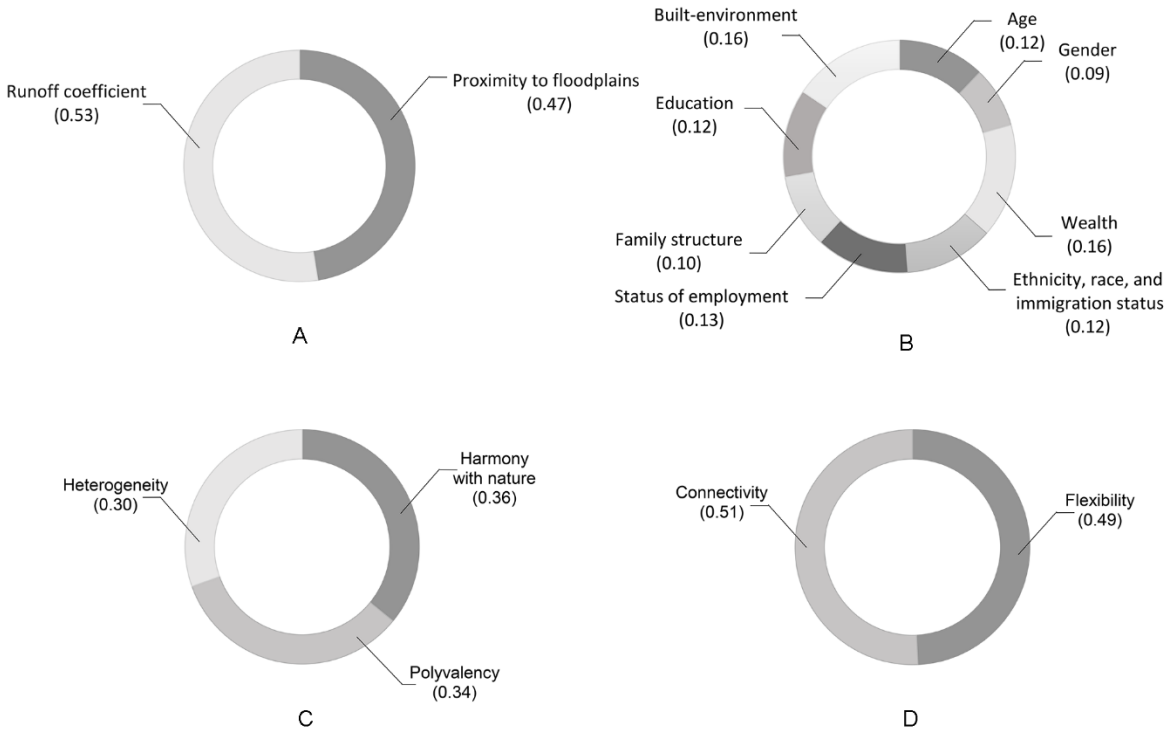

Figure 14. The average weights of risk drivers' indicators

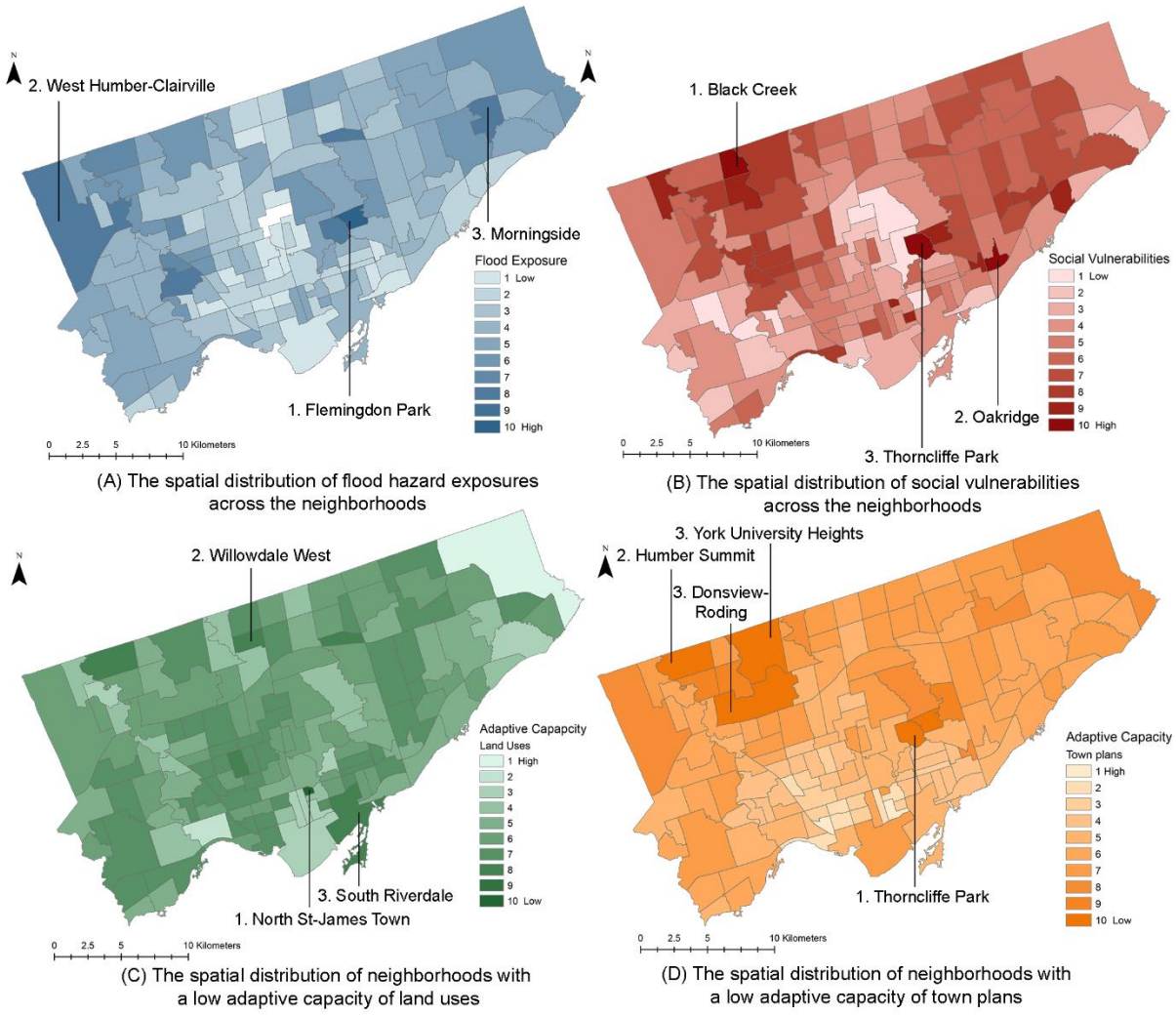

Figure 15. The spatial distribution of the four risk drivers.

Table 8. The list of neighbourhoods with the worst conditions in terms of each risk driver

	Neighbourhoods with the worst conditions		
	Ranks	Names	Values (see the legends in Figure 15)
(A) Exposure to flood hazards	1	Flemingdon park	10.0
	2	West Humber-Clairsville	7.8
	3	Morningside	7.7
(B) Social vulnerabilities	1	Black Creek	10.0
	2	Oakeridge	9.8
	3	Thorncliffe Park	9.6
(C) Adaptive capacity of land uses	1	North St. James Town	10
	2	Willowdale West	7.5
	3	South Riverdale	7.2
(D) The Adaptive capacity of town plans	1	Thorncliffe Park	10
	2	Humber summit	9.6
	3	York University heights	9.3
	3	Downsview-Roding	9.3

3.6.1.2 Social vulnerabilities

With regards to social vulnerabilities, the survey results show that wealth and built-environmental conditions (weighted at 0.16 each) have the greatest impact on social vulnerabilities, while gender (weighted 0.09) is the least impactful (Figure 14B). In addition, the overlay analysis of indicators' values by using their weights shows the disproportionate spatial distribution of social vulnerabilities within the city. In this respect, Black Creek neighbourhood followed by Oakridge and Thorncliffe Park have the highest social vulnerability weights to floods (Figure 15B and Table 8B).

3.6.1.3 The adaptive capacity of land uses

When it comes to the adaptive capacity of land uses, the survey results reveal that harmony with nature followed by polyvalency (weighted 0.36 and 0.34 respectively) have the highest impacts. In contrast, heterogeneity (weighted 0.30) maintains the minimum impact on land uses (Figure 14C). After overlaying these indicators' values (using their assigned weights), the results show that land uses in the North St. James Town neighbourhood followed by Willowdale West and South Riverdale have the lowest adaptive capacity (Figure 15C and Table 8C).

3.6.1.4 The adaptive capacity of town plans

Last, with regards to the adaptive capacity of the town plans, the survey results reveal that flexibility and connectivity (weighted 0.49 and 0.51 respectively) have relatively similar impacts on the adaptive capacity of town plans (Figure 14D). The results of our weighted overlay analysis using ArcGIS show variation in the town plans of Toronto's neighbourhoods adaptive capacities. As shown in Figure 15D and Table 8D, Thorncliffe Park followed by Humber Summit, York University Heights, and Downsview-Roding have the lowest adaptive capacity in their town plans.

3.6.2 Mapping the final flood risk map: identifying the priority neighbourhood

To map the final flood risk map and to identify which of Toronto's neighbourhoods should be prioritized for adaptation interventions, we overlay the maps of risk drivers (Figure 15) using the weights assigned by the experts. As the experts' survey results show (Figure 16), social vulnerabilities (0.32) have the highest impact on flood risks in Toronto, while exposure to floods (0.22) has the lowest impact. In addition, the experts believe that the adaptive capacity of land uses (0.23) and town plans (0.23) have similar impacts on flood risks. The results of the weighted overlay analysis reveal that Thorncliffe Park followed by Flemingdon Park, North St. James Town, and Black Creek are four neighbourhoods that are disproportionately at risk from flooding, hence, must be prioritized in urban form adaptation interventions (Figure 17 and Table 9).

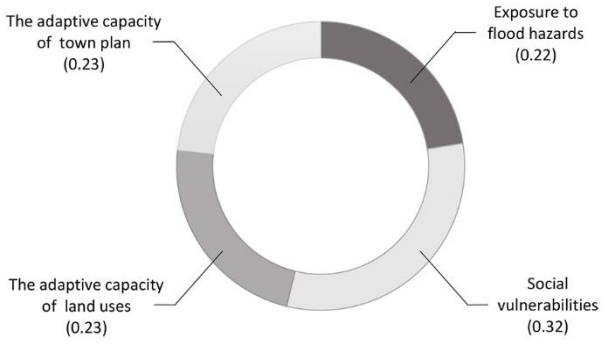

Figure 16. The average weights of risk drivers, assigned by experts.

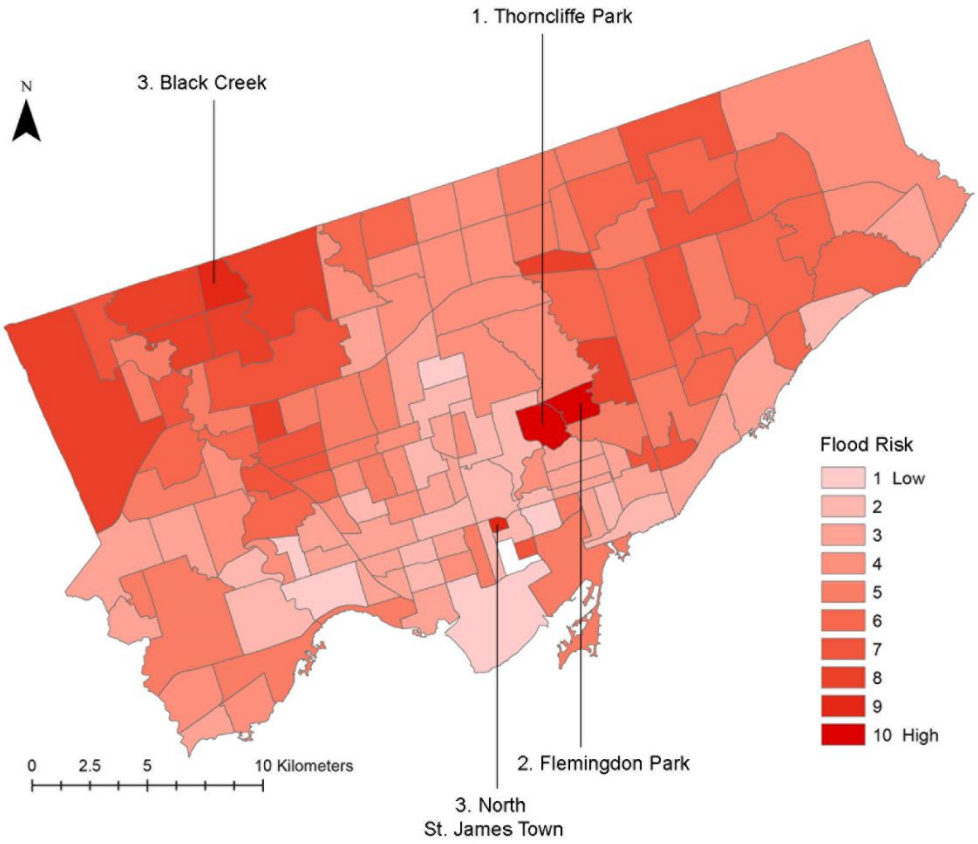

Figure 17. The spatial distribution of flood risks and the priority neighbourhoods for urban form adaptation in Toronto (the values are normalized from 1 to 10 when 1 shows low risks and 10 shows high risks)

Table 9. the priority neighbourhoods and their normalized risk value.

	The priority neighbourhoods		
	Ranks	Names	Values (see the legend in Figure 17)
The flood risk map	1	Thorncliffe Park	10.0
	2	Flemingdon park	9.4
	3	North St. James Town	8.2
	3	Black Creek	8.2

3.7 Discussion: delving deeper into the priority neighbourhoods

Our results show that social vulnerabilities, flood hazard exposures, and urban form adaptive interventions are distributed unequally within the City of Toronto, imposing disproportionate flood risks on three disadvantaged neighbourhoods: Thorncliffe Park, Flemingdon Park, North St. James Town, and Black Creek. These four neighbourhoods are high-density tower communities with aging infrastructure. They were built based on Le Corbusier's tower in the park concept during the 1950s and 1960s in response to the housing boom after the Second World War. Over time, the working middle-class's disinterest in occupying these towers turned them into "ethnic enclaves" for low-income immigrant families. Often, several families can be found living communally in one unit. The increase of population density in these towers led to disinvestments in their repair and maintenance, leading to dilapidated apartment units and amenities (E.R.A. Architects & University of Toronto, 2008; Hassen, 2021). The unfavorable conditions of the built environment, the concentration of poverty, and the impervious surface materials with high run-off coefficients are the main reasons behind the vulnerability to increased precipitation and exposure to increased flooding (Figure 18).

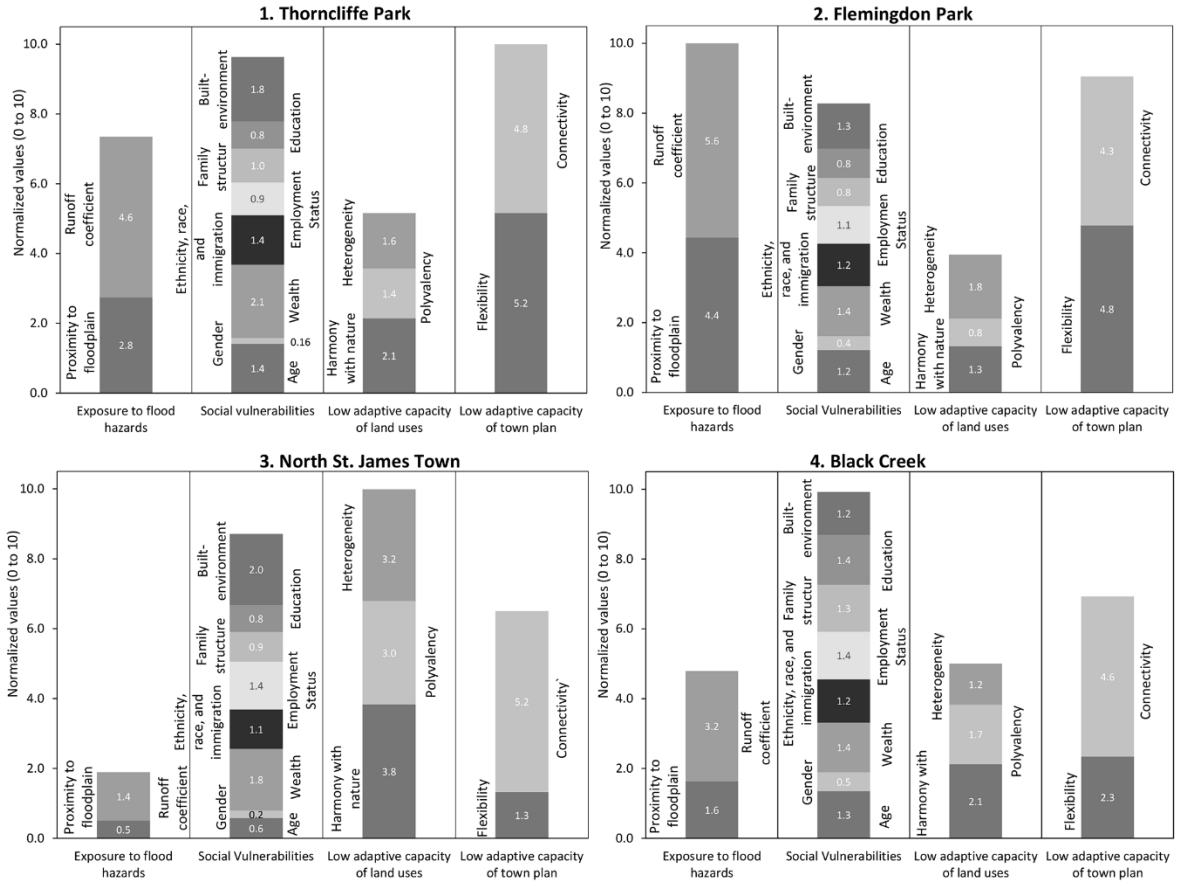

Figure 18. The values of risk drivers and their indicators in the four priority neighbourhoods

More importantly, our analysis of indicator values in Figure 18 shows inadequate adaptive capacities of these neighbourhoods' land uses and town plans. The high-rise developments and the separation of land uses have resulted in a lack of land-use heterogeneity as well as in urban form's large-grained blocks and disconnected streets (Figure 18). Although the ‘towers in the park’ urban form includes ample open green spaces, other factors reduce the urban form's flexibility to incorporate future changes and its ability to spread run-offs. This is due to the discriminatory policies, lack of maintenance, and more recently, infill development that have decreased and continue to reduce the quantity and quality of open green spaces and the land uses' harmony with nature. For example, North St. James Town has the lowest area of green space per person in Toronto since new apartment complexes have replaced open green spaces between the towers over time (Hassen, 2021; Nguyen, 2014) – see Figure 19. Additionally, in

Thorncliffe Park, Metrolinx[5] plans to replace some open spaces and business buildings with the train yards of the Ontario Line (AECOM Canada Ltd., 2021). These plans have raised the concerns of grassroots environmental justice activists (SaveTPARK Community, 2021).

Figure 19. Infill development (the displacement of open spaces with new constructions) in the North St. James Town. Blue highlights show the new developments (photo credit: the second author).

Yet, social vulnerabilities remain the most critical in triggering flood risks, particularly the lack of access to wealth when combined with unfavorable built-environmental conditions (Figure 16). Similarly, the run-off coefficient and harmony with nature are the most important indicators of flood exposure and adaptive capacity (Figure 14). Accordingly, we call for future theoretical and empirical studies to investigate how GBI interventions and nature-based solutions can address the root causes of vulnerability in tower communities in Toronto and elsewhere while advancing just adaptation to flooding. Furthermore, we propose that future research explores how low-income and disadvantaged communities and marginalized groups can participate and

[5] Metrolinx is a Government of Ontario's agency, which integrates and manages all transportation modes in the Greater Toronto and Hamilton areas (Metrolinx, 2022).

integrate their needs in the design and implementation of small-scale GBI in a way that curbs, if not altogether avoids, gentrification by maintaining housing affordability.

More importantly, our findings show that the need to prioritize tower communities for just adaptation to changing climate may not be specific to Toronto but applies globally. As they age and dilapidate over time, tower buildings that once were modern 20th century housing types have become the 21st century's affordable housing enclaves for low-income, marginalized, and vulnerable communities, particularly in Western Europe and North America. Over the last two decades, municipalities around the world have proposed strategies to advance social equity and to improve the conditions of the built-environment in similar tower buildings, whether through renovations, public realm improvements, mixed-use developments, and/or integrating urban agriculture (Benkő et al., 2018; E.R.A. Architects & University of Toronto, 2008; Veschambre, 2018). Some of these improvements include climate mitigation strategies (i.e., decreasing greenhouse gas emissions through improved energy efficiency) (Aragon et al., 2018; Seebauer et al., 2019). Yet, there is a need for studies that inform both research and policy on the adaptation of tower neighbourhoods to climatic events including flooding through participatory processes that are grounded in context-specific needs and the local communities' lived experiences as well as in the knowledge of local experts.

3.8 Conclusion

This study proposed a multicriteria model whose variables and indicators assess the spatial distribution of social vulnerabilities, flood hazard exposure, and urban form's adaptive capacity to facilitate an assessment of "who" is unequally at-risk to flooding events, hence, should be prioritized in adaptation interventions; "where" are the high-risk priority areas located; and "how" can urban form adaptive interventions prioritize advancing climate justice in these locations. Specifically, this model changes how risk inequalities are understood by combing social-demographic indicators with five configurational characteristics of resilient and adaptive land uses and town plans: harmony with nature, heterogeneity, polyvalency, flexibility, and connectivity. We tested the model in Toronto, through weighted overlay analysis using ArcGIS and an online survey of 120 Toronto-based flooding experts, to identify how social vulnerabilities, flood exposures, and adaptation interventions are distributed within Toronto's

urban form. This information enables us to identify which neighbourhoods are experiencing the highest risks of floods.

The results reveal the uneven spatial distribution of flood risks, hence, identify four neighbourhoods that should be prioritized for adaptation interventions: Thorncliffe Park, Flemingdon Park, North St. James Town, and Black Creek. Indeed, these are inner-city, high-density tower communities with old infrastructure and low-income, racialized, and migrant populations – typical of the 20 th century modern tower block communities dotted across North America, Europe, and Asia. This study was part of a bigger project. Building on the experts' surveys, the following steps include working with the vulnerable communities through participatory and interactive processes to develop small-scale adaptive GBI solutions grounded on place-based experiences, representing the neighbourhood residents' everyday lived experiences. Surely, as more empirical studies investigate the root causes of climate related risks in tower communities beyond Toronto and Canada, we will learn more about why certain communities will need to be prioritized in adaptation interventions and how we can work with them to advance just climate solutions that are grounded in the communities' context-specific needs.

3.9 Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

3.10 Author contribution

NM: research design, investigation, conceptualization, methodology, data curation, formal analysis, literature review, writing-reviewing, and editing

LK: research design, conceptualization, writing-reviewing and editing, supervision, funding acquisition, and project administration.

3.11 Funding

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Chapter 4

Manuscript III: Justice-oriented transformative adaptation to urban floods through green and blue infrastructure planning: Thorncliffe Park, Toronto

(Submitted to *Landscape and Urban Planning*)

Abstract

Evidence shows that green-blue infrastructure (GBI) planning relies on transformative large-scale projects based on technocratic and economic valuation approaches to manage sizeable climate-induced flooding without considering climate justice concerns. Contrasting epistemic justice against local experiential knowledge and the three-pillared climate justice framework, this study explores "how" and "why" GBI might exclude vulnerable communities and "how" it facilitates justice-oriented transformative adaptation. We focus on Thorncliffe Park, a dense tower neighborhood with a low-income immigrant population in Toronto, Canada, to: (1) explore the local experiential knowledge of the residents on floods and GBI; (2) "whether" and "why" this local experiential knowledge is mis/recognized in flood-adaptive GBI planning; (3) "how" to design GBI and "where" to allocate them to advance just transformative adaptation. The methodology includes 20 in-depth interviews with local leaders and Toronto-based planning experts, 199 online surveys of residents, 120 online participatory mapping activities, spatial analysis of surface run-offs, and policy reviews. Our findings show that the Thorncliffe Park residents are excluded from adaptive GBI planning because flood management is still a technocratic process based on cost-benefit rationales and technical justifications. We found four epistemic barriers that should be addressed for recognizing the residents in adaptive GBI planning: lack of social networks, citizenship rights, climate awareness opportunities, and communicational tools. We propose adopting new inclusive processes to design adaptive small-scale GBI in industrial and commercial sites of the neighborhood for both managing run-offs and providing socio-cultural benefits.

Keywords: climate justice, green-blue infrastructure, urban floods, climate change adaptation, epistemic justice, justice-oriented transformative adaptation

4.1 Introduction

Evidence indicates that climate adaptation interventions within the urban form rely on scientific knowledge and technical feasibility to protect valuable urban infrastructure, assets, and lands against hazards, excluding the most vulnerable and disenfranchised neighborhoods (Anguelovski et al., 2020). Particularly, decisions for siting "transformative" interventions in the form of large-scale green-blue (GBI) projects to manage sizeable flooding events are based on economic valuation approaches to assess ecosystem services in monetary terms without considering climate justice (Shokry et al., 2020). Urban transformation entails "a process of fundamental irreversible changes in infrastructures, ecosystems, agency configurations, lifestyles, systems of service provision, urban innovation, institutions, and governance" (Elmqvist et al., 2019). To avoid exclusionary outcomes and, simultaneously to take decisive measures against sizable climate hazards, emerging studies call for transformative adaptation that integrate justice considerations (Bahadur & Tanner, 2014; Shi & Moser, 2021). However, there is a shortage of theoretical and empirical studies that connect justice-oriented transformation with urban form adaptation (Lamb & Khirfan, 2022). This deficit might be rooted in the nascence of literature on the urban form that connects climate justice and adaptation (Mohtat & Khirfan, 2021).

This study underscores the concepts of epistemic justice (justice related to knowledge) and local experiential knowledge (socially-embedded knowledge) to unravel "why" and "how" flood-adaptive GBI planning may exclude vulnerable groups. Additionally, we draw on urban form interpretations of the three-pillared justice framework proposed by Lamb and Khirfan (2022) to understand "how" to design adaptive GBI and "where" to allocate them to advance distributive (equity of outcomes), recognitional (legitimization of difference), and procedural (inclusiveness of processes) justice. Accordingly, our theoretical framework proposes three pathways for the just transformation of adaptive GBI: (1) Revisiting the scale dimension of GBI; (2) restructuring adaptive GBI knowledge production systems to recognize local experiential knowledge; (3) reorganizing ecosystem service valuation approaches.

To operationalize our theoretical framework, we focus on the Thorncliffe Park neighborhood in Toronto, Canada, a post-war tower community with a dense population of low-income newly-arrived immigrants and old infrastructure. This neighborhood is the Toronto's most vulnerable

neighborhood to flooding events (Mohtat & Khirfan, 2022). Our research in Thorncliffe Park has three objectives: (1) To explore the local experiential knowledge of the neighborhood's residents on floods and GBI and "how" this knowledge is affected by their other everyday place-specific needs; (2) "whether" and "why" this experiential knowledge is mis/recognized in adaptive GBI decisions; (3) "how" to design GBI and "where" to allocate them in the neighborhood to advance justice-oriented transformative adaptation.

The methodology combines in-depth interviews with local leaders and Toronto-based planning experts, online surveys of residents, online participatory mapping activities, spatial analysis of surface run-offs, and policy reviews. The results confirm that despite vulnerabilities and exposures to flooding events, Thorncliffe Park residents are not recognized in adaptive GBI decisions due to the technocratic processes based on technical knowledge and cost-benefit rationales. Furthermore, the results show that this recognitional injustice relates to the lack of residents' access to material and rhetorical tools to impact adaptation decisions. Therefore, we propose adopting new inclusive processes to design adaptive small-scale GBI in industrial and commercial sites of the neighborhood for both managing run-offs and providing socio-cultural benefits.

4.2 Climate-induced floods and climate justice challenge

4.2.1 Structural vulnerabilities and flood risk inequities

As the intensity and frequency of precipitation rates have increased due to climate change, the growing urbanization patterns and old urban drainage infrastructure pose the risk of riverine flooding and rainwater run-off (Mohtat & Khirfan, 2022). Marginalized groups with lower socio-economic status are disproportionately vulnerable to the risk of financial, human, and livelihood losses due to their unequal exposures and lack of ability to prepare for, cope with, and recover from hazards (Thomas et al., 2019). Flood risk inequalities are associated with structural inequities in the access to resources and rights for racial, ethnical, and low-income groups due to the historical processes of domination and oppression embedded in market-based and technocratic urban development patterns (Michael et al., 2019). Empirical evidence shows that disenfranchised neighborhoods are located on under-invested, precarious, and low-value lands, like floodplains, as a result of unfair zoning policies based on racial segregation and

market principles (Herreros-Cantis et al., 2020). Some of these neighborhoods are homes to newly-arrived immigrants with insecure employment and livelihood conditions who can afford to live only in old and poorly maintained rental buildings susceptible to infrastructure damage once flooding happens. Their socio-economic conditions impede their ability to invest in insurance (Mohtat & Khirfan, 2022). Their limited social networks combined with language barriers, and insecure residence conditions severely limit their political power within formal urban governance systems-. Hence, they are rendered invisible in flood management, adaptation, and recovery programs (Maldonado et al., 2016).

4.2.2 Urban transformation through adaptive GBI

In response to the sizeable climate risks and compounded vulnerabilities, municipalities are increasingly integrating transformative interventions in climate change adaptation instead of tackling incremental adaptive measures (Kates et al., 2012). Urban transformation entails multifunctional, systematic, radical, and purposive interventions in urban systems as experiments for testing innovative solutions (Elmqvist et al., 2019; Kabisch & Kuhlicke, 2014).

Targeted Green-blue infrastructure (GBI) projects are examples of transformative interventions that municipalities adopt for adapting to climate-induced flooding events. Emerging in the 1990s, such purposeful GBI refers to the "strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of benefits to people and wildlife (ecosystem service)" (Ferreira et al., 2021, p. 1). Nature-based solutions (NbS) are a subset of purposeful GBI that specifically address adaptation. IPCC (2022, p. 391) define NbS as “Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits”. As a nature-based solution, adaptive GBI manages stormwater by mimicking natural infiltration, slow flow, detention, retention, and evapotranspiration processes. Accordingly, it supplements the centralized grey drainage infrastructure to manage climate-induced flooding events (IPCC, 2022; Liu et al., 2019).

As empirical studies indicate, transformational GBI usually manifests as expensive large-scale projects that are long-term and ecologically optimal, hence, are considered low-regret solutions for managing sizeable urban floods (Kates et al., 2012; Vojinovic et al., 2021). Examples of such transformative mega projects include large urban parks, green belts, and greenway

networks that fundamentally change urban structures and/or functions across multiple urban neighborhoods and/or districts (Anguelovski et al., 2020; Elmqvist et al., 2019). Despite its benefits, transformational adaptation that scales up GBI relies on scientific knowledge, technical feasibility, and managerial approaches to maximize the economic and ecological gains from ecosystem services without bearing climate justice concerns in mind (Connolly, 2019; Olsson, 2022). Such transformations are often supported by climate-resilient city branding strategies to encourage investments by real estate investors, the tourism industry, and the new sustainability class (Mohtat & Khirfan, 2022). In particular, Anguelovski et al. (2020) frame the transformational GBI planning as part of the 1990s' technocratic orthodoxy of green and resilient cities, which is based on the optimistic and apolitical assumption that scientific knowledge promises economic growth while guarantying win-win benefits for all.

4.2.3 Adaptive GBI: from economic valuation of ecosystem services to socio-cultural valuation approaches

Kumar and Kumar (2008, p. 810) define economic valuation of ecosystem services as "the attempt to assign quantitative values to the goods and services provided by ecosystems". Conventionally, decision-makers capitalize on the economic valuation of ecosystem services to assess the benefits of GBI for adaptation in monetary metrics that are based on cost-benefit analysis and technocratic principles (Peck & Khirfan, 2021; Shokry et al., 2020).

The economic valuation approaches to adaptive GBI decisions integrate both the use and non-use values of ecosystem services. The former indicates benefits associated with the in/direct use of ecosystem services while the latter relates to benefits not necessarily relevant to the actual use of ecosystem services but to satisfaction from the existence of ecosystem services (Gómez-Baggethun & Barton, 2013). For example, empirical evidence of investments in large-scale GBI in high-value lands (Anguelovski et al., 2020) shows how adaptive GBI planning capitalizes on the use values of ecosystems for stormwater management to avoid the monetary costs of flood damage to valuable urban assets/infrastructure (De Groot et al., 2002). Indeed, evidence of GBI planning in low-income neighborhoods indicates how adaptive GBI planning takes advantage of ecosystem services' non-use values to raise property values, rents, and taxes (Shi, 2020a).

Despite their benefits for the economic development of cities, the economic valuation of ecosystem services is based on "individual utility maximization" rather than on the provision of

public goods (Kumar & Kumar, 2008, p. 811). This rendered adaptive GBI planning a development agenda that commodifies ecosystem services while simultaneously ignoring the underlying causes of risk inequalities and structural vulnerabilities (Gómez-Baggethun & Ruiz-Pérez, 2011; Shokry et al., 2020). From the exclusion of disenfranchised neighborhoods to the relocation of vulnerable groups as the result of land expropriation and/or climate gentrification, empirical evidence abounds on the unjust outcomes of limiting valuation rationales to economic ones in planning for adaptive GBI (Henrique & Tschakert, 2019; Shi, 2020a). Inclusive valuation approaches are an imperative to overcome these unjust outcomes in adaptation and climate risk reduction because they focus on the broader non-monetary benefits of ecosystems to society (Peck & Khirfan, 2021; Santos-Martin et al., 2017). This gave rise to the socio-cultural valuation framework that "analyzes human preferences towards ecosystem services in nonmonetary units … without relying on market logics …" (Santos-Martin et al., 2017, p. 102) and that includes cultural benefits such as recreation, sense of place, and aesthetics (Gómez-Baggethun & Barton, 2013). In contrast to economic valuation in which experts identify the values through top-down approaches, it is the local people who define the values in socio-cultural valuation methods based on their context-specific priorities through participatory and deliberative processes (Scholte et al., 2015). To ensure inclusion, particularly of marginalized groups with no political power, socio-cultural valuation approaches take place in the early stages of adaptive GBI planning (Van Riper et al., 2017).

4.3 Toward just transformative climate adaptation

Shi and Moser (2021) propose that transformative adaptation actions must integrate justice to avoid the exclusionary outcomes of large-scale projects that systematically change urban systems. Accordingly, justice-oriented transformative adaptation entails "deliberately and fundamentally changing systems to achieve more just and equitable outcomes" (Shi & Moser, 2021, p. 372). It shifts attention from technocratic and financially-oriented large-scale adaptation responses, which entrench business-as-usual development patterns, to the underlying political structures and institutional patterns that have produced climate risk inequities and vulnerabilities (Bahadur & Tanner, 2014; Pelling et al., 2015). This study takes advantage of local experiential knowledge, the epistemic justice framework, and the three pillars of climate justice to unravel how adaptive GBI may facilitate justice-oriented transformative adaptation.

4.3.1 Local experiential knowledge

Empirical evidence points out that in order to avoid the unjust outcomes of technocratic adaptation responses, it is imperative to prioritize the needs, preferences, and choices of local communities by integrating their local experiential knowledge (Dhar & Khirfan, 2016; Rice et al., 2015). Local experiential knowledge relates to the knowledge derived from individuals' everyday lived experiences rooted in their socio-cultural backgrounds and place-based histories. This type of knowledge is context-specific and situation-based in contrast to scientific knowledge, which is externally generated, comprehensive, and generalizable (Dhar & Khirfan, 2016; Friedmann, 1993). Accordingly, its incorporation in knowledge production and adaptation decision-making processes complements scientific knowledge, assuring that adaptive responses are socially legitimate and ecologically efficient (Rice et al., 2015).

Many scholars have highlighted the role of local experiential knowledge, specifically the knowledge held by marginalized groups, in developing innovative adaptation decision-making processes that can reshape policies to address structural inequities (Dhar & Khirfan, 2016; Rice et al., 2015). For example, collaborative processes for integrating local experiential knowledge, such as through participatory GIS and risk dialogues, empower disenfranchised communities to express their needs and include them in the size, location, and type of GBI (Anguelovski et al., 2020). Additionally, such collaborative processes allow marginalized groups to direct policymakers on how to combine adaptation benefits with additional support, such as evacuation assistantships, emergency services, loans, and livelihood protection programs, to address the root causes of vulnerabilities (Shi et al., 2016).

4.3.2 Epistemic in/justice

The calls for including local experiential knowledge warrant identifying power asymmetry patterns that have shaped the hegemony of technical knowledge over the other types of knowledge. Byskov and Hyams (2022) specifically relate the underrepresentation of local experiential knowledge to the embedded patterns of epistemic injustice. Epistemic injustice refers to the unfair processes that underly whose knowledge is recognized, where the knowledge of powerful and privileged individuals is favored over those who lack power and privilege (Byskov, 2021). As Fricker (2007) proposes, this unfair treatment of knowledge is rooted in two types of injustice embedded in power structures: testimonial and hermeneutical injustice.

Testimonial injustice occurs when an individual's knowledge is not considered credible because of prejudices against their social background, income, race, ethnicity, and/or gender. Testimonial injustice results in hermeneutical injustice, which ensues from the disadvantaged individuals facing a lack of material and discursive tools to make sense of and interpret their experiences due to their historical underrepresentation in knowledge-production systems (Anguelovski et al., 2020; Byskov, 2021).

Accordingly, adaptive GBI planning recognizes and includes the local experiential knowledge of underrepresented individuals only when it overcomes the testimonial and hermeneutical barriers of epistemic injustice. In other words, underrepresented individuals should be equipped with material and rhetoric tools to articulate their knowledge, and simultaneously, decision-makers credit and acknowledge their knowledge claims so that adaptive GBI planning meet epistemic justice.

4.3.3 The three-pillared justice framework

To advance justice-oriented transformative adaptation, scholars, such as Ziervogel et al. (2017) and Schlosberg et al. (2017), proposed adaptation responses to consider the three interrelated pillars of climate justice: distributive, recognitional, and procedural. Distributive justice relates to the equity of outcomes by just distributing resources across space and time to maximize benefits to the most disadvantaged. Recognitional justice refers to legitimizing and identifying social, economic, and political differences. Procedural justice assures the inclusiveness and fairness of decision-making processes through participation and deliberation (Mohtat & Khirfan, 2021).

Particularly, in the context of urban design and form, Lamb and Khirfan (2022) indicate that this three-pillared justice framework advances transformative adaptation by producing "socio-ecological landscapes" and "socially-embedded morphologies" through "deeply inclusive design". Socio-ecological landscapes respond to both ecological processes and social patterns of the urban landscape, whereby the spatial distribution of adaptive responses mitigates climatic risks and equally benefits the socially vulnerable groups. We consider several small-scale GBI projects distributed across a city as an example of a socio-ecological landscape that efficiently mitigates flooding hazards (Simić et al., 2017) while preventing socially unequal outcomes such as gentrification (Wolch et al., 2014). Socially-embedded morphologies are spatial expressions

of recognitional justice, whereby urban form manifests place-based socio-environmental conditions and the history of space rather than being a "physical artifact … frozen in time" (Lamb & Khirfan, 2022, p. 4). Several researchers, including Lamb and Khirfan (2022), draw on local experiential knowledge to design socially-embedded morphologies. The deeply inclusive design represents procedural justice, which transfers power from economic elites to local communities to enable collective measures instead of individualistic actions that commodify urban lands (Lamb & Khirfan, 2022, p. 4). Regarding GBI, deeply inclusive design warrants a shift from economic valuation that instrumentalize ecosystem services to more inclusive valuation frameworks that integrate more plural perspectives (Lamb & Khirfan, 2022).

Accordingly, adaptive GBI planning advances justice-oriented transformative adaptation when decision-makers reshape power relations in climate adaptation to deeply include context-specific socio-ecological conditions of local communities in the design and implementation of GBI. It requires the GBI design processes to include locally-situated knowledge to shift the focus of ecosystem service valuation approaches from large-scale projects that make profits for the powerful elites to small-scale interventions that address the context-specific needs, root causes of vulnerabilities, and disenfranchised groups' lived experiences.

4.4 The theoretical framework

Accordingly, our theoretical framework combines urban form interpretations of the three-pillared justice framework with local experiential knowledge and epistemic justice to propose three inter-linked pathways for the just transformation of adaptive GBI interventions: (1) Revisiting the scale dimension (2) reorienting knowledge systems to recognize local experiential knowledge; (3) reorganizing ecosystem service valuation approaches (Figure 20).

4.4.1 Revisiting the scale dimension of GBI

Adaptation decision-makers can adhere to socio-ecological place-specific conditions of urban landscapes if they shift their focus from expensive, ecologically efficient, but socially unjust, large-scale GBI projects to cost-effective small-scale interventions, such as rain gardens, community parks, and bioswales (Wolch et al., 2014). Particularly, small-scale GBI projects that are equally distributed as a network across larger scales provide the local communities with accessible, neighborhood-oriented, and visually-appealing green-blue spaces while preventing

unequal outcomes such as gentrification and forced relocations. These small-scale dispersed projects are also effective solutions for managing run-offs and sizable floods, as empirical evidence such as Simić et al. (2017) indicate.

4.4.2 Restructuring adaptive GBI knowledge production systems to recognize local experiential knowledge

As much as we need to rescale GBI to produce socio-ecological landscapes, there is a need to transform adaptive GBI knowledge systems to produce socially-embedded morphologies. Emerging studies, such as Ziervogel et al. (2022) and Castán Broto et al. (2022), indicate that adaptation knowledge systems need structural changes to guarantee long-term collaborations among different stakeholders, including experts and local communities, for co-producing knowledge. Such structural changes are possible if we redefine power relations to enable the voices of the marginalized to be articulated and believed (Ziervogel et al., 2022) by identifying and addressing the hermeneutical and testimonial drivers of epistemic injustice (Castán Broto et al., 2022).

Accordingly, transformation in adaptive GBI knowledge systems starts by exploring "whether" marginalized groups access epistemic tools such as information and training to make sense of their risk experiences, compounding vulnerabilities, and expectations from GBI and "if" decision-makers trust their testimonies. Based on it, decision-makers need to empower and build the capacity for these marginalized groups to co-design GBI. Here, innovative tools, such as participatory mapping through GIS, facilitate articulating the spatial knowledge of marginalized groups in the places that need GBI to address their vulnerabilities (Anguelovski et al., 2020).

4.4.3 Reorganizing ecosystem service valuation

Rescaling GBI interventions and co-producing adaptive GBI knowledge require transferring power from economic elites to affected communities. To facilitate this power transfer, we propose restructuring ecosystem service valuation approaches to move away from narrow economic frameworks that commodify GBI based on the preferences of technocrat elites to include social constructions through socio-cultural valuation frameworks. (Gómez-Baggethun & Ruiz-Pérez, 2011; Peck & Khirfan, 2021).

Since the socio-cultural valuation framework extracts collective and communal perspectives of people regarding ecosystem service values through deliberative and participatory processes, it brings more pluralistic voices, perspectives, and actors into the design and implementation processes of adaptive GBI. Additionally, the framework's ability to elicit historical, political, and cultural structures that have shaped place-based interactions between under-represented groups and urban greenery contributes to adaptive GBI responses to include different identities and diverse forms of knowing (Himes & Muraca, 2018; Santos-Martin et al., 2017). This inclusiveness brings new ways to develop, control, and use urban lands, making socio-cultural valuation an appropriate framework that addresses immediate needs, root causes of vulnerability, and structural inequities. For instance, flood-adaptive rain gardens provide community gathering spaces in immigrant neighborhoods, providing community networks for socially-isolated residents (Anguelovski et al., 2020). Likewise, urban agriculture projects facilitate surface run-offs while addressing food insecurity challenges in disenfranchised communities (Säumel et al., 2019).

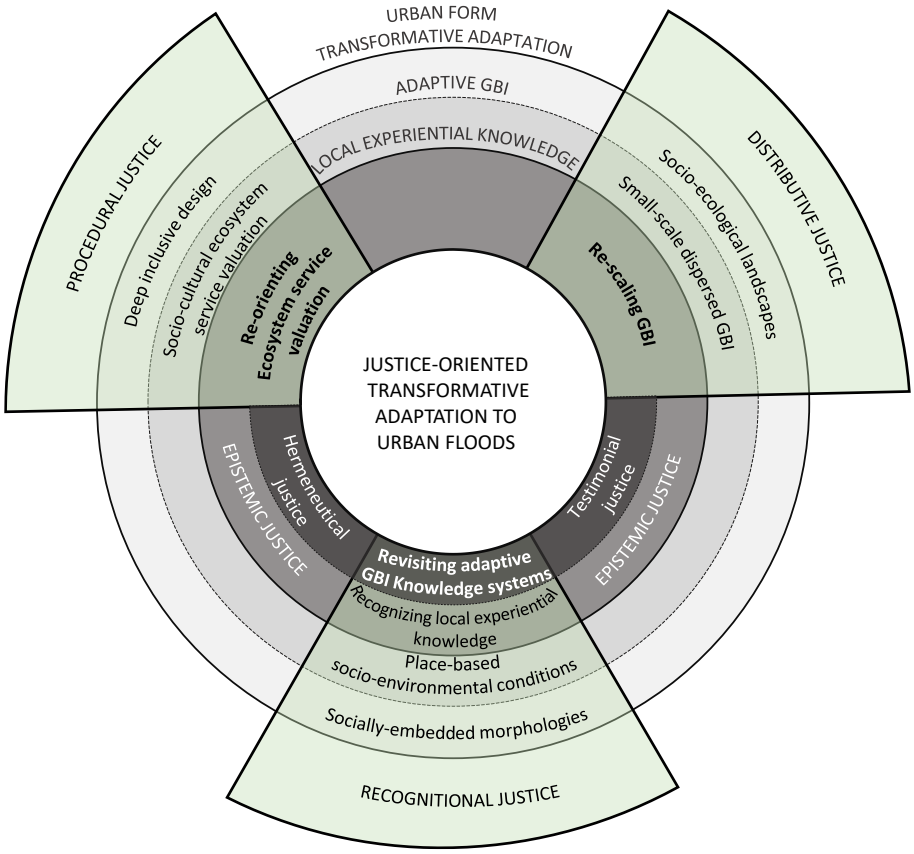


Figure 20. The theoretical framework

4.5 Methodology

We tackled a combined methodology consisting of qualitative and spatial strategies to operationalize our theoretical framework in Thorncliffe Park as the case study we Our combined methodology includes: semi-structured interviews with flooding experts and local leaders; an online participatory component for the neighborhood residents, including surveys and participatory mapping activities; a spatial analysis component for identifying areas exposed to run-offs; and policy reviews.

4.5.1 Research strategies and data collection

4.5.1.1 Primary data

Between October and April 2021, we conducted **semi-structured online interviews** with 14 local neighborhood leaders and six Toronto-based planning experts to unravel if Thorncliffe

Park residents' experiential knowledge have been recognized in previous decisions on adaptive GBI. Henceforth, we call these two series of interviews **local** versus **expert** interviews (see Table 10 for variables). We recruited local interviewees by searching the neighborhood's NGOs and social activists online. We combined this approach with snowball sampling, whereby participants introduce relevant people within their network. Our participants' search yielded 10 NGO activists, two local champions collaborating with the City on climate action programs, one independent refugee advocator, and one building manager. We conducted expert interviews with Toronto-based planners who had experience in at least one of the fields of flood management, social vulnerabilities, and climate action through GBI. We found expert participants by browsing the websites and relevant reports of organizations collaborating with the City of Toronto in framing the Toronto First Resilience Strategy and the Flood Resilient Toronto charter (City of Toronto, 2019b, 2020c).

Additionally, we conducted an online component using Qualtrics in Thorncliffe Park, which consists of surveys and participatory mapping activities. The population of these two participatory components was Thorncliffe Park residents. The survey, which had 16 open-ended, matrix, and multiple-choice questions, aimed to extract the residents' experiential knowledge on floods and GBI and their immediate needs. Ten questions measure variables relevant to the objectives (Table 10). Other questions consist of two screening questions to include only 18 years of age and older participants currently living in the neighborhood and four questions extracting participants' socio-demographic information on income, immigration status, race, and the number of years living in the community.

We used participatory mapping activities to understand which spaces in the neighborhood require GBI for socio-cultural benefits. Participatory mapping, also called participatory GIS (PGIS), is a prevalent method for assessing the socio-cultural values of ecosystem services (Santos-Martin et al., 2017). Our application of this method differs from similar studies (Plieninger et al., 2013), which usually use it for the socio-cultural valuation of existing GBI instead of making decisions regarding the locations they should be allocated. The activity includes nine heat-map questions in Qualtrics, asking participants to select on the neighborhood map areas that need green spaces for five (out of ten) socio-cultural ecosystem services proposed by Reid (2005): recreation, aesthetics, sense of place, social relations, and educational benefits. We dropped the other five Reid's (2005) ecosystem service types, namely, knowledge

systems, spiritual, inspiration, cultural heritage, and cultural diversity, since we thought it might not be evident for local participants to select spaces that need GBI for these benefits. To facilitate the data analysis, we defined a grid consisting of 159 150*150-meter cells on the map so that Qualtrics reports the number of responses per defined cell instead of the coordinates of clicks.

The recruitment of participants for these two online participatory components started on October 2021 and lasted until the end of June 2022. We used a convenience sampling approach for recruiting participants based on the participant's availability to the researchers. We posted the survey and the participatory mapping links on neighborhood-relevant pages on Facebook, Twitter, and Instagram, and invited 3000 users who have followed these groups through direct messaging. Additionally, we asked neighborhood leaders to share the links within their local WhatsApp groups. One of these leaders arranged for us to present our research at the school council meeting of Marc Garneau Collegiate Institute. The other recruited 20 participants, with language barriers and limited Internet access, to complete the hard copies of these two participatory components. Last, we placed 300 flyers, including the links' QR codes, on the public bulletins of residential and organizational buildings during April and May 2022. The surveys yielded 199 responses, 33% belonging to low-income families (annual income below $40,000), and 85% are visible minorities. The participatory mapping yielded 120 responses.

4.5.1.2 Secondary data

We conducted a spatial analysis component and a review of relevant policies to complete the primary data. The spatial analysis identifies the exposure of different neighborhood spaces to surface run-offs. For this analysis, we used the land-use open data source by the City of Toronto (2020f). For the policy review, our primary focus is on the Toronto First Resilient Strategy (City of Toronto, 2020c), which is an overarching document gathering, reviewing, and updating all the existing plans and strategies to respond to the Toronto's resilience challenges, including climate resilience and the increased inequalities. We furthermore reviewed the Flood Resilient Toronto charter (City of Toronto, 2019b), which develops a city-wide flood risk mapping tool based on the social cost-benefit analysis to decrease the vulnerability of equity-seeking disadvantaged groups. The tool informs urban renewal and environment improvement projects at other organizations outside the City, among which is the Sustainable Neighborhood Action

Program (SNAP) by Toronto and Region Conservation Authorities (City of Toronto, 2020c; TRCA, 2022). SNAP program is the third document that we reviewed.

4.5.2 Data analysis and management

4.5.2.1 Qualitative analysis

Once we reached a data saturation point for interviews, we transcribed the recordings and inductively coded them using NVIVO in three categories of compounding vulnerabilities, exclusion in GBI measures, and epistemic injustice patterns. We simultaneously exported the results of the online surveys from Qualtrics and analyzed them using statistical tools in Microsoft Excel. We supported our findings with the three policy documents.

4.5.2.2 Spatial analysis

The spatial analysis began with exporting the database of grid cells selected by participants in the participatory mapping activity from Qualtrics. After managing the data in Excel, we mapped variables by assigning their values to their associated cells in ArcGIS. We then did overlay analysis in ArcGIS through two stages: overlaying variables to produce maps showing grid cells that require GBI for the five socio-cultural ecosystem services and overlaying these five maps to draw a map showing areas that need GBI for socio-cultural benefits. We employed the Union Analysis tool and the average function (in the attribute table) for both stages to complete the overlay analysis.

We simultaneously used the same grid cells as the participatory mapping component and estimated run-off amounts per cell in ArcGIS, using the run-off coefficients[6] proposed by Thompson (2006) (

Table 12) for different land use types − see also Mohtat and Khirfan (2022). We first calculated the percentage of lands per grid covered by Thompson's (2006) proposed land use types (

[6] The amount of run-offs to the amount of precipitations (Mohtat & Khirfan, 2022)

Table 12) by intersecting the grid with land use data in ArcGIS. We then multiplied the percentage values with their associated coefficient amounts and produced a map showing the average amount of run-offs per grid.

Last, we overlaid the map showing grid cells that need GBI for socio-cultural benefits with the map showing run-off amounts per grid cell in ArcGIS to produce a final map highlighting areas for allocating GBI. Note that we have used linear scale transformation to normalize the variable values from 0 to 10 in all of these maps to facilitate data analysis.

Table 10. The variables associated with online interviews, the participatory component, and the spatial GIS analysis

Concepts	Indicators		Variables				
			Online interviews		Online participatory component		Spatial GIS analysis
			Experts	Locals	Surveys	Participatory mapping	
I. Restructuring adaptive GBI knowledge production	Epistemic causes of mis/recognition	Hermeneutical	(a) Barriers to include residents. (b) the disadvantaged's ability to communicate their needs.	(a) Residents' interests in and barriers civic engagement. (b) local NGO's reasons for capacity-building.			
		Testimonial	(c) If experts credit the local experiences.				
	Knowledge co-production	Local experiential knowledge on lived experiences, floods, and adaptive GBI		(c) If local organizations have collaborated with other organizations for adaptive GBI planning. (d) Participants' experiences on floods. (e) If flooding risks are serious for them. (f) Residents' top-priority needs. (g) Local organizations' programs for residents.	(a) How often participants experience river and sewer flooding and surface runoff. (b) How/where participants experience floods. (c) If participants expect more frequent/severe floods (d) The neighborhood's needs of GBI. (e) The abundance/quality of GBI. (f) If floods are serious for participants. (g) Participants' other needs.		
		Scientific knowledge: exposure to run-offs					(a)The average amounts of run-off correlation per a 150 ×150meter cell in the neighborhood.

Table 10 (continued). The variables associated with online interviews, the participatory component, and the spatial GIS analysis − *the participatory mapping variables are adopted from Plieninger et al. (2013)

Concepts	Indicators		Variables				
			Online interviews			Online participatory component	Spatial GIS analysis
			Experts	Locals	Surveys	Participatory mapping	
II. Rescaling adaptive GBI	Local experiential knowledge on the location of GBI for socio-cultural values.	Recreation				Spaces require GBI infrastructure for*: (a) Gathering (b)Walking/cycling (c) Children play	
		Aesthetic				(d) Making the neighborhood beautiful	
		Sense of place				(c) Feeling that the neighborhood is your home (d) Connection to nature (e) Making you proud of your neighborhood	
		Social relations				(f)Socialization and meeting	
III. Reorganizing ecosystem service valuation		Educational benefits				(g) Increasing environmental awareness.	

Table 11. Selected socio-cultural ecosystem services from (Millennium ecosystem assessment, 2005) – also used by (Plieninger et al., 2013).

Selected socio-cultural services	Definitions
Recreation	Green/blue spaces that provide recreational benefits, such as walking, gathering, and children's play.
Aesthetic	Green/blue spaces deliver a natural beauty
Sense of place	Green/blue spaces that raise the sense of belonging and attachment
Social relations	Green/blue spaces that provide spaces for meetings and social interactions
Educational benefits	Green/blue spaces that raise public awareness regarding ecosystems

Table 12. Thompson's (2006) proposed run-off correlations

Land use types	Coefficients
Utility and transportation	0.85
Industrial	0.8
Multi-family and apartment residential	0.65
Commercial	0.6
Open spaces	0.2

4.6 Case study

Thorncliffe Park is one of the first planned communities in Toronto, located in the North East of the downtown core (Figure 21). This neighborhood was developed based on Le Corbusier's Tower in the Park concept in the 1950s and the 1960s as an inner suburb to maximize density while providing open space for recreation and parking (Martin et al., 2015). Like other Toronto tower communities, the development of Thorncliffe Park was a response to the housing boom after the second world war to accommodate middle-income and working-class residents. However, over time, it became a densely populated ethnic enclave for the low-income and newly arrived migrants due to the working class's preference for living in the outer suburbs (Hassen, 2021). Currently, this neighborhood accommodates 21000 residents, 79% visible minorities, 64% immigrants, and 45% low-income, who mostly live in over-crowded low- and high-rise rental apartments (City of Toronto, 2019a). The City of Toronto's Strong Neighborhood Strategy has introduced Thorncliffe Park as one of the Neighborhood Improvement Areas (NIAs) due to its unfavorable built-environment conditions, lack of access to social, civic, and economic opportunities, and unsuitable physical/mental health conditions (City of Toronto, 2020e).

As Toronto flood risk mappings in previous studies show (Mohtat & Khirfan, 2022; Rincón et al., 2018), Thorncliffe Park is one of the vulnerable neighborhoods due to its exposure and the low adaptive capacity of its residents. The concentration of industrial and utility-transportation uses with impervious surfaces and the neighborhood's proximity to the Don River flood plain from the South, East, and North (Figure 21) increase the chance of surface run-off and river flooding events. The fact that 45% of neighborhood residents use public transportation as their primary mode of commuting increases the likelihood that flooding events adversely affect them. More importantly, it is more likely that the extra rainfalls and their subsequent run-off damage the old infrastructure of buildings, which are deteriorating due to the long years of disinvestment (City of Toronto, 2019a). Such damages can lead to power outage issues and impose extra costs on low-income residents who lack the financial resources to move to other places and afford the repair costs. Furthermore, the neighborhood is populated more than it was planned for, and the open spaces do not suffice to accommodate tenants temporarily in the face of emergency conditions. The tall buildings with slow elevators, the isolated non-permeable urban blocks, and the clustered uses also make emergency rescue challenging (Mohtat & Khirfan, 2022).

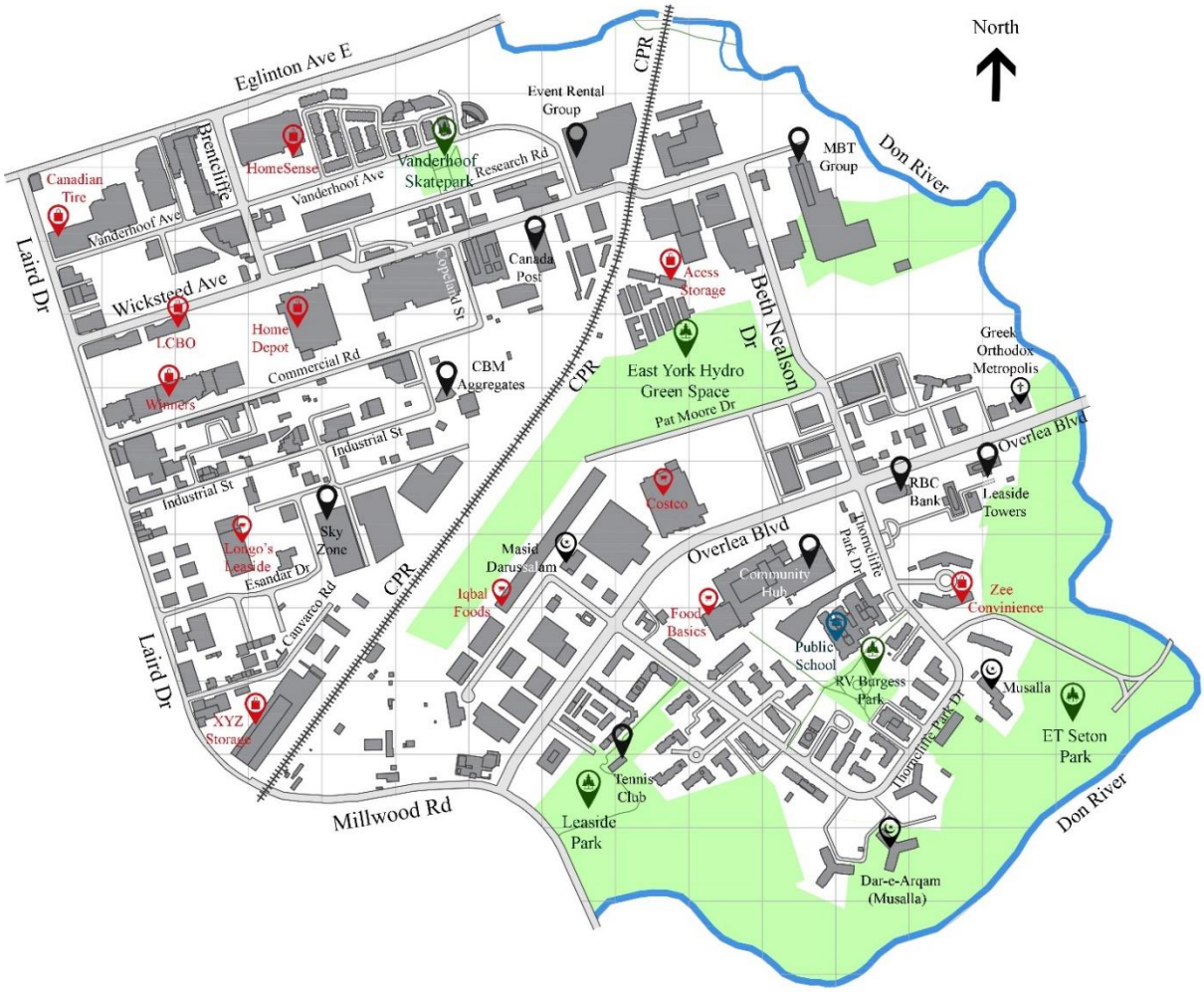


Figure 21. Thorncliffe Park map

4.7 Results

4.7.1 Compounding vulnerabilities

4.7.1.1 Vulnerability and exposure to flooding events

Our results show that the residents of Thorncliffe Park have witnessed different types of flooding events in the neighborhood. In particular, the majority of survey respondents have either frequently or rarely experienced surface run-offs (66%) and sewer floodings (69%), while a minority of them (39%) have witnessed river flooding (Figure 22).

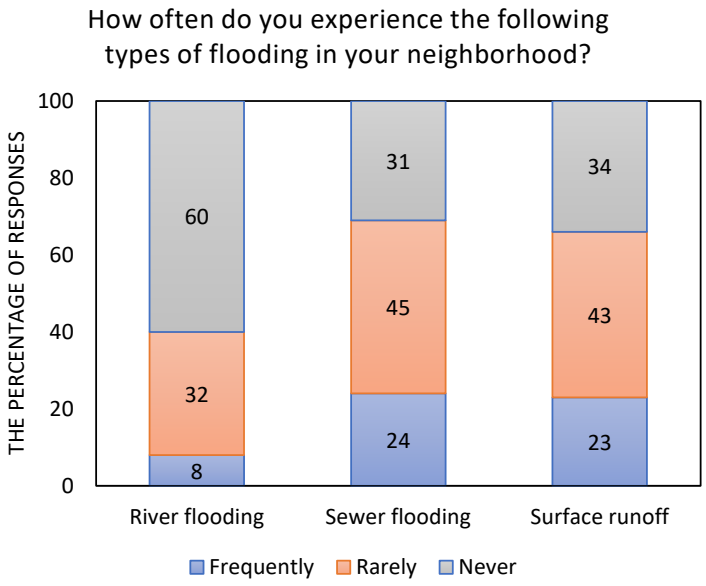


Figure 22. Participants' experiences of different types of flooding events in the neighborhood

Our results confirm the vulnerability of the built environment in Thorncliffe Park to heavy rainfall and snowfall melting. Some participants complained that the excess rainwater after heavy precipitation wicks through porous walls at ground levels and penetrates through unsealed windows, making the interior surfaces wet and causing sanitary issues such as molds. Others indicated their frequent experiences of basement flooding due to sewage back-up, which has damaged boilers, generators, and tenants' possessions in locker rooms, and have imposed lengthy and costly repairs. There is also evidence of the inundation of interior spaces in the basement of an office building, which damaged computers and electrical equipment.

Additionally, participants' experiences of inundation due to pipe breakage and its subsequent power, water, and heating outage, up to 48 to 72 hours, have raised their concerns regarding the probability of infrastructure failure in the face of flooding events. Specifically, with the slow/failed elevators and overcrowded buildings, the evacuation of seniors, children, and people with mobility limitations would be challenging in such emergency conditions.

In rain/snow-melt seasons, there is water puddling/pooling over the pavements and parking lots of buildings with a lower rent, which has raised concerns regarding the discriminatory management of towers by the same company. In addition, there are observations of river flooding events in Don Valley Parkway and Et Seton Park trails. More importantly, there are

experiences of run-off events, which have disrupted participants' daily activities, such as moving grocery shopping, taking their children to school, and commuting to work. These run-off events have mostly occurred over the tower community's surrounding streets, namely Overlea Boulevard and Thorncliffe Park Dr, and its inner pedestrian pathways to East York Town Centre, which lack sufficient green spaces (Figure 21).

67% and 61% of respondents believe that Thorncliffe Park needs more green spaces and water features to manage excess rainwater (Figure 23). In addition, lack of maintenance, cleaning, and discriminatory urban development patterns threaten the quality and quantity of existing green spaces, exacerbating upcoming run-off events. For example, Metrolinx's plan to replace existing green and open spaces with the train yards of the Ontario Line continues to increase impervious surfaces, raising grassroots environmental justice movements (SaveTPARK Community, 2021).

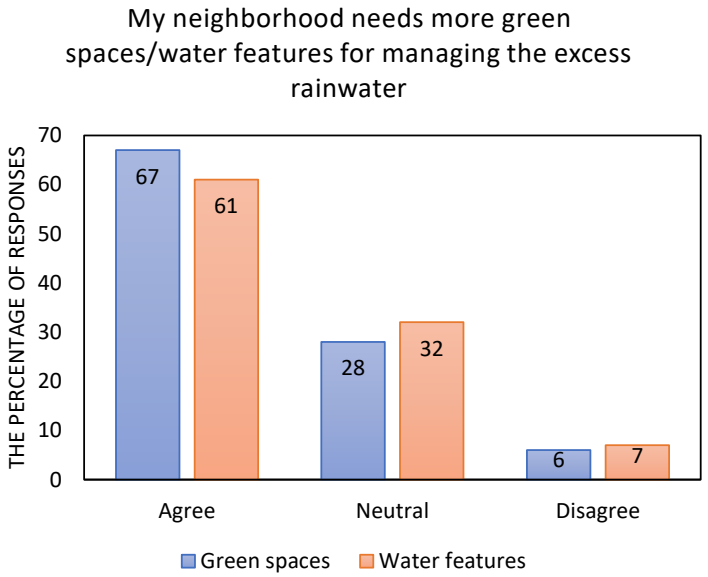


Figure 23. Participants' perspectives on the quantity and quality of green spaces and water features in the neighborhood.

Despite these vulnerabilities, only 28% of our survey participants are concerned about the risk of flooding, while only 32% and 33% expect more frequent and severe flooding events in the neighborhood. As the interviewees indicate, this lack of concerns might be rooted in residents having more immediate problems than flood management. The survey respondents confirmed this statement since they had assigned an average rate of 4.6 out of 10 when we asked how

much they agreed with this sentence: "floods are one of the most serious problems of people in Thorncliffe Park." Furthermore, only 35% of survey respondents mentioned that protection against floods is one of their top priorities (Figure 25).

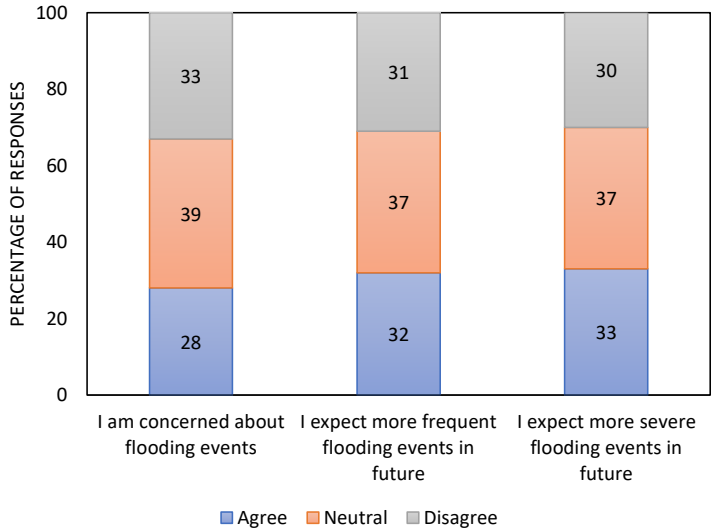


Figure 24. Participants' concerns regarding the current and future flooding events in the neighborhood.

4.7.1.2 Structural vulnerabilities

The residents' vulnerability to flooding events intersects with their other immediate needs. 85% of the survey participants have selected affordable housing as their top priority need (Figure 25). Because of the high living costs and rent prices, it is common for multiple families or generations of the same family to live in the same apartment unit. The other essential needs are employment and physical/mental health care, with 64% and 65% of respondents selecting them as their top priorities (Figure 25). As our interviewees indicate, the residents, who are often foreign-educated immigrants, lack access to stable job opportunities due to language barriers and the misrecognition of their credentials by the Canadian education system. Therefore, they are usually engaged in low-paying service jobs irrelevant to their expertise, leading to depression and mental health issues.

During the pandemic, these essential service jobs exposed them to COVID-19, making Thorncliffe Park a hotspot. The lockdown of schools and daycares forced parents to stay home to care for their children, limiting the hours they could work outside. Hence, it became hard for

residents to afford food and grocery. 40% and 32% of the survey respondents have selected childcare and food/beverage as top priority needs. Moreover, frequent lockdowns combined with the lack of recreational facilities have exacerbated social isolation in this neighborhood; hence 48% and 37% of participants have selected recreation and social interactions as their top priority needs (Figure 25).

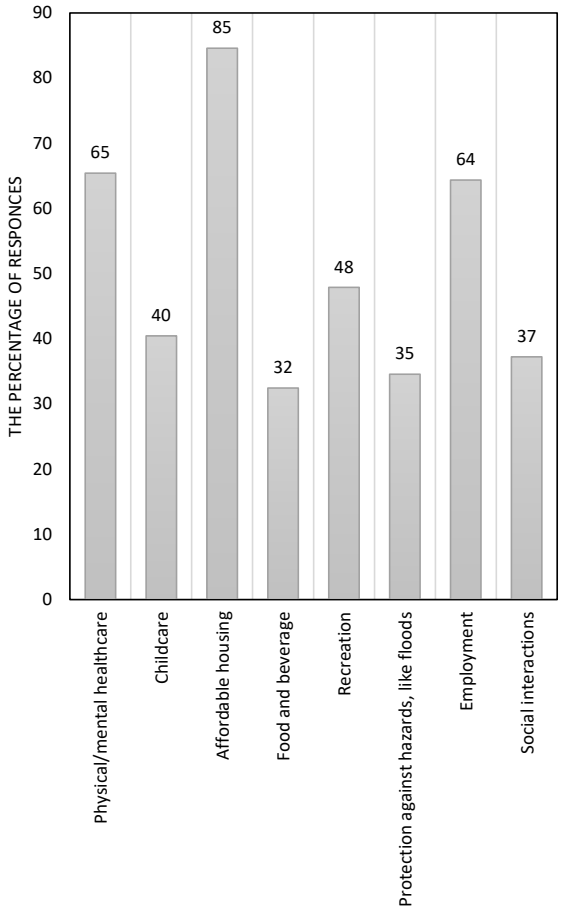


Figure 25. The top priority needs in Thorncliffe Park

4.7.2 Exclusion in adaptive GBI planning and epistemic injustice

Toronto Resilient Strategy plans to prioritize climate action, including both adaptation and mitigation, for equity-seeker groups in NIAs like Thorncliffe Park. However, our interviews show that the residents' engagement in climate action is only limited to carbon mitigation through environmental protection educational programs and food security measures through urban agriculture. While there is evidence of upgrading grey infrastructure for adaptation to

floods, such as stormwater catch basin improvements of R.V. Burgess Park, our interviews show no evidence of adaptive GBI projects.

The exclusion of residents in adaptive GBI planning might be rooted in the fact that flood management is still a technical process in Toronto, relying on large-scale infrastructural measures and cost-benefit rationales to manage broader flood hazard drivers beyond the neighborhood scales. Our findings show that equity and justice in the Flood Resilient charter are limited only to including social vulnerability indicators in the priority mapping tool to inform incremental climate actions and urban renewal projects, like SNAP (City of Toronto, 2020c; TRCA, 2022). In addition to the newness of this priority tool, our interviews show that embedded epistemic patterns of injustice might be a reason for the recognitional injustice in GBI planning.

4.7.2.1 Testimonial drivers of epistemic injustice

We did not find evidence that the identity of residents resulted in their exclusion from adaptive GBI. The expert interviewees asserted that they include underrepresented groups' perspectives by adopting creative tools in climate action projects. One of these innovative tools is the neighborhood championship programs, which educate local leaders on how to engage neighborhood residents, specifically the underrepresented individuals, to influence decision-makers at the municipality level.

A probable reason for misrecognizing Thorncliffe Park residents' testimonies is that the Toronto Resilient Strategy focuses specifically on protecting basement renters who are also among low-income and immigrant groups to advance equity in adaptation (City of Toronto, 2020c). While the Resilient Strategy includes building retrofit programs, such as Tower Renewal to reduce the chance of infrastructure failure in the face of hazards, like flooding events, more attention must be paid to adaptive GBI planning to reduce social vulnerabilities of tower communities like Thorncliffe Park.

4.7.2.2 Hermeneutical drivers of epistemic injustice

We found four hermeneutical injustice patterns leading to the misrecognition of Thorncliffe Park residents in municipal decision-making and adaptive GBI decisions. Table 13 shows how we have extracted these patterns from interviewees' quotations. First, Thorncliffe Park residents

do not have social networks to connect with the urban governance structure. Most neighborhood residents are immigrants who do not have ties to Canada and do not meet people outside their community. Some residents do not even have jobs or attend university/college. Although neighborhood organizations and local champions have collaborated with the City and NGOs for capacity-building and empowerment programs, a lack of financial resources and civic spaces are barriers to establishing connections.

Second, communicational, cultural, and livelihood barriers exclude residents from civic engagement. Many residents have a limited understanding of English or do not have access to the Internet and social media; hence, neither can they participate in social and political activities, capacity-building programs, and volunteer work nor become aware of them. Additionally, there are cultural barriers that impede residents from social life. For example, patriarchal and religious views in some cultures within the neighborhood exclude women from social life and force them to stay at home to do household tasks, leading to their loss of self-esteem and social communication skills. Last, some residents have to work even at weekends and overnight to afford their families' living expenses; hence they have no time to participate in optional programs of local organizations.

Third, some residents have restricted citizenship rights. Non-citizen residents are ineligible to participate in political elections to choose their representatives; therefore, their voices remain invisible in urban development decisions. There are refugees, asylum seekers, and people with no immigration status who are afraid to get in trouble if they attend social activities or ask for help from local organizations. Fourth, several residents are unaware of how extreme climatic events adversely affect their lives and how they can tackle emergencies. Only 5% of the survey respondents (10 out of 199) indicated that they had been engaged in flood adaptation educational and consultation events/venues. This lack of awareness impedes them from demanding adaptation support.

Table 13. The four hermeneutical injustice patterns and sample of interviewees' quotations.

	The hermeneutical injustice patterns	Quotation samples
1	Lack of social networks in urban governance systems	"Politically, there's like very little clout in Thorncliffe, and so it always gets screwed and doesn't get the amount of money that needs".

			"If you look at the Community Center in Thorncliffe it is tiny. Your mind explodes that that could be the Community Center for such a dense high population community, and it's because the city has prioritized other locations to build larger community centers…. I think we need stronger connections with the city".
			"That you know communities like ours like yeah, you may live in a bubble and everybody is kind of similar".
			"People belonging to different ethnicities, they are more comfortable in their own groups".
			"It's been a struggle during COVID with virtual, but it was a struggle before COVID too to just get people to come to programs".
			"Funding is also another challenge for connecting with people. We have to do several paperwork to get the funding, big procedures".
			"I think a lot of problems stem from lack of access and opportunity to jobs and further education".
2	Civic engagement barriers	Communicational	"Many people are not able to use technology and some of the buildings. Some buildings have lost the WIFI connection due to maintenance issues (some not all)" "They cannot afford Internet price".
			"Not all of people have the smart phone and computer knowledge …".
			"Language is an issue. English is not the first language of the majority of people so you have to make sure that communication in multiple languages is inclusive …".
			"Language is the biggest barrier".
		Cultural	"Religious issues. Some people are very shy.... Most of them are under the patriarchy system"
			"So, there's one layer of gender is being protected and all those things. But then we all the men make their decisions right".

	Livelihood	"Some of them might not be able to accommodate a time because they are doing part time jobs (in addition to their main job perhaps?). That is why I put the sessions in the weekends to have the whole family (for both patriarchy issues and their time limitations)".
3	Restricted citizenship rights	"It's been hard sometimes to get refugees to participate because they're not sure if they even have the right to participate, and sometimes programs aren't available to asylum seekers". "Or people didn't feel comfortable coming for their vaccine because they weren't sure it's because they didn't have a green OHIP card they were going to be allowed to get a vaccine or they would get in trouble".
4	Climate unawareness	"People are unaware about climate action because Thorncliffe Park is a very diverse multicultural community. People are new-commers and seniors". "All do not have climate knowledge...We need to talk them and raise their awareness".

4.7.3 Proposing locations to allocate small-scale GBI

Participants demand GBI for all the socio-cultural benefits around the community hub and East York Town Center adjacent to Overlea Boulevard (Figure 26). industrial areas around the Vanderhoof Skatepark and the transportation zone around the railway need GBI for recreational, aesthetic, and educational benefits. The commercial sites around LCBO beside Wicksteed Ave are selected for the sense of place benefits. Residential areas around the Greek Orthodox metropolis at the William Morgan Dr. in the East are chosen for social interactions, the sense of place, and aesthetic benefits (Figure 21 and Figure 22). Once we overlay the maps of these five ecosystem services, the results show four locations that need GBI for socio-cultural benefits (Figure 27a): commercial areas around the East York Town center around the Overlea Boulevard; residential sites at the East around the William Morgan Dr; industrial and residential uses at the east side of Vanderhoof Skatepark; commercial areas at the North West side of the neighborhood (Figure 21).

Regarding run-off management, our spatial analysis shows that the industrial zone at the North side of the railway, the commercial area at the center of the neighborhood, and the residential area at the intersection of Overlea Blv and Thorncliffe Park Dr. are in need of GBI (Figure 27b). When we overlay this map with the map of areas in need of GBI for socio-cultural benefits, the final resulting map shows four locations for allocating small-scale GBI (Figure 28): the North side of the railway, the North side of East York Town Center around the Overlea Boulevard; industrial areas around the Beth Nelson Ave, and sites around the Wicksteed Ave.

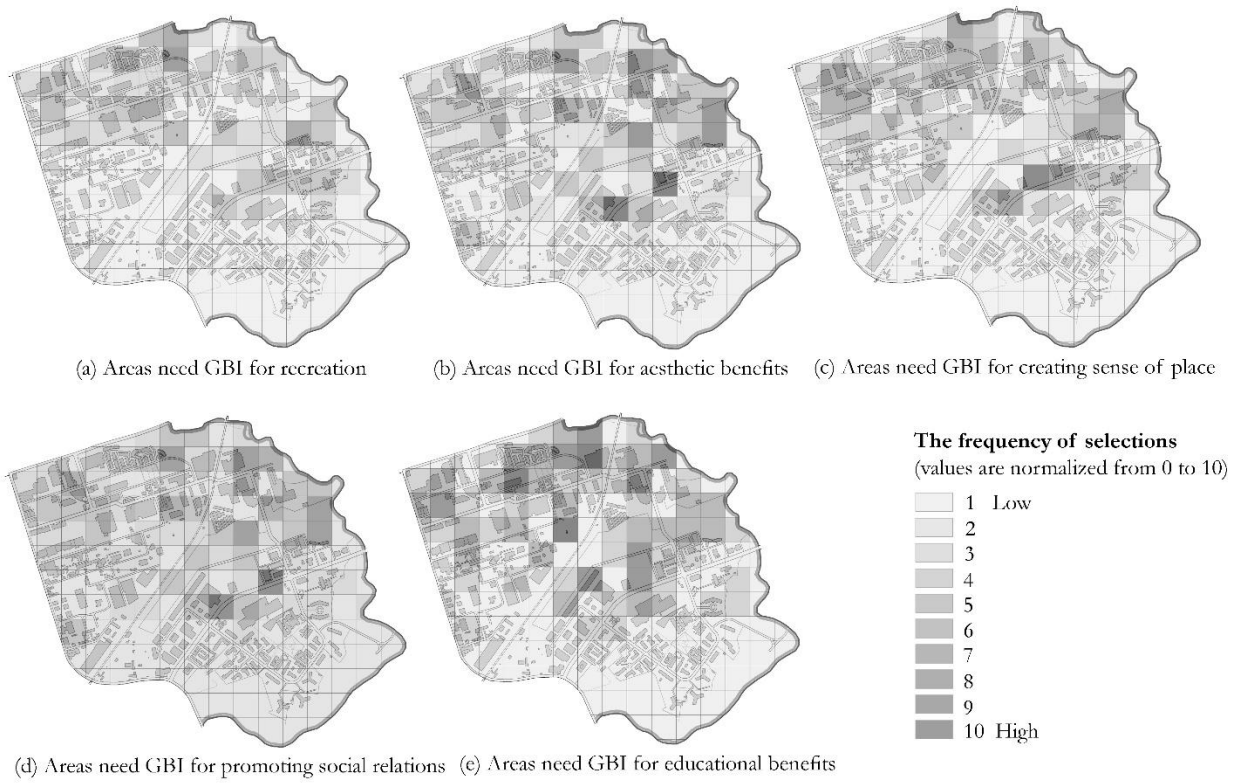
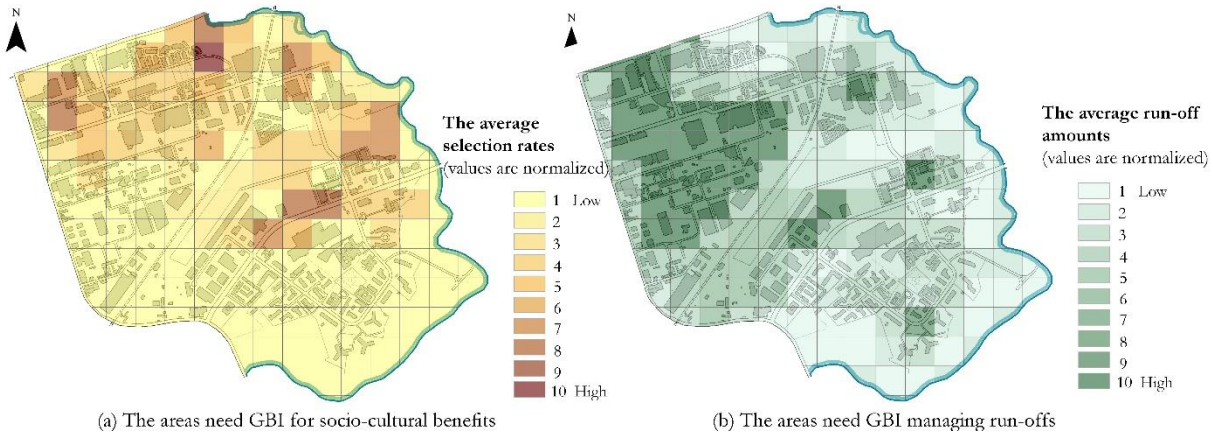


Figure 26. Participants' selections on areas that need GBI for socio-cultural benefits



(a) The areas need GBI for socio-cultural benefits (b) The areas need GBI managing run-offs

Figure 27. Areas need GBI for socio-cultural benefits versus areas need GBI for managing run-offs

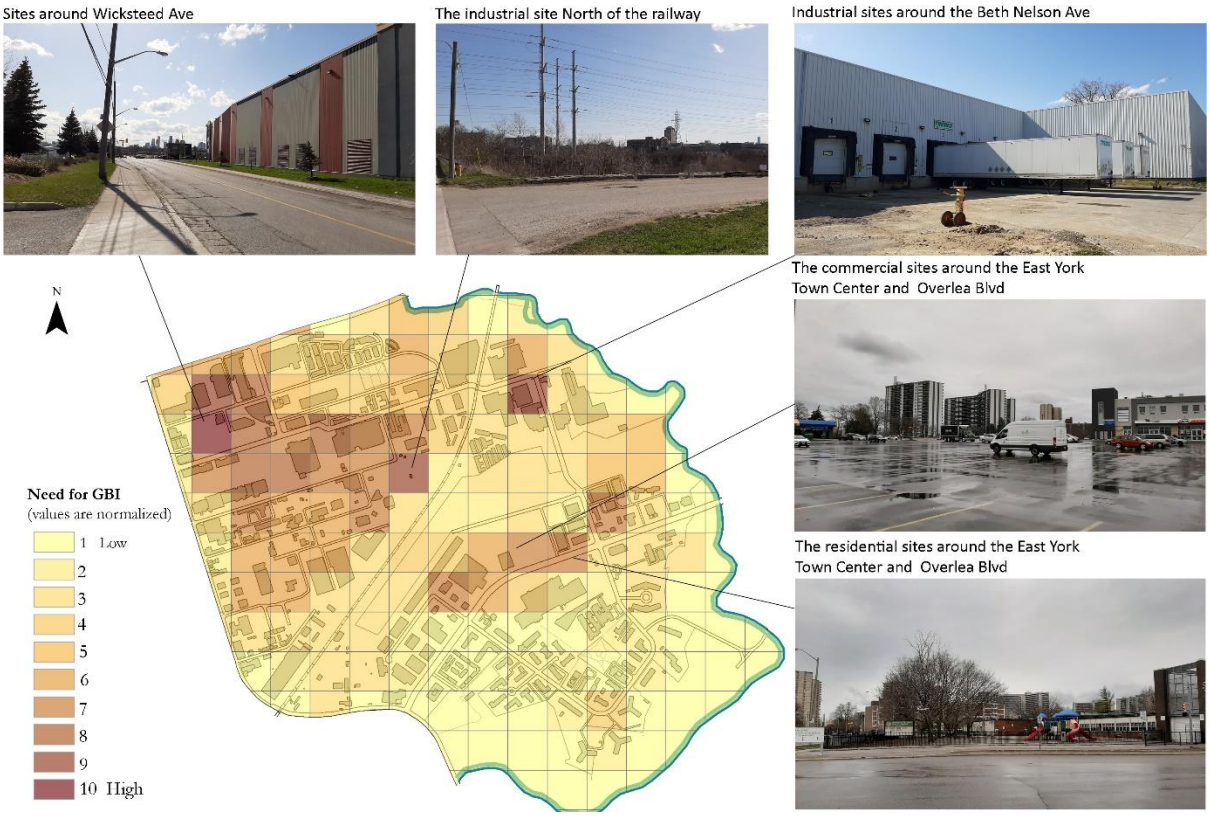


Figure 28. Areas need GBI for both socio-cultural benefits and managing run-offs

4.8 Discussion

The results show that Thorncliffe Park residents' exposure to different flooding events intersects with their structural vulnerabilities and lack of access to adequate and appropriate GBI. Although there are traces of implementing climate mitigation awareness programs as part of the Toronto Resilient Strategy in Thorncliffe Park, this neighborhood is excluded from adaptive GBI planning. The expert interviews and policy reviews unveil that this exclusion is rooted in Toronto's flood management relying on technocratic processes that invest in large-scale adaptive interventions based on cost-benefit rationales, misrecognizing disenfranchised neighborhoods. In Thorncliffe Park, we found that these recognitional injustices relate more to hermeneutical drivers of epistemic injustice than testimonial ones.

Building on our findings, we propose a shift in knowledge systems behind Toronto's GBI planning to integrate adaptation with measures that address hermeneutical drivers of epistemic injustice. Specifically, in Thorncliffe Park, such transformative measures should address four hermeneutical injustice patterns: Lack of social networks; Communicational, cultural, and livelihood barriers to civic engagement; Lack of citizenship rights; climate unawareness. We, furthermore, propose a change in the scale of GBI and ecosystem service valuation approaches in Toronto to integrate small-scale dispersed GBI projects planned and designed based on socio-cultural values rather than economic valuations. In Thorncliffe Park, such small-scale GBI should be distributed at the industrial and commercial uses around the railway and the North side of the East York Town Center to manage run-offs while providing socio-cultural benefits (Figure 28).

The exclusion of immigrant neighborhoods from adaptation responses within the urban form is not specific to Thorncliffe Park in Toronto but exists globally (Kashem et al., 2016). Accordingly, we propose future theoretical and empirical studies to investigate "how" GBI planning and design support equity in transformative adaptation to climate change. Central to these recommendations is developing new forms of inclusive GBI design that recognize local experiential knowledge through identifying and addressing hermeneutical and testimonial drivers of epistemic injustice, hence transferring power and control to impacted communities. We propose these new inclusive design processes to take advantage of innovative methodologies such as participatory mapping and the City of Toronto's devised local

championship processes to integrate adaptation with measures that address structural vulnerabilities through capacity-building.

4.9 Conclusion

Our theoretical framework combined epistemic justice, local experiential knowledge, and the three-pillared climate justice framework to investigate "why" adaptive GBI might exclude vulnerable communities and "how" it can facilitate just transformative adaptation through rescaling GBI, reorienting adaptation knowledge systems, and revisiting ecosystem service valuation approaches. We operationalized this framework in a socially vulnerable neighborhood of Toronto called Thorncliffe Park, using 20 in-depth interviews, 199 online surveys, 120 participatory mapping activities, spatial analysis of run-offs, and policy reviews. The results indicate that, despite their vulnerability and exposure to flooding events, Thorncliffe Park residents are excluded from adaptive GBI planning due to the technocratic processes based on technical knowledge and economic valuation approaches. Such processes misrecognize Thorncliffe Park residents who face hermeneutical barriers, such as a lack of social networks, citizenship rights, climate awareness opportunities, and communicational tools, to affect adaptation decisions. Building on our findings, we propose adopting inclusive processes to design adaptive GBI in industrial uses around the railway and the residential-commercial sites around Overlea Boulevard to manage run-offs while providing socio-cultural benefits. Considering that the systematic exclusion of historically vulnerable groups from adaptation responses abounds globally, this study calls for transforming urban form adaptation processes to transfer power to vulnerable communities by identifying and addressing epistemic barriers for including local experiential knowledge. It requires developing innovative methods for the inclusive design of adaptive interventions within the urban form.

Chapter 5
Conclusion

5.1 Study synopsis

This study was oriented around a central research question, that is how can urban form adaptation advance climate justice? The dissertation answered this question, and its associated sub-questions (see chapter 1), collectively by developing three interrelated and stand-alone manuscripts. Figure 29 briefly indicates how each manuscript responds to the research objectives and questions. I wrote the dissertation based on a manuscript-based format since it provided me with the opportunity to develop a step-by-step and sequential process that facilitated developing the research design of each manuscript based on the findings of the previous one, leading to more practical results. Moreover, this format enabled me to gain thorough insights and feedback during the peer-reviewed process from my supervisor and the journal reviewers while allowing me to have publishing experience during my Ph.D. studies.

All the manuscripts investigated the theoretical and empirical contribution of the three interrelated pillars of climate justice (distributive, procedural, and recognitional) to justice-oriented urban form adaptation. To date, the interconnections these three pillars have with climate change adaptation, in general, and through urban form, in particular, are still unexplored due to the relative nascence of the urban climate justice discourse (Bulkeley et al., 2014) and also, that of climate change adaptation through the urban form (Dhar & Khirfan, 2017a). Accordingly, the **first manuscript** capitalized on systematic literature review and content analysis of 136 peer-reviewed sources on climate justice vis-à-vis urban climate adaptation to investigate current research trends and future trajectories in the climate justice literature vis-à-vis urban form adaptation (see objective 1 in Figure 29 and chapter 1). The results showed several research shortcomings. Some of these shortcomings that have directed the next two manuscripts are:

1. There is a lack of empirical research that deploy the three-pillared climate justice framework either to assess urban form adaptation or propose pathways for justice-oriented adaptation in urban form. Accordingly, climate justice vis-à-vis urban form

adaptation discussions, in the literature, have remained normative without clarifying how to advance the three pillars.

2. There is an absence of studies that investigate how urban design morphological conditions (including size, geometry, orientation, and layout patterns of blocks, building footprints, and streets) relate to climate justice and its three pillars.
3. There is a dearth of studies on recognitional justice, in general, and its connections with urban form, in particular, which might be because of the nascence of theories on recognitional justice in comparison to distributive and procedural justice.

These three shortcomings are rooted in theoretical and methodological barriers. Theoretically, there has been a lack of historical engagement and amalgamation between social justice and urban form/design except for a few normative urban form theories such as Good City Form by Lynch (1984). This lack of connections causes empirical studies and urban design practices to lag behind the progress in theories on socio-climate justice and participatory planning/design. Methodologically, limitations for accessing spatial data pose barriers to utilizing spatial analysis processes for assessing urban form and morphological design interventions in terms of climate justice pillars. Additionally, the informal status of some of the vulnerable groups as well as their communication barriers, due to their lack of access to discursive and material tools for civic engagement, pose methodological barriers for climate justice researchers to assess if urban form adaptation meets climate justice pillars, specifically the recognitional justice.

The next two manuscripts addressed the research shortcomings by proposing theoretical frameworks that enable empirical studies to devise conceptual frameworks and methodologies for deploying the pillars of climate justice (see objective 2 in Figure 29). The **second manuscript** connected distributive justice with Dhar & Khirfan's (2017b) Urban Design Resilient Index (UDRI) to investigate how the adaptive capacity of urban form (through land uses and town plans) is connected to differential vulnerabilities and exposures to floods, and how urban form adaptation responses should be distributed to avoid flood risk inequities. Building on these theoretical links, the manuscript proposed a multi-criteria model that identifies urban areas/neighborhoods that are unequally at risk of flooding events and need to be prioritized in adaptive interventions within the urban form. The manuscript operationalized the model in Toronto using weighted overlay analysis in ArcGIS, where Toronto-based flooding

experts assigned weights to the spatial model's indicators. The findings unveiled four disenfranchised tower communities with old infrastructure as the high-risk neighborhoods that need to be prioritized in adaptive interventions within the Toronto's urban form. Furthermore, the findings identified high run-off coefficients and lack of harmony with nature, the most influential in the flood exposure of these neighborhoods and the low adaptive capacity of their urban form. Accordingly, it called for future theoretical and empirical studies to investigate how GBI interventions and nature-based solutions can address the root causes of vulnerability in tower communities in Toronto while advancing just adaptation to flooding.

The **third manuscript** responded to the second manuscript's call by developing theories and methodologies for justice-oriented transformative adaptation through GBI planning (see objective 3 in Figure 29). This manuscript complemented the second manuscript by investigating "how" decision-makers can build on local experiential knowledge to design GBI in disenfranchised neighborhoods exposed to a high risk of floods to shift technocratic adaptation responses and their exclusionary outcomes. Building on a theoretical framework that connects urban form interpretations of climate justice pillars with epistemic justice and local experiential knowledge, the manuscript proposed three pathways for justice-oriented transformative adaptation: rescaling GBI; restructuring adaptive GBI knowledge production systems to recognize local experiential knowledge; reorganizing ecosystem service valuation approaches. I operationalized the theoretical framework in the Thorncliffe Park neighborhood in Toronto, one of the high-risk priority neighborhoods the second manuscript identified, through in-depth interviews, online surveys, participatory mapping activities, spatial analysis of run-offs, and policy review. The findings unveiled locations in industrial and commercial-residential sites for designing small-scale GBI for both socio-cultural benefits and run-off management. The findings, furthermore, called urban form adaptation processes in Toronto and beyond to transfer power to vulnerable communities by identifying and addressing epistemic barriers for including local experiential knowledge.

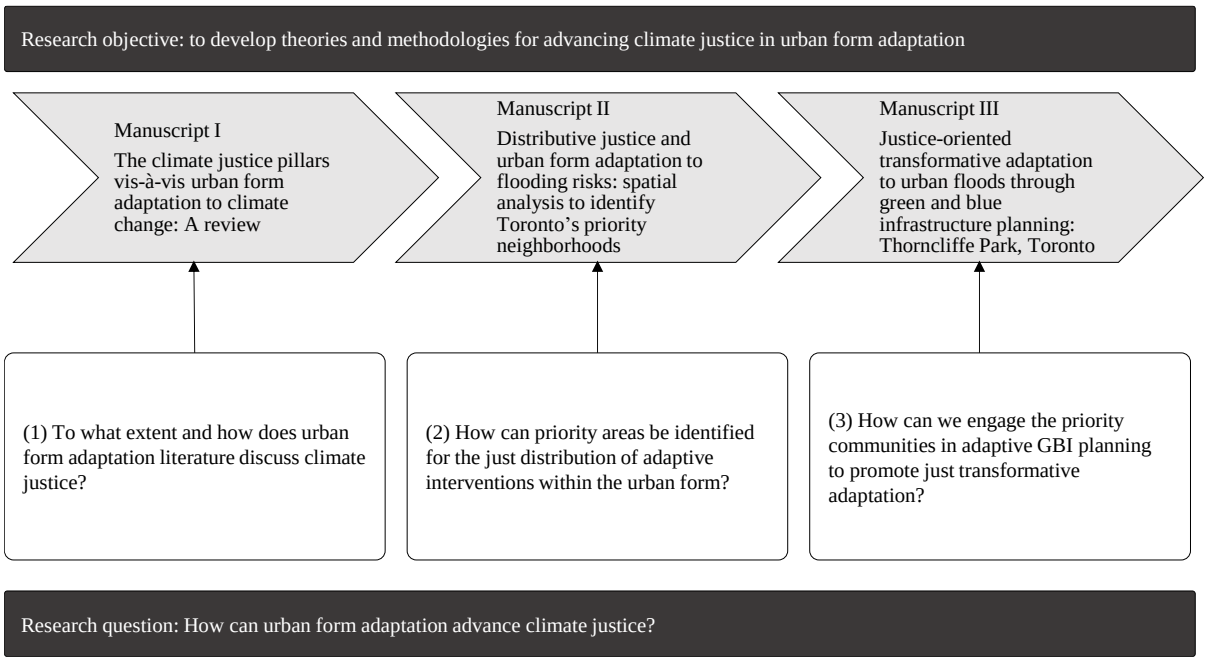


Figure 29. How the three manuscripts of this dissertation address the research objective and questions

5.2 Research contribution

While climate justice has appeared in urban climate adaptation discourse since 2008, there is still a lack of in-depth connections between urban form and climate justice. This dissertation showed that adaptation discussions on climate justice mainly exist in the realm of urban politics and governance (Figure 30). Furthermore, urban form and physical planning is the next most discussed topic in the literature on adaptation vis-à-vis climate justice. However, such urban form discussions are in the realm of normative suggestions/critiques because of divisions between theories on climate justice (such as the three-pillared justice framework) and urban form adaptation. This shortcoming results in the lack of empirical efforts to develop methodologies for advancing climate justice in urban form adaptive interventions, which leaves urban design and form practitioners unequipped with methodological tools to apply climate justice theory. Accordingly, this dissertation contributes to the application of climate justice in urban form adaptation in terms of theory, methodology, and practice.

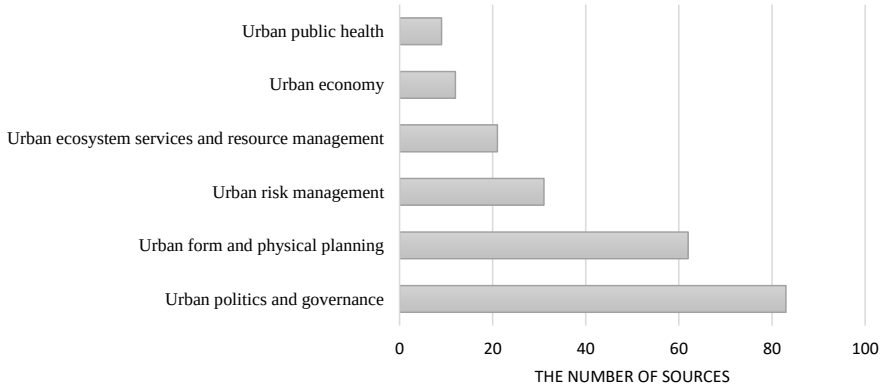


Figure 30. The frequency of sources discussing six different planning topics in the literature on climate justice vis-à-vis urban climate adaptation

5.2.1 Contributions to the theory

This research proposes new theoretical frameworks to bridge the divisions between urban form adaptation and climate justice. These theoretical contributions are through (1) expanding the realm of risk framework to integrate urban form; (2) expanding the three-pillared justice framework; (3) introducing pathways for justice-oriented transformative adaptation through GBI planning.

Expanding the realm of risk framework to integrate urban form

Theoretical scholarship relates climate risk inequalities to the different patterns of adaptive capacities, vulnerabilities, and exposures (the three drivers of risks). There are several debates on how the lack of access to adaptive capacities is associated with social vulnerabilities and exposures (Herreros-Cantis et al., 2020; Islam & Winkel, 2017; Suarez, 2002). Theoretical debates on adaptive capacities usually focus on access to individual, community, non/governmental, and public resources to cope with hazards (Islam & Winkel, 2017). Yet, connections the adaptive capacity of urban form has with differential vulnerabilities and exposures, hence risk inequalities, are still unexplored in the literature. This dissertation drew on the configurational characteristics that Dhar & Khirfan's (2017b) UDRI framework proposes to assess how the adaptive capacity of urban form (through land uses and town plans) is connected to flood hazard exposures, social vulnerabilities, and risk inequalities.

Expanding the three-pillared justice framework

The dissertation showed that the theoretical debates on the three-pillared climate justice framework are not connected to urban form adaptation, such as through GBI planning. Additionally, Anguelovski et al. (2020) assert that this framework might be restrictive in grabbing the lived experiences of vulnerable groups and the power imbalance patterns in adaptation responses within the urban form. The dissertation addresses these deficits by expanding the climate justice triad.

I expanded distributive justice both in macro (city-wide) and micro (neighborhood) scales. In macro scales, I combined distributive justice with the three drivers of risks (vulnerabilities, exposures, and the adaptive capacity of urban form) to identify urban areas that need to be prioritized in urban form adaptation interventions. In micro scales, I capitalized on theoretical and empirical debates on how the size of GBI can impact justice. Small-scale GBI projects that are equally distributed as a network across larger scales provide the local communities with accessible, neighborhood-oriented, and visually-appealing green-blue spaces while preventing unequal outcomes such as gentrification and forced relocations (Wolch et al., 2014). Accordingly, they can advance distributive justice.

I expanded recognitional justice to integrate the notion of epistemic injustice, which explains the unfair processes of recognizing knowledge (Byskov & Hyams, 2022). Few theoretical and empirical studies, such as (Chu & Michael, 2019), have focused on the epistemic interpretations of recognitional justice. This dissertation went further than what (Chu & Michael, 2019) offered by investigating how recognitional justice connect with two drivers of epistemic justice proposed by Fricker (2007): testimonial and hermeneutical justice. The former relates to under-represented groups' lack of access to material and rhetoric tools to make sense of their experiences, while the latter occurs when the knowledge of someone is not considered credible because of prejudices about their social background, income, race, ethnicity, and gender. The integration of these two epistemic justice drivers provides a lens to investigate why urban form adaptation might fail to recognize vulnerable groups and how decision-makers can empower under-represented groups.

Last, the dissertation capitalized on socio-cultural framework for valuing ecosystem services to explain how adaptive GBI planning can advance procedural justice. Socio-cultural valuation of

ecosystem services complements the prevalent economic valuation approaches by integrating collective and communal perspectives of people regarding ecosystem service values. The framework requires procedurally-just deliberative and participatory processes to include pluralistic voices, perspectives, and actors in the design and implementation processes of adaptive GBI.

Introducing pathways for justice-oriented transformative adaptation through GBI design

Transformation in urban form adaptation usually relates to fundamental and systematic changes in urban functions and structures through large-scale and innovative interventions to deal with massive climate impacts (Elmqvist et al., 2019; Kates et al., 2012; Lamb & Khirfan, 2022). Despite their benefits, these transformative interventions rely on scientific knowledge and cost-benefit rationales to protect valuable urban assets without considering climate justice concerns. In response to these exclusionary outcomes, emerging studies call for transformative adaptation that tackles decisive measures against sizable risks while redressing the underlying causes of structural inequities and vulnerabilities (Shi & Moser, 2021). However, there is a shortage of theoretical and empirical studies that connect justice-oriented transformation with urban form adaptation (Lamb & Khirfan, 2022).

This dissertation bridges theoretical divisions between justice-oriented transformation and urban form adaptation through GBI planning. It connects urban form interpretations of the three-pillared justice framework proposed by Lamb and Khirfan (2022) with epistemic justice and local experiential knowledge to propose three pathways for just transformative adaptation through GBI: (1) Revisiting the scale dimension of GBI; (2) restructuring flood-adaptive GBI knowledge production systems to recognize local experiential knowledge; (3) reorganizing ecosystem service valuation approaches.

5.2.2 Contributions to methodology

Building on spatial analysis, surveys, and interviews, the dissertation proposed a new methodology for integrating climate justice in urban form adaptation. My proposed methodology includes new techniques for (1) measuring the adaptive capacity of urban form; (2) integrating the configurational characteristics of urban form in flood risk modeling; (3) integrating climate justice in siting adaptive interventions within the urban form.

Measuring the adaptive capacity of urban form

While there is empirical studies that measure the adaptive capacity of urban form to heat-related climate hazards (Shashua-Bar et al., 2009; Sun & Chen, 2012), there is a deficit of studies that propose methodologies for measuring the adaptive capacity of urban form to urban floods (Mohtat & Khirfan, 2022). The few studies that assess the adaptive capacity of urban form to flooding events also focus only on the density of GBI as the indicator (Li et al., 2020; Meerow & Newell, 2017). These few studies do not delve into how the spatial arrangement of town plan elements (street networks, building footprints, and urban blocks) and land use patterns affect the adaptive capacity of urban form against climate-induced flooding events. The dissertation proposed a new method, based on spatial analysis, to assess and compare the adaptive capacity of different urban districts and neighborhoods to flooding events. This new method operationalizes part of the UDRI framework proposed by Dhar and Khirfan (2017b) by proposing variables for mapping five resilient configurational characteristics of urban form: harmony with nature, heterogeneity, polyvalency, connectivity, and flexibility in different neighborhoods. The proposed method can guide similar studies on how to measure the configurational characteristics of the resilient and adaptive urban form proposed by studies similar to Dhar and Khirfan (2017b) – see, for example, Sharifi (2019c).

Integrating the configurational characteristics of urban form in flood risk modeling

Several studies propose multicriteria models to identify the spatial distribution of flood risks. These proposed multicriteria models primarily include physical factors that cause flood hazards, such as slope, elevation, rainfall, and soil types (Hammami et al., 2019; Lin et al., 2019; Ogato et al., 2020). In recent decades, emerging studies have integrated exposure and social vulnerability indicators, such as critical infrastructure, population density, income, and age, in flood risk modelling (Rincón et al., 2018; Santos et al., 2020). However, less attention is paid to the role of the adaptive capacity of urban form in flood risk modelling. This study added the dimension of urban form to flood risk modelling by integrating the adaptive capacity of land uses and town plans proposed by Dhar and Khirfan's (2017b) UDRI framework.

Integrating climate justice in siting adaptive interventions within the urban form

Most importantly, the dissertation proposed a stage-by-stage methodology for operationalizing the three-pillared justice framework to site adaptive interventions, through GBI, in urban form.

This stage-by-stage methodology is entirely new in climate justice literature, which lacks empirical studies that propose methodologies for operationalizing climate justice in urban form adaptation (Mohtat & Khirfan, 2022). The proposed methodology, specifically, takes advantage of spatial analysis (using GIS) to identify the patterns of flood risk inequalities, hence the priority neighborhoods for the just spatial distribution of urban form adaptation responses.

The dissertation, furthermore, proposed a participatory component to propose "how" to include disenfranchised communities in GBI planning and "where" to site them to advance distributive, procedural, and recognitional justice. Part of this spatial analysis component consists of participatory mapping activities. Prominent scholars on climate justice, such as (Anguelovski et al., 2020), propose applying participatory mapping (also called PGIS) to include place-based local experiential knowledge in adaptation responses to advance climate justice. However, I found no efforts in the literature that have used this method. The application of participatory mapping in this research is inspired by this method's prevalent usage in the socio-cultural valuation of ecosystem services (Brown & Fagerholm, 2015) to identify locations that need GBI based on public perspective and opinions for socio-cultural benefits. The dissertation combined this method, which grabs the local experiential knowledge, with the spatial analysis of run-off amounts (based on scientific knowledge) to identify locations where GBI interventions need to be applied. Combining these two spatial methods can guarantee socially legitimate and ecologically efficient GBI interventions, contributing to justice-oriented transformative adaptation.

5.2.3 Contributions to practice

The dissertation contributes to climate change adaptation practice by integrating both urban form considerations and justice concerns. This contribution integrates three realms of flood risk management, GBI planning, and tower renewal programs in Toronto and beyond.

Flood management

Conventionally, municipalities in Canada and beyond have focused on hazard-based approaches to manage flooding events, whereby flood projection based on historical data informs flood protection, mitigation, and preparedness policies. Evidence on the economic costs of flooding events led to a paradigm shift in flood management toward risk-based approaches, such as through risk mapping, to include exposures and social/physical vulnerabilities in flood

management policies. In Canada, flood management policies are dominantly based on the conventional hazard-based approach with a primary focus on fluvial (riverine) flooding events (Henstra & Thistlethwaite, 2017; Thistlethwaite et al., 2018). In Toronto, for example, it was not until 2019 that the City of Toronto gathered a group of internal and external stakeholders, known as Flood Resilient Toronto Working Group, to design a flood risk mapping tool based on the critical infrastructure, social, and physical vulnerability (City of Toronto, 2019b). Additionally, the adaptive capacity of urban form and justice lens usually are not included in flood risk mapping and risk management policies in Canada and beyond (Mohtat & Khirfan, 2022).

Accordingly, the contributions of this research to flood risk mapping, and accordingly flood management policies, in Canada and beyond are three-fold. First, the dissertation paves the path for mapping flood risks in any city and town in Canada and beyond. Second, the dissertation, lays the foundations of adding new layers of urban form's adaptive capacity (or adaptation) and climate justice to flood risk mapping. The dissertation's focus on the configurational characteristics of resilient land uses and town plans based on the UDRI framework (Dhar & Khirfan, 2017b) to map risks contributes to the flood management practice to integrate urban form considerations. Additionally, the dissertation's contribution in combing the climate justice triad with the risk framework can guide flood risk management policies on how to integrate justice. Third, the dissertation informs municipal risk mapping strategies on how to integrate pluvial flooding hazards, "flooding that results from rainfall-generated overland flow and ponding before the runoff enters any watercourses, drainage system, or sewer" (Falconer et al., 2009, p. 199)

GBI planning

From the Flood Resilient Toronto Project (City of Toronto, 2019b) to the European Green Infrastructure Strategy (European Commission, 2015), there are examples of decision-makers' efforts for scaling up GBI networks to manage climate-induced flooding events. However, it seems that GBI strategies usually do not include equity and justice despite the raised concerns regarding the unjust outcomes of flood-adaptive GBI planning (Shi, 2020a). This dissertation guides GBI policies on how to advance justice and equity. It specifically guides GBI policies to focus on several small-scale but dispersed GBI projects rather than a handful of large-scale

concentrated projects to advance justice. It, furthermore, proposes GBI policies to take socio-cultural valuation approaches based on socially-embedded knowledge to address the underlying causes of vulnerabilities and risk inequalities rather than apolitical and technocratic economic assessment approaches.

The dissertation's proposed stage-by-stage methodology, from identifying the high-risk priority neighborhood to the participatory components in the high-risk neighborhood, including the participatory mapping activities, also can be useful for practitioners. The Sustainable Neighborhood Action Program (SNAP) team in Toronto and Region Conservation Authority (TRCA) invited me to present this dissertation. One of the senior project managers indicated that the dissertation goes beyond what they do in SNAP by integrating a justice lens for identifying the high-risk neighborhood and by utilizing participatory mapping to engage local communities in siting GBI interventions.

Tower renewal programs

Municipalities across the North America and Europe have proposed strategies to improve the conditions of the tower buildings built in the 1960s to 1970s such as through tower renewal programs. Some of these renewal programs integrate climate mitigation measures such as through urban agriculture interventions and energy efficiency educational programs. However, it seems that renewal policies have not paid enough attention to adapting these tower buildings to climate change impacts, specifically to flooding events. The dissertation's findings on the vulnerability and exposure of tower communities in Toronto to climate-induced flooding events inform tower renewal policies to integrate adaptation considerations in addition to mitigation. Instead of project-based adaptation and capacity-building programs, the dissertation proposed a shift in the renewal policies to integrate adaptation with measures that address structural inequities.

5.3 Research limitations

The dissertation built theoretical, methodological, and practical foundations to integrate climate justice in urban form adaptation. However, it has theoretical and empirical limitations that need to be addressed in future studies.

First, the dissertation's deployment of the three-pillared climate justice framework for advancing just urban form adaptation limits to identifying locations for allocating adaptive interventions in micro (neighborhood) and macro (city-wide) scales and deciding on the size of adaptive GBI. With this contribution, the dissertation took a step forward to fill theoretical divisions between climate justice and urban form adaptation. However, future studies still need to propose how to design adaptive interventions by changing the geometry, layout patterns, and orientation of streets, buildings, and blocks to advance climate justice.

Second, the dissertation's utilization of the three-pillared justice framework for assessing adaptive interventions had some limitations. The research took advantage of distributive justice to assess the adaptive capacity of urban form (land uses and town plans) in different neighborhoods of Toronto and all three pillars to assess if existing adaptive GBI policies and programs meet climate justice in a disenfranchised high-risk neighborhood (Thorncliffe Park). However, it did not assess city-wide urban form adaptation policies, strategies, and programs, such as the First Toronto Resilient Strategy and the SNAP project, through the lens of the three-pillared justice framework. Similarly, it did not assess the sitting of GBI pre- and post-implementation in terms of climate justice and its pillars.

Third, the dissertation proposed a new method for siting GBI based on their non-monetary socio-cultural benefits instead of economic values to address structural inequities and the root causes of vulnerability. However, it did not go further on designing, developing, and using urban lands for GBI to provide socio-cultural benefits based on diverse place-specific needs and perspectives of the most under-represented groups. Part of these limitations relate to COVID-19 conditions, which restricted me to tackle collaborative methodologies such as through holding in-person meetings and design events/workshops in the impacted communities. Accordingly, I propose future urban design research to investigate how planners and impacted communities can collaborate to decide on the types of plants, water features, and public spaces included in GBI interventions to provide secondary socio-cultural benefits while contributing to climate adaptation.

Fourth, the dissertation's application of the Dhar and Khirfan's (2017b) UDRI framework to measure the adaptive capacity of urban form has some limitations. The dissertation applied only four (out of seven) indicators the UDRI framework proposes. Additionally, while Dhar and

Khirfan (2017b) apply their resilient concepts collectively to all the three of Conzen's (1960) urban form components (i.e., land uses, town plans, and three-dimensional built form), I applied three indicators to land uses and one to town plans. I recommend future studies to investigate how the other three indicators of UDRI, indeterminacy, latency, and modularity, can be measured. In addition, I propose future research to examine how all the resilient indicators of UDRI can impact the adaptive capacity of the three-dimensional built form.

Fifth, the dissertation's contribution to justice-oriented adaptation of urban form to flooding events restricts to the management of pluvial flooding events. The dissertation has not investigated how urban form interventions for adapting to fluvial flooding events (riverine flooding), such as through protection, retreat, and accommodation measures, can impact climate justice.

5.4 Recommendations for future research

In addition to the above-mentioned recommendations, the dissertation proposes future climate justice vis-à-vis urban form adaptation studies to move beyond identifying locations to integrate adaptive interventions. It highly recommends including climate justice in adaptive urban design interventions by changing the layout patterns, orientation, and geometry of streets, buildings, and blocks or designing different GBI projects. Furthermore, the dissertation calls for studies that assess adaptive policies and interventions within the urban form before and after implementation in terms of climate justice. These recommendations warrant devising new theories to provide a lens for assessing and analyzing the design of adaptive interventions in terms of climate justice. At the same time, climate justice scholarship requires developing new methodologies to facilitate the justice-oriented design of adaptive interventions.

Theoretical recommendations

This dissertation showed that the triad of climate justice is a comprehensive framework, which applies in different planning areas from urban governance to urban form and design, to urban public health. Because this justice framework is too overarching, planning researchers need to combine it with other theories in any planning area to use it. The dissertation combined the framework with different theoretical debates on urban form resilience, transformative adaptation, epistemic justice, and local experiential knowledge, among others, to identify how urban form adaptation can advance climate justice.

However, the dissertation's contribution to justice-oriented urban form adaptation relates only to decisions for identifying the locations of adaptive GBI interventions to advance distributive justice in micro and macro scales. The dissertation does not investigate what design characteristics GBI should have to advance other types of justice in addition to distributive justice. This shortcoming unveils that the application of climate justice in urban form manifests mostly in distributive justice while procedural and recognitional justice relates to decision-making processes behind adaptive interventions. Accordingly, the three-pillared climate justice framework alone is unable to propose justice-oriented design characteristics for adaptive interventions within the urban form, specifically in micro scales, circumscribing our understanding of justice in designing, assessing, analyzing, and examining adaptive urban form interventions. This dissertation proposes future studies on adaptive urban form and design to add other types of justice with regards to urban design to the three-pillared justice framework.

This proposition is in line with Anguelovski et al. (2020), who indicate that the climate justice triad "only allows for a limited view of the ways in which residents experience (in)justice", and restricts the inclusion of vulnerable groups' everyday lived experiences in adaptation planning and design. I recommend future studies to expand justice boundaries in urban form adaptation through operationalizing the Anguelovski et al's. (2020, p. 1750) proposed three new principles based on the role of material and immaterial power structures in producing urban spaces: anti-subordination, intersectional, and relational greening. Anti-subordination, or emancipatory, greening entails liberating green spaces through proposing new policies and institutional arrangements that assure marginalized groups a secure and permanent use and control of green spaces. Intersectional greening refers to producing green spaces that reflect multiple identities, hence responding to multiple intersectional injustices and vulnerabilities. Last, relational greening moves urban greening away from economic valuation approaches based on individualized preferences, highlighting the role of socio-cultural relations embedded in people's interaction with nature in shaping green spaces. Adopting these three principles facilitates designing more inclusive and equitable adaptive GBI interventions at different scales.

Methodological recommendations

The dissertation's application of a combined method, consisting of spatial analysis, participatory mapping, interviews, and surveys, facilitated the application of climate justice in urban form

adaptation. However, the dissertation's limitations warrant developing new methodologies to facilitate justice-oriented urban design adaptive morphological and spatial interventions and pre-post assessment of urban form adaptation in terms of climate justice. Accordingly, the dissertation calls for integrating two methodological approaches in future research

First, future studies should develop place-based collaborative processes through in-person focus group discussions, community meetings, and participatory workshops/events to engage local communities in adaptation knowledge production, assessments of adaptive intervention, and adaptation decision-making processes (Moran et al., 2016). Central to these collaborative processes should be design charrettes, in reference to "intensive and time-constrained participatory design" that includes interactive dialogues and drawing activities (Dhar & Khirfan, 2016, p. 239). Regarding climate justice, design charrettes can provide an arena for urban designers and planning experts to empower vulnerable communities to express their needs and include them in the design of adaptive urban form interventions. In other words, they allow the co-design of adaptive interventions by the most under-represented groups and planning experts (Ziervogel et al., 2022).

Second, I propose future studies on urban form vis-à-vis climate justice to adopt new methodologies that integrate design into the research processes. Among these innovative methodologies is research through design (RTD), which is "an iterative process in which designing and testing alternate." The researcher develops and tests design options in each iteration using diverse methodologies (Cortesão et al., 2020b, p. 2; Lenzholzer & Brown, 2016). While there are empirical studies on the application of RTD in designing adaptive urban form interventions and testing them through quantitative evaluations and qualitative participatory techniques, I found no evidence of their application in climate justice research (Cortesão et al., 2020a; Lenzholzer & Brown, 2016). This dissertation, particularly, proposes upcoming climate justice studies to tackle the qualitative and participatory modes of RTD to involve local communities in designing adaptive urban form interventions and testing them in terms of climate justice through design workshops and interactive activities.

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Appendices

Appendix A: Experts' weighting surveys

Information letter

Title of project: The just adaptation of Toronto's urban form to floods originated from the global climate change

Principal investigator: Luna Khirfan, PhD, School of Planning, Faculty of Environment, University of Waterloo. Phone: 519-888-4567 ext. 43906, Email: lkhirfan@uwaterloo.ca

Student investigator: Niloofar Mohtat, PhD candidate, School of Planning, Faculty of Environment, University of Waterloo. Email: nmohtat@uwaterloo.ca

Dear Sir/Madam,

You are invited to participate in a web-based survey, which is part of my (Niloofar Mohtat) PhD thesis project. This four-year PhD project is fully funded by Internal UWaterloo funding, and have three objectives, namely: (1) Finding the urban neighborhood in Toronto that is bearing the highest levels of flood risks and which need to be prioritized in climate adaptation decisions; (2) Identifying why the residents of this priority neighborhood are unequally experiencing this highest level of flood risks; (3) Proposing policy recommendations for the adaptation of this priority neighborhood to floods. The results of this study will be used for developing the PhD thesis and for publishing peer-reviewed papers.

Participants of this survey are experts in at least one of the fields of urban climate change adaptation, flood management, and urban form. If you decide to participate, you will be asked to complete a 15-minute online survey that is completed anonymously. The survey asks you to rate the importance of some concepts (i.e., flood hazards, social vulnerability, and low adaptive capacity of land uses and urban-form physical elements) and their associated indicators on creating or mitigating flood risks in Toronto neighborhoods. It also includes a background question about the name of organizations(s) that you are collaborating or have collaborated with. We use your ratings for weighting and overlaying maps in ArcGIS software so as to identify the neighborhood bearing the highest levels of flood risks in Toronto.

Participation in this study is voluntary. You may decline to answer any question(s) that you do not wish to answer and you can withdraw your participation at any time by not submitting your responses. After submitting your answers, however, you cannot withdraw because we have no way to know which answers are yours (the surveys are unidentifiable). There are no known or anticipated risks from participating in this study and no remuneration is offered for taking part.

Your identity will remain confidential. All of the data will be summarized and no individual could be identified from these summarized results. You will be completing the study by an online survey operated by Qualtrics Survey Software. When information is transmitted or stored on the internet, privacy cannot be guaranteed. There is always a risk your responses may be intercepted by a third party (e.g., government agencies, hackers). Qualtrics temporarily collects your ID and computer IP address to avoid duplicate responses in the dataset, but will not collect information that could identify you personally. If you would prefer not to submit your survey responses through this software, please contact the student investigator Niloofar Mohtat using the contact details listed below, so you can participate using an alternative method, such as an emailed questionnaire. The alternative method may decrease anonymity but confidentiality will be maintained.

The data, with no personal identifiers, collected from this study will be maintained on a password protected external hard drive in a secure and restricted-access space at University of Waterloo. Only the research team (i.e., Niloofar Mohtat and Dr. Luna Khirfan) will have access to this data. The data will be retained for a minimum of 7 years, after which they will be destroyed.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (ORE #42887). If you have questions for the Board, contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca.

Once all the data are collected and analyzed, we plan to share the results through conference presentations and journal articles. If you would like to receive a copy of the results (anticipated to be completed by the end of 2022), or need additional information to assist you in reaching a decision about participation, please email Niloofar Mohtat at nmohtat@uwaterloo.ca.

Thank you for your interest.

Yours sincerely,

Niloofar Mohtat, PhD candidate

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Consent form

By agreeing to participate in the study you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study:

□ Yes, I agree to participate

□ No, I do not wish to participate

Questions

1) Several studies indicate that flood risks are the result of intersections among flood hazards **exposures**, social **vulnerabilities**, and the low **adaptive capacity** of **land uses** and **town plans**– please role the mouse cursor over the bolded words to see the their definitions.

In each row, based on your personal knowledge, please indicate how important each concept is compared to its pair concept in creating flood risks in Toronto? (where 1 is equal importance and 9 is extremely more important).

	Extremely more				Equally important				Extremely more	
	9	7	5	3	1	3	5	7	9	
Flood hazard exposures	□	□	□	□	□	□	□	□	□	Social vulnerabilities
Social vulnerabilities	□	□	□	□	□	□	□	□	□	The low adaptive capacity of land uses
The low adaptive capacity of land uses	□	□	□	□	□	□	□	□	□	Flood hazard exposures
The low adaptive capacity of town plans	□	□	□	□	□	□	□	□	□	Flood hazard exposures
The low adaptive capacity of land uses.	□	□	□	□	□	□	□	□	□	The low adaptive capacity of town plans.
The low adaptive capacity of town plans.	□	□	□	□	□	□	□	□	□	Social vulnerabilities

2) Based on your personal knowledge and experience, please rate the impact of the following indicators on **flood hazard exposure** in Toronto (where 0 is not impactful while 10 is extremely impactful) − role the mouse cursor over the bolded words to see their definition.

	0	1	2	3	4	5	6	7	8	9	10
Distance to floodplains	□	□	□	□	□	□	□	□	□	□	□
Precipitation rates	□	□	□	□	□	□	□	□	□	□	□
Run-off coefficient	□	□	□	□	□	□	□	□	□	□	□

3) Based on your personal knowledge and experience, please rate the impact of the following indicators on **social vulnerability** to floods in Toronto (where 0 is not impactful while 10 is

extremely impactful) – please role the mouse cursor over the bolded words to see their definitions.

	0	1	2	3	4	5	6	7	8	9	10
Age	□	□	□	□	□	□	□	□	□	□	□
Gender	□	□	□	□	□	□	□	□	□	□	□
Wealth	□	□	□	□	□	□	□	□	□	□	□
Ethnicity and race	□	□	□	□	□	□	□	□	□	□	□
Employment status	□	□	□	□	□	□	□	□	□	□	□
Family structure	□	□	□	□	□	□	□	□	□	□	□
Education	□	□	□	□	□	□	□	□	□	□	□
Built-environment conditions	□	□	□	□	□	□	□	□	□	□	□

4) Based on your personal knowledge and experience, please rate the impact of the following indicators on the **adaptive capacity** of **land uses** (where 0 is not impactful while 10 is extremely impactful) – please role the mouse cursor over the bolded words to see their definitions.

	0	1	2	3	4	5	6	7	8	9	10
Harmony with nature	□	□	□	□	□	□	□	□	□	□	□
Polyvalency	□	□	□	□	□	□	□	□	□	□	□
Spatial heterogeneity	□	□	□	□	□	□	□	□	□	□	□

5) Based on your personal knowledge and experience, please rate the impact of the following indicators on the **adaptive capacity** of **town plans** (where 0 is not impactful while 10 is extremely impactful) − role the mouse cursor over the bolded words to see their definitions.

	0	1	2	3	4	5	6	7	8	9	10
Flexibility	□	□	□	□	□	□	□	□	□	□	□
Connectivity	□	□	□	□	□	□	□	□	□	□	□

Background question

Please select the name of the organization(s) that you are collaborated and/or have collaborated with (select all that apply):

□ Clean Air Partnership

□ Climate Risk Institute

□ Toronto Environmental Alliance

□ Toronto Climate Action Network

□ the Institute of Catastrophic Loss Reduction

□ Ontario Ministry of Environment

□ Public Safety Canada

□ Toronto and Region Conservation Authority

□ City of Toronto

□ Intact Center

□ Partners for Action

□ None of the above

□ Prefer not to answer

Appendix B: In-depth interviews with experts

Information letter

Title of project: The just adaptation of Toronto's urban form to floods originated from the global climate change

Principal investigator: Luna Khirfan, PhD, School of Planning, Faculty of Environment, University of Waterloo. Phone: 519-888-4567 ext. 43906, Email: lkhirfan@uwaterloo.ca

Student investigator: Niloofar Mohtat, PhD candidate, School of Planning, Faculty of Environment, University of Waterloo. Email: nmohtat@uwaterloo.ca

Dear Sir/Madam,

You are invited to participate in an in-depth interview, which is part of my (Niloofar Mohtat) PhD thesis project. This four-year PhD project is fully funded by Internal UWaterloo funding, and have three objectives, namely: (1) Finding the urban neighborhood in Toronto that is bearing the highest levels of flood risks and which need to be prioritized in climate adaptation decisions; (2) Identifying why the residents of this priority neighborhood are unequally experiencing this highest levels of flood risks; (3) Proposing policy recommendations for the adaptation of this priority neighborhood to floods. The results of this study will be used for developing the PhD thesis and for publishing peer-reviewed papers.

we would like to include you in this study as we believe your valuable expertise in climate change adaptation and flood management in Toronto’s urban form are best suited for the study. If you decide to participate, you will be asked to complete a one-hour online interview focusing on your knowledge on urban floods adaptation (particularly on green projects for adaptation) and your opinions on the recognition of local people as knowers for adaptation purposes. Interview will be conducted through Microsoft Teams or similar software, such as Skype. With your permission, the audio and video of interview session will be recorded to be transcribed later.

Participation in this study is voluntary. You may decline to answer any question(s) that you do not wish to answer and you can withdraw your participation at any time during the interview by

asking for a withdrawal. After the interview, you can still withdraw your consent and have your data destroyed by contacting the interviewer (Niloofar Mohtat).

Your identity will remain confidential. When information is transmitted over the internet, privacy cannot be guaranteed. There is always a risk your responses may be intercepted by a third party (e.g., government agencies, hackers). University of Waterloo researchers will not collect or use internet protocol (IP) addresses or other information which could link your participation to your computer or electronic device without first informing you. We just keep the recordings for 72 hours to transcribe them. After this time, all the recordings will be destroyed. The de-identified transcripts will be labelled with a participant code. We will keep the list of participant names and codes so that if someone later wanted to withdraw, we could identify their transcript. All of the data will be summarized and no individual could be identified from these summarized results. The transcripts and the list of participants names and codes will be maintained on a password-protected external hard drive in a secure and restricted-access space at University of Waterloo. Only the research team (i.e., Niloofar Mohtat and Dr. Luna Khirfan) will have access to this data. The data will be retained for a minimum of 7 years, after which they will be destroyed.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (ORE #42887). If you have questions for the Board, contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca.

Once all the data are collected and analyzed, we plan to share the results through conference presentations and journal articles. If you would like to receive a copy of the results (anticipated to be completed by the end of 2022), or need additional information to assist you in reaching a decision about participation, please email Niloofar Mohtat at nmohtat@uwaterloo.ca.

Thank you for participating in this study

Yours sincerely,

Niloofar Mohtat, PhD candidate
School of Planning, Faculty of Environment
University of Waterloo
nmohtat@uwaterloo.ca

Luna Khirfan, PhD
School of Planning, Faculty of Environment
University of Waterloo
519-888-4567 ext. 43906
lkhirfan@uwaterloo.ca

Consent form

By providing your consent, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

I have read the information letter about the research entitled “The just adaptation of Toronto's urban form to floods originated from the global climate change”, which is conducted by Dr. Luna Khirfan and Niloofar Mohtat at School of Planning, University of Waterloo. I agree my online interview being audio and video recorded for transcription and analysis purposes. I have had the opportunity to ask questions related to the study and have received satisfactory answers to my questions and any additional details.

I was informed that participation in the study is voluntary and that I can withdraw this consent any time during and after the interview.

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For all other questions email Niloofar Mohtat at nmohtat@uwaterloo.ca.

With Full knowledge of all foregoing, I agree, of my own free will, to participate in this in-depth interview.

Print name: _____

Signature: _____

Date: _____

Section I. Knowledge of floods and adaptation to it

1) Please rate (from 0 to 10) the degree to which you agree with this statement:

"Floods are the most serious climatic hazards in Toronto."

Would you please indicate why you chose this number for rating?

2) Does your organization have any programs for managing floods through providing green and blue infrastructure (GBI)?

3) Does your organization prioritize urban areas (or neighborhoods) for adaptation to floods through GBI provision? If yes, how does the organization specify priorities?

4) Is justice an issue for your organization in flood management through GBI provision? Please describe.

5) Do you or your organization have experience in adapting Thorncliffe Park neighborhood (or other low-income neighborhoods) to floods? (If yes, could you please describe briefly).

Section II. The Recognition of local people as knowers

6) Please describe how interested your organization is in involving people, their needs, preferences, and experiences in flood adaptation decisions (like GBI project)? In case that your organization is interested in public engagement, how does it engage local people (e.g., exhibitions and presentations? education programs? Consultation workshops?)

7) Does your organization (or its partners) combine flood adaptation programs (through GBI) with poverty alleviation programs and other programs that target immediate needs of people? (that other programs that address immediate needs)If yes, could you please bring an example?

8) How much does your organization take local people's experiences on floods, preferences, and their immediate needs seriously? Do you think that people's experiences and needs are reliable?

9) How interested are different local people to be involved in your organization's flood adaptation decisions through GBI provision? Why?

10) Are there any barriers to including local people (specifically, the disadvantaged groups) in flood management decisions?

11) Does your organization have specific plans to include socially disadvantaged groups (e.g., low-income people, visible minorities, and new migrants) in flood mitigation decisions through GBI provision? Would you please explain if there is any?

12) To what extent can disadvantaged groups communicate their needs in participatory programs of your organization? In your opinion, how can this communication be facilitated?

Appendix C: In-depth interviews with local leaders in Thorncliffe Park

Information letter

Title of project: The just adaptation of Toronto's urban form to floods originated from the global climate change

Principal investigator: Luna Khirfan, PhD, School of Planning, Faculty of Environment, University of Waterloo. Phone: 519-888-4567 ext. 43906, Email: lkhirfan@uwaterloo.ca

Student investigator: Niloofar Mohtat, PhD candidate, School of Planning, Faculty of Environment, University of Waterloo. Email: nmohtat@uwaterloo.ca

Dear Sir/Madam,

You are invited to participate in an in-depth interview, which is part of my (Niloofar Mohtat) PhD thesis project. This four-year PhD project is fully funded by Internal UWaterloo funding, and have three objectives, namely: (1) Finding the urban neighborhood in Toronto that is bearing the highest levels of flood risks and which need to be prioritized in climate adaptation decisions; (2) Identifying why the residents of this priority neighborhood are vulnerable to flood risks; (3) Proposing policy recommendations for the adaptation of this priority neighborhood to floods. The results of this study will be used for developing the PhD thesis and for publishing peer-reviewed papers.

We would like to include you in this study as we believe your valuable experiences in Thorncliffe Park are best suited for the study. If you decide to participate, you will be asked to complete a one-hour online interview focusing on your experiences regarding public participation in your organization’s general initiatives and that of plans for flood management (if exist). The interview will be conducted through Microsoft Teams or similar software, such as Skype. With your permission, the audio and video of interview session will be recorded to be transcribed later.

Participation in this study is voluntary. You may decline to answer any question(s) that you do not wish to answer and you can withdraw your participation at any time during the interview by asking for a withdrawal. After the interview, you can still withdraw your consent and have your data destroyed by contacting the interviewer (Niloofar Mohtat).

Your identity will remain confidential. When information is transmitted over the internet, privacy cannot be guaranteed. There is always a risk your responses may be intercepted by a third party (e.g., government agencies, hackers). University of Waterloo researchers will not collect or use internet protocol (IP) addresses or other information which could link your participation to your computer or electronic device without first informing you. We just keep the recordings for 72 hours to transcribe them. After this time, all the recordings will be destroyed. The de-identified transcripts will be labelled with a participant code. We will keep the list of participant names and codes so that if someone later wanted to withdraw, we could identify their transcript. All of the data will be summarized and no individual could be identified from these summarized results. The transcripts and the list of participants names and codes will be maintained on a password-protected external hard drive in a secure and restricted-access space at University of Waterloo. Only the research team (i.e., Niloofar Mohtat and Dr. Luna Khirfan) will have access to this data. The data will be retained for a minimum of 7 years, after which they will be destroyed.

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Thank you for participating in this study

Yours sincerely,

Niloofar Mohtat, PhD candidate
School of Planning, Faculty of Environment
University of Waterloo
nmohtat@uwaterloo.ca

Luna Khirfan, PhD
School of Planning, Faculty of Environment
University of Waterloo
519-888-4567 ext. 43906
lkhirfan@uwaterloo.ca

Consent form

By providing your consent, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

I have read the information letter about the research entitled “The just adaptation of Toronto's urban form to floods originated from the global climate change”, which is conducted by Dr. Luna Khirfan and Niloofar Mohtat at School of Planning, University of Waterloo. I agree my online interview being audio and video recorded for transcription and analysis purposes. I have had the opportunity to ask questions related to the study and have received satisfactory answers to my questions and any additional details.

I was informed that participation in the study is voluntary and that I can withdraw this consent any time during and after the interview.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (ORE #42887). If you have questions for the Board, contact the Office of Research Ethics, at 1-519-888-4567 ext. 36005 or ore-ceo@uwaterloo.ca.

For all other questions email Niloofar Mohtat at nmohtat@uwaterloo.ca.

With Full knowledge of all foregoing, I agree, of my own free will, to participate in this in-depth interview.

Print name: _____

Signature: _____

Date: _____

Questions

1) What are the top priority needs of people living in Thorncliffe Park?

2) Could you please let me know about the participatory programs in your organization? Have your organization collaborated with governmental institutions (such as the City of Toronto) to consult with people regarding urban projects? (if you have collaborated with other organizations for climate change adaptation).

3) To what extent are Thorncliffe Park residents interested in participating in your organization's programs and initiatives?

4) Are specific social groups (in terms of economic and migration status, among others) participate more than the others in the programs? Why?

5) What are the social barriers to public participation in your organization's initiatives for the neighborhood residents?

6) How serious are flood hazards in the Thorncliffe Park neighborhood?

7) Have you experienced run-off (over the paved surfaces) in your neighborhood when it rains?

8) Please rate (from 0 to 10) the degree to which you agree with this statement:

"Floods are one of the most serious problems of people in Thorncliffe Park neighborhood."

Would you please indicate why you chose this number for rating?

9) Have your organization done any participatory environmental initiatives (like green and blue infrastructure) in the neighborhood? If yes, could you please describe the initiatives?

10) Does your organization have engaged the neighborhood residents in any climate change adaptation/mitigation programs and projects? If yes, have any of these programs/projects been related to the management of floods in the neighborhood? Please explain.

11) To what extent are the neighborhood residents interested in participating in climate change initiatives? Why?

Appendix D: The online survey of Thorncliffe Park residents

Information letter

Title of project: The just adaptation of Toronto's urban form to floods originated from the global climate change

Principal investigator: Luna Khirfan, PhD, School of Planning, Faculty of Environment, University of Waterloo. Phone: 519-888-4567 ext. 43906, Email: lkhirfan@uwaterloo.ca

Student investigator: Niloofar Mohtat, PhD candidate, School of Planning, Faculty of Environment, University of Waterloo. Email: nmohtat@uwaterloo.ca

Dear Sir/Madam,

You are invited to participate in a web-based survey, which is part of my (Niloofar Mohtat) PhD thesis project. This four-year PhD project is fully funded by Internal UWaterloo funding, and have three objectives, namely: (1) Finding the urban neighborhood in Toronto that is bearing the highest levels of flood risks and which need to be prioritized in climate adaptation decisions; (2) Identifying why the residents of this priority neighborhood are unequally experiencing this highest level of flood risks; (3) Proposing policy recommendations for the adaptation of this priority neighborhood to floods. The results of this research will be used for developing the PhD thesis and for publishing peer-reviewed papers.

To participate in this survey, you must be at least 18 years old and currently live in Thorncliffe Park neighborhood. If you decide to participate, you will be asked to complete a 20-minute online survey that is completed anonymously. The survey questions are categorized in five groups, namely: (1) the immediate needs of neighborhood residents; (2) local perceptions regarding floods; (3) public preferences regarding flood management; (4)the recognition of local people as knowers in flood management; (5) socio-demographic information. Your tasks during the survey include reading and answering multiple-choice, rating, ranking, matrix, and open-end questions based on your opinions and beliefs.

Participation in this study is voluntary and you can participate only once. You may decline to answer any question(s) that you do not wish to answer and you can withdraw your participation at any time by not submitting your responses. After submitting your answers, however, you cannot withdraw because we have no way to know which answers are yours (the surveys are unidentifiable). There are no known or anticipated risks from participating in this study. In appreciation of your time for participating in this study, you can enter your name into a draw for one of the three 40$ Amazon gift cards. Your odds of winning one of the prizes is based on the number of individuals who participate in the study. We expect that approximately 350 individuals will take part in the study. To enter your name in the draw and receive the gift card, you will be asked to enter your name, email, and telephone number (optional) in a separate Google Form at the end of the survey. This identifying information will not be linked to the study data in any way and will be stored separately. We will destroy this information once remuneration has been provided. The amount received is taxable. It is your responsibility to report this amount for income tax purposes.

Your identity will remain confidential. All of the data will be summarized, and no individual could be identified from these summarized results. You will be completing the study by an online survey operated by Qualtrics software. When information is transmitted or stored on the internet privacy cannot be guaranteed. There is always a risk your responses may be intercepted by a third party (e.g., government agencies, hackers). Qualtrics temporarily collects your ID and computer IP address to avoid duplicate responses in the dataset, but will not collect information that could identify you personally. If you would prefer not to submit your survey responses through this software, please contact the student investigator **Niloofar Mohtat** using the contact details listed below, so you can participate using an alternative method, such as an emailed questionnaire. The alternative method may decrease anonymity but confidentiality will be maintained.

The anonymized data collected from this study will be maintained on a password-protected external hard drive in a secure and restricted-access space at University of Waterloo. Only the research team (i.e., Niloofar Mohtat and Dr. Luna Khirfan) will have access to this data. The data will be retained for a minimum of 7 years, after which they will be destroyed.

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Thank you for your interest.

Yours sincerely,

Niloofar Mohtat, PhD candidate
School of Planning, Faculty of Environment
University of Waterloo

nmohtat@uwaterloo.ca

Luna Khirfan, PhD
School of Planning, Faculty of Environment
University of Waterloo
519-888-4567 ext. 43906
lkhirfan@uwaterloo.ca

Consent form

By agreeing to participate in the study you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study:

□ Yes, I agree to participate

□ No, I do not wish to participate

Questions

1) From 1 to 10, please indicate to what extent you agree with this statement:

"Floods are one of the most serious problems of people in Thorncliffe Park neighborhood."

Disagree									Agree
1	2	3	4	5	6	7	8	9	10
□	□	□	□	□	□	□	□	□	□

2) Which of the following items do you need the most? (Select all that apply)

□ Physical/mental Healthcare	□ Recreation
□ Childcare	□Protection against hazards, like floods
□ Affordable housing	□ Employment
□ Food and beverage	□Social interactions

If you have other urgent needs, please indicate:

3) How often do you experience the following types of floods in your neighborhood?

	Frequently	Rarely	Never
River flooding	□	□	□
Surface runoff	□	□	□
Sewer flooding	□	□	□

River flooding occurs when the water level in watercourses rises and spills over banks.

Surface runoff occurs when excess stormwater flows over pavements, causing problem or damage.

Sewer flooding occurs when the storm, sanitary sewer, or other drainage systems are overloaded, causing surcharge and back-up into basements.

4) Have you ever been affected by flood events in your neighborhood?

□Yes □ No

If yes, could you please explain how and when flood events affected you:

5) To what extent do you agree with the following statements regarding flood events in your neighborhood?

	Disagree	Neutral	Agree
a) I am concerned about flood events in my neighborhood.	□	□	□
b) I experience floods more severely than before in my neighborhood.	□	□	□
c) I experience floods more frequently than before in my neighborhood.	□	□	□
d) I expect more frequent floods in future years in my neighborhood.	□	□	□
e) I expect more severe floods in future years in my neighborhood.	□	□	□

6) Have you ever witnessed rainwater flowing over the pavements and streets in your neighborhood?

□Yes □ No

If yes, please specify the difficulties the rainwater over the pavements create for you.

□ Challenges in walking

□ Challenges for social gatherings

□ Challenges for using public transportation

□ It did not create any difficulty for me

□ Problems for moving your grocery shopping

□ None of the above

□ Delays for commuting to work

7) Below is a list of actions flooding experts adopt to manage the excess rainwater. Which ones do you prefer for your neighborhood? (Please select all that apply).

□ Adding parks and lawns

□ Designing rainwater storage tanks for buildings

□ Restoring water features to their natural conditions

□ Designing green roofs

□ Planting trees

□ Adding vegetated swales along streets

□ Designing impervious pavements

□ None of the above

8) To what extent do you agree with the following statements regarding green spaces and water features in your neighborhood:

	Disagree	Neutral	Agree
a) My neighborhood needs more green spaces for	□	□	□

managing the excess rainwater.			
b) My neighborhood needs more water features for managing the excess rainwater.	□	□	□

9) Which of the following problems apply to green spaces in your neighborhood?

□ They are not sufficient	□ They lack water features
□ They are not accessible	□ They are not appropriate for walking/cycling
□ They lack enough spaces for sitting	□ They are not appropriate for gathering
□ They lack enough spaces for children to play	□ None of the above

Please indicate other problems of green spaces in your neighborhood:

10) Please specify the extent to which you agree with the following statements:

	Disagree	Neutral	Agree
a) I trust **experts** for managing floods in my neighborhood.	□	□	□
b) I am interested in participating in flood management decisions.	□	□	□

c) Experts pay attention to my experiences of flooding.	□	□	□
d) Experts pay attention to my needs and preferences in flood management decisions.	□	□	□
e) It is easy for me to communicate my flood experiences, needs, and preferences to experts.	□	□	□

11) In your opinion, which of the following might prevent you from communicating your experiences, needs, and preferences to flood experts?

□ Your economic conditions
□ Your education
□ Your race
□ Your immigration status
□ Your language skills
□ None of the above

12) In your opinion, which of the following might prevent flood experts from taking your experiences and needs into account?

□ Your economic conditions
□ Your education
□ Your race
□ Your immigration status
□ Your language skills
□ None of the above

13) Have you ever been invited to participate in flood management decisions?

□ Yes

□ No

If yes,

(a) Which of the following organizations invited you to participate in flood management decisions? (Select all that apply).

□ City of Toronto

□ The Institute of Catastrophic Loss Reduction

□ Toronto and Region Conservation Authority

□ Credit Valley Conservation Authority

□ Toronto Environmental Alliance

□ Clean Air Partnership

□ Toronto Climate Action Network

□ Climate Risk Institute

□ Intact Center (in University of Waterloo)

□ I do not know

□ Ontario Ministry of Environment, Conservation, and Parks

□ None of the above

(b) Which of the following statements is correct about your engagement.

□ I engaged in an educational program related to the management of floods.

□ I took part in an event that informed people about floods and how relevant organizations manage them.

□ An organization consulted with me about its flood management decisions through surveys, phone calls, and/or interviews (among other tools).

14) What is your annual household/family income before taxes?

□ Less than 40,000 CAD

□ 40,000 to 59,999 CAD

□ 60,000 and above

□ Prefer not to say

15) What is the highest level of education you have completed?

□ High school and under
□ College diploma
□ Associate and Bachelor degree
□ Master degree and above
□ Prefer not to say

16) Which of the following best describes your citizenship/immigration status in Canada?

□ Canadian citizen, by birth
□ Canadian citizen, by naturalization
□ Permanent resident of Canada
□ Temporary visa holder
□ Refugee or protected person
□ I do not know
□ Prefer not to say

17) Canada is one of the most racially diverse countries. Would you please indicate which of the following best describes your race? (Select all that apply)

□ First Nations, Métis, or Inuit
□ White or Caucasian
□ Black
□ South, East Asian and/or Southeast Asian
□ Middle Eastern
□ Hispanic/Latinx
□ Other
□ I do not know

18) How long have you lived in the Thorncliffe Park neighborhood?

□ Less than two years
□ Two to less than five years
□ Five to less than ten years
□ Ten years and above
□ Prefer not to say

Appendix E: The participatory mapping activity in Thorncliffe Park

Information letter

Title of project: The just adaptation of Toronto's urban form to floods originated from the global climate change

Principal investigator: Luna Khirfan, PhD, School of Planning, Faculty of Environment, University of Waterloo. Phone: 519-888-4567 ext. 43906, Email: lkhirfan@uwaterloo.ca

Student investigator: Niloofar Mohtat, PhD candidate, School of Planning, Faculty of Environment, University of Waterloo. Email: nmohtat@uwaterloo.ca

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To participate in this survey, you must be at least 18 years old and currently live in Thorncliffe Park neighborhood. If you decide to participate, you will be asked to complete a 15-minute online survey that is completed anonymously. The survey questions are categorized in two groups. The first group asks you to mark on your neighborhood map locations that, in your opinion, require green spaces to provide five benefits, namely: recreational activities, beauty, emotional relationship with urban spaces, social interactions, and environmental awareness. The second group asks you to tell us which of the five benefits is the most important and which is the least important for you.

Participation in this study is voluntary and you can participate only once. You may decline to answer any question(s) that you do not wish to answer and you can withdraw your participation at any time by not submitting your responses. After submitting your answers, however, you

cannot withdraw because we have no way to know which answers are yours (the surveys are unidentifiable). There are no known or anticipated risks from participating in this study. In appreciation of your time for participating in this study, you can enter your name into a draw for one of the three 40$ Amazon gift cards. Your odds of winning one of the prizes is based on the number of individuals who participate in the study. We expect that approximately 350 individuals will take part in the study. To enter your name in the draw and receive the gift card, you will be asked to enter your name, email, and telephone number (optional) in a separate Google Form at the end of the survey. This identifying information will not be linked to the study data in any way and will be stored separately. We will destroy this information once remuneration has been provided. The amount received is taxable. It is your responsibility to report this amount for income tax purposes.

Your identity will remain confidential. All of the data will be summarized and no individual could be identified from these summarized results. You will be completing the study by an online survey operated by Qualtrics software. When information is transmitted or stored on the internet privacy cannot be guaranteed. There is always a risk your responses may be intercepted by a third party (e.g., government agencies, hackers). Qualtrics temporarily collects your ID and computer IP address to avoid duplicate responses in the dataset, but will not collect information that could identify you personally. If you would prefer not to submit your survey responses through this software, please contact the student investigator **Niloofar Mohtat** using the contact details listed below, so you can participate using an alternative method, such as an emailed questionnaire. The alternative method may decrease anonymity but confidentiality will be maintained.

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Thank you for your interest.

Yours sincerely,

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School of Planning, Faculty of Environment
University of Waterloo

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lkhirfan@uwaterloo.ca

Consent form

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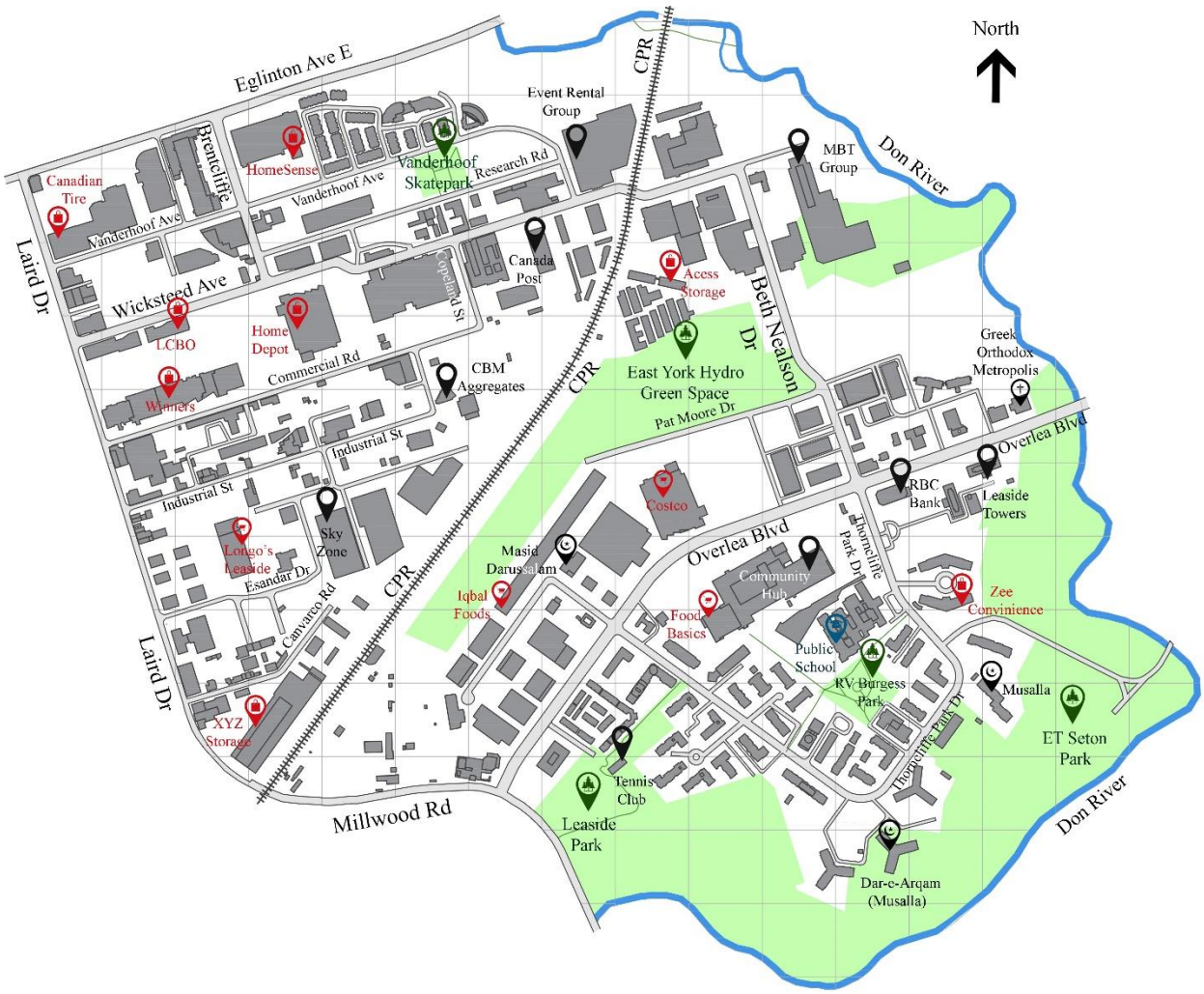
With full knowledge of all foregoing, I agree, of my own free will, to participate in this study:

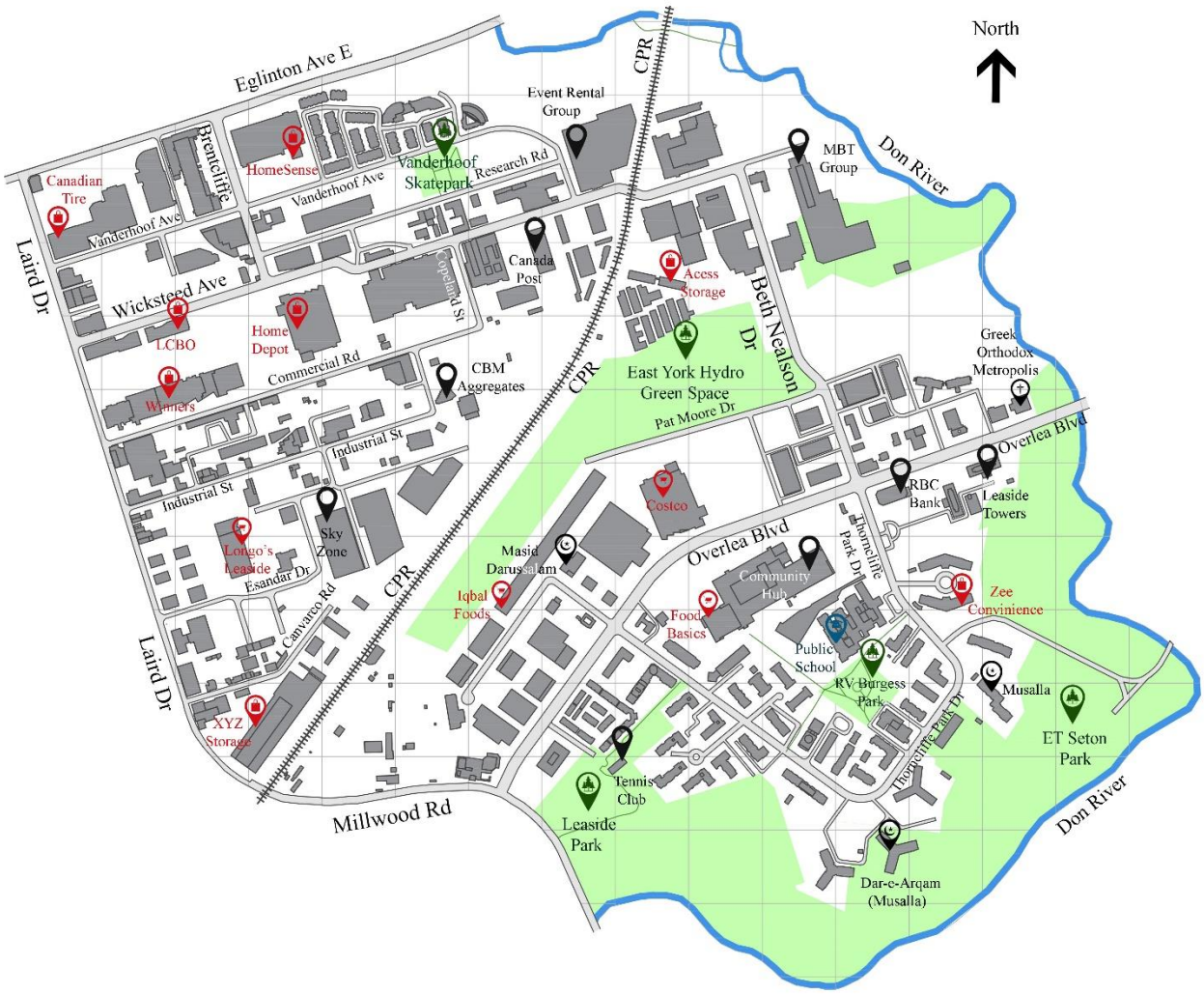
□ Yes, I agree to participate

□ No, I do not wish to participate

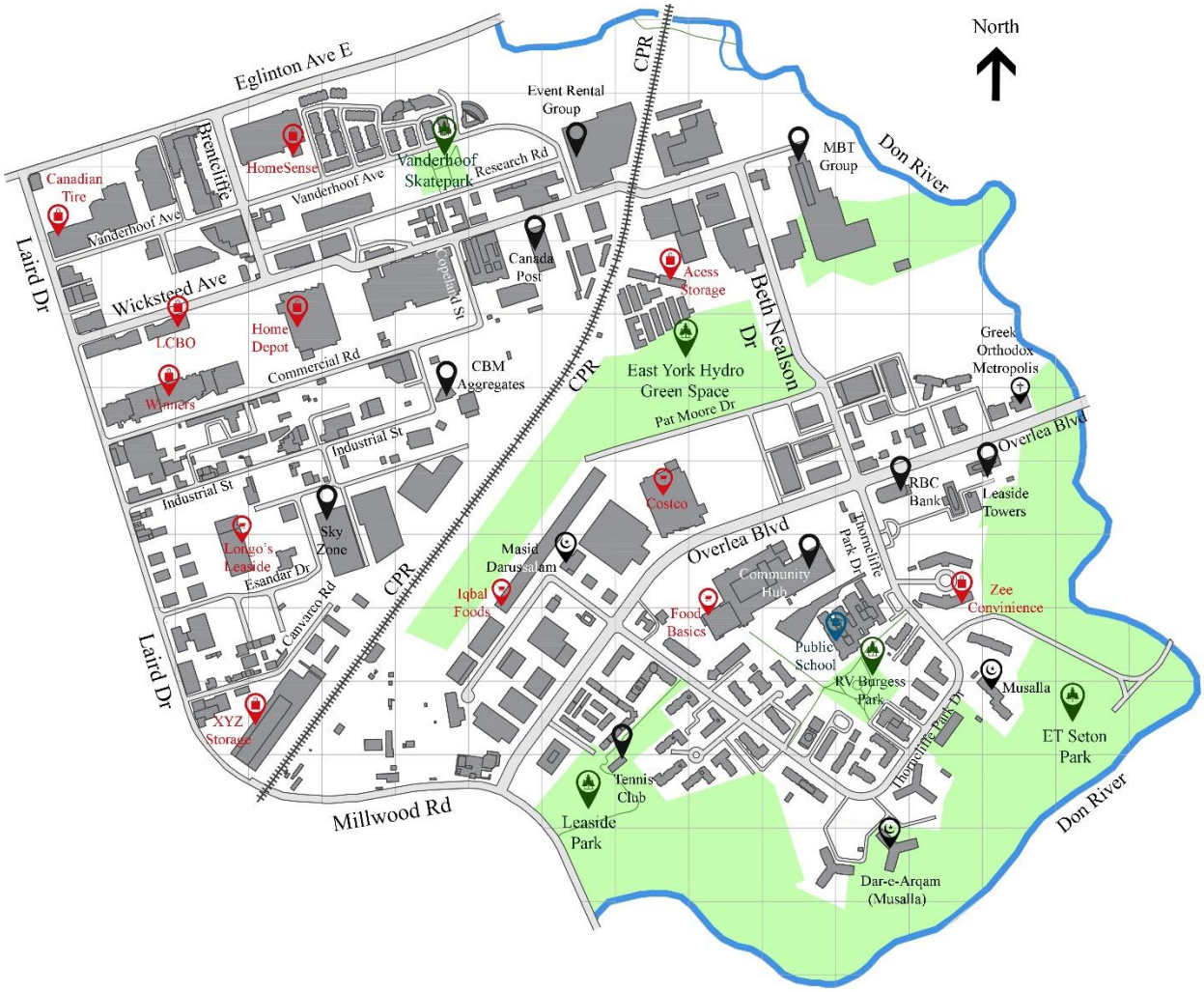
1) In the map below, please mark locations that, in your opinion, require green spaces for gathering (you can mark up to 10 locations):



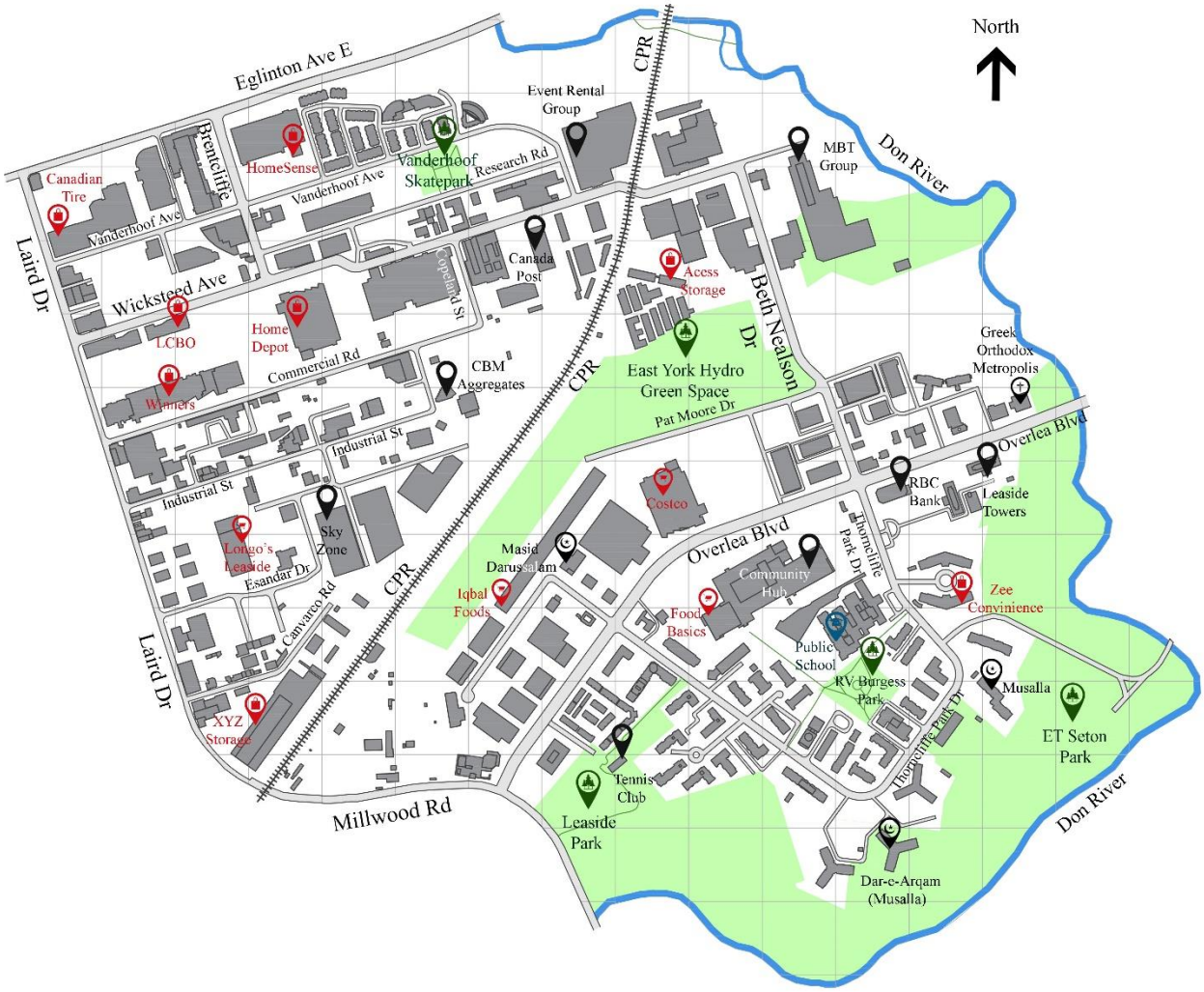
2) In the map below, please mark locations that, in your opinion, require green spaces for **walking** and **cycling** (you can mark up to 10 locations).



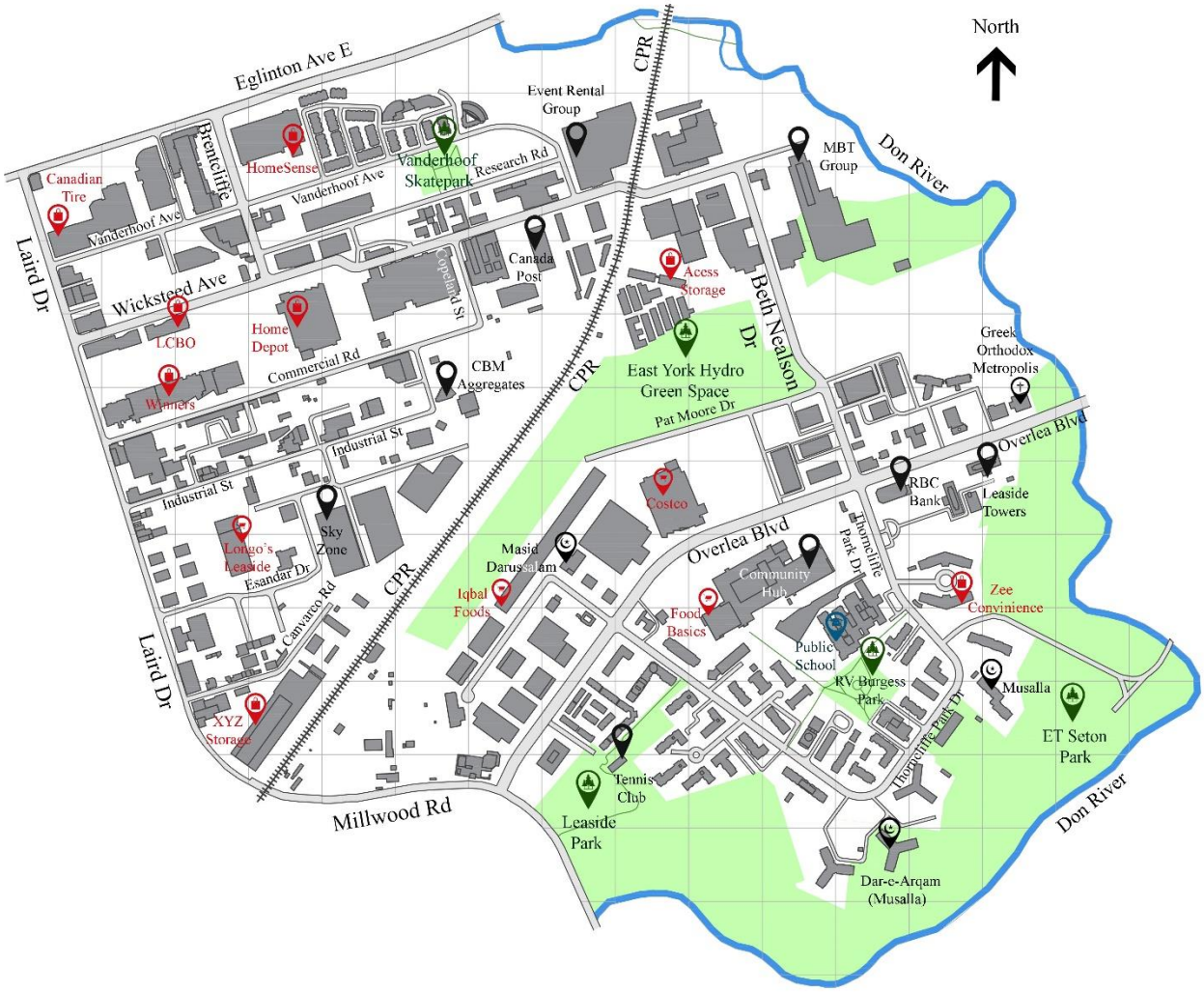
3) In the map below, please mark locations that, in your opinion, require green spaces for **children** to **play** (you can mark up to 10 locations):



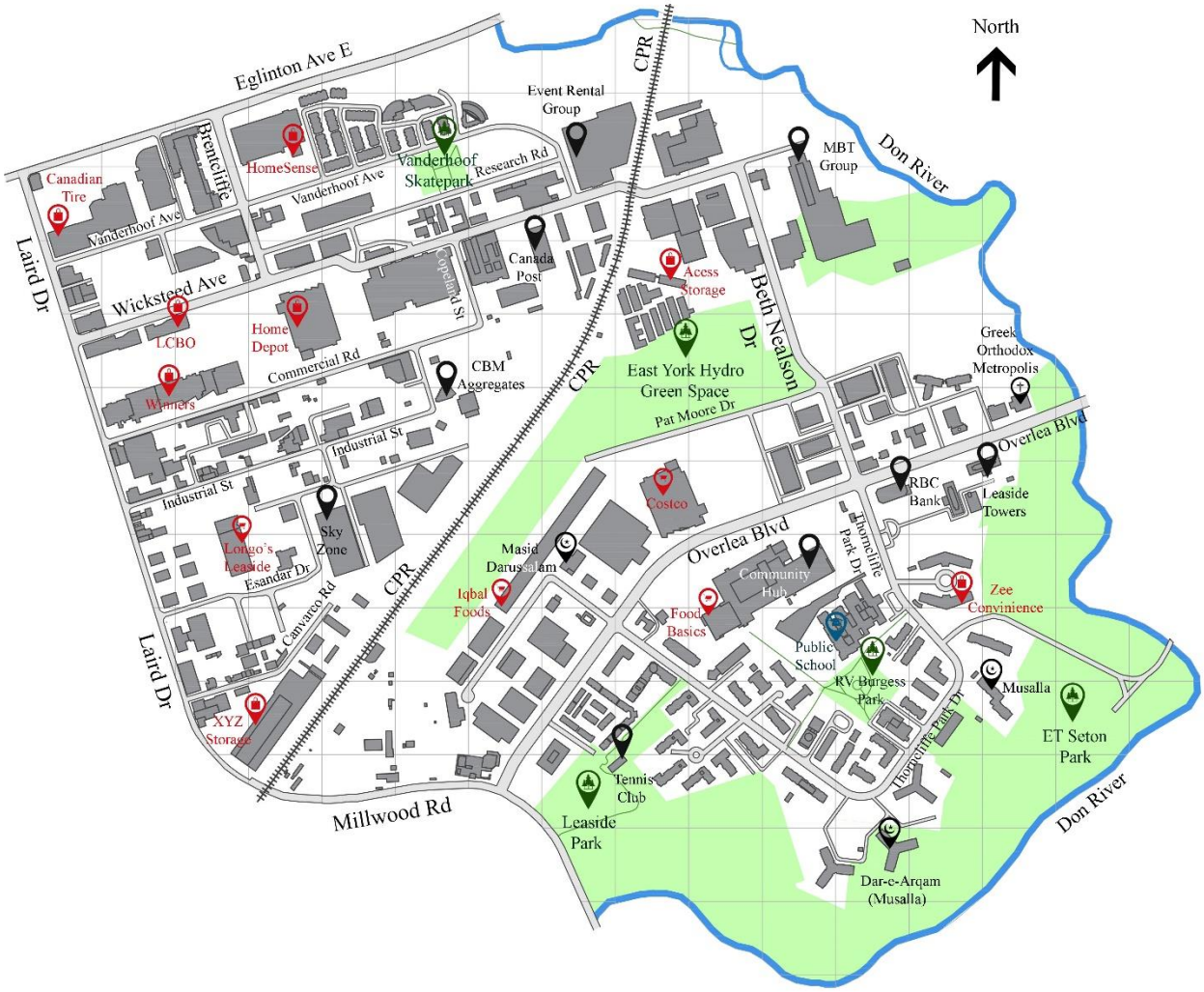
4) In the map below, please mark locations where adding green spaces can make Thorncliffe Park beautiful (you can mark on up to 10 locations):



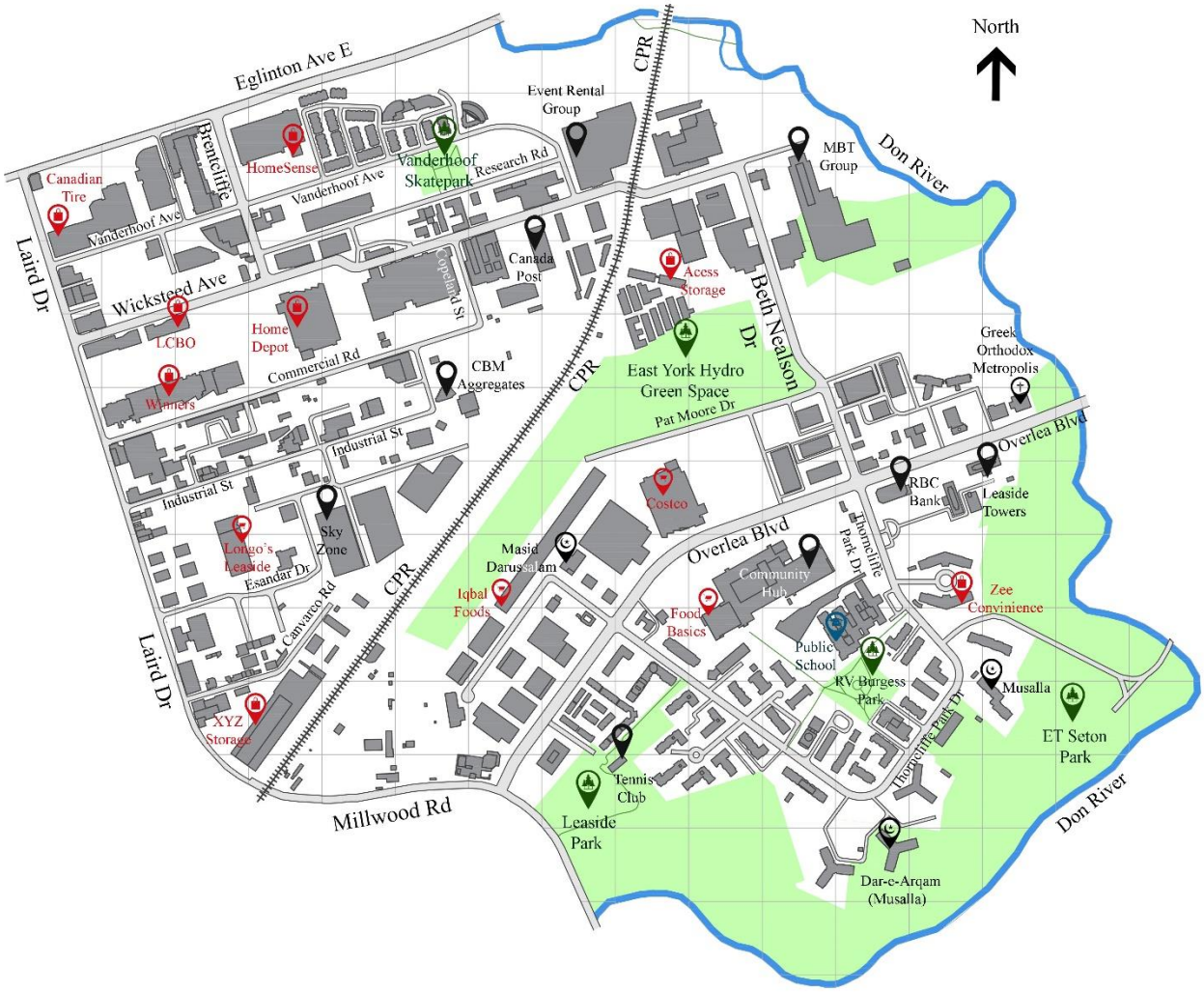
5) In the map below, please mark locations where adding green spaces can create the **feeling** that Thorncliffe Park is your **home** (you can click on up to 10 locations):



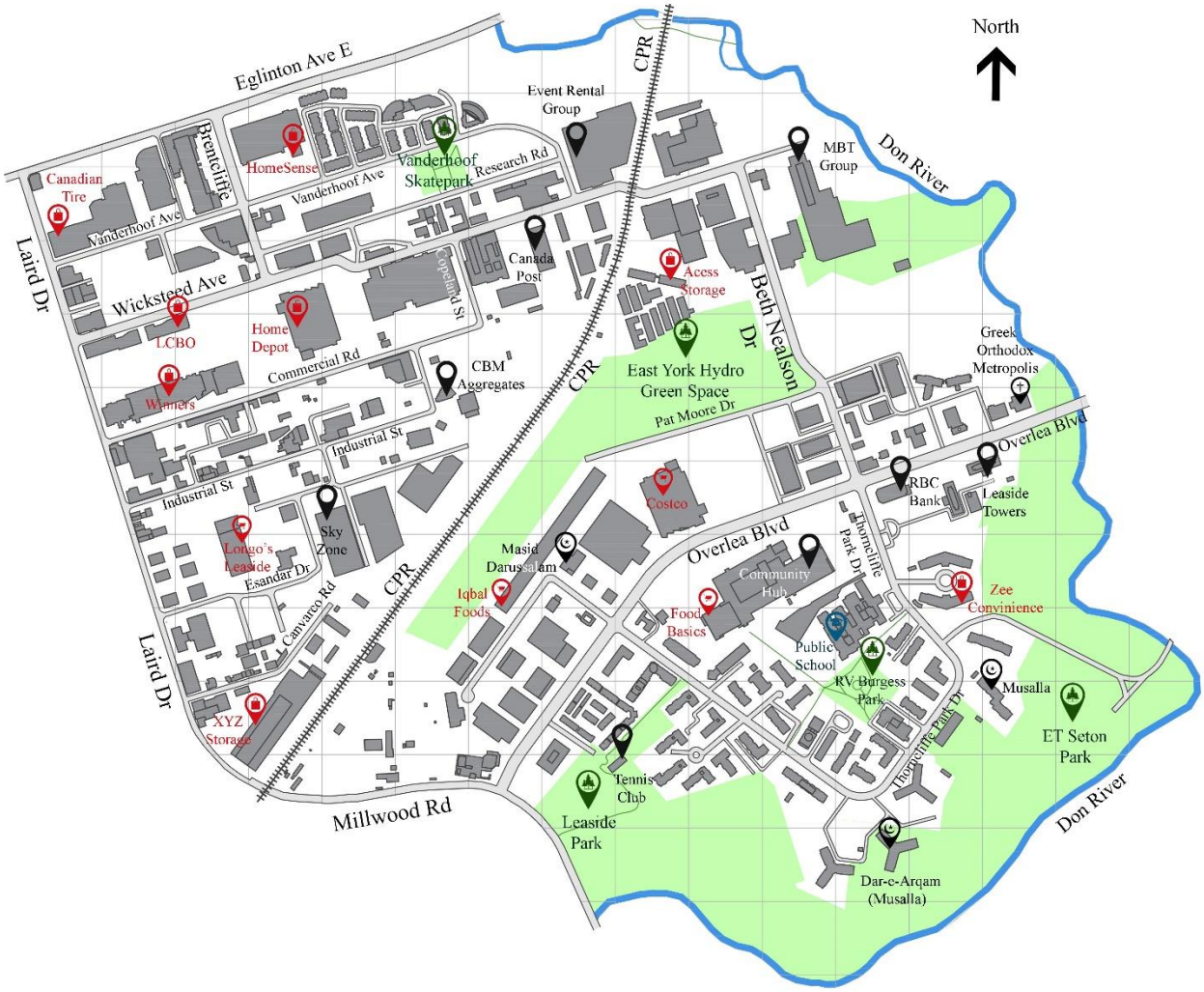
6) In the map below, please mark locations where adding green spaces increases your **connections to nature** (you can mark up to 10 locations):



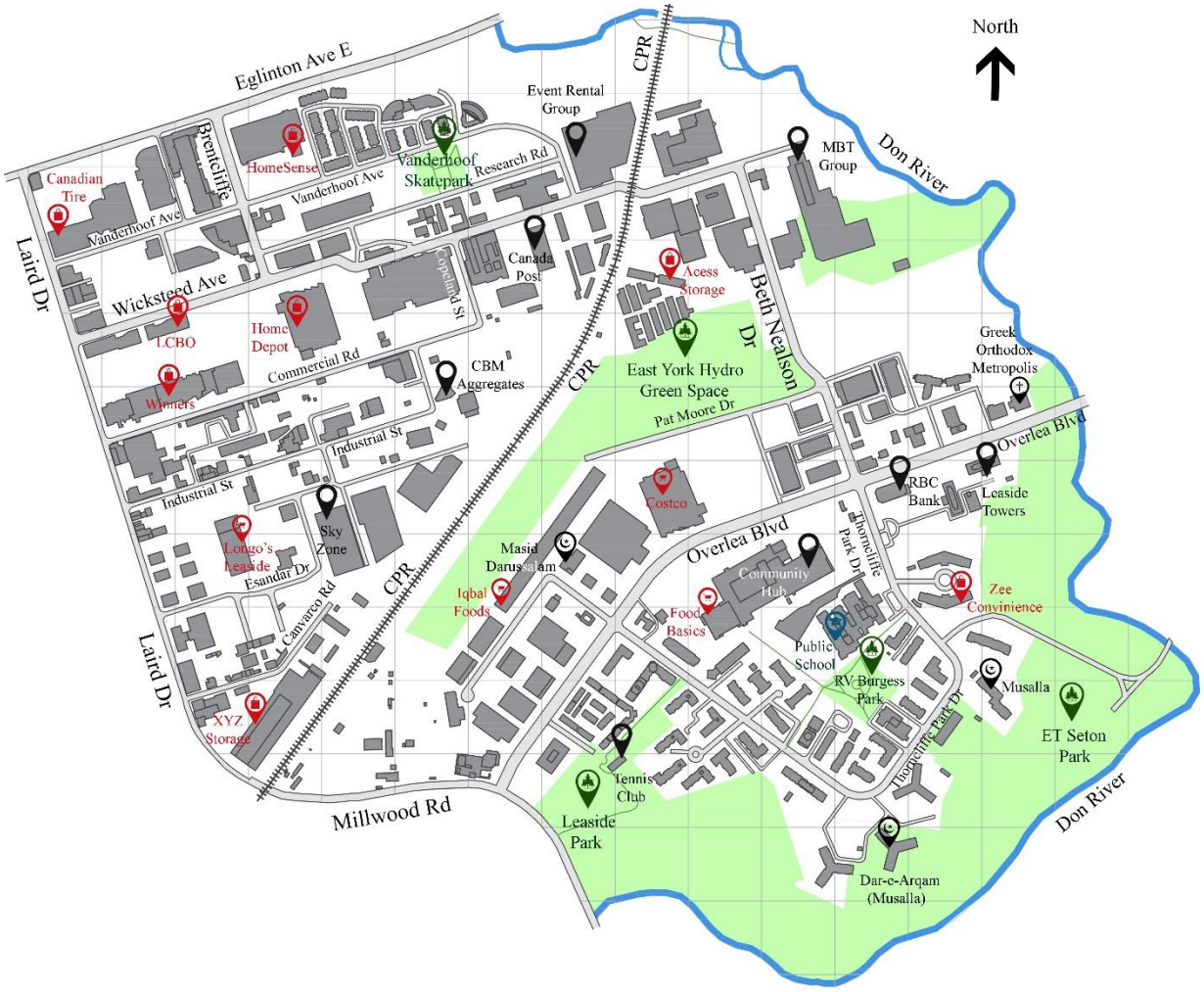
7) In the map below, please mark locations where adding green spaces makes you **proud** about your neighborhood (you can mark up to 10 locations):



8) In the map below, please mark locations where adding green spaces is useful for you to **interact with other people** and **meet your friends** (you can click on up to 10 locations):



9) In the map below, please mark locations where adding green spaces can raise your **awareness** on environmental issues and climate change (you can mark up to 10 locations):



9) Green spaces have several benefits. Please tell us which of the following benefits of green spaces are the most important and which are the least important for you:

The most important		The least important
□	Recreational benefits (such as gathering, walking, children playing)	□
□	Beaty and attractiveness	□
□	Improving emotional relationships with urban spaces	□
□	Providing spaces for social interactions	□
□	Increasing environmental awareness	□