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Designing Temporary Installations beneath Toronto's Gardiner Expressway to Enhance Thermal Comfort during Shoulder Seasons

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Abstract: Urban underutilized spaces, often the secondary by-products of large infrastructure projects, are often overlooked, despite their potential to enhance city life. With meaningful design interventions, these neglected areas can be transformed into inclusive public environments that offer social, environmental, and cultural value. This research investigates how modular, temporary installations beneath Toronto's Gardiner Expressway, in Canada, can enhance thermal comfort and foster community engagement during the shoulder seasons. Using a multi-step methodology, including literature review, thermal comfort guidelines, site-specific climate analysis, and precedent studies, the research identifies key design strategies tailored to the unique microclimatic and social conditions of under-bridge spaces. The study culminates in the proposal of a flexible system of movable panels that provide wind protection, solar control, and opportunities for gathering, interaction, and rest. By reimagining these unnoticed infrastructure zones as adaptable, climate-responsive public spaces, this research contributes to sustainable urban design and highlights the importance of design strategies that address the challenges of a warming and increasingly variable climate.

Key words: Thermal comfort, under bridge, public space, temporary installation, climate adaptation, modular design, microclimate, seasonal design.

1. Introduction

Urban infrastructure frequently generates underutilized spaces, such as residual areas beneath bridges, highways, and overpasses. These spaces are often neglected in design and programming but hold significant potential for enhancing urban life. With thoughtful design interventions, these areas can be transformed into inclusive public environments that provide social, environmental, and cultural value. In Toronto, the spaces beneath the Gardiner Expressway offer a unique opportunity to reimagine public life in these overlooked zones. Given the city's increasingly unpredictable weather patterns, designing for thermal comfort in public spaces has become an essential part of sustainable urban planning. While summer and winter are marked by extreme climatic conditions, Toronto's shoulder seasons—transitional periods such as March to May and September to October—offer moderate temperatures that create greater potential for outdoor comfort and usability. These transitional months provide a valuable window for activating public spaces through adaptable and inclusive design strategies that encourage extended seasonal use.

This thesis explores how modular, temporary installations beneath Toronto's Gardiner Expressway can enhance thermal comfort and community engagement during these shoulder seasons. The research aims to investigate how underutilized spaces beneath the Gardiner Expressway can be reimagined through temporary installations strategies that enhance thermal comfort and support social activity during Toronto's shoulder seasons. To achieve this goal, the research is guided by specific objectives: to identify the thermal

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comfort challenges and user needs specific to shoulder seasons; to analyze the site's existing microclimatic and spatial conditions; to explore relevant strategies from precedent studies, guidelines, and art installations; and to develop a set of design considerations tailored to the site and seasonal context.

The methodology for this research involved a multi-step process, including literature reviews on underutilized spaces, thermal comfort guidelines, and precedent studies, combined with site-specific climate analysis. This approach identifies design considerations tailored to the microclimatic and social conditions of these under-bridge spaces. The study culminates in the proposal of a flexible system of movable panels designed to offer wind protection, solar control, and opportunities for gathering, interaction, and rest. By reimagining overlooked infrastructure zones as adaptable public spaces, this research contributes to sustainable urban design and emphasizes the importance of climate-responsive strategies in addressing the challenges of an increasingly variable and warming climate.

2. Literature Review

This research draws upon a review of relevant literature covering three key areas: the spatial and social potential of underutilized spaces, particularly under bridge areas; the role of artistic installations in public environments; and the principles of thermal comfort, including guidelines, microclimatic design strategies, and addressing comfort during shoulder seasons.

2.1 Underutilized Spaces

Underutilized spaces, also known as residual or leftover spaces, are unintended by-products of urban development, emerging in the gaps, edges, and voids of the built environment. These areas are often overlooked during the planning of primary infrastructure. Albert Pope (2014) refers to these as "the voids of contemporary city… the residue or detritus deposited by urban development catastrophes," resulting from projects like highways, bridges, and railways. Despite their marginal status, they hold significant potential for improving urban life, especially in cities like Toronto, where the downtown core has become a "concrete jungle" with limited public green space.

Observing the daily use of these neglected spaces, particularly under bridge areas like those beneath the Gardiner Expressway, sparked the idea for this research. These spaces often appear gray, unwelcoming, and unsafe, yet they are essential paths for pedestrians and informal gathering spots. Urban planners and designers increasingly recognize the potential of these spaces, moving beyond viewing them solely as transportation corridors to framing them as architectural opportunities.

Underpasses, the areas beneath highways and bridges, are common typologies of residual spaces [1]. They are typically perceived as unsafe, polluted, and not pedestrian-friendly. However, their structural enclosure offers potential for shelter, artistic expression, and community interaction. Challenges for revitalizing these spaces include overcoming physical constraints, contextual mismatches, potential social resistance from nearby communities concerned about unfamiliar changes or gentrification, and environmental factors such as pollution, limited accessibility, and exposure to extreme weather.

Under bridge spaces, formed beneath elevated infrastructure, are often neglected but possess the potential to become vibrant public areas when thoughtfully redesigned. Projects like The Bentway in Toronto demonstrate this potential, transforming underutilized spaces into multifunctional zones for cultural, social, and recreational activities. Challenges specific to under bridge spaces include safety issues due to poor lighting and visibility, environmental problems like pollution, noise, and lack of green infrastructure, and negative public perceptions. Opportunities for revitalization involve addressing design and functionality to transform these spaces [2].

The Gardiner Expressway is a significant example of such infrastructure in Toronto. Construction began in 1956 and it was completed in segments, finished in

1965 at a cost of approximately $103 million. Named after Frederick G. Gardiner, a strong advocate for the project, the expressway extends 18 km from Highway 427 in the west to Logan Avenue in the east. It comprises an 11-kilometre at-grade section (Highway 427 to 300 m east of Dufferin Street) with 32 structures like bridges and retaining walls, and a 7-kilometre elevated section (east of Bathurst Street to the Don Valley Parkway ramp) with 17 ramps and 335 spans on 334 support structures (bents). The elevated section features different bridge structures (concrete t-beam, steel girder, concrete box girder) due to historical construction periods and material/method innovations [3].

The primary goal of the Gardiner Expressway was to facilitate vehicular traffic, connecting downtown to western suburbs. However, it introduced significant challenges, acting as a physical and social barrier dividing neighborhoods, increasing noise and pollution, and creating neglected underutilized spaces beneath it. The expressway's imposing structure contributes to uninviting, dark, and often unsafe environments, further reducing integration into the urban fabric [4].

The City of Toronto has initiatives to revitalize surrounding areas, including the Public Realm Plan, which emphasizes creating accessible, vibrant public spaces under and around the expressway. Projects like The Bentway exemplify these efforts by transforming underutilized areas into dynamic cultural and recreational spaces through improved lighting, landscaping, and amenities that foster community engagement and enhance safety. Ongoing rehabilitation of the expressway is also taking place as part of the Strategic Rehabilitation Plan, expected to finish in 2029. This presents an opportunity to reimagine the underutilized spaces, incorporating innovative design strategies like green infrastructure, shading elements, and microclimatic design to make spaces more appealing, including during harsh winters [2].

2.2 Art Installation

The twentieth century saw the rapid development of post-modern art, profoundly impacting design forms, concepts, and aesthetics. Installation art, as a new expression language, began integrating into various levels of design, leading to new landscape art and design practices. Originating in Europe in the early 20th century, installation art's essence is a non-shelf art derived from Marcel Duchamp's "ready-made art". It involves misplacement, vacancy, segmentation, and superimposition of ready-made items to reconstruct and assign new meaning. This approach disturbs existing properties of objects and creates impactful collisions on the viewer. Early examples included using garbage in exhibitions to raise environmental awareness [5].

Installation art uses modern art methods and diverse materials to update traditional artistic concepts and forms, resulting in diversified performance characteristics. It intersects with creative thinking, realistic environment, and historical changes [6].

Public art, a related concept, plays a crucial role in fostering community identity and pride by reflecting cultural and historical aspects. Projects like Philadelphia's "Mural Arts Program" demonstrate how public art can engage communities, beautify neighborhoods, and strengthen social bonds [7].

Public art includes functional and expressive forms, temporary or permanent. Public space is not just physical but also a medium for communication [8]. Public art can broaden personal horizons by encouraging exploration of public space and embracing concepts of the unknown, surprise, experiments, and adventure. Installation art intervention in public space can present disharmony with location, materials, or form, challenging traditional aesthetics. Regardless of the venue, art intervention breaks inherent awareness and provides a broader space for communication and experience, enhancing urban vitality and creativity [5].

Beyond aesthetics, public art installations can contribute to well-being and social cohesion. Studies suggest exposure to public art can positively affect mental health and sense of belonging. Interactive installations foster social connections and spontaneous encounters [5]. Art installations can also be educational, offering insights into artistic processes, cultural histories, and environmental issues. Using recycled materials, for example, can raise awareness about sustainability [9].

Installation art typically updates public space in a subtle way, attached in a new state without excessive remodeling. This approach reduces intervention in the original space, conducive to continuing urban texture and culture while meeting the need for art intervention. With technological advancements, interactive installations use digital media, enabling audience participation. The concept of the "Pseudo-Environment", as described by Walter Lippmann, involves an image reconstructed from reality, incorporating physical, media, and mental layers. The Shannon-Weaver Model can analyze communication structures in interactive installations [10].

Installation art creates visual impact through bold colors, exaggerated shapes, diverse materials, and unconventional ideas, often forming a contrasting visual experience with urban public spaces (e.g., static vs. dynamic, abstract vs. reality). An example in Milan, Italy, used ribbons and wind to create a dynamic, visually interesting installation on a street, transforming idle space [6].

Intervening installation art attracts attention and creates opportunities for communication and extended stays. Public art interventions can activate underutilized or neglected areas, revitalizing them and increasing accessibility and appeal. Temporary art interventions can activate vacant lots and derelict spaces, creating temporary hubs for cultural exchange and community engagement [9].

In landscape design, installation art plays an increasing role, focusing on cultural connotation and integration with the natural environment. It can reflect specific topics or ideas and enhance the quality of urban landscape and space. Urban landscape installation art has strong visual impact and expressiveness, serving as a focal point [5]. Public art enhances urban landscapes by embedding cultural and social expression, using installations with natural or synthetic, temporary or permanent materials. The uplift aesthetics, communicate identity, foster a sense of place, and can address social issues and support the local economy. Installation art is a powerful tool for urban and social transformation, reshaping spaces, fostering community identity, and enhancing urban landscapes by integrating artistic expression with public engagement. Its increasing incorporation of interactive and sustainable elements ensures its relevance in contemporary design and urban planning [11].

2.3 Thermal Comfort

Integrating thermal comfort into urban planning has a long history, dating back centuries with considerations for solar orientation and wind protection. Increased urban density contributes to the urban heat island effect. Today, cities like Toronto face challenges including reduced natural ventilation, uncomfortable public spaces, and excessive heat retention. Re-integrating climatic considerations is essential for enhancing thermal comfort and creating sustainable, livable cities [4]. Thermal comfort is defined as the state of feeling neither too warm nor too cold in a given environment. American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) 55-66 (1966) defines it as "That condition of mind which expresses satisfaction with the thermal environment". A person in thermal comfort desires no change in temperature. This satisfaction is a universal human condition [12].

Seven factors influence human thermal comfort: air temperature, radiant temperature, humidity, air velocity, metabolic heat from activity, clothing worn, and adaptive opportunities. All seven must be considered; thermal comfort cannot be specified based on a subset. The interaction of the first six is well-researched, while designing for adaptive opportunities is newer in environmental design. People adapt behaviorally (e.g., changing location, clothing) and physiologically (e.g., acclimatization, morphological adaptations) to thermal conditions [12]. Research on thermal comfort for diverse populations exists. Studies show no significant differences between adults and schoolchildren, suggesting adult standards apply to children. For elderly populations, studies show varied preferences, sometimes preferring warmer conditions or experiencing lower metabolic heat production. Physiological requirements for comfort do not change significantly with age or disability, but adaptive opportunities do. Psychological and social factors influence perceived discomfort, with people in hot climates finding "cool" desirable and those in cold climates favoring "warm". Research on thermal comfort for people with disabilities is limited, but studies suggest physical limitations restrict adaptive opportunities, often leading to a preference for higher temperatures due to reduced mobility and inability to adjust clothing or location. Studies emphasize the need for design methods that include disabled individuals [12].

Influential thermal comfort standards include ISO (International Organization for Standardization) 7730 (2005) and ASHRAE 55-2017, primarily for indoor environments but adaptable for outdoor spaces like those under the Gardiner. Both uses PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) indices based on key environmental and personal factors. ASHRAE 55 includes an adaptive approach, relevant for outdoor spaces as it accounts for behavioral adjustments. It defines comfort zones using operative temperature and humidity, useful for designing temporary installations responding to fluctuating conditions. PMV/PPD models, though indoor-focused, can help evaluate interventions in outdoor spaces, potentially using computational models to simulate scenarios. Adaptive models are particularly useful for outdoor spaces as they consider personal adjustments and climate context [12].

2.4 City of Toronto Guidelines for Thermal Comfort

Toronto's consideration of thermal comfort dates back to the 1990 study "Sun, Wind, and Pedestrian Comfort", which led to performance standards for sunlight access and pedestrian wind comfort, incorporated into City Plan '91. This study identified wind and sunlight as primary factors influencing comfort in Toronto and established quantifiable performance levels for urban designs. A 2018 study, "On Shade and Shadow", examined the impact of shade, differentiating beneficial intentional shade (vegetation) from potentially negative unintentional overshadowing (buildings), noting that shade is beneficial in summer but can intensify cold in winter. The current Thermal Comfort Guidelines integrate lessons from these studies with modern data and methodologies to balance sunlight access, wind mitigation, and seasonal comfort [4].

The City of Toronto is adopting Thermal Comfort Guidelines to enhance public space quality and comfort in response to climate change and urban densification. As extreme weather increases, designing outdoor environments for year-round comfort is crucial, especially in rapidly growing Toronto. Public spaces provide recreation and relief from indoor heat. The guidelines use advanced technologies and methodologies, aligning with wind and sun/shadow studies for large developments. They apply to large projects and sites over 5 hectares. A methodology and Design Toolbox offer strategies for improving comfort in streets, parks, and public spaces, supporting sustainable design and promoting vibrant, year-round urban life [4].

The guidelines include guiding principles, performance metrics, a design toolbox, and appendices. Guiding principles, developed through public and stakeholder consultations, including indigenous communities, establish a framework prioritizing thermal comfort. Key principles include Equity (prioritizing vulnerable populations), Life-Centric Approach (considering all living beings and ecological balance, noting the role of trees and vegetation), Seasonal Shade and Comfort (flexibility and adaptability for year-round comfort, using deciduous trees for seasonal benefits), Shoulder

Seasons (focusing on extending usability in spring/fall), Different Modes of Transportation (considering comfort for pedestrians, cyclists, transit users, motorists), and Toronto-Specific Standards (considering local context like topography, built form, Lake Ontario influence, and extreme winds). Designing for seasonal adaptability is key, involving elements that provide sunlight access in colder months and shade in warmer months, and block wind in colder months while allowing breezes in warmer months [4].

Performance metrics define target thermal comfort levels using the UTCI (Universal Thermal Climate Index). UTCI evaluates perceived temperature based on air temperature, relative humidity, wind speed, and radiant temperature, offering a globally recognized "feels-like" measure for assessing heat and cold stress. Toronto uses specific targets due to its semi-continental climate and Lake Ontario influence. Acceptable UTCI ranges vary seasonally: 9 °C to 26 °C during shoulder seasons (March-May, Sep.-Oct., 8 AM-8 PM); 9 °C to 32 °C in summer (Jun.-Aug., 6 AM-9 PM); and 0 °C to 26 °C in winter (Nov.-Feb., 8 AM-5 PM). These targets, based on sensitivity assessments at test sites across Toronto, aim for achieving comfort for >65% time in summer, >30% in winter, and >45% in shoulder seasons (Fig.1). The guidelines also aim to prevent annual comfortable hours from decreasing by more than 5% compared to existing conditions [4].

The Design Toolbox offers strategies for integrating thermal comfort into projects, serving as a planning tool and mitigation strategy. It emphasizes balancing environmental and design elements for well-being. Strategies include understanding Toronto's climate, conducting microclimate analyses, assessing human activity, applying an equity lens, and incorporating adaptable elements. Strategies are organized by spatial scale: neighborhood (optimizing street/open space orientation, using natural features like ravines/lakes, urban cooling strategies like green spaces, tree canopies, green roofs), block (strategically placing buildings for wind control, optimizing sunlight, designing parks/plazas/Privately-Owned Publicly Accessible Spaces (POPS) for sun/wind balance and seasonal adaptability), and site (landscaping with deciduous trees, water features, shelters, surface materials). Overall strategies prioritize thermal comfort from project start, design for well-being, consider built environment influence

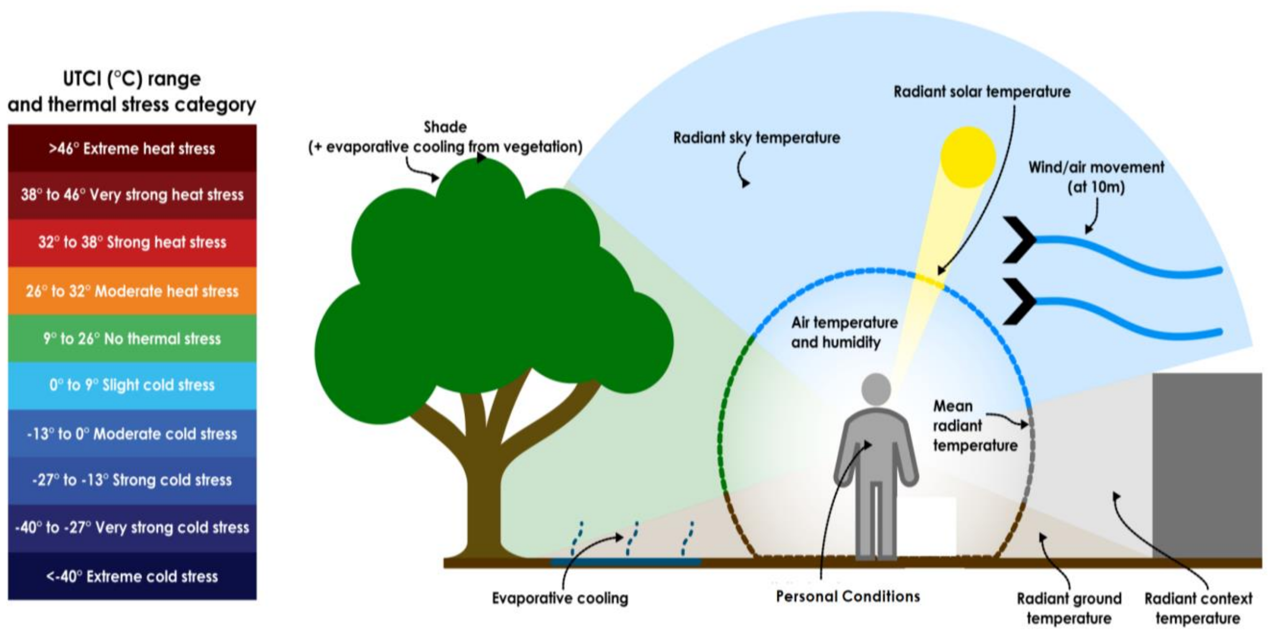

Fig. 1 UTCI is a method of quantifying thermal comfort based on air temperature, radiant temperature, air speed, and relative humidity [4].

(materials, layout, shading, wind exposure), and ensure year-round usability. Key factors impacting comfort and design strategies include prioritizing thermal comfort early, mitigating urban heat island effect, microclimate-based design, human-centered planning, material selection, and incorporating flexibility and adaptability [13-15]. Ensuring thermal comfort in the public realm (all public/private spaces with public access) is essential for physical and mental well-being, especially with increasing extreme heat events in Toronto. Projections indicate over 60 additional days above 30 °C annually compared to the 1980s, while very cold days become rarer. Unpredictable precipitation and seasonal variability pose challenges. Prioritizing thermal comfort ensures outdoor areas remain usable year-round, fostering a vibrant, resilient, and livable city.

The guidelines align with the TGS (Toronto Green Standard) Version 4, which requires 75% of non-roof hardscape to mitigate heat using strategies like cool paving, tree canopy shading, and structures. TGS promotes tree planting for 40% canopy cover. Hardscape solutions provide immediate effects, while natural elements offer long-term adaptability. These standards are integrated with development requirements [4].

Thermal comfort principles transform urban areas into spaces supporting year-round outdoor activities. Effective design includes vegetative elements for shade and heat reduction, water features for evaporative cooling, and appropriate material selection to reduce surface heating. Understanding intended use and timing of outdoor spaces is important [15]. Studying site-specific weather data and surrounding infrastructure is crucial for practical guidelines. Tailoring models/indices to climate/culture and prioritizing sustainability is essential [16].

2.5 Addressing Thermal Comfort during Shoulder Seasons

While extreme weather limits outdoor usability, shoulder seasons (spring and fall) offer opportunities to extend comfort through thoughtful design. These seasons have moderate yet variable conditions, making them ideal for targeted interventions. The focus is on mitigating shoulder season challenges through design solutions that enhance comfort. Interventions during these months are more feasible than in extreme weather. Designing for seasonal adaptability through vegetation (shade, windbreaks), shade and shelter (protection from wind chill and sun), and wind management (windbreaks, building orientation) is key. A desktop study found that approximately 52% of the time during shoulder months (March-May, Sep.-Oct.) is thermally comfortable based on UTCI, with a target of >45% for public spaces [4, 14].

2.6 Microclimatic Design

Microclimatic design involves manipulating small-scale climatic conditions using landscape elements. Brown and Gillespie highlight how prevailing climate interacts with objects (vegetation, ground cover, structures) to create microclimates that enhance thermal comfort. Key principles are understanding and application. Landscape architects influence the placement and type of objects. Wind and solar radiation can be significantly controlled, while air temperature and humidity are harder to modify [17].

Energy Budget Theory explains microclimate formation: solar radiation heats the ground, evaporates water, and heats the air. In dry landscapes, more energy heats surfaces and air; in wet landscapes, evaporation reduces temperature. For humans, energy comes from solar radiation and metabolic heat. Overheating occurs if received energy exceeds dissipation. Landscape modifications can improve thermal comfort [17].

Landscape elements modify microclimate. Vegetation density, ground cover type, and structures affect wind and radiation. Understanding effective modifications is key. Surface roughness alters wind speed, but dense evergreen tree rows significantly reduce wind speeds, improving comfort and potentially reducing building heating costs [17].

Designers should apply a structured approach. Historical and vernacular strategies offer insights, but no single rule applies universally. Orientation of outdoor spaces is crucial. In the Northern Hemisphere, south-facing spaces maximize winter sun. Overhanging structures should block high summer sun but allow low winter sun. Effective design considers site energy budget, landscape element properties, and human responses. Microclimatic factors affecting comfort include temperature, solar radiation, terrestrial radiation, wind, humidity, and precipitation. Understanding these factors and how landscape elements modify them is essential. Design should prioritize common use conditions [17].

Microclimatic design has ancient roots, often empirical. Historical examples include cliff dwellings (natural shading/insulation) and walled gardens/courtyard houses (comfortable outdoor spaces). Challenges arise from inappropriate design, like exporting European styles to unsuitable climates. Many modern outdoor spaces lack good microclimatic planning. Contemporary examples exist, like university campus seating designed for year-round comfort. Key principles involve tailoring solutions to specific uses/conditions, using south-facing spaces in cold climates, employing windbreaks (carefully placed), and using overhead structures for precipitation protection and solar regulation [17].

Table 1 summarizing microclimatic factors and strategies highlights challenges like strong/cold wind (mitigated by windbreaks, barriers), direct sun (mitigated by deciduous trees, shading devices, orientation), humidity (hard to manage, water bodies in dry areas), radiation (manipulate surfaces, vegetation), and precipitation (overhead structures).

3. Methods

The methodology employed is a multi-step process to develop a climate-responsive design proposal for spaces beneath the elevated Gardiner Expressway. It combines literature review, precedent studies, and site-specific analysis to identify environmental and social factors influencing thermal comfort in underutilized urban spaces. This process integrates insights from thermal comfort guidelines, microclimatic strategies, site challenges, and case study findings (Fig.2). These findings are synthesized to inform design considerations, guiding the development of a proposal aimed at enhancing usability and comfort during shoulder seasons. The process flows from literature review and guidelines, through precedent studies and site analysis, leading to design considerations and the final proposal.

Table 1 Microclimatic design strategies table [17].

Microclimatic factor	Design challenge	Landscape design strategies
Wind	Strong or cold wind can decrease thermal comfort, especially in winter.	Use windbreaks (e.g., evergreen trees), physical barriers, building orientation, dense shrubs, or berms.
Solar radiation	Direct sun in summer can cause overheating; insufficient sun in winter reduces comfort.	Use deciduous trees, shading devices, reflective materials, south-facing orientation, overhead structures.
Precipitation	Rain or snow affects usability and comfort of outdoor spaces.	Overhead structures, permeable surfaces, rain gardens, drainage systems.
Air temperature	Difficult to control; extreme temperatures reduce comfort.	Indirectly managed via shade, wind control, and surface materials that retain or reflect heat.
Humidity	Hard to manage; can intensify discomfort in high humidity areas.	Use of water bodies for evaporative cooling in dry areas, strategic planning.
Radiation (solar + terrestrial)	Heat gain from sun and surfaces can cause discomfort.	Manipulate surface materials, vegetation for shading, understand solar geometry for optimal placement.

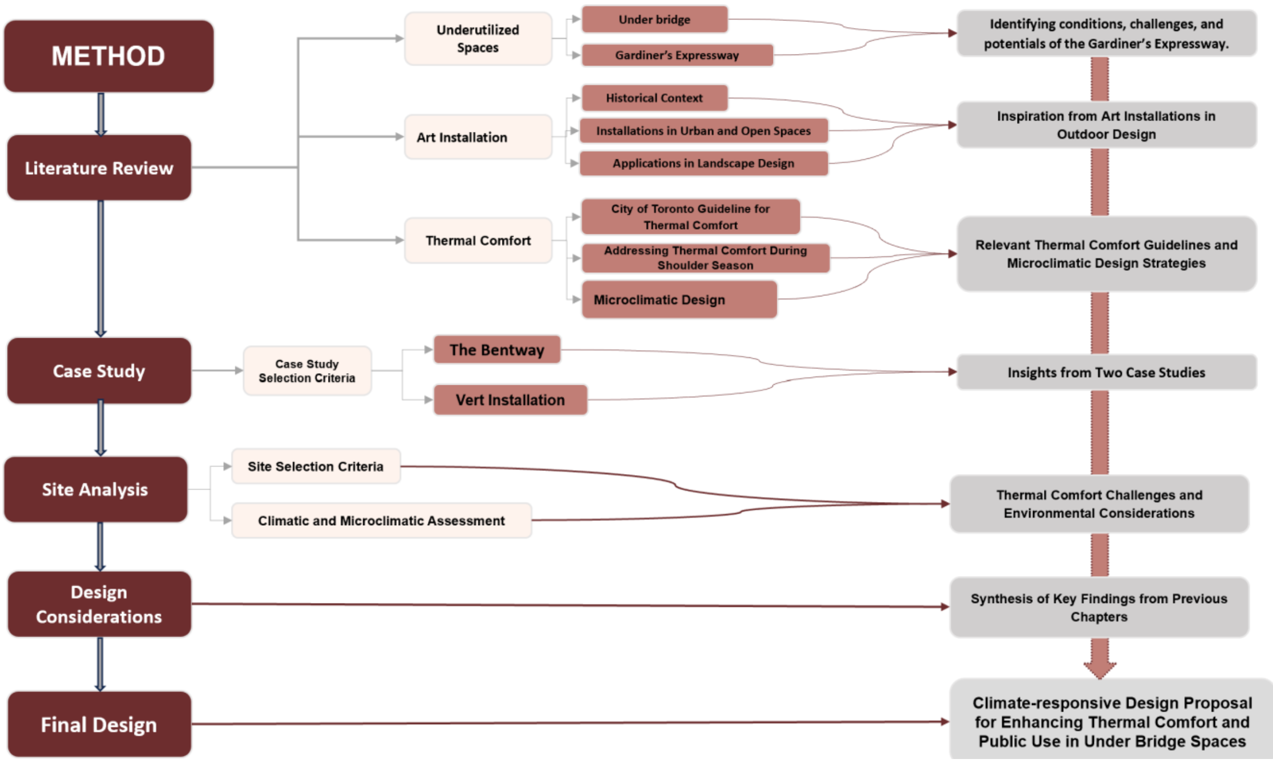

Fig. 2 Methodology framework.

3.1 Case Study Selection and Analysis

Selecting appropriate case studies was crucial for understanding how temporary installations in underutilized spaces can enhance thermal comfort and public engagement. Criteria for selection ensured relevance to the thesis objectives:

- Relevance to thermal comfort: Incorporating strategies for thermal conditions (passive/active design, microclimate regulation like shading, wind protection, materials).
- Urban context: Located in underutilized urban areas, especially under highways, demonstrating transformation potential.
- Temporary and flexible nature: Emphasizing temporary, modular, or adaptable installations rather than permanent structures, illustrating seasonal usability enhancement.
- Climatic and seasonal considerations: Chosen from regions with climatic similarities to Toronto, focusing on interventions suitable for shoulder seasons and extending usability beyond peak months.
- Public engagement and social interaction: Prioritizing community engagement, demonstrating how design influences behavior, comfort, and accessibility, including cultural programming that activates space year-round.

Two case studies were selected based on these criteria:

- The Bentway (Toronto, Canada): A transformation project beneath Toronto's Gardiner Expressway. Selected for its direct relevance to the research context, repurposing Gardiner underpasses into an active civic space. It integrates seasonal adaptability, including a winter skating trail and summer splash pad, demonstrating extended outdoor usability. It incorporates microclimate strategies like wind protection from the structure and landscape elements for shade and stormwater management. The Bentway enhances social interaction through public programming, serving as a successful precedent for activating underused areas. The project transformed a 1.75 km space beneath the elevated Gardiner, including Fort York National Historic Site lands, into public spaces. The framework design by Ken Greenberg and PUBLIC WORK included a multi-use trail, a bridge over Fort York Boulevard, a grand staircase doubling as seating, and flexible, year-round programming spaces. The project connects seven downtown neighborhoods and aims to reclaim the underused space as a hub for diverse community events. It was funded by a $25-million donation and opened in January 2018 [18]. The project concept was based on the expressway's concrete columns ("bents") creating "civic rooms" for diverse programming [19]. The underside is repurposed as a large-scale asset, and the ground is designed for movement, stormwater management, and landscape restoration recalling the historic shoreline. Materiality includes recycled debris and reflective paint on bents for wayfinding. Key features include the Four Seasons of Bentway Culture (skating trail/splash pad) and stormwater management systems (bioretention, swales, infiltration trenches) for runoff from the Gardiner [20]. Native, salt-tolerant plantings were used where feasible to manage highway runoff [21]. A report by The Bentway and partners found public spaces like The Bentway are critical health tools that foster social connection and combat urban loneliness. Public art areas at The Bentway were found to be "stickier spaces", supporting longer stays and enhanced social interactions [22]. Bentway Staging Grounds is a temporary installation demonstrating urban ecology and stormwater management concepts [23].

- Vert Installation (London, UK): A temporary, modular structure enhancing urban cooling and biodiversity. Selected for exploring passive cooling strategies using climbing plants and modular timber structures to create shaded, thermally comfortable spaces, the design is lightweight, adaptable, and movable, aligning with the concept of temporary installations. It demonstrates sustainability through material selection (engineered hardwood, red oak glulam). Vert serves as a prototype for urban greening and climate-responsive public space design, making it relevant for Toronto. The structure consists of timber triangles with sails covered in climbing plants to fix carbon dioxide and create cooling shade. Red oak glulam is denser and more stable than standard timbers, requiring less material and allowing for disassembly, movement, and reassembly, supporting longevity. Increased use of underutilized red oak promotes forest diversity. The modular triangular design adapts to various urban environments and facilitates expansion/reconfiguration. Vert is projected to cool air by up to 8 ºC, cast significant shade, and produce biomass comparable to an old tree [24].

3.2 Site Analysis

This section involves an in-depth site analysis for a selected portion of the Under Gardiner corridor, identifying climate-related conditions and environmental factors influencing comfort during shoulder seasons.

3.2.1 Site Selection Criteria

The elevated section of the Gardiner Expressway, known as the Under Gardiner corridor, was the focus. The City of Toronto's PRP (Public Realm Plan) divides this corridor into seven districts. The Bentway-Fort York district was chosen for further exploration and design development. The specific site selected for design consideration is located between Bent 51 and Bent 52, within the western stretch of this district, between Strachan Avenue and Bathurst Street.

Factors contributing to this site selection include:

- Light access and spatial openness: Better sunlight exposure compared to narrower, heavily shaded segments, making it suitable for microclimatic interventions.
- Contextual setting: Bordered by a public park and low-rise residential area, offering a calmer environment with reduced noise and pollution.
- Safety and defined circulation: Clearly defined pedestrian pathways, vehicular lanes, and parking minimize conflicts and enhance safety.
- Proximity to cultural and historic assets: Near Fort York National Historic Site, increasing visibility, foot

traffic, and public interest as a destination.

- Topography and air quality: Slight elevation and open layout with adjacent green space contribute to better air circulation and reduced pollution, enhancing comfort.
- Sufficient space for gathering: Offers enough area to comfortably support gathering functions like seating and resting, unlike narrow, fragmented areas.

In summary, the site at Bent 51-52 is accessible, safe, and contextually rich, providing a strong foundation for exploring microclimatic design and developing inclusive gathering spaces under elevated infrastructure. The broader context of the Under Gardiner corridor, stretching seven kilometers and divided into districts based on surrounding neighborhoods and features, informs the analysis. The Bentway-Fort York district itself is located between Strachan Avenue and Bathurst Street and is home to The Bentway Phase 1.

3.3 Climatic and Microclimatic Assessment

This assessment covers general climate and localized microclimate. It uses three sources: quantitative climate data from Billy Bishop Toronto City Airport (temperature, wind speed/direction, humidity) for March, April, May, September, October 2024, climate-related insights from a Transsolar Klima Engineering study on the Bentway (applicable due to proximity), and on-site observation (land cover, vegetation, surface materials). Understanding the interaction between climate and landscape features is key to effective microclimatic strategies.

The UTCI is used to quantify thermal comfort based on air temperature, relative humidity, wind speed, and radiant temperature. Toronto uses specific comfort criteria and targets for different seasons. For shoulder months (Mar.-May, Sep.-Oct., 8 AM-8 PM), the target is >45% comfortable time within the 9-26 °C UTCI range. Achieving these targets can be challenging but attainable [4].

The Under Gardiner microclimate is unique due to natural phenomena (radiation, humidity, weather) and human activity byproducts (noise, pollution). Analyzing the microclimate involves considering proximity to water, topography, built environment, and vegetation. Site-specific factors like solar radiation, wind direction, and land cover are important. For example, tall buildings nearby can create glare and localized discomfort [25].

3.3.1 Sunlight Analysis

Understanding seasonal sun exposure is essential. A site with limited winter sun might be less comfortable and require different strategies. In Toronto, warmer months risk heat stress from direct sun; colder months risk cold stress from reduced sun. Areas with more sunlight may be cooler at night due to higher sky visibility. The weather station data provide relevant parameters for climate analysis [25].

3.3.2 Air Temperature

Analyzing hourly temperatures in March, April, May, September, and October 2024 shows seasonal transitions. March 2024 was consistently cool with temperatures below 9 °C for most of the daytime. April 2024 saw mixed conditions with days below 9 °C and days within the comfortable range. May 2024 included early cool days and later warmer periods with temperatures exceeding 26 °C, indicating the transition towards summer. September 2024 had warm days (above 26 °C) early in the month, showing a transition from summer, with comfortable conditions most other days. October 2024 returned to cooler conditions, with temperatures below 9 °C on more than half the days, and no hot days. The data highlight the temperature variability characteristic of shoulder seasons [26].

3.3.3 Wind Study

Wind speed and direction analysis at Billy Bishop Toronto City Airport for the shoulder months of 2024 is relevant. Thermal comfort studies for the Bentway project considered pedestrian level wind conditions using inland and coastal data zones. Wind flow patterns were analyzed for areas like the Under Gardiner Islands and Glass Gardiner districts. Between March and October 2024, wind conditions changed seasonally.

March and April had frequent fresh breezes, with strong winds on April 14-15. May was mostly calm, with a few breezy days. In September, moderate afternoon winds returned, peaking around September 6. October was the windiest month, especially from October 28-30, with sustained strong breezes [26].

3.3.4 Humidity Comfort Levels

Analysis of humidity comfort levels for the shoulder months in 2024 from Billy Bishop Toronto City Airport between 8 AM and 8 PM showed periods outside the "comfortable" range. March had comfortable humidity levels throughout. April had humid to muggy conditions in the afternoon/evening late in the month. May saw periods of humid to muggy and even humid to oppressive conditions, particularly in the latter half of the month. September experienced muggy to oppressive conditions early in the month, followed by humid to muggy, and later more oppressive periods. October had humid to muggy conditions early in the month and humid conditions late in the month for short periods. This indicates that humidity can contribute to discomfort during shoulder seasons, especially in September and May [26].

3.3.5 Land Cover

The type of land cover impacts thermal comfort. Materials like asphalt and concrete contribute to the urban heat island effect by absorbing and storing heat. Grass and vegetation absorb less heat and provide cooler environments through evapotranspiration. The site predominantly has hardscape (asphalt, concrete). Asphalt contributes to localized warming. Concrete walkways reflect more sun but still retain heat. Wooden deck platforms offer lower thermal conductivity, increasing comfort. While mostly hardscape, selective soft/semi-permeable surfaces provide moderate thermal relief and shape the microclimate.

3.3.6 Vegetation

To the south of the site, a grassy mound with sparse young trees offers slight cooling but minimal shading or wind mitigation. To the north, the Fort York green space has open lawn and mature deciduous trees. Nearby trees may contribute to wind buffering, shading, and humidity retention, especially when leafy in summer. The combination of lawn and tree canopy creates a softer edge and enhances environmental comfort in the surroundings.

The site analysis highlights thermal comfort challenges, particularly related to wind and temperature fluctuations during shoulder seasons. Wind tunnel effects from the expressway intensify discomfort. The elevated structure provides shelter but also creates limitations. There is a need to prioritize strategies mitigating cold wind and precipitation. Ongoing climate change reinforces the need for adaptable design strategies.

4. Results and Discussion

The analysis of the site's climate and microclimate, combined with insights from literature and case studies, reveals key challenges and opportunities for enhancing thermal comfort under the Gardiner Expressway, particularly during the shoulder seasons. The quantitative climate data for March-May and September-October 2024 from Billy Bishop Toronto City Airport illustrate the significant temperature variability within these transitional months. March and October experienced prolonged periods below 9 °C, indicating cold stress risks, while May and September had days exceeding 26 °C, posing heat stress concerns, especially early/late in those seasons. This confirms the need for designs that can adapt to fluctuating temperatures within the shoulder season target range of 9-26 °C UTCI.

Wind data analysis also showed variable wind speeds and directions. The pedestrian-level wind study highlighted how the surrounding built form and expressway structure influence wind flow patterns. On-site observations corroborate this, noting wind tunnel effects created by the expressway. High winds, particularly cold winds in early spring and late fall, pose a significant challenge to thermal comfort under the elevated structure. The provided summary table

(Table 1) on humidity comfort levels also showed periods outside the comfortable zone, particularly in May and September, suggesting that humidity can exacerbate thermal discomfort even within moderate temperatures [25].

Land cover, predominantly hardscape at the selected site, contributes to heat absorption, although existing soft surfaces and vegetation offer some localized relief. The limited amount of mature vegetation under the structure means its impact on shading, wind mitigation, and humidity retention is minimal. These site-specific conditions underscore the importance of microclimatic design strategies, particularly those focused on modifying wind, solar radiation, and radiant temperature, as air temperature and humidity are harder to control directly.

The literature review provided crucial context for these challenges. Understanding that underutilized spaces like those under the Gardiner are often perceived as unsafe and unwelcoming due to environmental issues like pollution and noise frames the revitalization effort as needing to address not just thermal comfort but also perceived safety and usability. The history of the Gardiner Expressway highlights its role as a barrier, reinforcing the goal of transforming the under-space into a connecting public realm.

Insights from the City of Toronto's Thermal Comfort Guidelines emphasize the importance of designing for all seasons, focusing on shoulder seasons as a key opportunity, and using a human-centered, equity-focused approach. The guidelines' performance targets for shoulder seasons (>45% comfortable time) provide a benchmark for design success. The Design Toolbox strategies, such as incorporating adaptable elements, microclimate analysis, and appropriate material selection, directly inform potential design solutions.

The case studies offer practical examples of addressing these challenges. The Bentway demonstrates the successful transformation of under-expressway space into a vibrant public realm with seasonal programming and microclimate strategies like stormwater management and wind protection from the structure. Crucially, The Bentway's study highlights how public spaces, especially those with public art, enhance social connection and well-being, linking thermal comfort to social outcomes. The Vert Installation provides a precedent for temporary, modular interventions using vegetation for passive cooling and shade. Its focus on lightweight, adaptable structures built from sustainable, reassemblable materials directly supports the concept of temporary, flexible installations. Its projected microclimatic benefits (cooling, shade) validate the potential of such interventions.

Synthesizing these insights leads to a set of design considerations. The site analysis confirms that wind is a primary challenge, requiring windbreaks and protection. Variable temperatures necessitate adaptable shading for sun control in milder shoulder days and access to sun in colder shoulder days. The under-bridge context limits natural light and vegetation, necessitating engineered solutions for shade and potentially incorporating plant elements. The need for social interaction and usability identified in the literature and reinforced by The Bentway case study suggests including elements that support gathering, rest, and activity. The temporary nature of the proposed intervention, inspired by Vert and aligning with the ongoing Gardiner rehabilitation, requires modularity, flexibility, and ease of reconfiguration. The goal is to create comfortable zones that mitigate the identified microclimatic challenges while fostering social engagement, directly addressing the research question and objectives.

5. Design Considerations

This chapter synthesizes research findings to develop climate-responsive design considerations for the site under the Gardiner Expressway. Building on thermal comfort studies, site analysis, case studies, and artistic precedents, the approach is grounded in the research question and objectives.

The process traces the link from the central research question—investigating how underutilized spaces under the Gardiner can be reimagined through temporary installations and landscape architectural strategies to enhance thermal comfort and support social activity during shoulder seasons—through four supporting objectives. Each objective is supported by specific sources of analysis: identifying challenges/needs involves literature reviews (underutilized spaces, thermal comfort), analyzing site conditions involves site analysis (climatic/microclimatic assessment), exploring strategies uses precedent studies (Bentway, Vert) and guidelines (Toronto thermal comfort, microclimatic design), and developing design considerations integrates findings from all previous steps. This synthesis of findings leads to the final design proposal (Fig.3).

Key principles from the City of Toronto Thermal Comfort Guidelines, such as prioritizing shoulder seasons, balancing seasonal shade and comfort, and applying a life-centric approach, are crucial. Design strategies from microclimatic landscape design literature emphasize seasonal adaptability and comfort optimization at various scales, considering factors like wind, solar radiation, and vegetation. Art installations offer insights into adaptability, cultural relevance, and enhancing thermal comfort and social interaction in public space. Case studies like The Bentway and Vert Installation provide lessons in modularity, seasonal usability, and community-driven design under infrastructure. Finally, the site analysis highlights specific climatic challenges (wind, temperature, humidity) and site conditions (vegetation) that inform design implications.

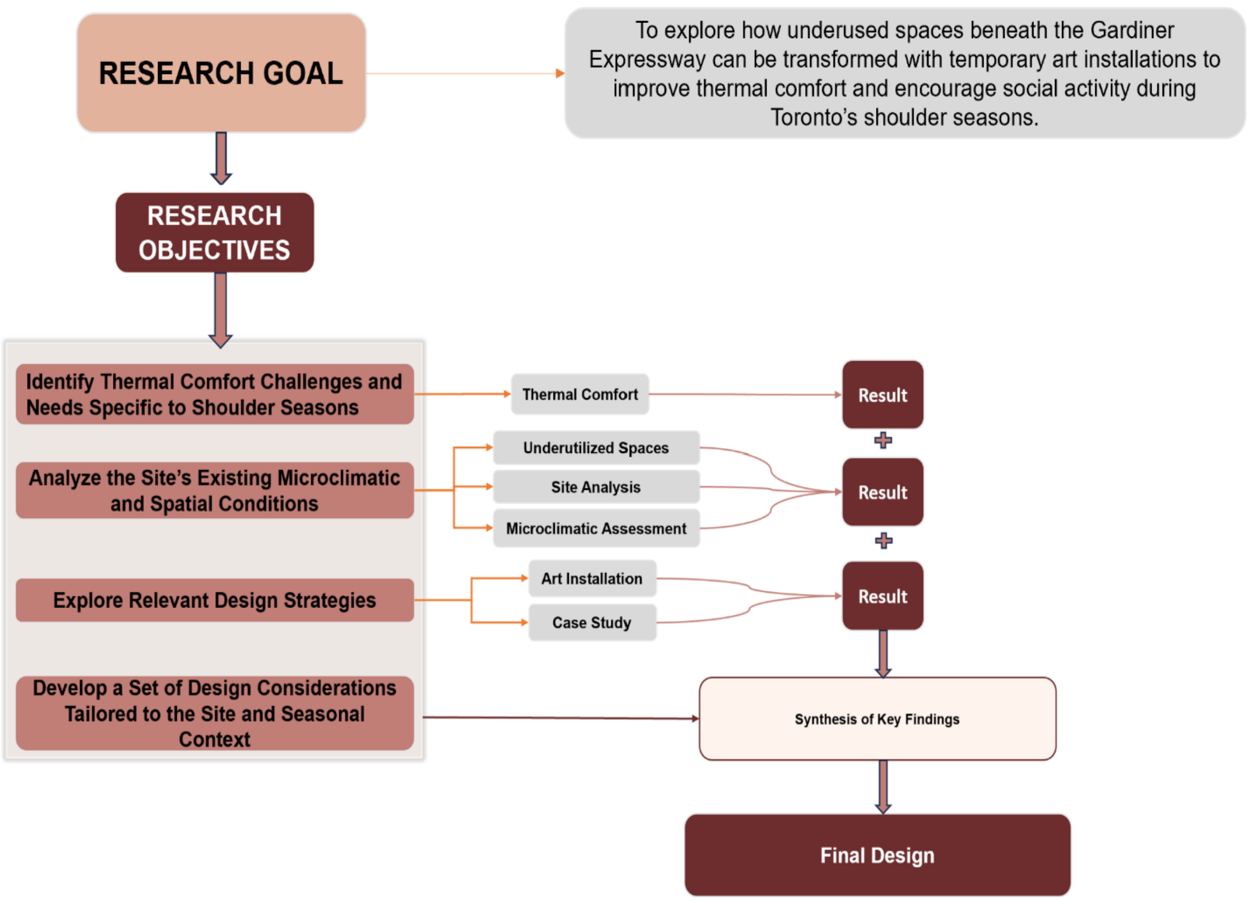

Fig. 3 Visual mapping of how each research objective is supported by specific sources of analysis, leading to the synthesis of key findings and the final design proposal.

The synthesis of these insights directly informed the development of modular panel solutions. A table linking design insights to modular panel solutions illustrates this relationship. Key insights translated into design include:

- The need for wind protection: Leading to panels designed as wind filters or windbreaks.
- The need for solar control/shade: Leading to panels offering solar protection or acting as green screens with vegetation.
- The importance of adaptability and flexibility: Reinforcing the choice of a modular, movable system.
- The potential for social interaction: Leading to panels that define gathering spaces and incorporate elements like seating.
- The desire to integrate nature: Incorporating vegetation into panels where possible.

This synthesis resulted in a proposed system of modular, movable installations, designed to mitigate thermal discomfort and enhance usability, creating a more participatory and adaptable public space. The system comprises a series of panel types, ranging from basic to multifunctional:

(1) Basic Wooden Frame Panel

Basic wooden frame panel is a minimal structural module (approx. 2 m high, 1 m wide) on wheels, defining space and serving as a base unit (Fig.4).

Fig. 4 Basic wooden frame panel.

(2) Transparent Wind Filter Panel

Transparent wind filter panel likely incorporates materials that allow light through but filter wind, potentially using mesh or perforated materials, informed by wind control strategies (Fig.5).

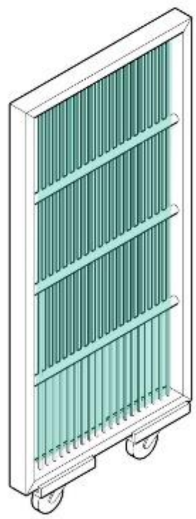

Fig. 5 Transparent wind filter panel.

(3) Solar Protection Panel

Solar protection panel is designed to block direct sunlight, potentially using opaque or semi-opaque materials, drawing on solar radiation control strategies (Fig. 6).

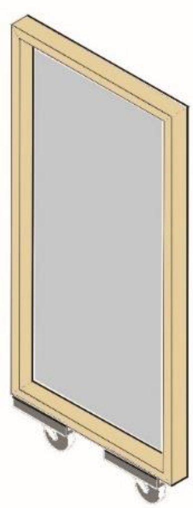

Fig. 6 Solar protection panel.

(4) Portable Deciduous Planter Panel

Portable deciduous planter panel is movable panel with seasonal shade, evaporative cooling, and light wind protection and enhances comfort and ecology through flexible placement (Fig.7).

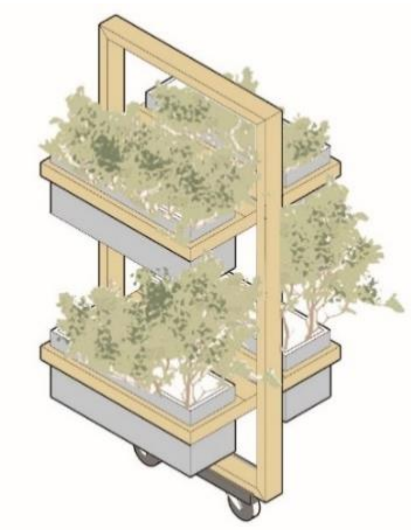

Fig. 7 Portable deciduous planter panel.

(5) Portable Evergreen Planter—Windbreak Unit

Portable evergreen planter—windbreak unit is a movable panel with evergreen planting that offers wind protection, especially effective in colder months (Fig.8). It helps create semi-enclosed microclimates and can be clustered to control wind in gathering areas.

Fig. 8 Portable evergreen planter—windbreak Unit.

(6) Green Screen Panel

Green screen panel incorporates vegetation, likely climbing plants, to provide shade and cooling through evapotranspiration, inspired by Vert Installation (Fig.9).

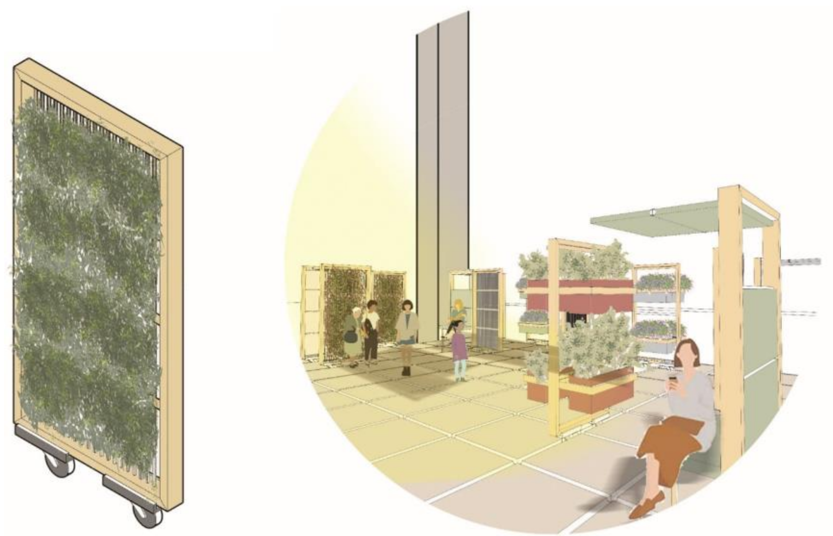

Fig. 9 Green screen panel.

(7) Combined Function Panels

Combined function panels incorporates elements like seating or tables to support user activities and gathering, enhancing social interaction opportunities (Fig.10).

(8) Windbreak Canopy Panel

Windbreak canopy panel potentially combines overhead protection with wind filtering elements (Fig.11).

(9) Portable Interactive Panel

Portable interactive panel is a movable unit combining play, education, and light wind protection and encourages public engagement and place-making through interactive and informative features (Fig.12).

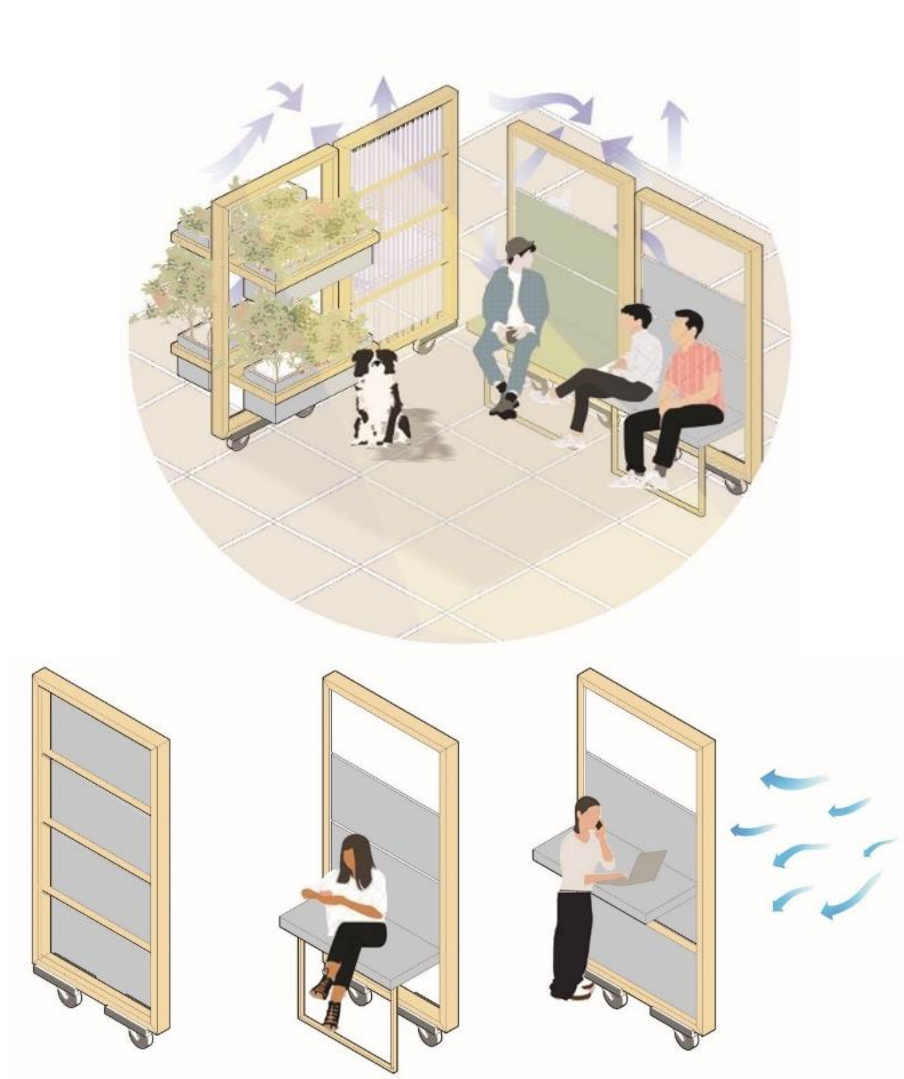

Fig. 10 Combined function panels.

Fig. 11 Windbreak canopy panel.

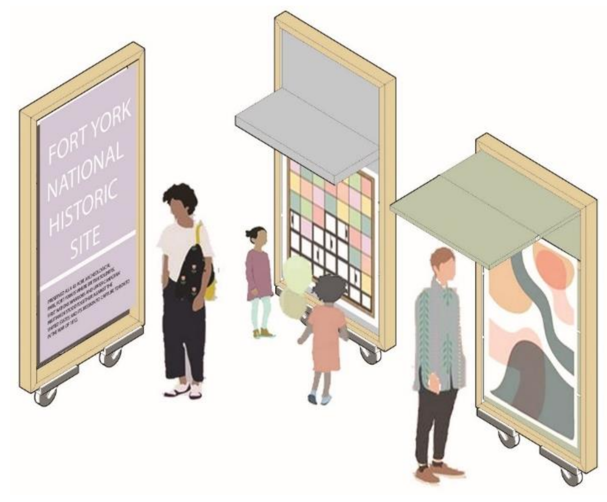

Fig. 12 Portable interactive panel.

The modular nature allows for numerous combinations and spatial flexibility. Panels can be combined to form shelter clusters, aligned as screens, or arranged to define semi-private zones (Fig.13). Their integration with planters, benches, or information elements adds ecological and functional value, offering continuous reusability and transformability based on seasonal changes or social dynamics.

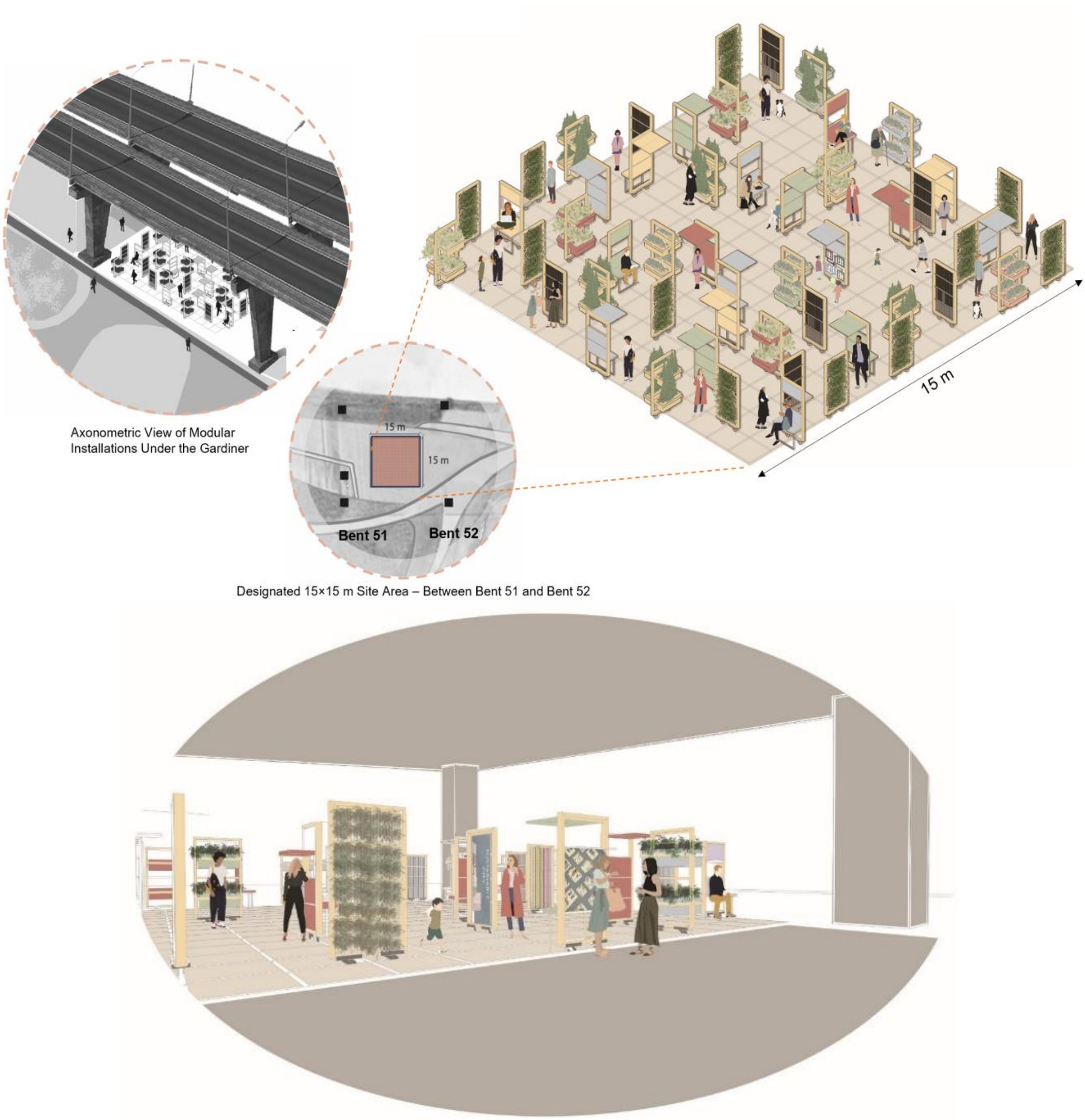

Fig. 13 Modular combinations and spatial flexibility.

6. Conclusion

This thesis explored the potential of temporary, flexible design interventions to enhance thermal comfort and social value in underutilized public spaces, specifically beneath Toronto's Gardiner Expressway. Recognizing the increasing need to leverage overlooked urban environments, the research focused on the shoulder seasons as a period offering significant potential for extending outdoor usability.

The methodology involved a comprehensive review of literature on underbridge spaces, art installations, and thermal comfort, complemented by analysis of precedent projects, site observations, and environmental data. This approach yielded valuable insights into the physical and experiential challenges of the site, particularly concerning the microclimatic conditions impacting user comfort.

Based on the findings, the research proposed a system of modular, movable installations designed to be adaptive and accessible, capable of responding to seasonal conditions and user needs. This proposal aims to activate the under-bridge space, transforming it into a welcoming and climate-responsive public realm. The research contributes to the growing body of work in landscape architecture that emphasizes flexibility, sustainability, and thermal comfort in the context of urban and environmental change.

The proposed installation system offers several opportunities, primarily its flexibility, which allows users to customize their immediate environment for comfort, whether seeking shade, shelter from wind/rain, or space for activities. This adaptability encourages longer stays outdoors and increases the appeal of public spaces during the shoulder seasons. The potential challenges include vandalism, material durability under harsh conditions, and potential community resistance, although thoughtful design can help minimize these.

The research faced limitations, including the reliance on secondary climate data from Billy Bishop Toronto City Airport, which could not fully capture the site-specific microclimatic variations influenced by the elevated structure and surrounding urban fabric. Attempts to obtain more site-specific data or consult with experts were limited by availability and data sharing restrictions. Time and resource constraints prevented the use of advanced thermal comfort simulations like Physiological Equivalent Temperature (PET) or Computational Fluid Dynamics (CFD) modeling, necessitating reliance on observational and literature-based methods to identify challenges and guide design. Furthermore, the proposed design is conceptual and has not undergone testing through user engagement or engineering feasibility studies.

These limitations highlight opportunities for future research. Long-term on-site microclimate monitoring beneath the Gardiner using sensors could provide more accurate environmental data to validate and refine thermal comfort assumptions. Developing and testing prototypes through field studies and user surveys could assess the effectiveness of the installations in improving thermal comfort and social interaction, helping optimize the design based on user behavior and preferences. Future studies could extend the design approach to other underutilized areas under the Gardiner, including narrow segments, or apply the framework to underutilized spaces in different contexts to test its adaptability. Expanding the scope to address extreme winter and summer conditions with similar design strategies is another avenue. Finally, research into material performance (durability, sustainability, aesthetic integration) and integration with existing infrastructure like lighting or programming would support real-world implementation.

In conclusion, this research emphasizes the significant untapped potential of overlooked urban spaces like those beneath elevated expressways. As urban density increases and access to green space becomes limited, these forgotten areas can become vital components of the public realm through thoughtful landscape architectural design. Landscape architecture, with its integrative and human-centered approach, is well-suited to respond to this need. By focusing on thermal comfort and leveraging environmental elements such as vegetation, movable shading, and wind protection, spaces can be designed to adapt to seasonal changes, supporting user comfort and well-being. Ultimately, these efforts contribute to creating healthier, more livable cities and fostering more positive interactions between people and their urban environments.

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