

1

Cold

**Walkability**

Cold surfaces uncomfortable for sitting/resting

**Bikeability**

Cold handlebars uncomfortable to grip

**Spatial Design**

Inadequate thermal comfort discourages use

Heated waiting areas and shelters

Oslo: intelligent bus shelter networks

Oslo's smart city strategy includes initiatives like solar-powered infrastructure, connectivity for public transport users through the Ruter app, and a focus on sustainability.

4

Cold

**Walkability**

Doorways become icy from repeated melting/freezing events at threshold

**Bikeability**

Bike parking pads have icy patches from building heat lost at base wall

**Spatial Design**

Thermal bridges near entrances create condensation, slipperiness

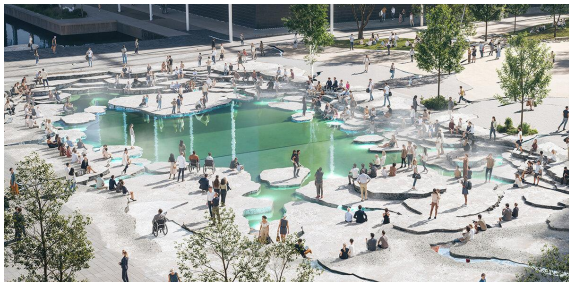
Insulation at threshold areas

Oslo: targeted anti-slip matting for entrances and racks

Oslo has implemented various winter safety measures including installing anti-slip materials, such as mats and textured coverings, in high-traffic pedestrian areas and around public transport stops, entrances to public buildings, and bike parking zones to prevent accidents during the winter season.

2

Cold

**Walkability**

Thermal discomfort reduces outdoor activity

**Bikeability**

Thermal discomfort reduces cycling duration

**Spatial Design**

Cold surfaces create uncomfortable microclimates

Public space thermal confort design**Copenhagen: thermal comfort public space design**

Copenhagen's public space design for thermal comfort emphasizes a "people-first" approach by integrating green infrastructure, water features, and urban morphology to mitigate heat and enhance well-being. Key strategies include optimizing the ratio of green to hard surfaces, utilizing strategic tree planting, ensuring continuity of green networks, and incorporating urban water elements to create more pleasant and functional public spaces, even in the face of a changing climate.

2

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**Spatial Design**

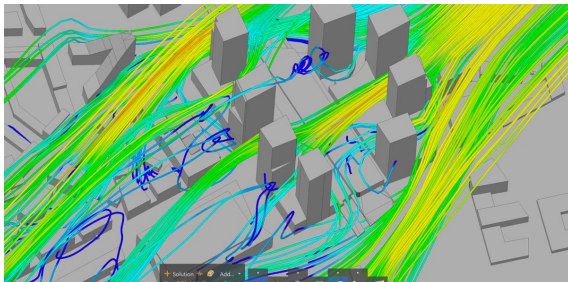
Cold surfaces create uncomfortable microclimates

Public space thermal confort design**Stockholm: microclimate management**

Stockholm has embedded the principles of green and blue infrastructure into its urban planning fabric. This is evident in the city's "Environment Programme 2030" and "Climate Action Plan 2030," which outline concrete measures to create a more resilient and sustainable urban environment.

3

Cold

**Walkability**

Wind chill affects exposed skin

**Bikeability**

Wind chill creates dangerous exposure

**Spatial Design**

Wind chill reduces usable outdoor spaces

Wind protection microclimate design

Helsinki: comprehensive wind protection urban planning

The city's strategic documents, such as the Helsinki City Strategy and various climate adaptation plans, explicitly recognize strong winds as an extreme weather event that requires proactive mitigation measures. A key principle embedded in these plans is the "control of increased wind pressure" in all new developments.

3

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**Bikeability**

Wind chill creates dangerous exposure

**Spatial Design**

Wind chill reduces usable outdoor spaces

Wind protection microclimate design

Oulu: integrated comfort strategies

The city is a prominent member of the Winter Design Cities network, a global platform for cities to share best practices in creating livable winter environments. Oulu's approach is a blend of practical solutions and a cultural embrace of the season.

5

Darkness

**Walkability**

Reduced visibility increases accident risk

**Bikeability**

Reduced visibility to/from other road users

**Spatial Design**

Reduced visibility in public spaces

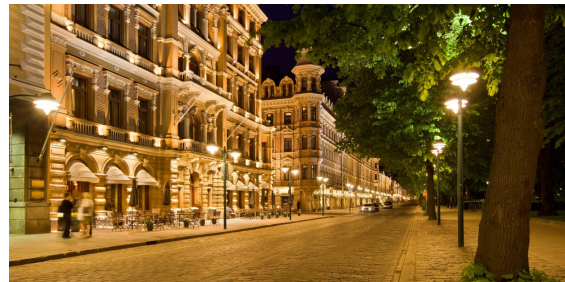
Enhanced LED street lighting

Stockholm: LED lighting upgrades

Stockholm has been actively upgrading its urban lighting infrastructure with LED technology as part of its sustainability and energy efficiency initiatives. Key projects include replacing conventional streetlights with LED luminaires equipped with advanced presence control sensors that adjust the light intensity based on pedestrian or cyclist presence

5

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**Bikeability**

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**Spatial Design**

Reduced visibility in public spaces

Enhanced LED street lighting

Helsinki: comprehensive street illumination

Helsinki has implemented a comprehensive and smart street illumination system that integrates advanced LED technology and intelligent control to enhance energy efficiency, safety, and urban quality. With approximately 100,000 luminaires under dynamic control by partners like C2 SmartLight, Helsinki's lighting adapts to real-time conditions such as pedestrian presence and events, optimizing light levels by location and usage.

6

Darkness

**Walkability**

Fear of walking in dark areas

**Bikeability**

Inadequate lighting on bike infrastructure

**Spatial Design**

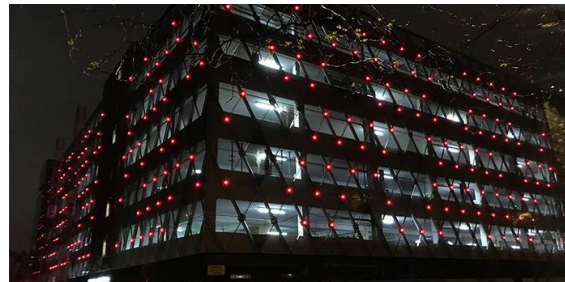
Poor lighting creates unsafe areas

Smart lighting systems with sensors**Copenhagen: smart lighting with motion sensors**

Copenhagen has implemented a city-wide smart lighting upgrade featuring LED streetlights integrated with motion sensors and adaptive control systems. Over 18,800 streetlights, representing about half the city's lighting fleet, have been replaced with energy-efficient LED luminaires equipped with presence/absence detection to automatically adjust brightness based on pedestrian, cyclist, or vehicle movement.

6

Darkness

**Walkability**

Fear of walking in dark areas

**Bikeability**

Inadequate lighting on bike infrastructure

**Spatial Design**

Poor lighting creates unsafe areas

Smart lighting systems with sensors**Malmö: adaptive brightness systems**

Malmö has implemented advanced adaptive brightness street lighting systems as part of its smart city initiatives to optimize energy consumption and enhance road safety. A prominent example is the installation of over 600 IZYLUM luminaires with integrated adaptive color temperature technology, allowing the LEDs to adjust their brightness and color temperature dynamically from 3,000K to 2,000K depending on the time of night and traffic density. This ensures optimal visibility during busy periods while significantly reducing light pollution and energy use during low-traffic hours.

8

Darkness

**Walkability**

Difficulty identifying hazards in low light

**Bikeability**

Difficulty seeing road hazards at night

**Spatial Design**

Inadequate lighting infrastructure coverage

Comprehensive lighting master plans**Stockholm: comprehensive pedestrian lighting master plan**

Stockholm has a comprehensive pedestrian lighting plan that is part of its broader Pedestrian Plan and urban mobility strategies. This plan prioritizes pedestrian safety, comfort, and accessibility by implementing smart LED lighting systems along pedestrian routes.

8

Darkness

**Walkability**

Difficulty identifying hazards in low light

**Bikeability**

Difficulty seeing road hazards at night

**Spatial Design**

Inadequate lighting infrastructure coverage

Comprehensive lighting master plans**Gothenburg: integrated lighting design**

Gothenburg has a well-developed integrated lighting design approach that plays a crucial role in the city's urban planning and sustainability strategies. One hallmark project is the extensive lighting design for the "World of Volvo" building, which combines advanced indoor and outdoor lighting solutions to highlight the building's unique wooden architecture while adapting to seasonal changes in natural light.

9

Darkness

**Walkability**

Difficulty being seen by traffic

**Bikeability**

Difficulty being seen by traffic

**Spatial Design**

No significant issues

Increase lighting near major roads

Stockholm: highway lighting upgrades

Stockholm is undergoing significant highway lighting upgrades as part of the E4 Förbifart Stockholm (Stockholm Bypass) project, one of Europe's largest infrastructure developments. The project involves constructing a new 21-kilometer highway bypass west of Stockholm, with around 18 kilometers built underground in tunnels. This lighting system includes LED strips and floodlights designed to enhance safety, visibility, and energy efficiency within the tunnels.

9

Darkness

**Walkability**

Difficulty being seen by traffic

**Bikeability**

Difficulty being seen by traffic

**Spatial Design**

No significant issues

Increase lighting near major roads

Helsinki: pedestrian overpass illumination

Helsinki features several pedestrian overpass illumination projects that prioritize safety, aesthetics, and sustainability. Notably, the Kruunuvuori Bridge, which is part of the city's Crown Bridges tram and pedestrian network, incorporates integrated lighting designed to maintain comfort and safety throughout the year despite long winter darkness. This includes lighting that shields pedestrians from harsh weather while providing clear visibility and an open atmosphere.

11

Extreme Cold



Walkability
No significant issues



Bikeability
No significant issues



Spatial Design
Extreme cold damages electronic systems

Cold-weather electronic protection

Moscow: cold-weather electronic protection protocols

Moscow employs extensive cold-weather electronic protection protocols designed to ensure the reliable operation and longevity of critical electronic equipment during the extreme winter conditions the city faces. These protocols include the use of specially engineered enclosures, heating elements, and insulation materials that maintain optimal operating temperatures for electronics even when ambient temperatures plunge below -30°C.

11

Extreme Cold



Walkability
No significant issues



Bikeability
No significant issues



Spatial Design
Extreme cold damages electronic systems

Cold-weather electronic protection

St. Petersburg: system winterization

these protocols include preventative maintenance and upgrades to heating, insulation, and anti-freezing systems used across municipal utilities, transportation networks, and public services. For example, water and sewage systems are winterized by replacing liquids with antifreeze compounds and insulating pipes to prevent freezing and damage.

**Walkability**

Cold reduces manual dexterity

**Bikeability**

Cold reduces brake effectiveness

**Spatial Design**

Cold reduces infrastructure flexibility

Flexible infrastructure design

Copenhagen: adaptive construction standards

Copenhagen's adaptive construction standards emphasize resilience, sustainability, and flexibility to meet future urban challenges. The standards incorporate principles such as design for disassembly and adaptability (DfD and DfA), which enable buildings and infrastructure to be easily modified, expanded, or repurposed over time. These approaches promote the reuse and recycling of materials, reducing environmental impact and extending the lifespan of structures.

14

Extreme Cold



Walkability
No significant issues



Bikeability
Cold temperatures drain e-bike batteries faster, metal components become brittle in cold



Spatial Design
Extreme temperatures affect material properties

Cold-resistant material specifications

Anchorage: extreme cold material specifications

For Anchorage's extreme cold, construction material specifications prioritize frost protection, such as requiring concrete to be free of ice and using heated water and aggregates for masonry, while structures require durable, cold-resistant materials like concrete, wood, brick, stone, and metal.

14

Extreme Cold



Walkability
No significant issues



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Cold temperatures drain e-bike batteries faster, metal components become brittle in cold



Spatial Design
Extreme temperatures affect material properties

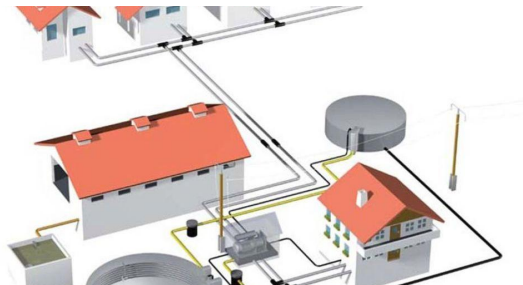
Cold-resistant material specifications

Fairbanks: arctic construction standards

Fairbanks adheres to the Alaska Building Code, which is based on the International Building Code but includes specific amendments for permafrost and cold climates, mandating a minimum footing depth of 42 inches below grade to prevent frost heave.

15

Extreme Cold

**Walkability**

Cold weather limits time outdoors

**Bikeability**

No significant issues

**Spatial Design**

Cold weather increases energy demands

Energy-efficient heating systems

Reykjavik: geothermal district heating integration

Since the 1930s, the city has developed one of the largest and most sophisticated geothermal district heating networks globally, which now supplies around 90% of the city's buildings with hot water for heating. This system harnesses geothermal wells and power plants, such as those at Hellisheidi and Nesjavellir, to produce renewable hot water that is distributed through an extensive pipeline network.

15

Extreme Cold

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Cold weather increases energy demands

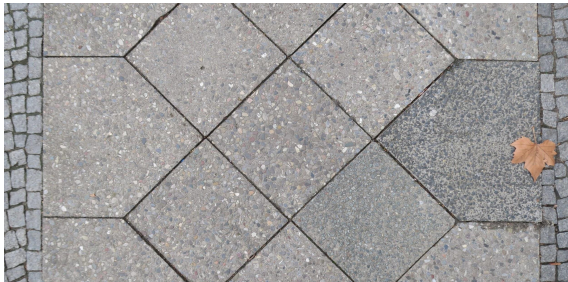
Energy-efficient heating systems

Akureyri: renewable energy systems

All heating in Akureyri arrives from geothermal hot water that is extracted from boreholes (100% renewable) and all electricity is produced with either hydropower or geothermal power (100% renewable).

16

Extreme Cold

**Walkability**

Condensation and surface frost at thermal bridges on walks

**Bikeability**

Sudden traction changes at expansion joints and cold spots

**Spatial Design**

Thermal bridges in pavement cause hidden localized ice

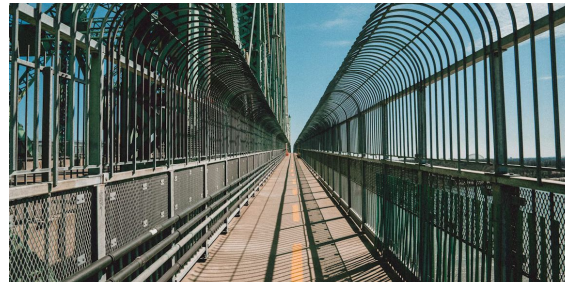
Insulated pavement and joint retrofits

Berlin: integrated insulation in reconstructed sidewalks/pavement

Reconstruction projects often include layers of thermal insulation beneath pavement to reduce heat loss from underlying soils and infrastructure, thereby mitigating frost damage and prolonging pavement life. Materials such as expanded polystyrene (EPS) are commonly used for their durability and insulating properties. In some cases, systems include drainage and waterproofing membranes to prevent moisture ingress, which combined with insulation helps control freeze-thaw cycles and associated pavement cracking.

16

Extreme Cold

**Walkability**

Condensation and surface frost at thermal bridges on walks

**Bikeability**

Sudden traction changes at expansion joints and cold spots

**Spatial Design**

Thermal bridges in pavement cause hidden localized ice

Insulated pavement and joint retrofits

Montreal: expansion joint retrofits

A flagship example is the custom expansion joint system developed for the Samuel-De Champlain Bridge, which supports the Réseau express métropolitain (REM) rapid transit network. This system provides a wide expansion range of 24 to 27 inches (60 to 70 cm), far exceeding standard joints, allowing the bridge deck to accommodate substantial thermal movement from summer heat to harsh winter cold.

17

Freeze-Thaw Cycles



Walkability

Uneven surfaces create trip hazards



Bikeability

Surface damage creates cycling hazards



Spatial Design

Repeated freeze-thaw creates potholes

Pavement management

Calgary: comprehensive pothole prevention programs

Calgary's comprehensive pothole programs include preventative measures like the Annual Paving Program for road rehabilitation and responsive maintenance like cold patch and hot asphalt repairs throughout the year. Residents contribute by reporting potholes via 311, and the city uses pothole maps and service requests to track and address repairs, aiming to balance timely fixes with long-term road health.

17

Freeze-Thaw Cycles



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Spatial Design

Repeated freeze-thaw creates potholes

Pavement management

Edmonton: proactive road management

The city's Safe Mobility Strategy (2021-2025) emphasizes data-driven decision-making to identify high-risk areas and deploy timely interventions such as road repairs, pothole fillings, and resurfacing before major damage occurs. Edmonton uses advanced infrastructure management tools that monitor road conditions in real time and optimize resource allocation.

18

Freeze-Thaw Cycles

**Walkability**

Damaged pavements unsafe for wheelchairs

**Bikeability**

Pothole damage to wheels and frames

**Spatial Design**

Frost action loosens pavement materials

High-quality base layer construction

Germany: high-performance pavement base

German concrete pavement construction often features stabilized bases, such as lean concrete, and emphasizes drainage through granular blanket layers and edge drains to ensure strong support and manage moisture under the pavement. Specifications for high-performance permeable bases, when used, typically require a high void content (over 20%) and a compressive strength above 15 MPa, with a low permeability coefficient.

24

Ice

**Walkability**

Ice makes assistive devices ineffective

**Bikeability**

Ice makes bike handling unpredictable

**Spatial Design**

Ice blocks drainage and water systems

Heated infrastructure elements

Wageningen: heated cycling infrastructure pilots

In Wageningen, a 50-meter stretch of cycle path is heated by underground pipes. This energy-efficient system maintains the bike lane surface temperature above freezing to prevent ice formation and snow accumulation. The system uses stored thermal energy collected in summer and may also use waste heat from nearby industrial sources, controlled automatically by sensors measuring temperature and moisture.

19

Freeze-Thaw Cycles

**Walkability**

Surface instability affects balance

**Bikeability**

Uneven surfaces affect bike stability

**Spatial Design**

Thermal cycling weakens infrastructure joints

Expansion joint maintenance

Amsterdam: thermal expansion management systems

These systems include expansion joints, sliding bearings, and flexible connection elements designed to absorb thermal expansion and contraction without causing damage or deformation to the structures.

19

Freeze-Thaw Cycles

**Walkability**

Surface instability affects balance

**Bikeability**

Uneven surfaces affect bike stability

**Spatial Design**

Thermal cycling weakens infrastructure joints

Expansion joint maintenance

Rotterdam: joint predictive maintenance

Rotterdam employs predictive maintenance aided by sensors and digital twins to monitor the condition of expansion joints and pavement surfaces in real time, enabling timely interventions before severe deterioration occurs.

20

Freeze-Thaw Cycles

**Walkability**

Trip hazards at ramps and crosswalks after midwinter thaw

**Bikeability**

Bike lanes become rough with heaved asphalt sections

**Spatial Design**

Frost heave causes unleveled pedestrian crossings

Annual crosswalk re-leveling programs

Calgary: seasonal crosswalk grinding and repair

The City of Calgary's pavement marking program, which runs from May to October, includes repainting and maintenance of over 8,500 crosswalks annually, with locations near schools receiving twice-yearly attention. While the program mainly focuses on repainting, grinding and minor repairs are performed to smooth uneven or damaged surfaces that cause hazards for pedestrians and cyclists.

20

Freeze-Thaw Cycles

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Frost heave causes unleveled pedestrian crossings

Annual crosswalk re-leveling programs

Helsinki: annual pavement inspections post-thaw

Visual road condition measurements are performed at low speeds by inspectors using vehicles equipped for detailed assessments. The evaluations focus on identifying frost heave damage, cracks, and unevenness caused by water infiltration and freezing under the pavement surface during winter.

**Walkability**

Invisible hazards cause unexpected falls

**Bikeability**

Unexpected sliding and crashes

**Spatial Design**

Black ice invisible on roads/sidewalks

Heated pavement systems

Oulu: heated downtown pedestrian zone

Oulu, Finland, utilizes an innovative system of heating some of its downtown pedestrian and cycling paths to melt snow and ice, making the area safer and more accessible for pedestrians and cyclists in its harsh winters. This experimental system uses excess steam from other energy sources to warm the pavement, a testament to the city's commitment to being a global leader in winter cycling infrastructure.

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Invisible hazards cause unexpected falls

**Bikeability**

Unexpected sliding and crashes

**Spatial Design**

Black ice invisible on roads/sidewalks

Heated pavement systems

Reykjavik: Geothermal pavement heating

This geothermal heating system melts snow and ice on outdoor surfaces, significantly enhancing snow removal efficiency and safety for pedestrians and vehicles. The availability of abundant geothermal resources allows the city to implement these heated pavements sustainably and cost-effectively compared to traditional methods.

23

Ice

**Walkability**

Senior pedestrians especially vulnerable

**Bikeability**

Studded tires required for safety

**Spatial Design**

Ice expansion cracks infrastructure

Regular ice removal and gritting

Helsinki: sand/grit cleared annually before May 1st

In Helsinki, sand and grit used for winter road and sidewalk traction are systematically cleared annually before May 1st as part of the city's spring street cleaning program. This removal process typically begins in March and continues through April when the winter maintenance season ends, and the thawing renders sand and grit unnecessary and potentially damaging to the environment.

23

Ice

**Walkability**

Senior pedestrians especially vulnerable

**Bikeability**

Studded tires required for safety

**Spatial Design**

Ice expansion cracks infrastructure

Regular ice removal and gritting

Tampere: comprehensive cleaning

The removal of sand and grit used during the winter season is part of the city's spring maintenance tasks. The cleaning of the biggest and busiest streets, as well as main pedestrian and cycling routes, is expected to be completed by early May.

25

Ice

**Walkability**

Ice creates psychological fear of walking

**Bikeability**

Icy conditions prevent safe stopping

**Spatial Design**

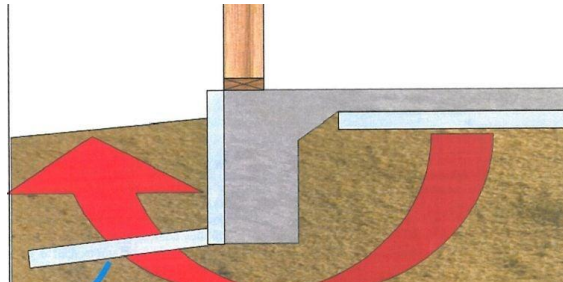
Frost heave damages pavement structures

Frost-resistant pavement design**Anchorage: permafrost-adapted pavement design**

Anchorage adapts its pavement designs to permafrost conditions by using thick insulating gravel layers, thermal insulation materials, and staged construction methods to minimize thawing of the underlying permafrost. The designs also focus on avoiding sensitive areas, controlling heat transfer, and accommodating ground movement through flexible pavement structures, ensuring long-term stability and durability.

25

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Ice creates psychological fear of walking

**Bikeability**

Icy conditions prevent safe stopping

**Spatial Design**

Frost heave damages pavement structures

Frost-resistant pavement design**Fairbanks: frost-resistant construction**

Fairbanks utilizes frost-resistant construction to protect buildings from permafrost thaw and frost heave by using methods such as insulating foundations, placing buildings on gravel pads, installing post foundations, or using piles with refrigeration coils to keep the ground frozen.

26

Ice



Walkability
No significant issues



Bikeability
No significant issues



Spatial Design
Ice accumulation on transit infrastructure

Proactive ice prevention protocols

Reykjavik: geothermal heated bus stops

Bus stop platforms in Reykjavik often feature geothermal heated heating, a system implemented across the city's downtown to keep pedestrians warm during the cold Icelandic winters by using the abundant natural geothermal energy available.

21

Ice



Walkability
Extremely high fall risk on icy surfaces



Bikeability
Complete loss of traction possible



Spatial Design
Ice forms on surfaces creating hazards

Anti-icing chemical application

Minneapolis: proactive de-icing 2 hours before storms

Minneapolis employs a proactive de-icing strategy that involves applying anti-icing chemicals, such as liquid brine, to road surfaces approximately 2 hours before an anticipated storm. This pre-treatment prevents snow and ice from bonding to the pavement, making it easier to remove accumulation during the storm and reducing the need for large amounts of deicing chemicals afterward.

**Walkability**

Curb ramp puddles freeze, blocking strollers and wheelchairs

**Bikeability**

Icy gutter accumulations create dangerous merging zones

**Spatial Design**

Icy curb ramps and street crossings block inclusive access

Targeted de-icing

Toronto: curb ramp auditing/retrofit

Toronto has a structured curb ramp auditing and retrofit program guided by the Toronto Accessibility Design Guidelines (TADG), which ensure all curb ramps meet accessibility and safety standards. The city prioritizes the installation and retrofitting of curb ramps at all pedestrian crossings and transit stops to provide safe and barrier-free access.

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Curb ramp puddles freeze, blocking strollers and wheelchairs

**Bikeability**

Icy gutter accumulations create dangerous merging zones

**Spatial Design**

Icy curb ramps and street crossings block inclusive access

Targeted de-icing

Minneapolis: winter street crossing design upgrades

These upgrades include the installation of clearly marked crosswalks with high-visibility pavement markings, curb extensions to shorten crossing distances, pedestrian safety islands, and improved ADA-compliant curb ramps.

**Walkability**

Limited traction for people with mobility aids and canes

**Bikeability**

Few riders equip studded or winter tires for icy/snowy days

**Spatial Design**

Absence of citywide studded tire programs leaves icy routes unsafe

Tire subsidy or distribution programs

Edmonton: free studded tire program

Edmonton offers a free studded tire program for winter cycling. The program provides eligible participants with free studded winter tires to promote safe year-round cycling and lower car dependence during the winter months.

**Walkability**

Limited traction for people with mobility aids and canes

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**Spatial Design**

Absence of citywide studded tire programs leaves icy routes unsafe

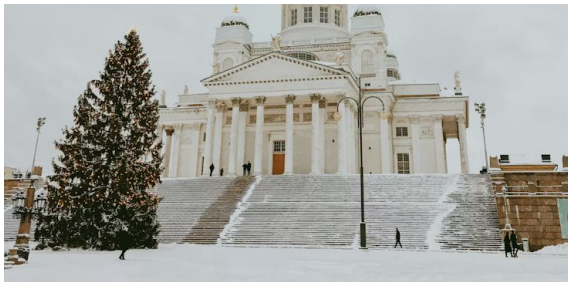
Tire subsidy or distribution programs

British Columbia: community tire swap events

The province regularly encourage drivers to swap winter tires after April 30 or install them from October 1, hosting various garages and regional campaigns for tire changes

30

Ice



Walkability
No significant issues



Bikeability
Gravel dangerous for cyclists



Spatial Design
City puts gravel to prevent slipping

Timely gravel removal in spring

Helsinki: gravel removal program

Helsinki, like other Finnish cities, uses a spring street sweeping program to remove the anti-skid gravel and grit used during winter.

30

Ice



Walkability
No significant issues



Bikeability
Gravel dangerous for cyclists



Spatial Design
City puts gravel to prevent slipping

Timely gravel removal in spring

Oulu: use of non-slip surfacing

Oulu extensively uses anti-skid treatments including gritting on packed snow surfaces for bike lanes. The city maintains bike paths with anti-skid treatment rather than bare pavement, creating safer packed snow surfaces.

32

Ice



Walkability
No significant issues



Bikeability
Ice accumulation affects bike parking



Spatial Design
No significant issues

Proactive icicle removal

St. Petersburg: icicle removal brigades

St. Petersburg has dedicated municipal services to remove large, dangerous icicles and snow from buildings to prevent them from falling on pedestrians and vehicles during winter.

32

Ice



Walkability
No significant issues



Bikeability
Ice accumulation affects bike parking



Spatial Design
No significant issues

Proactive icicle removal

Montreal: heated gutter systems

Heated roof systems in Montreal are primarily used for de-icing to prevent ice dams, icicles, and subsequent water damage, which are major concerns due to the city's winter climate.

33

Rain/Freezing Rain

**Walkability**

Pedestrians soaked by splashes

**Bikeability**

Reduced visibility for cyclists

**Spatial Design**

Splashing water from passing cars

Splash guards on vehicles

Massachusetts: mandatory splash guards

In Massachusetts, splash guards are mandatory for all motor vehicles and trailers except for passenger motor vehicles. Any passenger vehicle with tires that extend beyond the fenders or body must also be equipped with flaps or guards.

33

Rain/Freezing Rain

**Walkability**

Pedestrians soaked by splashes

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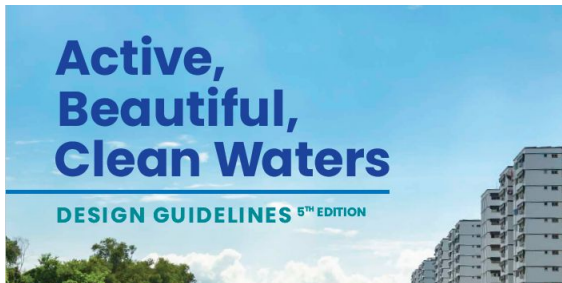
**Spatial Design**

Splashing water from passing cars

Splash guards on vehicles

London: curbside splash protection

Known for pioneering permeable paving slabs and roadside pollutant capture trials to reduce splash and urban runoff pollution.

**Walkability**

Wet conditions increase slip risk

**Bikeability**

Wet brakes less effective

**Spatial Design**

Water pooling leads to flooding

Improved drainage and SUDS

Singapore: ABC Waters program

The Active, Beautiful, Clean Waters (ABC Waters) Programme aims to create inviting waterscapes for all to enjoy. It offers both residents and visitors many features like lookout decks and pedestrian bridges, and attracts walking, jogging and cycling enthusiasts too.

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Wet brakes less effective

**Spatial Design**

Water pooling leads to flooding

Improved drainage and SUDS

Copenhagen: comprehensive green infrastructure

Copenhagen has implemented a comprehensive and advanced green infrastructure system, including Sustainable Urban Drainage Systems (SUDS). The city is internationally recognized for its integrated approach to climate adaptation, resilience, and sustainable urban living.

35

Rain/Freezing Rain

**Walkability**

Flooding blocks pedestrian routes

**Bikeability**

Visibility reduced in rain

**Spatial Design**

Drainage systems overwhelmed

Permeable surfaces and bioswales

Amsterdam: permeable pavements

Amsterdam and other Dutch municipalities use permeable pavements to manage stormwater by allowing water to infiltrate through the surface and into underlying layers, which helps recharge groundwater and reduce urban flooding

35

Rain/Freezing Rain

**Walkability**

Flooding blocks pedestrian routes

**Bikeability**

Visibility reduced in rain

**Spatial Design**

Drainage systems overwhelmed

Permeable surfaces and bioswales

Rotterdam: integrated rain gardens

Rotterdam has been developing integrated rain garden projects, such as the "Regentuin" (rain garden) at the Hofbogen to manage stormwater and create green spaces, as part of its broader strategy to adapt to climate change and prevent flooding.

36

Rain/Freezing Rain

**Walkability**

Puddles and wet surfaces dangerous

**Bikeability**

Road spray affects cyclist comfort

**Spatial Design**

Freeze-thaw cycles damage pavement

Proactive drainage maintenance

Montreal: comprehensive neighborhood snow removal

Montreal clears snow from roads, sidewalks, bike paths, and public spaces with a fleet of around 1,000 vehicles and about 3,000 workers, managing approximately 10,000 kilometers of streets annually.

38

Rain/Freezing Rain

**Walkability**

Wet weather discourages outdoor activity

**Bikeability**

Wet conditions cause mechanical issues

**Spatial Design**

Wet surfaces become slippery danger zones

Non-slip surface treatments

Berlin: anti-slip pathway systems

Berlin has strict snow clearance regulations with designated clearing widths (1-1.5 meters) and anti-slip requirements. Property owners must clear and grit sidewalks; failure to comply constitutes an administrative offence with fines up to €10,000.

37

Rain/Freezing Rain

**Walkability**

Ice rain creates extremely hazardous conditions

**Bikeability**

Freezing rain makes cycling impossible

**Spatial Design**

Ice dams form on infrastructure

Ice dam prevention systems

Oslo: advanced ice dam prevention

Norway has regulations regarding roof snow protection to prevent avalanches from roofs, and roof snow guards are part of standard building practices in Norwegian winter cities. These systems help prevent ice dams by controlling snow accumulation and preventing sudden releases

37

Rain/Freezing Rain

**Walkability**

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Ice dams form on infrastructure

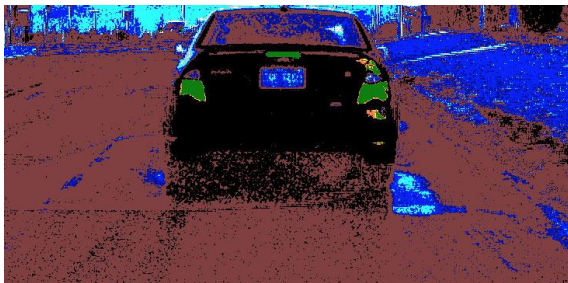
Ice dam prevention systems

Bergen: roof system management

Bergen has snow sensor-activated heating systems for sidewalks and plazas. Property owners are required to remove snow and ice with fines for non-compliance, creating comprehensive roof management responsibilities.

40

Rain/Freezing Rain

**Walkability**

Unexpected ice patches at sheltered entrances

**Bikeability**

Abrupt ice near intersections, approaching traffic signals

**Spatial Design**

Refreezing runoff forms isolated hazardous ice patches

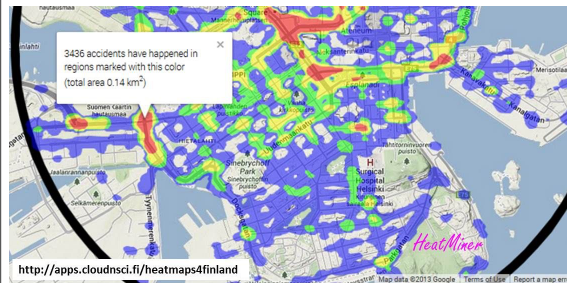
Thermal cameras

Black ice sensor pilot program

These systems use infrared temperature sensors to measure road surface temperature in real-time, providing early warning when conditions approach freezing. Similar systems have been implemented in vehicles and infrastructure projects globally.

40

Rain/Freezing Rain

**Walkability**

Unexpected ice patches at sheltered entrances

**Bikeability**

Abrupt ice near intersections, approaching traffic signals

**Spatial Design**

Refreezing runoff forms isolated hazardous ice patches

Thermal cameras

Helsinki: gritting mapped to collision data

Helsinki maintains comprehensive traffic accident data since 2000 and has sophisticated winter maintenance protocols. The city uses data-driven approaches for traffic safety.

41

Slush

**Walkability**

Slush soaks through footwear

**Bikeability**

Slush creates unpredictable handling

**Spatial Design**

Slush pools block pedestrian paths

Rapid slush removal systems

Minneapolis: real-time slush removal response teams

Minneapolis has substantial snow removal operations with over 300 workers responding to weather events and maintains extensive public works operations with dedicated winter maintenance crews.

41

Slush

**Walkability**

Slush soaks through footwear

**Bikeability**

Slush creates unpredictable handling

**Spatial Design**

Slush pools block pedestrian paths

Rapid slush removal systems

St. Paul: rapid response protocols

St. Paul has 96-hour Snow Emergency protocols with three distinct phases. More than 70 plow crews clear over 1,800 lane miles in less than 24 hours during Night and Day Plow Route Phases. The city provides multilingual alerts and dedicated snow emergency apps.

**Walkability**

Splashing slush creates uncomfortable walking

**Bikeability**

Slush spray reduces visibility

**Spatial Design**

Slush splash from vehicles creates mess

Vehicle splash guards installation

Maine: mandatory vehicle splash guards in winter zones

Maine requires splash guards for trucks and commercial vehicles.

**Walkability**

Splashing slush creates uncomfortable walking

**Bikeability**

Slush spray reduces visibility

**Spatial Design**

Slush splash from vehicles creates mess

Vehicle splash guards installation

Cambridge: vehicle compliance programs

Cambridge (Ontario, Canada) has snow event parking enforcement and compliance monitoring. The city actively tickets and tows vehicles during snow events.

43

Slush

**Walkability**

Slush provides unpredictable traction

**Bikeability**

Slush provides unpredictable traction

**Spatial Design**

Slush infiltrates building entrances

Heated entrance mats and systems

Zurich: heated building systems

Zurich's extensive district heating network and heat interface units for buildings build sophisticated thermal energy distribution.

51

Snow

**Walkability**

Snow obstructs navigation landmarks

**Bikeability**

Snow reduces visibility of road markings

**Spatial Design**

Snow creates visual barriers and sight line issues

Clear sight line maintenance protocols

Helsinki: snow visibility management protocols

The city has detailed protocols for snow clearing with different priority levels and timing requirements to maintain visibility and safety.

44

Slush



Walkability
No significant issues



Bikeability
Slush makes stopping distances longer



Spatial Design
Slush damages street surface materials

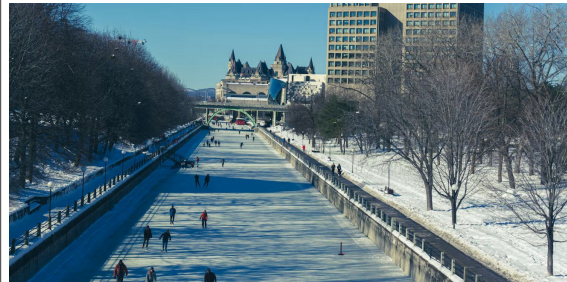
Durable surface materials selection

Toronto: winter-grade pavement material standards

Toronto's pavement design guidelines include material specifications using Superpave asphalt mix designs and consideration of freeze-thaw cycles. Toronto's guidelines address resilient modulus for subgrade soils and design parameters that account for Ontario's climate conditions, including frost susceptibility.

44

Slush



Walkability
No significant issues



Bikeability
Slush makes stopping distances longer



Spatial Design
Slush damages street surface materials

Durable surface materials selection

Ottawa: cold-weather specifications

Ottawa has detailed cold weather standards including minimum heat requirements: not less than 16.67C (62F) at night and not less than 20C (68F) during daytime. The city maintains extensive winter maintenance quality standards and operates an Extreme Heat, Cold and Smog Planning Committee.

45

Snow

**Walkability**

Slippery packed snow surfaces

**Bikeability**

Reduced traction and steering control

**Spatial Design**

Streets accumulate snow, narrowing lanes

Snow plowing of bike lanes first

Oulu: maintain white packed snow surface

The city implements a specific strategy where packed snow surfaces are preferred over bare asphalt for bike lanes. Oulu maintains a thin layer of packed snow and applies anti-skid treatment through gritting.

45

Snow

**Walkability**

Slippery packed snow surfaces

**Bikeability**

Reduced traction and steering control

**Spatial Design**

Streets accumulate snow, narrowing lanes

Snow plowing of bike lanes first

Copenhagen: clear bike lanes by 8 AM

Copenhagen has an official policy that all bicycle infrastructure is cleared of snow by 08:00 AM. The cities of Copenhagen and Frederiksberg salt before snow falls and, after snow is on the ground, bike lanes are cleared before streets.

**Walkability**

Difficulty walking through deep snow

**Bikeability**

Bike lanes blocked by snow piles

**Spatial Design**

Snow blocks bike lanes and sidewalks

Small plows for narrow paths

Montreal: specialized small plows

Montreal uses compact specialized plows and pickup trucks with mounted snow blades for bike paths. The city explained: Most of the time we're using pickups, four by fours, equipped with a shovel on the front. These smaller vehicles are specifically chosen because bike paths are too narrow for large street plows but wider than sidewalks

**Walkability**

Difficulty walking through deep snow

**Bikeability**

Bike lanes blocked by snow piles

**Spatial Design**

Snow blocks bike lanes and sidewalks

Small plows for narrow paths

Stockholm: cargo bike maintenance teams

Stockholm has cycling maintenance workers (cykeljouren) equipped with cargo bikes who use them with tools to clear debris, fill potholes, and remove ice and snow.

**Walkability**

Reduced walking speeds and comfort

**Bikeability**

Difficulty maintaining balance

**Spatial Design**

Snow storage takes up valuable urban space

Strategic snow storage areas in design

Toronto: designated snow storage space

Toronto has a network of five snow storage sites throughout the city. The city's snow removal operations involve transporting snow to these designated facilities.

**Walkability**

Reduced walking speeds and comfort

**Bikeability**

Difficulty maintaining balance

**Spatial Design**

Snow storage takes up valuable urban space

Strategic snow storage areas in design

Montreal: designated snow storage space

Montreal operates 28 snow disposal sites managing over 13 million cubic meters of snow annually. The city has strict regulations requiring snow to be taken to authorized disposal sites, including both snow dumps and snow melters.

48

Snow

**Walkability**

Fall risk increases 32x in snowy conditions

**Bikeability**

Cannot use standard tires effectively

**Spatial Design**

Packed snow becomes slippery when compressed

Maintain packed snow vs. bare asphalt

Oulu: packed snow preferred over bare asphalt

The city implements a specific strategy where packed snow surfaces are preferred over bare asphalt for bike lanes. Oulu maintains a thin layer of packed snow and applies anti-skid treatment through gritting.

48

Snow

**Walkability**

Fall risk increases 32x in snowy conditions

**Bikeability**

Cannot use standard tires effectively

**Spatial Design**

Packed snow becomes slippery when compressed

Maintain packed snow vs. bare asphalt

Helsinki: quality corridor standards

Finland introduced "quality corridors" for pedestrian and cycling routes with higher maintenance standards than regular categories. Quality corridors may have night-time quality requirements with Maintenance category K1 providing the highest service level. Cities including Helsinki have implemented these corridors.



Walkability
No significant issues



Bikeability
No significant issues

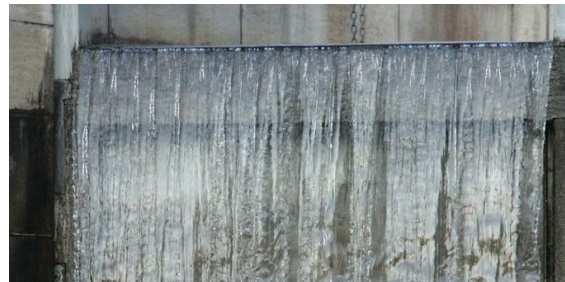


Spatial Design
Snow accumulation blocks drainage systems

Improved drainage design

Minneapolis: integrated sidewalk drainage systems

Minneapolis maintains an extensive Surface Water & Sewers Division that oversees integrated stormwater management systems. The city has implemented comprehensive drainage solutions including features designed to handle snowmelt and prevent flooding, with programs like Adopt-A-Drain to maintain storm drain functionality.



Walkability
No significant issues



Bikeability
No significant issues

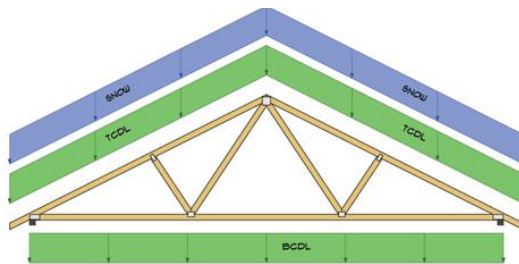


Spatial Design
Snow accumulation blocks drainage systems

Improved drainage design

Ottawa: priority network drainage

Ottawa maintains priority-based winter maintenance including drainage management. Roads are designed to drain based on sewer capacity, and roadside ditches are cleared to provide drainage for spring melt. The city operates Rain Ready Ottawa programs for stormwater management.

**Walkability**

Snow blocks wheelchair accessibility

**Bikeability**

Snow clogs derailleurs and brakes

**Spatial Design**

Heavy snow loads damage infrastructure

Structural design for snow load

Winnipeg: structural snow load standards exceed 150 kg/m²

Winnipeg's structural design guidelines specify a ground snow load (S_s) of 1.9 kPa.

**Walkability**

Snow blocks wheelchair accessibility

**Bikeability**

Snow clogs derailleurs and brakes

**Spatial Design**

Heavy snow loads damage infrastructure

Structural design for snow load

Calgary: infrastructure capacity planning

Calgary has comprehensive snow and ice control capacity planning with a \$54 million annual budget. The city plans for snow storage site development, with recommendations to rehabilitate existing sites at \$16 million and develop new sites at \$36 million.

**Walkability**

Wheelchair users and caregivers cannot reach public transit

**Bikeability**

Bike racks and docking stations inaccessible due to snow

**Spatial Design**

Snow piles at transit stops hinder wheelchair and stroller access

Clear transit stops and mobility corridors

Ottawa: accessibility audits for snow removal
Ottawa conducts extensive accessibility audits through the "Snow Mole" campaign organized by the Council on Aging. These citizen-led audits specifically assess winter walkability for seniors and people with mobility concerns, examining inaccessible crosswalks, pedestrian walk buttons and bus stops, impassable intersections.

**Walkability**

Wheelchair users and caregivers cannot reach public transit

**Bikeability**

Bike racks and docking stations inaccessible due to snow

**Spatial Design**

Snow piles at transit stops hinder wheelchair and stroller access

Clear transit stops and mobility corridors

Montreal: dedicated sidewalk plow teams for transit access

Montreal operates specialized sidewalk plowing with mechanical equipment across the city using dedicated "sidewalk plow" machines. There have been calls to create more specialized teams specifically for accessibility zones including transit access.

**Walkability**

Long waits at unsheltered stops in extreme cold

**Bikeability**

Bike/transit hubs blocked by snow reduce mode shift options

**Spatial Design**

Bus shelters fill with snow and become impassable

Heated/snow-free mobility hubs

Reykjavik: geothermal heated stops

Reykjavik has extensive geothermal heating infrastructure for streets and sidewalks, and uses geothermal energy extensively throughout the city.

**Walkability**

Long waits at unsheltered stops in extreme cold

**Bikeability**

Bike/transit hubs blocked by snow reduce mode shift options

**Spatial Design**

Bus shelters fill with snow and become impassable

Heated/snow-free mobility hubs

Edmonton: pilot snow-free mobility hub design

Edmonton has piloted heated transit shelters and explored enhanced transit facilities, with studies examining heated and/or wind-protected transit shelters. The Assisted Snow Removal Pilot Program supports accessibility.

54

Snow

**Walkability**

Hazard for pedestrians near buildings

**Bikeability**

Snow piles at entrances block cyclists

**Spatial Design**

Falling snow from roofs

Snow guards and heated roof systems

Oslo: mandatory roof snow guards

Norwegian building codes include requirements for roof construction to handle snow loads and prevent dangerous snow slides, with snow guard systems being standard practice in Nordic countries.

54

Snow

**Walkability**

Hazard for pedestrians near buildings

**Bikeability**

Snow piles at entrances block cyclists

**Spatial Design**

Falling snow from roofs

Snow guards and heated roof systems

Helsinki: heated roof pilots

Helsinki and Helen Ltd conduct pilot projects using AI technology to optimize district heating in schools and sports facilities (Systemic Heat Shift pilot). Helsinki Airport uses sub-surface heating for aircraft parking areas.

55

Snow

**Walkability**

Signs unreadable for drivers and pedestrians

**Bikeability**

Hidden cycling wayfinding signs

**Spatial Design**

Snow covers traffic signs

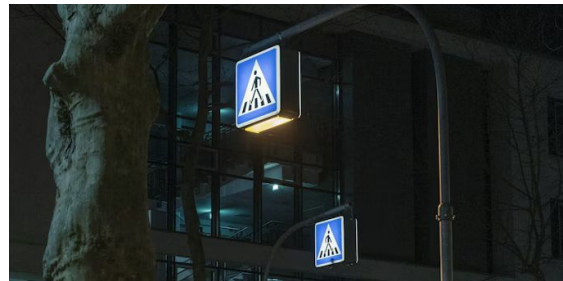
Project traffic signs digitally on snow

Liila: Snow-sign projection pilots

The challenge for cycling and pedestrian paths in the winter is the darkness, snow and sanding that may make the signs painted on the road hard to see. Liila projected traffic sign marks pedestrian and cyclist lanes by reflecting traffic signs on them.

55

Snow

**Walkability**

Signs unreadable for drivers and pedestrians

**Bikeability**

Hidden cycling wayfinding signs

**Spatial Design**

Snow covers traffic signs

Project traffic signs digitally on snow

Tampere: raised, illuminated signposts

Tampere is piloting illuminated road markings that project light onto snow when regular markings are covered. When regular road markings are concealed by snow, pedestrians and cyclists are guided by light-generated markings resembling traffic signs on the road surface. This innovation received the highest votes from residents.



Walkability
No significant issues



Bikeability
No significant issues



Spatial Design
Space for storing snow after removed

Dedicated snow storage

Tallinn: narrow corridors next to sidewalks for snow storage

Tallinn has specific winter maintenance protocols that include snow storage considerations in urban design. The city expanded sidewalk snow clearing operations, particularly in the Kesklinn and Põhja-Tallinn districts, where "narrow, winding sidewalks" are characteristic. Municipal regulations require that "when snow is piled on the sidewalk, there must be at least 1.20 meters of clear walking space", indicating planned accommodation for snow storage alongside pathways.



Walkability
No significant issues



Bikeability
No significant issues



Spatial Design
Space for storing snow after removed

Dedicated snow storage

Tallinn: three-stage snow storage system

Tallinn operates multiple snow storage sites (eight sites documented) with staged capacity management. The city removed more than 595,000 cubic meters of snow during the snowiest winter in a decade. Tallinn Airport has dedicated snow collection areas with seasonal separation and meltwater channelling.

**Walkability**

Slippery roads cause traffic hazards

**Bikeability**

No significant issues

**Spatial Design**

Lack of knowledge about surface conditions on roads

IoT road sensors**Estonia: national road info services**

Estonia operates "Tark Tee" (Smart Road), a comprehensive traffic information system providing real-time road conditions. The system uses IoT sensors and weather stations to monitor road conditions and provides forecasted road conditions up to 48 hours in advance. The system includes mobile and in-road sensors that gather the necessary information and can communicate with each other and forward information.

**Walkability**

Slippery roads cause traffic hazards

**Bikeability**

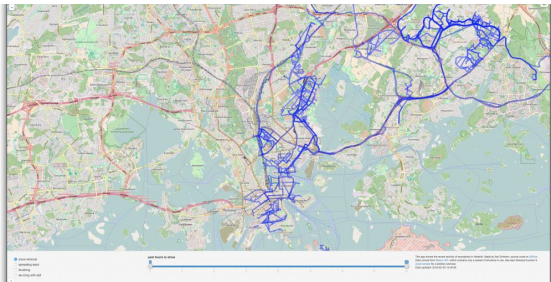
No significant issues

**Spatial Design**

Lack of knowledge about surface conditions on roads

IoT road sensors**Tallinn: road weather sensor deployment**

Estonia operates "Tark Tee" (Smart Road), a comprehensive traffic information system using IoT sensors and weather stations nationwide. Mobile and in-road sensors gather information and communicate with each other, providing forecasted road conditions up to 48 hours in advance.



Walkability
No significant issues



Bikeability
No significant issues



Spatial Design
Lack of knowledge about which streets have been cleaned

Snowplow GPS tracking

Helsinki: open snowplow tracking map

Helsinki provides real-time GPS tracking of snowplows through an open data API. The system was introduced in 2012 when Stara introduced an electronic production control system that produces GPS location data. The public can access live maps showing snowplow locations and activities incl. snow removal, spreading sand, de-icing with salt.



Walkability
No significant issues



Bikeability
No significant issues



Spatial Design
Lack of knowledge about which streets have been cleaned

Snowplow GPS tracking

Stockholm: live plow GPS dashboard

Stockholm has GPS tracking infrastructure and a traffic app "Trafiken.nu i Stockholm" with real-time information. The app provides traffic cameras and real-time road condition information.

60

Wind

**Walkability**

Strong winds can knock pedestrians off balance

**Bikeability**

Crosswinds affect bike stability

**Spatial Design**

Cold wind increases fall risk

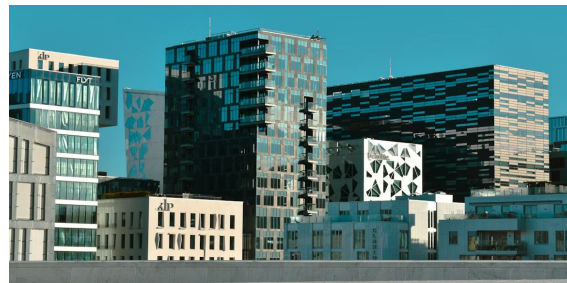
Wind barriers, protective street design

Copenhagen: evergreen windbreaks

Copenhagen has extensive tree planting initiatives and a tree protection policy, with goals to plant 100,000 additional trees.

60

Wind

**Walkability**

Strong winds can knock pedestrians off balance

**Bikeability**

Crosswinds affect bike stability

**Spatial Design**

Cold wind increases fall risk

Wind barriers, protective street design

Oslo: strategic building orientation

Norwegian buildings incorporate climate-responsive design including orientation for snow load management and wind considerations. Research examines how different orientations affect energy performance in Norwegian climates. Oslo experiences significantly calmer winds compared to many other locations due to surrounding mountains.

61

Wind

**Walkability**

Difficulty navigating with reduced visibility

**Bikeability**

Loss of balance, damage for collision with debris

**Spatial Design**

Debris and snow blown into walkways

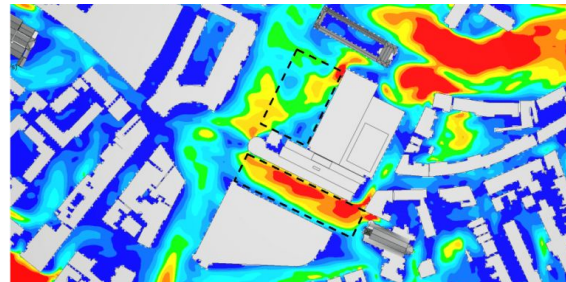
Regular debris clearing

Calgary: pathway maintenance teams

Calgary has dedicated pathway management teams that maintain approximately 800 km of pathways and provides regular maintenance incl. debris clearing. Calgary also hosts annual Pathway and River Cleanup events with thousands of volunteers.

62

Wind

**Walkability**

Wind reduces effectiveness of winter clothing

**Bikeability**

Wind reduces battery life of e-bikes

**Spatial Design**

Wind reduces effectiveness of heating systems

Sheltered heating systems design

Toronto: wind comfort assessment for developments

Toronto requires Pedestrian Level Wind Studies for all new developments taller than 20 meters. These comprehensive studies use computational fluid dynamics (CFD) to assess wind comfort and safety, with specific criteria for different pedestrian activities.

**Walkability**

Sudden snow drifts obscure tactile surfaces for the visually impaired

**Bikeability**

No significant issues

**Spatial Design**

Windblown snow creates drifts blocking midblock crossings

Snow fencing, directional wind breaks

Winnipeg: urban snow fencing program

Winnipeg is working on expanding snow fences throughout the city, to install them on an annual basis, to mitigate the amount of drifting snow.

**Walkability**

Sudden snow drifts obscure tactile surfaces for the visually impaired

**Bikeability**

No significant issues

**Spatial Design**

Windblown snow creates drifts blocking midblock crossings

Snow fencing, directional wind breaks

Chicago: targeted windbreak planting at crossings

Chicago has a major tree planting initiative with \$46 million investment to plant 75,000 trees, prioritizing underserved neighborhoods on South and West sides. Windbreak principles are documented in general landscaping guidance.

65

Wind

**Walkability**

Risk of falling branches for walkers

**Bikeability**

Obstacles and hazards from debris

**Spatial Design**

Tree branches fall or obstruct space

Regular tree maintenance and pruning

Copenhagen: urban tree trimming policy

Copenhagen has a comprehensive **tree protection policy passed in 2016 that addresses tree maintenance and protection.

65

Wind

**Walkability**

Risk of falling branches for walkers

**Bikeability**

Obstacles and hazards from debris

**Spatial Design**

Tree branches fall or obstruct space

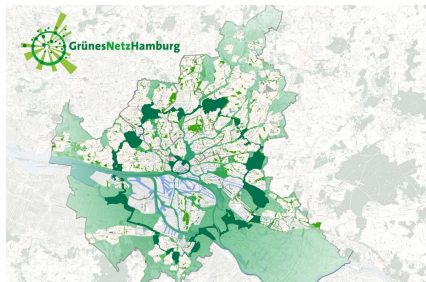
Regular tree maintenance and pruning

Stockholm: safety checks during storms

Sweden and Stockholm have comprehensive winter weather warning systems and safety protocols. When weather is particularly severe, authorities may advise the public not to drive and public transport might be cancelled. SMHI issues weather warnings in three levels (yellow, orange, red).

66

Wind



Walkability
No significant issues



Bikeability
No significant issues



Spatial Design
Wind tunnels and gusts create discomfort

Green to disperse and redirect wind

Hamburg: wind-break tree corridors

Hamburg has the "GrünesNetzHamburg" (Green Network Hamburg), an extensive urban planning scheme featuring green corridors that connect the city to countryside. The system includes "landscape axes" and "green rings" with tree-lined streets. This network was designed to provide recreational access and environmental benefits, incl. wind mitigation effects.

66

Wind



Walkability
No significant issues



Bikeability
No significant issues



Spatial Design
Wind tunnels and gusts create discomfort

Green to disperse and redirect wind

Malmö: vegetation buffers in open squares

Malmö's development incorporates vegetation buffers and wind management through strategic planning. The variations in the grid shield use areas from the weather, and suggested measures to improve wind control include adding vegetation and wind barriers. Research shows trees moderate wind speed; large trees with lower shrubberies significantly reduce wind movement.