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POLYTECHNIQUE MONTRÉAL

affiliée à l'Université de Montréal

**Mobilité active et infrastructures vertes de gestion des eaux pluviales : états
des connaissances et analyse des synergies potentielles**

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Mémoire présenté en vue de l'obtention du diplôme de *Maîtrise ès sciences appliquées*

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présenté par **Charlotte LEMIEUX**

en vue de l'obtention du diplôme de *Maîtrise ès sciences appliquées*

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RÉSUMÉ

Alors que les villes se densifient, il est essentiel de repenser l'espace urbain afin de construire un milieu de vie agréable pour tous. Par exemple, les villes tentent de mettre en place des infrastructures vertes (IV) afin de revégétaliser les milieux urbains. Les IV peuvent être définies comme un réseau d'espaces verts comprenant notamment les arbres, parcs, toits verts, etc. Selon de récentes études, ces infrastructures pourraient fournir des bénéfices écologiques tels que la réduction des îlots de chaleur et l'amélioration de la qualité de l'air. De plus, un effort considérable est mis en place afin de maximiser les fonctions d'un même espace. Ainsi, un type d'IV est de plus en plus utilisé, soit les infrastructures vertes de gestion des eaux pluviales (IVGEP). Les IVGEP diffèrent des IV par leur fonction première qui vise à collecter les eaux de ruissellement. Ces infrastructures sont parfois mises en place en bordure de rue afin de collecter les eaux pluviales qui ruissellent sur la chaussée et les trottoirs. Les IVGEP permettent de diminuer les volumes et débits d'eau acheminés vers le réseau d'égout pluvial.

La construction des IVGEP dans l'emprise routière modifie considérablement la configuration des rues. Par exemple, les noues végétalisées, qui s'apparentent à des fossés végétalisés peu profonds et larges, sont souvent installées en bordure de rue permettant l'isolement du trottoir. Les saillies drainantes sont quant à elles souvent installées aux intersections des rues de façon similaire aux saillies de trottoir qui permettent de réduire la largeur de la rue à traverser pour les piétons. Ces aménagements diffèrent des IV standard comme les arbres de rue ou les bandes de gazon notamment de par leur profondeur, la présence d'une diversité de végétaux et leur empreinte dans le cadre bâti. Afin de mieux concevoir les IVGEP pour maximiser leurs bénéfices secondaires, il est nécessaire d'étudier leurs effets sur la mobilité active. Concevoir les IVGEP en tenant compte des besoins en termes d'infrastructures de transport actif contribue à maximiser les fonctions de l'espace public.

Par conséquent, ce mémoire vise à analyser les effets des IVGEP, plus spécifiquement celles construites dans l'emprise routière, sur la mobilité active (marche et vélo). Bien que plusieurs effets environnementaux des IVGEP soient largement documentés, peu d'études s'intéressent directement aux effets sur la mobilité active. Comme leur mise en place modifie la configuration des rues, il est essentiel de bien comprendre les répercussions tant positives que négatives sur la

mobilité active. La compréhension de ces enjeux permettra une conception qui optimise les bénéfices pour la gestion des eaux et pour la mobilité active.

Le premier objectif de ce mémoire vise à analyser quels sont les effets connus des IVGEP sur la mobilité active. Pour y parvenir, une revue de la littérature scientifique sur le potentiel de synergie entre les IVGEP et la mobilité active a été réalisée. Comme très peu d'études s'intéressaient directement à cette relation, cette analyse comprend également une revue des articles quantitatifs traitant des effets des IV sur la mobilité active. En tout, 70 articles scientifiques ont été analysés, dont 28 traitants spécifiquement des IVGEP. Cette analyse a permis de souligner que les IV contribuent à une augmentation de la fréquence, la durée, la distance et la probabilité de se déplacer à la marche ou à vélo. Les IV apportent également des bénéfices au niveau de la sécurité routière et de la santé physique et psychologique. L'analyse des études spécifiques aux IVGEP a démontré le potentiel de ces infrastructures à améliorer les déplacements actifs en réaménageant les rues pour mieux partager l'espace entre les différents modes, en isolant les modes non motorisés des modes motorisés et en embellissant les rues. Par ailleurs, certaines études soulèvent des préoccupations spécifiques aux IVGEP, notamment la perte d'espace pour les déplacements automobiles, la sécurité des piétons qui peuvent tomber dans les IVGEP lorsqu'elles sont profondes et le temps requis pour que les végétaux soient matures.

Les résultats de cette analyse ont permis d'identifier plusieurs lacunes, notamment le besoin de :

- 1) Identifier quels indicateurs utiliser pour quantifier la présence des IV par rapport à la mobilité active et selon le contexte de l'étude;
- 2) Analyser les effets des IV sur la mobilité selon les caractéristiques de l'infrastructure (hauteur, superficie, position, etc.) et selon le milieu bâti dans lequel elles sont mises en place;
- 3) Comprendre les caractéristiques sociodémographiques qui exercent une influence sur les effets des IVGEP sur la mobilité active;
- 4) Distinguer les effets selon le mode utilisé (marche versus vélo);
- 5) Analyser les facteurs qui limitent l'acceptabilité sociale de tels projets, en d'autres termes, discerner les éléments qui suscitent un sentiment défavorable chez les citoyens à l'égard de la mise en place des IVGEP.

Le second objectif découle des lacunes identifiées dans la revue de littérature. Très peu d'études ont spécifiquement analysé les effets des IVGEP sur les perceptions en termes de déplacements actifs. Ainsi, une étude de cas comprenant un sondage (N = 296), des entrevues avec différentes parties prenantes (N = 12) et des groupes de discussion avec des jeunes (N = 13) a été réalisée pour comprendre les effets des noues végétalisées sur les perceptions en lien avec la mobilité active. Le cas étudié comprend la réfection de cinq rues résidentielles à Saint-Charles-Borromée, une petite ville située dans la province de Québec, avec l'ajout de noues végétalisées en bordure de rue.

Les résultats indiquent que les noues végétalisées permettent d'augmenter la satisfaction par rapport aux infrastructures pour la marche et le vélo. Cette étude a permis de confirmer plusieurs effets identifiés dans la littérature scientifique. D'abord, le réaménagement de la rue avec des IVGEP permet de bien définir l'espace alloué aux modes actifs. Les usagers actifs se sentent plus en sécurité grâce à l'isolement du trottoir ou de la piste cyclable par rapport aux voies automobiles. Puis, les résultats indiquent que les personnes qui ont un comportement écoresponsable, accordent de l'importance à l'aménagement de leur quartier et pensent que les noues végétalisées peuvent apporter des bénéfices socio-environnementaux, notamment en favorisant la mobilité active, sont davantage satisfaites des configurations de rues avec des noues végétalisées. Par ailleurs, les résultats soulèvent également quelques facteurs limitant la satisfaction pour les noues végétalisées, soit les désagréments engendrés pour les déplacements automobiles et un moins grand niveau d'accord avec les bénéfices socio-environnementaux qu'elles peuvent apporter.

En somme, ce mémoire contribue significativement à l'avancement des connaissances quant à la synergie entre les IVGEP et la mobilité active. D'abord, il brosse un portrait clair de l'état des connaissances, puis identifie les lacunes dans la littérature scientifique. Ensuite, une étude de cas permet de combiner des analyses quantitative et qualitative afin d'identifier les opportunités et défis liés à la mise en place d'IVGEP dans l'emprise routière. Ainsi, ce mémoire met de l'avant les bénéfices que peuvent fournir les IVGEP sur la mobilité active lorsqu'ils sont mis en place directement dans l'emprise routière. Les résultats de ce mémoire seront utiles aux chercheurs, urbanismes et décideurs municipaux qui souhaitent mieux comprendre les multiples bénéfices des IVGEP pour mieux planifier leur mise en place.

ABSTRACT

As cities become denser, it is essential to rethink the urban space to create a pleasant living environment for everyone. For instance, cities are implementing green infrastructure (GI) to increase the density of vegetation in urban areas. According to some authors, GI consists of a network of green spaces including trees, parks, green roofs, etc. It can provide ecological benefits such as reducing heat islands and improving air quality. Moreover, significant efforts are being made to maximize the functions of public space. Thus, one type of GI increasingly used is green stormwater infrastructure (GSI). GSI differs from traditional GI in its primary function, which aims to collect stormwater runoff. This type of infrastructure is often implemented along streets to collect runoff from roadways and sidewalks. GSI helps reduce the volume and flow of water directed to the storm sewer system.

The implementation of GSI within the right-of-way significantly changes the street configuration. For instance, bioswales, which resemble shallow and wide vegetated ditches, are often installed along the roadside, allowing to isolate the sidewalks. Stormwater curb extensions are also frequently installed at street intersections, providing similar benefits as curb extensions that reduce the street crossing width for pedestrians. These vegetation features differ from standard GI features such as street trees or grass strips, mainly due to their depth, the presence of diverse vegetation, and their footprint within the built environment. To better design GSI and maximize their secondary benefits, studying their impact on active mobility is essential. Designing GSI while considering the needs for active transportation infrastructure contributes to enhancing the functions of the public space.

Therefore, this master thesis aims to analyze the effects of GSI, more specifically those implemented within the right-of-way, on active mobility (walking and cycling). While several environmental effects of GSI are well-documented, few studies directly focus on their impact on active mobility. As their implementation changes the street configuration, it is essential to thoroughly understand both the positive and negative repercussions on active mobility. Understanding these issues will enable a design that optimizes the benefits for stormwater management and active mobility.

The primary objective of this thesis is to analyze the known effects of GSI on active mobility. To achieve this, a comprehensive review of scientific literature on the potential synergy between GSI and active mobility was conducted. As very few studies directly addressed this relationship, this analysis also included a review of quantitative articles dealing with the effects of GI on active mobility. In total, 70 scientific articles were analyzed, of which 28 specifically addressed GSI. This analysis highlighted that GI can contribute to an increase in the frequency, duration, distance, and likelihood of walking or cycling. GI can also bring benefits in terms of road safety, as well as improving physical and psychological health. The analysis of studies specific to GSI demonstrated the potential of this infrastructure to improve active transportation by redesigning streets to better share space between different modes, segregating non-motorized modes from motorized ones, and enhancing the streets' aesthetics. However, some studies raised concerns that are specific to GSI, including the loss of space for motor vehicle travel, pedestrian safety risks from falling into the GSI, and the time required for vegetation to mature.

The results of this analysis revealed several gaps, including the need to:

- 1) Identify which indicators to use for quantifying the presence of GSI in line with active mobility, and according to the study's context;
- 2) Analyze the effects of GI on mobility based on infrastructure characteristics (height, area, position, etc.) and the built environment in which it is implemented;
- 3) Understand the socio-demographic characteristics that influence the effects of GSI on active mobility;
- 4) Distinguish the effects based on the mode of transportation used (walking versus cycling);
- 5) Analyze the factors limiting the social acceptability of such projects, in other words, identify the elements that elicit a negative sentiment among citizens regarding the implementation of GSI.

The second objective arises from the gaps identified in the literature review. Very few studies have specifically analyzed the effects of GSI on perceptions related to active transportation. Thus, a case study was conducted, including a survey (N = 296), interviews with various stakeholders (N = 12), and focus groups with children (N = 13), to understand the effects of bioswales on perceptions regarding active mobility. The studied case involves the redesign of five residential streets in Saint-

Charles-Borromée, a small city located in the province of Quebec, with the addition of bioswales along the roadside.

The results indicate that bioswales increase satisfaction regarding walking and cycling infrastructure. This study confirmed several effects identified in the scientific literature. Firstly, redesigning streets with GSI helps define the space allocated to active modes. In particular, active users feel safer due to the separation of sidewalks or bike lanes from the motorized lanes. Secondly, the results show that individuals with eco-friendly behaviour, who value the aesthetics of their neighbourhood and believe that bioswales can provide socio-environmental benefits, especially by promoting active mobility, are more satisfied with street configurations featuring bioswales. Additionally, the results highlight some factors limiting satisfaction with bioswales, such as inconveniences for car travel and a lower degree of agreement with the socio-environmental benefits they can provide.

In conclusion, this thesis significantly contributes to advancing knowledge about the synergy between GSI and active mobility. Firstly, it provides a clear overview of the state of knowledge and identifies gaps in scientific literature. Then, a case study combines quantitative and qualitative analyses to identify opportunities and challenges related to the implementation of GSI within the right-of-way. As such, this thesis highlights the benefits that GSI can provide for active mobility when implemented directly within the right-of-way. The findings are valuable to researchers, urban planners, and municipal decision-makers seeking a better understanding of the numerous benefits of GSI to plan their implementation effectively.

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LISTE DES SIGLES ET ABRÉVIATIONS

EFA Exploratory factor analysis

IV Infrastructure verte

IVGEP Infrastructure verte de gestion des eaux pluviales

GI Green infrastructure

GSI Green stormwater infrastructure

GVI Green View Index

NBS Nature-based solution

NDVI Normalized Difference Vegetation Index

LISTE DES ANNEXES

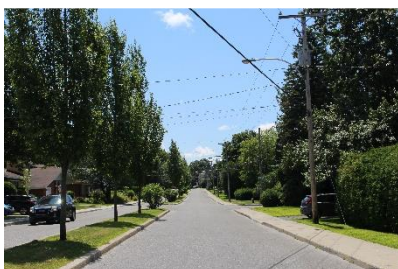
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CHAPITRE 1 INTRODUCTION

1.1 Problématique

Dans le contexte d'aménagement de villes durables, la construction des rues doit être optimisée afin de permettre la cohésion des multiples fonctions de cet espace (Ferguson, 2012). L'île de Montréal comprend près de 6000 km de voies routières (Ville de Montréal, 2023). Les infrastructures de transport forment une énorme surface minéralisée causant une forte augmentation des eaux de ruissellement acheminées vers l'usine de traitement des eaux. Il convient donc d'intégrer aux infrastructures de transport, des aménagements qui permettent une meilleure gestion des eaux pluviales notamment en réduisant les surfaces imperméables de la chaussée.

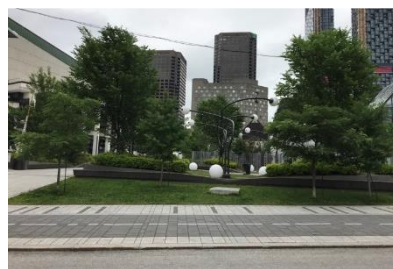
L'intégration d'infrastructures vertes (IV) dans l'emprise routière permet de réduire les surfaces minéralisées tout en apportant de multiples bénéfices socio-environnementaux. Les IV constituent un réseau d'espaces verts qui vise à fournir des services écosystémiques (Benedict & McMahon, 2012). La Figure 1-1 illustre plusieurs exemples d'IV installés à proximité du réseau de transport.



a) Rue Grove, Granby.
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b) Rue University, Montréal.
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c) Boul. De Maisonneuve, Montréal.
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Figure 1-1 Exemples d'infrastructures vertes visibles de la rue

Parmi les IV, les infrastructures vertes de gestion des eaux pluviales (IVGEP) sont spécifiquement conçues pour minimiser les débits de pointe, diminuer les volumes d'eau acheminés vers les réseaux d'égouts et filtrer une partie des polluants contenus dans les eaux de ruissellement (Hunt et al., 2012). Les IVGEP situées en bordure de rue comme les noues végétalisées ou les biorétentions se distinguent des IV par leur fonction principale visant à collecter les eaux de ruissellement, notamment les eaux de pluie qui ruissellent sur la chaussée et les espaces de stationnement. Les noues végétalisées et les biorétentions comprennent une zone de rétention de surface (c.-à-d., un bassin qui permet le stockage temporaire de l'eau de pluie), divers types de végétaux et un substrat (Hunt et al., 2012). La Figure 1-2 illustre des exemples d'IVGEP en bordure

de rue. La profondeur des IVGEP varie beaucoup. Par exemple, sur l'image de gauche, la pente est assez abrupte et facilement visible alors que sur l'image de droite le dénivelé est progressif. Il est également possible de constater le changement visuel dû à la croissance des végétaux.



Figure 1-2 Exemples d'infrastructures vertes de gestion des eaux pluviales visibles de la rue

Tel qu'identifié dans des revues de littérature, de nombreuses études scientifiques mentionnent les bénéfices socio-économiques et environnementaux qui découlent des IV, incluant les IVGEP (Tzoulas et al., 2007; Venkataramanan et al., 2020). Ces bénéfices comprennent notamment la réduction des îlots de chaleur (Johnson et al., 2021), l'amélioration de la qualité de l'air (Abhijith & Kumar, 2019) et un meilleur bien-être psychologique (Liu et al., 2019; Roe et al., 2020). De plus, les plans de mobilité des villes intègrent souvent une stratégie de verdissement des routes pour favoriser les déplacements actifs. En effet, augmenter la densité de végétation en milieu urbain, notamment par la plantation d'arbres, permet de favoriser les déplacements à la marche et à vélo (Ki & Lee, 2021; Lu et al., 2018; Nawrath et al., 2019). Par ailleurs, peu d'études scientifiques s'intéressent spécifiquement aux effets des IVGEP sur la mobilité active, quoique largement discutés dans la littérature grise. En effet, plusieurs documents gouvernementaux proposent de mettre en place des IVGEP dans l'emprise routière pour rendre les rues plus attractives pour les déplacements actifs ou agir comme mesure d'apaisement de la circulation (City of Portland, 2010; LADCP, 2016). Or, il y a encore peu d'études scientifiques spécifiquement consacrées à ce sujet.

1.2 Objectifs de recherche

Afin de mieux comprendre les interactions entre les infrastructures de gestion des eaux urbaines et de transport, ce mémoire vise à analyser les effets des IVGEP sur la mobilité active (marche et vélo). La recherche comprend deux principaux objectifs :

- 1) Brosser un portrait et une analyse critique de l'état des connaissances sur le potentiel de synergie entre les IVGEP et la mobilité active.
- 2) Évaluer les effets des noues végétalisées sur la mobilité active en analysant les perceptions des individus.

Le premier objectif comprend une analyse exhaustive de 70 articles scientifiques (28 portant spécifiquement sur les IVGEP et 42 sur les IV). Ces résultats permettent de comprendre quels sont les effets connus et potentiels des IVGEP sur la mobilité active. L'inclusion d'études sur les IV permet de déterminer les effets potentiels des IVGEP de par leur similitude avec ces dernières. Puis, les études sur les IVGEP mettent en lumière des préoccupations ou contraintes spécifiques aux IVGEP. Cette analyse vise à identifier les lacunes et les perspectives de recherche.

Le second objectif vise à approfondir notre compréhension des perceptions des individus par rapport à la mise en place d'IVGEP dans l'emprise routière. Les perceptions des individus découlent de leur rapport au lieu, de l'usage qu'ils en font et des sensations qu'ils éprouvent lorsqu'ils se déplacent dans ce lieu. L'analyse vise spécifiquement à comprendre comment les gens perçoivent la mise en place des IVGEP par rapport à la mobilité (en matière de confort, esthétisme, sécurité, etc.). Il est primordial d'étudier les perceptions des individus par rapport à ce nouveau type d'infrastructure considérant que plusieurs études ont démontré que les perceptions influencent les comportements de mobilité pour la marche et le vélo (Dill & Voros, 2007; Jamal et al., 2020; Kamruzzaman et al., 2016; Ma et al., 2014). Pour répondre à cet objectif, un projet réalisé dans la Ville de Saint-Charles-Borromée est étudié. Le projet comprend le réaménagement de cinq rues résidentielles avec l'intégration de noues végétalisées de chaque côté de la rue, isolant le trottoir ou la piste cyclable des voies automobiles. Le secteur étudié présente des caractéristiques assez représentatives des villes québécoises en milieu rural. On y observe une faible mixité de l'environnement bâti, avec une prédominance de zones résidentielles et peu d'options de transport alternatives à la voiture. Une étude de cas par méthodes mixtes est employée, combinant un sondage, des entretiens ainsi que des groupes de discussion. Cette analyse à la fois quantitative et qualitative permet d'avoir une compréhension globale des opportunités et défis d'intégrer des IVGEP dans l'emprise routière.

Les résultats de ce mémoire contribuent à une meilleure compréhension des enjeux entourant la planification intégrée des infrastructures de transport et de gestion des eaux urbaines. Ils fournissent

également un constat clair de l'état des connaissances et des pistes de réflexion qui doivent être abordés dans de futures études.

1.3 Plan du mémoire

Ce mémoire est structuré de la manière suivante : le chapitre 2 présente la démarche de ce travail de recherche. Les méthodologies utilisées afin de répondre à chacun des objectifs du mémoire sont justifiées et expliquées. Les grandes étapes du projet sont exposées, soit la revue de littérature, la collecte de données et l'analyse des données.

Le chapitre 3 présente l'article scientifique « Synergy between green stormwater infrastructure and active mobility: A comprehensive literature review » accepté le 28 août 2023 pour publication dans le journal *Sustainable Cities and Society*. Cet article a également été présenté le 20 juillet 2023 à la World Conference on Transport Research Society. L'article a été rédigé par l'auteure de ce mémoire sous la direction de Geneviève Boisjoly et la codirection de Françoise Bichai. Cet article fait office de revue de littérature et répond au premier objectif. Il détaille d'abord la méthodologie utilisée pour recenser 70 articles scientifiques portant sur la synergie entre les IV, dont les IVGEP, et la mobilité active. Ensuite, les études quantitatives sur les effets des IV sur la mobilité active sont détaillées. La synergie entre les IVGEP et la mobilité active est ensuite étudiée. Enfin, une discussion sur les effets mesurés et potentiels des IVGEP est faite afin d'identifier les lacunes et les opportunités de recherche.

Le chapitre 4 présente l'article scientifique « Green Stormwater Infrastructure and Active Mobility: A Case Study Investigating the Effects of Bioswales on Individuals' Perceptions » qui a été soumis pour présentation à la conférence Transportation Research Board le 30 juillet 2023. L'article a également été soumis au numéro spécial Green Transportation and Travel Behavior du journal *Travel Behaviour and Society* le 21 août 2023. La version présentée dans ce mémoire est la version longue qui a été soumise au journal. L'article a été rédigé par l'auteur de ce mémoire sous la direction de Geneviève Boisjoly et la codirection de Françoise Bichai et Francesco Ciari. De plus, l'analyse qualitative a été réalisée par la stagiaire Sara Lach Gar sous la supervision de l'auteure de ce mémoire. Cet article a également été présenté au colloque Planification et gouvernance des infrastructures vertes urbaines : outils et processus décisionnels lors du 90^e Congrès de l'Acfas. Afin de répondre au second objectif du mémoire, cet article comprend l'analyse d'une étude de cas sur le réaménagement de cinq rues résidentielles avec des noues végétalisées à Saint-Charles-

Borromée (Québec). L'article comprend l'analyse d'un sondage ($N = 296$), d'entrevues avec des planificateurs, des citoyens qui habitent ou travaillent dans le secteur à l'étude ($N = 12$) et de deux groupes de discussion avec des jeunes de 10 à 11 ans ($N = 13$). D'abord, des régressions linéaires sont présentées pour évaluer le niveau de satisfaction par rapport aux noues végétalisées pour la marche et le vélo. Puis, une analyse typologique des répondants permet d'évaluer si le niveau de satisfaction des noues végétalisées varie selon les caractéristiques sociodémographiques et les attitudes des répondants par rapport aux retombées potentielles des noues végétalisées. Enfin, l'analyse qualitative des entrevues et groupes de discussion est présentée. Cette analyse vise à comprendre les divergences d'opinions par rapport à la mise en place de noues végétalisées dans l'emprise routière en identifiant les opportunités et défis liés à leur mise en place.

Le chapitre 5 contient une brève discussion quant aux analyses et résultats obtenus dans les deux articles présentés précédemment. Cette discussion permet de mettre en commun les résultats des deux articles qui constituent ce mémoire. En particulier, elle permet de nuancer les effets des IVGEP mentionnés dans la littérature scientifique en soulignant les résultats obtenus dans l'étude de cas. De plus, la réalisation de ces deux études a permis de formuler des recommandations concernant la mise en place des IVGEP dans l'emprise routière.

Enfin, le chapitre 6 conclut ce mémoire par une synthèse des résultats et un rappel des contributions majeures tout en abordant les limites de ces études et les perspectives de recherche.

CHAPITRE 2 DÉMARCHE DU TRAVAIL DE RECHERCHE

Cette section présente la démarche utilisée pour répondre à l'objectif principal de ce mémoire, soit d'analyser les effets des IVGEP sur la mobilité active. La Figure 2-1 présente un schéma conceptuel détaillant les principales phases du travail de recherche, les objectifs de recherche et les principales étapes méthodologiques.

2.1 Phase 1 – Identification des objectifs de recherche

Les objectifs de cette recherche découlent du désir de mieux comprendre les multiples fonctions d'une rue afin de maximiser les bénéfices socio-environnementaux de cet espace public. Parmi les fonctions principales d'une rue, assurer les déplacements des personnes ainsi que la gestion des eaux pluviales sont des éléments indispensables. Comme identifié sur la Figure 2-1, une première revue de littérature exploratoire a permis de cibler les lacunes et de développer des objectifs de recherche en termes d'optimisation des systèmes de gestion des eaux urbaines et de mobilité. Dans une perspective de développement de villes résilientes, plusieurs études mentionnent les bénéfices de réduire les surfaces imperméables et de gérer les eaux de pluie à la source, c'est-à-dire de tenter d'infiltrer l'eau dans le sol le plus près possible de son point de chute (Condon & Isaac, 2003; Engel-Yan et al., 2005; Low et al., 2008). Les IVGEP permettent de répondre à ce besoin en réduisant la surface imperméable et en collectant les eaux de ruissellement pour les réinfiltrer en partie ou en totalité dans le sol. Au niveau de la mobilité, les modes actifs comme la marche et le vélo sont mis de l'avant afin d'améliorer le bien-être des populations et de réduire les émissions de CO₂ (de Nazelle et al., 2011; Neves & Brand, 2019). À la lecture de documents gouvernementaux comme des plans de mobilité ou des plans d'urbanisme (e.g., EPA (2021), City of Philadelphia (2014) et National Association of City Transportation Officials (s.d.)), une interaction a pu être identifiée entre la mise en place des IVGEP et l'amélioration de la mobilité active. Les bénéfices mentionnés dans ces documents comprennent une amélioration de la sécurité des usagers actifs due à la mise en place des IVGEP, une plus grande accessibilité aux modes actifs et l'amélioration de l'esthétisme des rues (EPA, 2021). Bien que ces bénéfices soient discutés dans la littérature grise, la recherche exploratoire a révélé que très peu d'études scientifiques permettent de quantifier ces effets. À la suite de ces constats, deux objectifs ont pu être identifiés. Afin de bien comprendre l'état des connaissances sur les interactions entre les IVGEP et la mobilité active, il était nécessaire de réaliser une revue de littérature exhaustive (objectif 1). Cette démarche visait à identifier quels sont

les effets mesurés des IVGEP sur la mobilité active en plus d'identifier les effets potentiels qui doivent être davantage documentés. Ensuite, il était nécessaire d'analyser et de quantifier les effets des IVGEP sur la mobilité active (objectif 2). Cet objectif s'est précisé lors de l'analyse exhaustive de la littérature afin de tenir compte des lacunes existantes dans le design de l'étude.

2.2 Phase 2 – Revue de littérature exhaustive

La deuxième phase du projet répond au premier objectif de ce mémoire. Le produit de cette phase de l'étude est l'article scientifique « Synergy between green stormwater infrastructure and active mobility: A comprehensive literature review ». La méthodologie pour la sélection des articles est inspirée de l'article « How to Write a Literature Review Paper? » de Van Wee & Banister (2016) ainsi que d'une revue systématique dans le domaine des transports (Scheepers et al., 2014). Les bases de données Scopus et Web of Science ont été sélectionnées dû à leur utilisation fréquente dans des revues de la littérature sur la mobilité active ou sur les IVGEP (p. ex., Arellana et al., 2020; Caparrós-Martínez et al., 2020; Fonseca et al., 2022).

Une recherche par mots clés a été développée afin de repérer un maximum d'articles sur le sujet. De plus, l'utilisation d'une recherche par mots structurée permet de modifier les critères d'inclusion au cours de l'étude afin d'ajouter ou de retirer des articles une fois que les objectifs de l'étude se précisent. Cela permet également de facilement mettre à jour la sélection d'articles, par exemple en ajoutant les articles publiés pendant la réalisation de l'étude. Cette recherche a été testée plusieurs fois et validée par l'ensemble des auteurs de l'article et par une bibliothécaire de Polytechnique Montréal. Le choix des articles inclus et exclus est justifié dans l'article (chapitre 4).

Au cours de la première phase de la recherche, il avait été identifié qu'un nombre limité d'articles permettaient de quantifier les effets des IVGEP sur la mobilité active. Ainsi, il a été décidé d'inclure également des articles (uniquement quantitatifs) sur la relation entre les IV en général et la mobilité active. Comme illustré sur la Figure 2-1, ces articles fournissent une meilleure compréhension des effets potentiels des IVGEP sur la mobilité active. En effet, il est possible de déterminer des effets potentiels des IVGEP de par leurs caractéristiques similaires avec les IV (p. ex., densité de la végétation et emplacement dans l'emprise routière). Des critères de sélection différents ont été utilisés pour les articles portant sur les IV et ceux portant spécifiquement sur les IVGEP. Notamment, les études qualitatives sur les IV n'ont pas été incluses puisqu'il y avait suffisamment

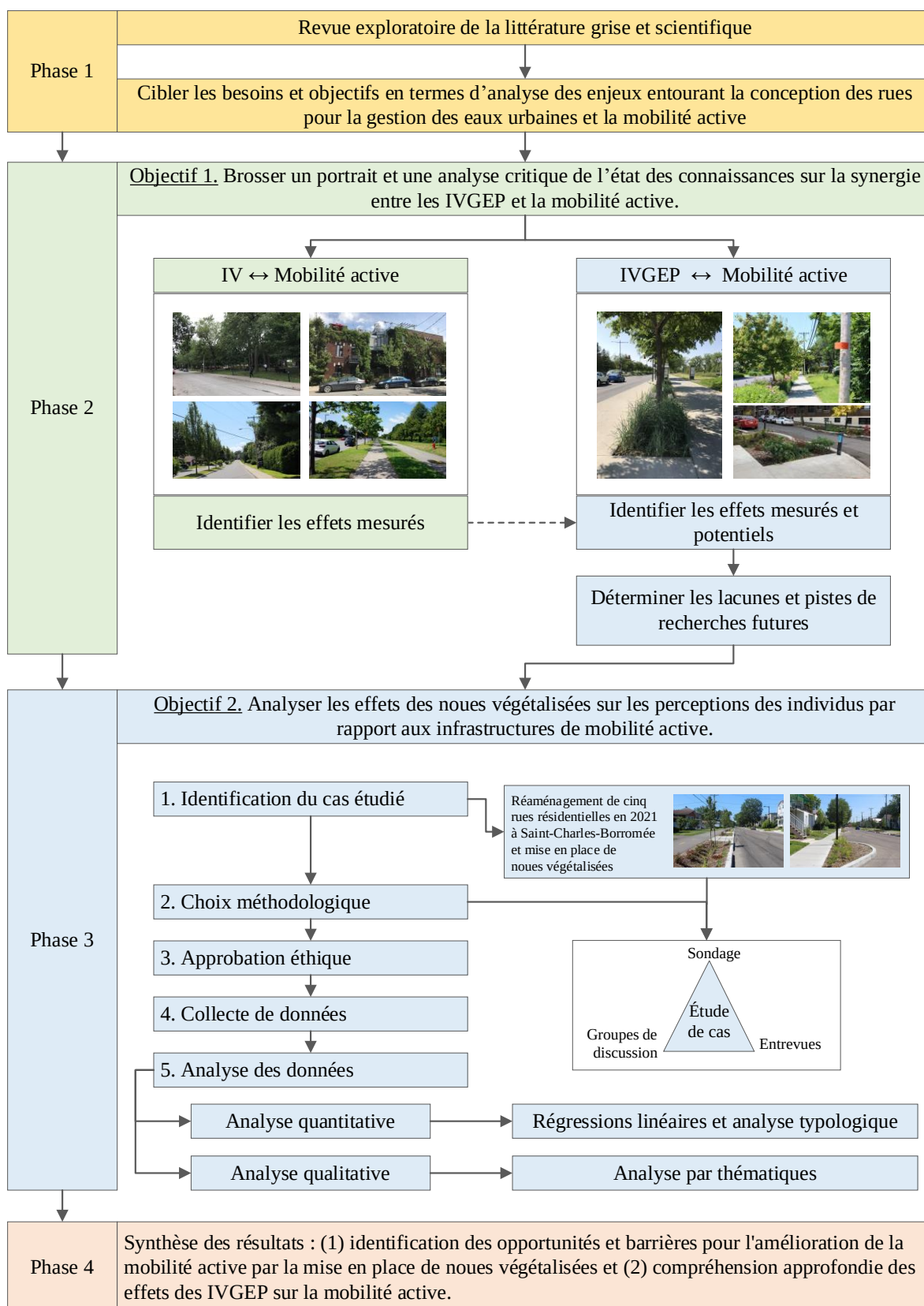


Figure 2-1 Démarche du travail de recherche, © 2023 images et schéma par C. Lemieux.

d'études qualitatives sur la relation entre les IVGEP et la mobilité active. Pour les études sur les IVGEP, les critères de sélection étaient plus larges. Les articles comprennent diverses approches de recherche tant qualitative que quantitative.

Les résultats de l'analyse d'articles sont divisés en deux principales sections. D'abord, les effets mesurés des IV sont documentés assez sommairement. Puis, les effets mesurés et potentiels des IVGEP sont détaillés en analysant en profondeur chacun des articles. Une discussion permet de faire le lien entre les effets quantifiés des IV sur la mobilité active et les effets potentiels des IVGEP. Enfin, les lacunes et les opportunités de recherche sont discutées.

Cette analyse a notamment permis de souligner le manque d'études portant spécifiquement sur la relation entre la présence d'IVGEP dans l'emprise routière et les perceptions des individus lors de leurs déplacements (objectif 2).

2.3 Phase 3 – Étude de cas

La troisième phase du projet répond au deuxième objectif du mémoire. Cette phase comprend la rédaction du second article scientifique intitulé « Green Stormwater Infrastructure and Active Mobility: A Case Study Investigating the Effects of Bioswales on Individuals' Perceptions ». Comme indiqué sur la Figure 2-1, la première étape de cette phase consistait à choisir un projet ayant mis en place des IVGEP dans l'emprise routière. Le choix du projet à l'étude était basé sur l'année de construction, l'envergure du projet et la possibilité de collaborer avec la Ville pour obtenir de l'information sur le projet et sonder la population. Ainsi, un projet réalisé en 2021 à Saint-Charles-Borromée (Québec) a été choisi. Cette petite ville de 15 285 habitants (Statistics Canada, 2023) est située à 75 km de Montréal dans la région de Lanaudière. Le projet comprend le réaménagement de cinq rues résidentielles avec la mise en place de noues végétalisées en bordure de rue. Comme le projet était très récent, il était possible de questionner les différents intervenants sur les objectifs fixés lors de la conception du projet ainsi que les contraintes survenues pendant le projet. Pareillement, les citoyens pouvaient s'exprimer sur les changements survenus dans leur quotidien, surtout au niveau de leurs déplacements, en comparant les configurations des rues avant et après les travaux.

Une fois le projet choisi, une méthodologie a été conçue pour répondre à l'objectif de recherche. Une étude de cas comprenant la réalisation d'un sondage, d'entrevues et de groupes de discussion a été sélectionnée. L'étude de cas permet d'explorer un concept nouveau peu documenté en

adaptant l'étude selon le contexte du lieu choisi et de recueillir de l'information par plusieurs méthodes pour rejoindre une diversité d'acteurs afin d'avoir une vue d'ensemble des enjeux (Gagnon, 2012; Meyer, 2001). Afin de rejoindre une diversité d'acteurs, différentes méthodes de collecte de données ont été utilisées. Le sondage auprès des résidents de la Ville, les entrevues avec des planificateurs et des résidents ou travailleurs du secteur réaménagé ainsi que les groupes de discussion avec des jeunes âgés de 10 à 11 ans ont permis de considérer les besoins de différentes parties prenantes.

La plateforme en ligne Poly-Opinion a été utilisée pour le sondage en ligne. La diffusion a été gérée par la Ville, notamment par le biais de courriels et de messages texte rejoignant un total de 1677 citoyens. De plus, une version papier du sondage a été distribuée en personne sur les cinq tronçons de rue réaménagés. Cette version du sondage qui comprend les mêmes questions que le sondage en ligne est présentée à l'annexe A. La collecte a été effectuée par l'auteure de ce mémoire avec l'aide d'étudiants de Polytechnique Montréal. Elle a permis d'obtenir un plus grand nombre de réponses parmi les gens qui vivent directement dans ce secteur et de rejoindre des gens typiquement sous-représentés dans les sondages en ligne. Au total, 296 réponses complètes ont pu être collectées dont 63 réponses de résidents vivant à moins de 400 m du secteur à l'étude.

Pour la réalisation des entrevues, deux guides d'entrevue ont été utilisés : un pour les résidents ou commerçants du secteur réaménagé et un pour les planificateurs. Ces guides sont présentés respectivement dans les annexes B et C. Les entrevues étaient semi-dirigées pour permettre aux différents intervenants de s'exprimer sur des enjeux qui n'avaient pas forcément été identifiés lors de la création des guides d'entrevue. Des enjeux similaires étaient abordés auprès des deux groupes afin d'évaluer si les opinions différaient selon le type d'intervenants. Le recrutement des planificateurs a été géré directement avec la Ville puisque les planificateurs étaient soit des employés de la Ville ou des élus. Le recrutement des citoyens et commerçants a été réalisé en partie en personne. Lors du porte-à-porte, l'auteure du mémoire a proposé aléatoirement à des citoyens de prendre part à une entrevue au lieu de répondre au sondage. Pour le recrutement des commerçants, une priorité a été donnée aux commerces situés le plus près du secteur réaménagé. Une collaboration avec une école située dans le secteur réaménagé a également permis de recruter des parents et membres du personnel.

Pour inclure les perspectives des enfants dans l'étude, deux groupes de discussion ont été réalisés dans cette même école. Une classe de 5^e année a été sélectionnée pour participer à l'étude. L'ensemble des élèves de cette classe avaient la possibilité de participer sous l'autorisation parentale. Afin d'établir un premier contact avec les élèves pour faciliter la discussion, une première rencontre a eu lieu avec l'ensemble de la classe. Lors de cette rencontre, la responsable de la recherche (i.e., l'auteure de ce mémoire) a présenté le métier d'ingénieur civil. Tous les élèves ont participé à l'activité. Une semaine plus tard, les groupes de discussion ont été réalisés. Les 13 participants ont été divisés en deux groupes afin de faciliter la discussion et de permettre à chacun de s'exprimer. Les deux groupes ont été menés par la même personne, soit l'auteure de ce mémoire. Le guide utilisé pour les groupes de discussion est présenté à l'annexe D.

L'ensemble des activités de recherche (sondage, entrevues et groupes de discussion) ont été approuvées par le Comité éthique de Polytechnique Montréal avant que le processus de recrutement soit enclenché.

Enfin, l'analyse des données est détaillée dans l'article. Elle comprend une analyse quantitative du sondage avec des régressions linéaires et une analyse typologique, ainsi qu'une analyse qualitative des entrevues et groupes de discussion. Il convient de noter que lors de la collecte des sondages en porte-à-porte, les échanges et remarques des citoyens ont été consignés afin de les intégrer à l'analyse qualitative.

2.4 Phase 4 – Synthèse des résultats

Ce mémoire permet de mettre en commun les résultats des deux études, soit la revue exhaustive de la littérature scientifique sur la synergie entre les IVGEP et la mobilité active ainsi que l'étude de cas permettant d'analyser les effets d'un type d'IVGEP sur les perceptions des individus quant aux déplacements actifs. Ces deux articles sont intimement liés et permettent l'avancement des connaissances quant à la planification intégrée des infrastructures de gestion des eaux et de transport. Les résultats permettent d'identifier les opportunités et barrières liées à la mise en place des IVGEP pour améliorer la mobilité active en plus détailler les effets des IVGEP sur la mobilité active. La discussion et la conclusion de ce mémoire fournissent une synthèse des résultats tout en soulignant les limites de ces études.

CHAPITRE 3 ARTICLE 1 : SYNERGY BETWEEN GREEN STORMWATER INFRASTRUCTURE AND ACTIVE MOBILITY: A COMPREHENSIVE LITERATURE REVIEW

SUSTAINABLE CITIES AND SOCIETY, 13 JANVIER 2023

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Abstract

Green stormwater infrastructure (GSI) is increasingly used in urban planning to replace grey infrastructure and achieve socio-environmental benefits. Its design can result in a substantial reallocation of space and thereby contribute to active mobility (walking and cycling), especially when implemented in the right-of-way. Yet, few studies have investigated the relationship between GSI and active mobility. This paper comprehensively reviews 70 scientific articles on GSI and more broadly green infrastructure (GI) in the context of active mobility. Our primary aim is to assess the potential synergy between GSI and active mobility. While empirical studies on GSI and active mobility are lacking, the review highlights the potential effects of GSI based on its common characteristics with GI. The main potential benefits identified are increasing active travel, enhancing road safety and improving street aesthetics. The review also addresses car mobility, safety and aesthetic concerns associated with GSI implementation. Findings demonstrate the complex relationship between GI, GSI, and active mobility, warranting further studies to

understand the nuanced effects of different types of infrastructure on active travel. This study is relevant for researchers and planners seeking insights into GSI specificities to better guide future studies and projects supporting both urban water management and active mobility.

Keywords

Green stormwater infrastructure; Vegetation; Active mobility; Urban design; Integrated planning

Highlights

- Green stormwater infrastructure (GSI) has the potential to support active travel
- Further studies are needed to assess the nuanced effects of different types of GSI
- The existing scientific research on GSI and active travel is mostly qualitative
- New indicators using large-scale data to quantify GSI features are necessary
- Designing multifunctional streets is key to maximize GSI socio-environmental benefits

3.1 Introduction

Cities are implementing green infrastructure (GI) in urban areas to reduce climate change vulnerability and provide socio-environmental benefits for populations. The term GI refers to “an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to people and wildlife” (Benedict & McMahon, 2012). As shown in Figure 3-1, GI includes all types of green features including green stormwater infrastructure (GSI). The term GSI is used to define GI primarily designed to capture and infiltrate runoff. In this study, we separate GSI from the rest of GI features to better understand the specific synergies between stormwater management objectives and active mobility. Hence when we synthesize findings from literature on GI, we typically exclude studies on GSI. It is important to note that GI is often used in the literature in reference to stormwater management functions.

GSI is particularly interesting due to the multiple co-benefits that a single infrastructure can support. As such, studies have shown that implementing GSI can reduce heat island effects (Shafique & Kim, 2017), reduce runoff (Luan et al., 2019), improve the resilience of drainage systems (Casal-Campos et al., 2018), and improve air quality (Abhijith & Kumar, 2019), while having the potential to support active mobility (Adkins et al., 2012). Yet, its implementation is a challenge for urban planners due to space competition in dense urban areas. In that sense, cities should optimize its implementation to maximize its secondary benefits (Dagenais et al., 2016), such as active mobility.

An increasing number of cities have come up with a greening strategy, including GSI in their mobility plans to facilitate and promote active mobility (walking and cycling). As shown in Figure 3-1, GSI can be directly implemented in the street to capture runoff from impermeable surfaces. When implemented in a built environment, its implementation requires a reallocation of the space, often more considerable than other GI types (which are not primarily designed to collect rainwater). GSI is generally implemented between the roadway and the sidewalk. Thus, the redesign of the street might have a significant impact on travel behaviour and individuals' perceptions. Although several literature reviews have identified studies investigating the socio-economic and environmental benefits of GI (Bartesaghi Koc et al., 2018; Tzoulas et al., 2007), and GSI (Venkataramanan et al., 2020), the effects of GSI on active mobility are little documented in scientific literature.

Green infrastructure (GI)



Figure 3-1 Examples of green infrastructure and green stormwater infrastructure, © 2023 par C. Lemieux

The aim of this study is to provide a comprehensive overview of the knowledge on the synergy between GSI and active mobility. To our knowledge, there is no comprehensive synthesis of studies addressing the specific relationship between GSI and active mobility. This article provides an understanding of the current state of scientific knowledge on this subject and identifies further research needs. As GSI is a type of GI and given the few studies that empirically examined the relationship between GSI and active mobility, we decided to also consider GI in our review. Therefore, we first focus on the understanding of the effects of GI on active travel given that GI has been studied more extensively than GSI in that respect. Then, we address the literature specifically on GSI and active mobility while raising the common characteristics between GSI and GI that have the potential to yield similar outcomes for active travel. Thus, through a comprehensive review of the scientific literature published in peer-reviewed journals, we seek to answer the following questions:

- What indicators are used to quantify GI when assessing its effects on active mobility?
- What are the empirical relationships between GI and active mobility?
- What methodologies are used for analysing the synergy between active mobility and GSI in the scientific literature?
- What are the potential benefits of GSI implementation on active mobility?
- What are the gaps in the literature regarding the effects of GSI on active mobility?

This comprehensive review provides a synthesis of the relationships of GI and GSI with active travel, physical activity, road safety, and health. It also provides an overview of the challenges regarding the implementation of GSI in the built environment, namely with respect to the perceptions of the population. This study is of relevance to urban planners, municipal stakeholders, and researchers aiming to better understand issues surrounding the implementation of various types of GSI and their potential benefits regarding active mobility.

3.2 Methodology for the selection of the literature studies

An exploratory review of previous studies on GSI and active mobility has revealed that few studies focused directly on documenting this synergy. Hence, we first identified and analyzed empirical studies on the effects of GI (excluding GSI) visible from the right-of-way on individuals' behaviours and perceptions during active travel. This allowed us to understand potential effects that GSI can provide for active mobility through its common characteristics with GI (e.g., types of plants, density of vegetation, etc.). Then, we examined the studies that explicitly analyzed types of GSI and addressed their synergy potential with active travel. A literature search was conducted in Scopus and Web of Science, as these databases have been widely used in literature reviews on active transportation and GSI (Arellana et al., 2020; Caparrós-Martínez et al., 2020; Fonseca et al., 2022) and adequately cover the field of natural sciences and engineering (Mongeon & Paul-Hus, 2016). The flow chart for the study selection is shown in Figure 3-2.

The search methodology was inspired by the article on the process of writing a literature review written by Van Wee & Banister (2016) and the systematic review of Scheepers et al. (2014) on modal shifts. For the Scopus database, the search was limited to articles. For the Web of Science database, irrelevant documents (non-articles) were removed after extraction. Data was extracted on May 31, 2023. There were no restrictions based on the year of issue. The detailed search strategy

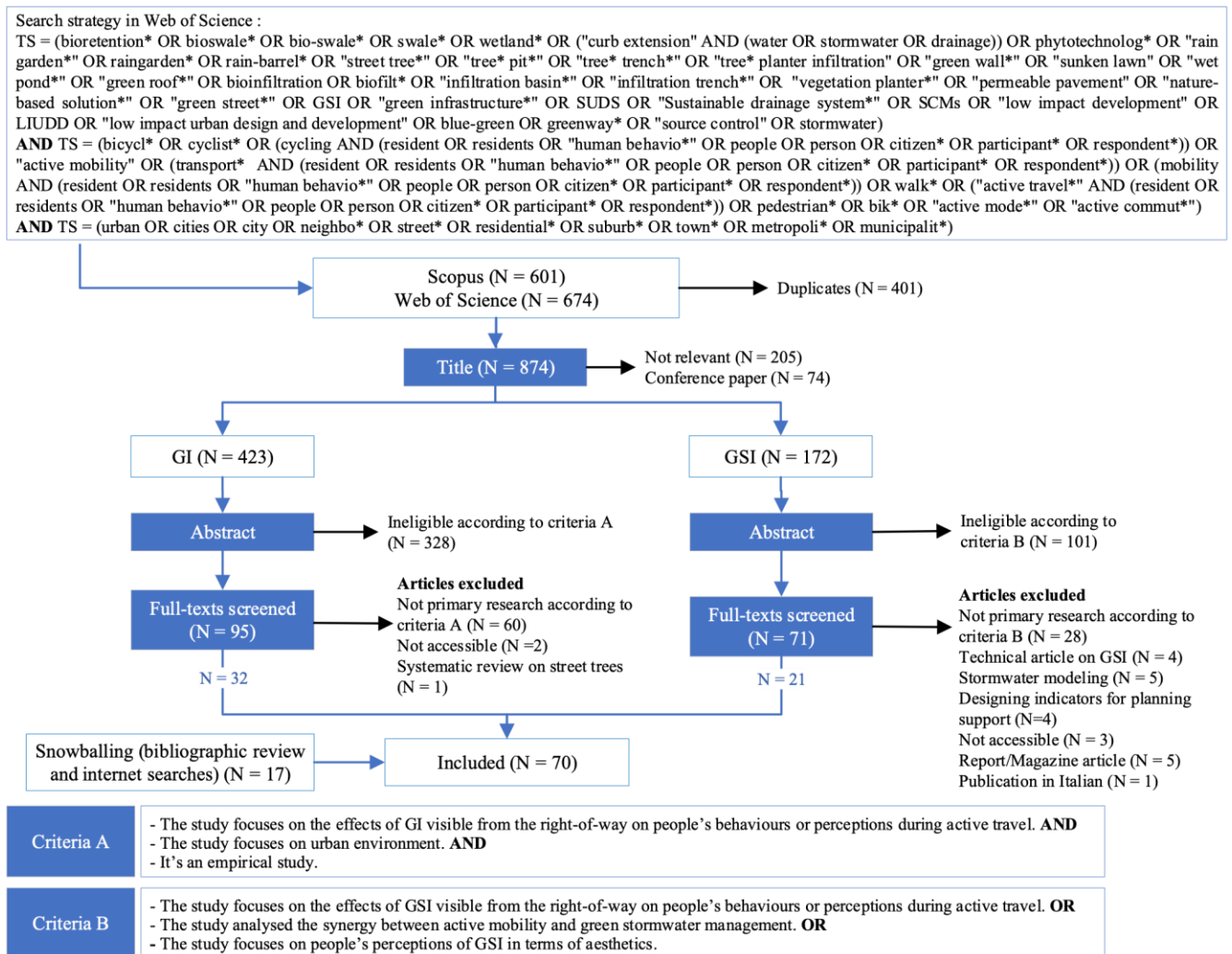


Figure 3-2 Flow chart for search strategy and selection of studies

used in Web of Science is depicted in Figure 3-2. The same terms were used in Scopus, but the truncation was adjusted to fit in Scopus. The search strategy was divided into two main subjects: active mobility and GI. Since the focus of the study is on GSI, many specific terms were included such as “bioretention*”, “rain garden*”, “swale*”, etc. All the terms described by Fletcher et al. (2015), in an article reviewing the history of the terms used in urban drainage, were tested. For active mobility, modes included are walking and cycling. An additional category was used to target only studies conducted in urban areas. The boolean operator ‘AND’ was used between the three main categories (active mobility, GI or GSI, and urban areas), and the boolean operator ‘OR’ was used within the categories. One librarian and three researchers tested each term for relevance and optimized and adapted the search for each database. For example, some words such as “cycling”

and “transport” that can have more than one meaning, especially when related to urban drainage, were linked with other words to avoid finding non-relevant articles.

Different inclusion criteria were used to distinguish articles that relate to GI (Criteria A) from those that are specific to GSI (Criteria B). Figure 3-2 shows the study selection process and describes both sets of criteria. During the selection process, the reading of selected articles led to the identification of themes. For each theme, we analyzed the relevance of the theme to understand the relationship between GSI and active mobility, and then refined the selection criteria. The articles were analyzed by types of infrastructure (GI and GSI). The eligibility criteria for GI are stricter since it is not the main subject of the study.

For GI, selected studies had to focus on the impact of GI located on the right-of-way (street trees, average greenery on the street, green medians, etc.) on individuals’ perceptions or behaviours related to active travel. The identified themes included studies evaluating the effects of GI on walking or cycling activities, physical activity, road safety, and health benefits related to active travel. Studies focusing on parks, green spaces, and greenways out of the street were excluded unless the study specifically mentioned that the infrastructure was visible from the street (e.g., Vich et al. (2019) considered the proportion of park area within a 20 m buffer zone of the individual's route.). Even if these types of infrastructure can contribute to active mobility (Hogendorf et al., 2020; Ki & Lee, 2021; Lu et al., 2018), they meet different needs than street-level infrastructure, especially since they often constitute a destination (Ki & Lee, 2021; Lu et al., 2018). We also excluded studies that evaluated the impacts of the built environment on active travel by including variables such as the street tree canopy without specifically discussing/focusing on it in the analysis.

For GSI, the selection criteria¹ include those for GI, as well as studies analyzing the potential synergy between active mobility and GSI, such as studies investigating people’s perceptions of GSI in terms of street design and road safety. Moreover, we included studies focusing on the aesthetics of GSI since preferences for different types of GSI might influence their effects on active travel.

¹ Contrairement aux critères spécifiques aux IV, les études portant sur les IVGEP ne sont pas nécessairement empiriques. Étant donné le peu d'études se penchant sur la relation entre les IVGEP et la mobilité active, il était nécessaire d'incorporer des études non empiriques afin de saisir les interactions potentielles entre les IVGEP et la mobilité active.

We excluded, both for GI and GSI, studies focusing on outcomes not directly related to people's perceptions and behaviour during active travel, such as air quality, thermal comfort, and efficiency of stormwater facilities. During the selection process, we found over 60 studies on thermal comfort and over 30 studies on air quality. Literature clearly reports that GI and GSI can help improve thermal comfort and air quality for pedestrians and cyclists (Abhijith & Kumar, 2019; Detommaso et al., 2021; Jia et al., 2021; Sylliris et al., 2023; Zölch et al., 2016). Additionally, comprehensive reviews on these impacts of GI and GSI have already been published (Abhijith & Kumar, 2019; Piracha & Chaudhary, 2022; Taleghani, 2018). However, previous studies rarely analyse individual perceptions and behaviours during active travel. While these benefits are important, our study focuses on understanding more specifically how GI and GSI directly influence human behaviour in terms of active mobility, i.e., in addition to the benefits of improved air quality and thermal comfort.

3.2.1 Summary of the studies

The search strategy led to a final selection of 42 studies on GI and 28 studies on GSI for further analysis, i.e., 70 articles published between 2001 and 2023 in total (including 51 articles published since 2016). Table 3-1 summarizes the main properties of the reviewed studies. They were mostly conducted in North America, East Asia and Europe. As shown in Table 3-1, a large proportion of them were conducted on small samples (29 studies with fewer than 1000 observations). A large proportion addressed the following types of vegetation: trees, rain gardens, bioswales, green spaces, and parks. Several studies investigated the effects of global vegetation indices which measure

Table 3-1 Properties of the reviewed studies

Property	Categories (number of studies)
Year of publication	Published between 2001-2005 (4), 2006-2010 (4), 2011-2015 (11), 2016-2020 (26), and 2021-2023 (25)
Geography	Regions included in analysis are North America (23), East Asia (17), Europe (18), Australia (1), North America and Europe (1), Africa (2), multiple regions (3), and not specified (5)
Study design	Quantitative with more than 1000 observations (20), quantitative with fewer than 1000 observations (29), qualitative – observations, interviews or focus groups – (4), experimental study (1), conceptual framework (9), and description of projects (7)
Main subject of the study	Green infrastructure: active mobility (19), safety (11), health (5), physical and outdoor activities (2), perceptions of street designs with GI (4), and purposes of visiting GI (1). Green stormwater infrastructure: integrated urban projects (11), perceptions of GSI (9), active mobility (6), mobility (1), and outdoor activities (1).
Most common green features analyzed or discussed*	Trees (48), rain gardens and bioswales (22), global vegetation indices (15), green spaces and parks (15), ground vegetation and landscape buffers (6), urban greenways (6), flowers (3), and water reservoir (2).

*Some studies included multiple types of vegetation

the overall proportion of green features in an area. Finally, for GI, most of the studies were on active mobility and road safety. For GSI, most of the studies did not directly assess active mobility.

3.3 Results

In this section, we first analyse the studies on GI. We describe all types of vegetation included in the reviewed articles. Then, we investigate the effects of GI on active travel, safety, and health. Lastly, we analyze the potential synergy between GSI and active mobility by reviewing the studies that specifically consider GSI. These consist of conceptual frameworks, case studies, and examples of projects.

3.3.1 Studies on green infrastructure

3.3.1.1 Types of GI analysed

This section presents a review of the types of vegetation assessed in relation to active mobility, as well as the indicators and methods used to quantify them. Understanding how the different types of vegetation are measured is essential to then examine the relationship between GI, GSI and active mobility. Table 3-2 presents the indicators used in the reviewed studies. Overall, two types of approaches are predominantly used. The first one measures a global vegetation index, while the second directly assesses the presence of one type of GI (mainly trees). These indicators were found in studies looking at GI, and do not make the distinction between GI or GSI. Measuring the effects of global vegetation indices (i.e., greenness) on active mobility is central to understanding the effects of GI and GSI since these types of infrastructure contribute to increasing the overall greenness of a city.

3.3.1.1.1 Global vegetation indices

Global vegetation indices presented in Table 3-2 are intended to measure the density of vegetation within a specific area or along a street segment. The most commonly used indicators are the Normalized Difference Vegetation Index (NDVI) and, more recently, the Green View Index (GVI). The NDVI uses multispectral satellite imagery to measure the density of vegetation, whereas the GVI is calculated from street view images. According to the studies analyzed, the GVI seems to be a better indicator to reflect pedestrians' and cyclists' experiences and adequately includes some vegetation that could be overlooked by the NDVI such as green walls and vegetation under canopies of trees (Ki & Lee, 2021; Lu et al., 2019; Wu, Jiayu et al., 2020). In addition, this indicator allows to measure the average or total vegetation exposure during a trip without having to delimit

a buffer zone around the route. Roscoe et al. (2022) used an alternative technique that distinguishes ground cover vegetation (less than 2.5 m) from tree cover vegetation (greater than or equal to 2.5 m). Although these three indicators are used to assess exposure to greenery, they do not measure the overall effect of GI on active mobility, which extends beyond the presence of vegetation.

Table 3-2 Types and characteristics of the green features' indicators found in the reviewed literature

Indicators	Additional information about the indicators (studies using the indicator)
Global vegetation indices	
Normalized Difference Vegetation Index (NDVI) – 3 studies	
Circular buffer around the centroid of participants' neighbourhood	- 1000 m (Liu et al., 2019).
Circular buffer around home	- 400 m, 800 m and 1600 m (Lu et al., 2019). - 500 m (Sarkar et al., 2015).
Green View Index (GVI) – 10 studies	
Rating of images by participants	- (Dai et al., 2021).
Circular buffer around home	- 400 m, 800 m and 1600 m (Lu et al., 2019). - 500 m (Ki & Lee, 2021). - 800 m (Lu et al., 2018; Yang et al., 2019).
Network buffer from home or from metro stations	- 500 m, 1000 m and 1500 m (Wang et al., 2020)
Mean GVI for each street segments	- (Ta et al., 2021; Wu, Jiayu et al., 2022; Wu, Jiayu et al., 2020)
Mean GVI at census tract level	- (Li & Ghosh, 2018)
Other indicator – 1 study	
Tree-cover (≥ 2.5 m), ground-cover (< 2.5 m), and green walkability (all)	- 1000 m network buffer around home and 50 m road buffer (Roscoe et al., 2022)
Green infrastructure	
Tree canopy density – 6 studies	
Road buffer	- Area between the buildings closest to the road (Harvey & Aultman-Hall, 2015; Harvey et al., 2015) - Area within the public right-of-way (Lee, S. et al., 2022). - The percent of the areas covered by the tree canopy within 15.2 m (50 ft) buffers from the right-of-way (Kim, D., 2019). - Sidewalk focal area on each side of the road (7.5 m beyond the road edge and 1 m overlap with the road) and 50 m buffer (25 m each side of the centreline) for a 500 m, 750 m, 1000 m, and 1250 m network buffer around home (Tsai et al., 2019). - Proportion of road pavement and footpath covered by tree canopy (Zhu et al., 2022). - Approximate (Botes & Zanni, 2021).
Circular buffer around home	- 500 m, 750 m, 1000 m, and 1250 m buffers (Tsai et al., 2019).
Number of trees – 6 studies	
Density of street trees within a buffer around home (Nb of trees/area)	- Circular buffer of 500 m around home (Ki & Lee, 2021). - Network buffer of 500 m (Akinci et al., 2021) or 1 km (Sarkar et al., 2015) around home.
Number of trees within a buffer surrounding the road	- Number of trees per unit length for a 15.2 m (50 ft) buffer (Chen, P. et al., 2018). - Number of trees on pavement or footpath per unit road length (Zhu et al., 2022). - Number of trees per unit area for a 20 m buffer (Vich et al., 2019)
Presence of trees – 7 studies	
Physical presence of trees	- (Kweon et al., 2021)
Physical presence of vegetated tree pits	- (Nawrath et al., 2019)
Perceived presence of trees	- (Coleman et al., 2021; Hong et al., 2018; Lee, H. S. & Park, 2015; Ozbil et al., 2021; Takano et al., 2002)
Parks – 1 study	
Percentage of the area covered by parks	- 20 m buffer surrounding the road (Vich et al., 2019).

3.3.1.1.2 Green infrastructure

GI can take many forms and it can be difficult to analyze a specific type of infrastructure with regards to active mobility. Some types of GI such as street trees, green walls or vegetated curbs are part of the road landscape and can influence daily travelling. Each type of infrastructure, through its diverse characteristics (functions, location, footprint in the urban landscape, etc.), can influence people's perceptions and mobility behaviour differently. As a result, the indicators used to represent GI vary significantly across studies. The most common studied infrastructure are street trees. As mentioned in section 3, we only included studies on GI visible from the right-of-way. We have included one study investigating the effects of parks on walking time since this study measured the area of parks within a buffer from the road (Vich et al., 2019).

There are two principal sources of data for street trees (in studies looking at the influence of GI on active mobility): number of trees and tree canopy, which refers to the ground projection of the crown of trees including leaves, branches, and stems visible from the sky. The selection of the indicator (either road buffer or circular buffer around a location) and the distance considered vary widely (Akinici et al., 2021; Botes & Zanni, 2021; Chen, P. et al., 2018; Harvey & Aultman-Hall, 2015; Harvey et al., 2015; Kim, D., 2019; Sarkar et al., 2015; Tsai et al., 2019; Vich et al., 2019). Harvey & Aultman-Hall (2015) used a method only considering trees in front of the buildings to better capture the streetscape space that would be visible by a street-level user. This technique points out that using an invariable buffer size may lead to mistakes both in considering trees that pedestrians cannot see and in failing to consider some visible trees. As shown in Table 3-2, other studies have measured perceived presence of street trees (Coleman et al., 2021; Hong et al., 2018; Lee, H. S. & Park, 2015; Ozbil et al., 2021; Takano et al., 2002) or compared scenarios with different configurations of streets sometimes including trees (Kweon et al., 2021; Nawrath et al., 2019). The results obtained with different indicators vary and point to the need to understand which indicator is suitable for a particular purpose.

Some studies attempted to measure other GI such as ground vegetation (herbaceous, low-landscaping and flowers) (Botes & Zanni, 2021; Tsai et al., 2019; Vich et al., 2019). Tsai et al. (2019) analyzed the effect of herbaceous cover and aggregate greenery on active transportation for the road focal area (25 m each side of the centreline) and the circular buffer around home. The authors defined herbaceous cover as herbaceous and emergent wetlands, and aggregate greenery

as trees, herbaceous, woody wetlands, and emergent wetlands. Their analysis showed that an increased density of herbaceous cover reduced the odds of participating in active transportation at least once a week. The aggregate greenery variable was only significant for a circular buffer around home, and an increased density of aggregate greenery was associated with higher odds of participating in active transportation. Since the buffer considered for the herbaceous cover was 50 m wide, this indicator does not specifically assess the infrastructure implemented in the right-of-way, which may have differentiated impacts. For example, planted strips or vegetated curb extension implemented in the right-of-way may modify the configuration of the street by reducing the space allocated to cars and isolating pedestrians from motor vehicles. On the contrary, the presence of herbaceous cover in the backyard of a residence is not visible to a pedestrian.

Many studies used questionnaires with small samples to evaluate the effect of specific interventions (Botes & Zanni, 2021; Nawrath et al., 2019; Piselli et al., 2018). This method allows comparing different interventions including one or more types of GI, and specifically examining individuals' perceptions with respect to these urban landscapes. Conducting studies with questionnaires appears to be relevant to examine how specific GI designs relate to individuals' perceptions and behaviour. In comparison, large-scale data, often focusing on general green features (e.g., tree canopy or global vegetation index) is limited in comprehensively capturing all features of GI that together can impact active mobility. However, conducting questionnaires for a specific intervention can be time-consuming and is often limited to small samples and small study areas due to the scale of the intervention. It can be challenging to extrapolate the results of these studies to different urban contexts.

3.3.1.2 Effects of GI on behaviours and perceptions during active travel

We now examine the findings on the relationship between the indicators of green features and GI, and active mobility. The indicators are divided between global vegetation indices and green infrastructure as above. Table 3-3 shows the measured outcomes of global vegetation indices (GVI, NDVI and green walkability) and GI (street trees and parks) on active travel, walking, and cycling. Studies analysing preferences among various types of GI are not included in Table 3-3 and are discussed later. All the studies on the GVI are located in East Asia, whereas other studies are located across Europe and East Asia.

Table 3-3 Measured outcomes of green features on active mobility

Green feature	Country	N	Distance, time or frequency of			Probability of choosing the mode			Satisfaction while			Physical activity
			AT	W	C	AT	W	C	AT	W	C	
Global vegetation indices												
GVI												
Ki and Lee, 2021	South Korea	2350		+								
Lu et al., 2019	China	5701						+				
Lu et al., 2018	China	90,445 (6770 ¹)		+				+				
Ta et al., 2021	China	213 (912 ²)							+	+	0	
Wang et al., 2020	China	167			+							
Wu et al., 2020	China	594 (6487 ²)		+/-	+/-		+/-					
Yang et al., 2019	China	10,700 (1083 ¹)		+				+				
NDVI												
Sarkar et al., 2015	England	15,354 (8610 ¹)		+				0				
Other indicator												
Roscoe et al., 2022	England	57,726 (12,986 ³)					+					+
Indicator not mentioned												
Jiao et al., 2022	South Korea	(12,200 ²)			+							
Green infrastructure												
Street trees												
Akinci et al., 2021	Spain	103 (686 ⁴)										0/-
Ki and Lee, 2021	South Korea	2350		0								
Lee and Park, 2015	South Korea	437					+/0					
Nawrath et al., 2019	Germany	1404			+							
Ozbil et al., 2021	Turkey	749						+/0				
Sarkar et al., 2015	England	15,354 (8610 ¹)		+				+				
Vich et al., 2019	Spain	127 (772 ²)		+								
Parks												
Vich et al., 2019	Spain	127 (772 ²)		+								

N : the number of participants, AT : Active travel, W : Walking, C : Cycling.

+ indicates an increase, - indicates a decrease and 0 means no effect.

¹ Number of participants who walked. ² Number of trips. ³ Number of observations with accelerometer information.

⁴ Number of days with data.

3.3.1.2.1 Global vegetation indices

Many of the reviewed studies have found a positive relationship between active travel and global vegetation indices. Several studies found that the GVI (a measure of eye-level greenness) was positively associated with an increase in walking (Ki & Lee, 2021; Lu et al., 2018; Yang et al., 2019) and cycling activities (Lu et al., 2019; Wang et al., 2020). Ta et al. (2021) found that higher GVI values significantly increase people's satisfaction with active travel (walking, biking, and electric biking). However, when they performed models for individual modes (walking or biking), they only found a significant result for walking. Wu, Jiayu et al. (2020) showed that an increase in the GVI is only associated with an increase in distances travelled (for cycling and walking) for small roads with low traffic. Overall, the literature indicates that GVI has a positive effect on active travel, although more research studying itineraries and built environment characteristics is needed to understand how the effects of green features and GI vary based on street designs and characteristics in which they are implemented.

Regarding other indicators, Sarkar et al. (2015) found that higher values of the NDVI (an overhead measure of greenness) were associated with longer distances travelled, whereas there was no significant relationship between NDVI and the odds of walking. By dividing the vegetation in two levels (vegetation below and vegetation equal or above 2.5 m from the ground), Roscoe et al. (2022) found that the vegetation equal or above 2.5 m (i.e., tree cover) had the highest positive effects on physical activity. Again, these findings illustrate the need for more nuances in the examination of the relationship between GI and active mobility. Specifically, future research would be required to further understand the different impacts of various types of vegetation on active mobility, such as GSI.

3.3.1.2.2 Green infrastructure

Almost all the quantitative studies studying the effects of GI on active travel analyzed street trees. As shown in Table 3-3, street trees showed a positive influence on walking activities (Lee, H. S. & Park, 2015; Sarkar et al., 2015; Vich et al., 2019). Interestingly, Ki & Lee (2021) found no significant effect between the number of street trees and walking time when controlling for the GVI. Ozbil et al. (2021) found that children in Istanbul were more likely to walk to/from school when there were shade-casting trees along the roads, according to parents' perceptions. Qualitative analysis conducted in England has revealed that trees were valued in terms of the environmental benefits they can provide such as heat island effect, pollution or carbon sequestration, and providing habitat for wildlife (Coles et al., 2013). People with motor disabilities mentioned that street trees can stimulate physical activity by increasing pedestrians' comfort and safety, improve aesthetics, and increase people's well-being despite possible disservices they may cause (tiles bulging, falling branches, allergies, etc.) (Wojnowska-Heciak et al., 2022).

Several studies compared different types of GI or different levels of greenery. A study using different green streetscapes showed that cyclists were more inclined to cycle on a greener street, and leisure riders would even change their route for a greener one (Nawrath et al., 2019). This result suggests that green streets may be more important for leisure cycling activities (Nawrath et al., 2019). Moreover, it has been shown that increasing overall greenery and combining different mitigation strategies, such as cool pavements, vegetation, and photovoltaic trees can increase pedestrian's perception, comfort, and tolerability of thermal conditions, air pollution, and noise pollution (Piselli et al., 2018). Botes & Zanni (2021) found that people preferred street designs with

ground cover vegetation, whereas street trees and flowers were not significant in most models. Finally, Vich et al. (2019) found a positive association between the presence of large parks along the road and increased time spent walking.

As shown in Table 3-3, most of the results showed a positive or non-significant relation between GI and active travel. Non-significant results may be due to multicollinearity when several variables representing a green feature are included in the same model or because of differences across socio-demographic groups. Overall, there seems to be a positive effect of GI on walking and cycling activities. However, these findings draw some distinctions between the effects of GI on walking and cycling, the different types of green features, and the built environment in which they are implemented. Since there are fewer studies on cycling, there is less evidence of the effects of green features on cycling activities.

3.3.1.3 Influence of socio-demographic and contextual factors in the relationship between GI and active travel

Heterogeneity is observed in the relationship between GI and active travel, namely with respect to socio-economic groups and environmental contexts. Wu, Jiayu et al. (2022) found that men are exposed to more greenness (assessed with the GVI) than women when considering the total exposure during a specific period. However, for the same distance travelled, women were likely to be exposed to more greenness than men. Dipeolu et al. (2020) found that the visiting purposes of GI varied based on household size and rank-in-job (a proxy of income level).

Regarding environmental contexts, a study on elderly women conducted in South Korea showed that determinants of walking vary between rural and urban women (Lee, H. S. & Park, 2015). Results showed that proximity to parks and street trees were significantly associated with higher odds of attaining the recommended level of walking for rural women. In addition to these differences across urban or rural areas, some places can have particularities that influence people. For example, Chang (2020) found that adults in Taiwan living near a greenway with more water features engaged less frequently in outdoors activities. The authors mentioned that this result could be caused by the risk of contracting dengue virus via mosquitoes present near water features. Overall, these results raise the importance of understanding the socio-economic and environmental contexts around the implementation of GI to adequately interpret the potential interplay between GI and active mobility.

3.3.1.4 Effects of GI on safety and health

In addition to the behaviours and perceptions related to walking and cycling, the literature search also yielded studies on topics closely related to active travel. Ten studies investigated how GI can improve safety and five studies analyzed the benefits of active mobility on physical and mental health in relation to GI. These topics are discussed below as they are intimately linked to the understanding of the benefits of GI and GSI on active mobility.

Several studies investigated the effects of landscape designs on road safety. In the past, trees have been considered a roadside hazard because they would reduce drivers' visibility. Chen, H. et al. (2016) demonstrated that trees that meet a certain standard do not increase the risk of collisions as opposed to trees that do not meet the standard. Furthermore, studies have found that street trees were associated with a lower risk of collisions involving pedestrians (Zhu et al., 2022), including elderly pedestrians (Kim, D., 2019), a decrease in severe crashes (Harvey & Aultman-Hall, 2015), and a decrease in elderly pedestrian fall incidents (Lee, S. et al., 2022). Harvey & Aultman-Hall (2015) suggested that more enclosed, human-scale streetscapes with trees, which reduce drivers' field of vision, can encourage responsible driver behaviour such as driving at slower speeds. The hypothesis that street trees are associated with slower driving speeds has been validated in a pilot study using a driving simulation environment with different landscape designs (Naderi et al., 2008).

Other studies have shown that street trees and buffer landscape can increase perceived safety (Harvey et al., 2015; Kweon et al., 2021; Landis et al., 2001). In some studies, pedestrians were perceiving higher safety and comfort when the lateral separation between the sidewalk and the motor vehicle was larger (Kweon et al., 2021; Landis et al., 2001). Conversely, Coleman et al. (2021) did not find that street trees had a strong significant effect on the safety perception of pedestrians. However, the qualitative analysis of respondents' comments related to street trees revealed that a clear majority had positive feelings toward them regarding aesthetics, shading, cooling, air quality, and other benefits. Using a different approach, Hong et al. (2018) analyzed interaction effects between green spaces and pedestrian safety. They found that within a safe neighbourhood for pedestrians, an increased number of street trees was associated with a higher level of social cohesion (Hong et al., 2018).

Some studies focused on the physical and mental health benefits of GI in relation to active mobility or physical activity. Studies found that higher density of vegetation (Liu et al., 2019) and walking

on green streets (Roe et al., 2020) were associated with higher mental well-being. Green scenery and trees have been associated to a decrease in the heart rate of runners (Paraskevopoulou et al., 2022). Li & Ghosh (2018) found mixed results by studying the effects of the mean GVI at census tract level on the mean body mass index. Higher neighbourhood vegetation density was significantly associated with lower mean body mass index only for certain groups based on age and gender. Takano et al. (2002) found that walkable green spaces such as parks and tree-lined streets were positively influencing longevity of senior citizens in dense urban areas. Overall, these studies point toward the fact that GI can promote active travel by providing safe environments for pedestrians (especially for the elderly) and cyclists. Since the terms used in the search strategy did not directly assess physical and psychological health, these results are limited. However, they still point to a relation between GI and people's physical and psychological health and need to be further investigated.

3.3.2 Studies on green stormwater infrastructure

So far, most studies analyzed do not distinguish between GI and GSI. This section examines the studies that explicitly analyze GSI. These studies consist of conceptual frameworks (9 studies), qualitative and quantitative studies (12), and examples of specific projects (7). The conceptual frameworks discuss general concepts of urban planning that bring active mobility and GSI together. The qualitative and quantitative studies analyzed the effects of GSI on the perceptions of a specific group by conducting surveys, interviews or focus groups. Unlike the studies on GI discussed in Section 3.2, the main focus of these studies is not active mobility. The examples of projects are studies describing and discussing projects that have implemented GSI, and some authors support their ideas with quantitative measures such as vehicle speeds or collisions. By analyzing these studies, including several qualitative studies, we aim to understand how the potential synergy between GSI and active mobility is addressed in the literature and identify potential co-benefits and barriers.

3.3.2.1 Conceptual frameworks

Within the selected articles, we identified few studies conceptually discussing how GSI can be implemented and the potential benefits it can provide, including supporting active mobility. In general, these studies focus mainly on the benefits in terms of stormwater management (e.g., reducing runoffs and peak flows) (Condon & Isaac, 2003; Engel-Yan et al., 2005; Low et al., 2008;

Moretti & Loprencipe, 2018; Rayan et al., 2022; Rybicki et al., 2022; Wen et al., 2022). Nonetheless, many studies highlighted the necessity to build multifunctional streets and open spaces to optimize the space (Artmann et al., 2019; Condon & Isaac, 2003; Engel-Yan et al., 2005; Moretti & Loprencipe, 2018), often considering the mobility function of the streets/spaces. For example, Condon & Isaac (2003) studied the East Clayton green infrastructure plan in British Columbia, Canada. This plan focused on stormwater management, active mobility and lowered infrastructure costs. In addition to the benefits of trees on moderating hydrologic fluctuations and shading the street, they mentioned that open spaces and parks can be used to implement naturalized wetland and overflow ponds, which can make parks more attractive and support recreational walking. Along riparian areas², they recommended implementing greenways and riparian parkways to provide a multi-use transportation corridor that can play an important role in water management and provide a safe environment for cyclists and pedestrians. The benefits emphasized in the plan suggested that a project that aimed at densifying and diversifying services, and setting up green streets to encourage active travel should reduce the modal share of motorized travel by offering an interesting alternative (Condon & Isaac, 2003). Along the same line, some studies raised the importance of understanding the interactions between infrastructure systems (for water, transportation, and buildings) to design sustainable neighbourhoods (Engel-Yan et al., 2005; Rybicki et al., 2022). For instance, Engel-Yan et al. (2005) emphasized that trees can intercept rainfall (i.e., reduce stormwater runoff), create sidewalk shading, act as a barrier to traffic noise, and provide shade and wind barriers for buildings. Another study emphasized that GSI can reduce the risk of flooding, which can compromise the safety of road users, especially pedestrians (Moretti & Loprencipe, 2018).

In line with these studies, Ferguson (2012) proposed a conceptual framework to assess the multiple functions of a street. The author mentioned that different elements in the street are interacting and can be designed to enhance the functions of other features. Ferguson (2011) discussed the spatial allocation of GI and GSI in order to enable human and environmental functions. The framework highlights that it is necessary to understand how different zones (e.g., the pedestrian through zone, the furnishing zone between pedestrian path and the curb, the moving zones for vehicles, etc.) relate to each other and what the activities are within each zone. Then, it is possible to take advantage of

² Dans ce contexte, une bande riveraine (riparian area) fait référence à la zone adjacente à une rivière.

the multiple potential roles of the street by implementing new infrastructure such as GSI to meet nature and human goals. For instance, the pedestrian through zone should enable pedestrians to move without obstacles, whereas the furnishing zone must meet several needs, such as space for transit stop, bike storage, access to parked cars, seating, GSI (Ferguson, 2012). These elements should be designed to ensure all human and environmental functions are met. The Green Axes, an ongoing project in Barcelona, Spain, has been described as an example of multifunctional streets that aim to facilitate active travel, create human spaces, maximize greening, and improve natural drainage (Magrinyà et al., 2023). The interconnected streets were designed to prioritize active modes over motorized modes and allow social use of the space by creating square gardens at the intersection of the green axes. The design provides a continuous structural soil suitable for plant growth and a sustainable drainage system that maximises on-site infiltration (Magrinyà et al., 2023). Overall, the frameworks, although mostly focusing on sustainable stormwater management, consider the potential benefits on mobility through multifunctional streets and reallocation of space.

3.3.2.2 Qualitative and quantitative studies

The literature search revealed a few case studies that looked into perceptions and behaviours related to the implementation of GSI (6 studies), preferences across different types of GI and GSI (5 studies), and affordance of GSI for children (1 study). Table 3-4 summarizes the 12 case studies by providing the sample, the main goal of the study, and the co-benefits and barriers to implementation. As in the previous section, the review of the studies revealed that the main objective behind the implementation of GSI was to improve stormwater management (e.g. Hérivaux & Coent (2021) and Mottaghi et al. (2021)), whereas active mobility was considered a side benefit. In this section, we focus on the potential co-benefits and barriers of the implementation of GSI related to active mobility found in the qualitative and quantitative studies reviewed. These are: improved aesthetics, increased attractiveness of the street for walking and cycling, allocated space for walking and cycling, creation of recreational opportunities for children, and increased safety.

Regarding mobility, several concerns were related to cars. These include GSI making it more difficult to access certain places by car from the perspective of drivers (Seymour et al., 2010), increasing traffic congestion levels (Ferreira et al., 2021) or reducing parking spaces (Everett et al.,

2015). Hérivaux & Coent (2021) highlighted that implementing an ambitious nature-based solutions (NBS) policy by reducing the place for cars can be a source of inequality for people living further from the city centre and having no alternative to the car. Conversely, people living near the city centre have more concerns about air quality and temperature regulation. With respect to active mobility, Seymour et al. (2010) found that bioswales, native vegetation, and walking paths could improve the attractiveness of active travel. Fischer & Gopal (2021) found that people were willing to change their walking or cycling route to use green street corridors.

However, some concerns were mentioned about safety and aesthetics of bioswales. Everett et al. (2015) found that people appreciated the function of the bioswale, but complained about plant choices, waste in the bioswales and, in general, aesthetics. However, Suppakittpaisarn et al. (2020) found no relation between perceived messiness of the bioswales and overall preferences for a specific type of GSI. People are worried that tall vegetation in bioswales might obstruct drivers' sight, which could compromise pedestrians' safety (Everett et al., 2015). Similarly, it has been shown that cyclists prefer a dense tree canopy cover while limiting the height of shrubs to ensure good visibility (Shan et al., 2022).

Regarding preferences between types of GI and GSI, trees were the most preferred (Ferreira et al., 2021; Fischer & Gopal, 2021; Suppakittpaisarn et al., 2020), whereas Suppakittpaisarn, Larsen, et al. (2019) found that flowers were the most preferred, followed by street trees and well-maintained bioretention cells. A combination of multiple features such as trees, bushes, and low landscaping was also associated with a high level of preference (Fischer & Gopal, 2021; Jakstis et al., 2023). These findings illustrate the various factors that come into play when designing a GSI, beyond the level of vegetation.

Although some of the reviewed studies revealed that some people are aware of the GSI benefits such as shading and cooling effects as well as stormwater management (Seymour et al., 2010), other studies found that respondents were not aware of the main benefits of GSI such as stormwater management and filtration of pollutants (Everett et al., 2015). Shandas (2015) compared the perceptions of GSI from people living in different neighbourhoods and having received different levels of education materials about GSI. The results showed that people who received high levels of outreach and education materials on the project were more likely to be positive towards the implementation of GSI (Shandas, 2015). Moreover, stakeholders' low awareness and insufficient

Table 3-4 Qualitative and quantitative studies analyzing the effects of green stormwater infrastructure

Study (locality)	Sample	Goal	Results – Potential co-benefits and barriers of implementing GSI
Seymour et al., 2010 (Los Angeles, US)	Five focus groups with 39 participants living near alleys. The study areas were dealing with issues of flooding, safety or trash pollution, and had poor park conditions. One alley had already been turned into a green alley.	Investigate perceptions of green alley projects in low-income residential neighbourhoods following the creation of a Green Alleys Program that aims to reduce runoff and increase active mobility and safety.	Mobility: Participants were concerned about maintaining access for vehicles in the alley. The authors mentioned that bioswales, native vegetation, and walking paths in the alleys can promote active living. Preferences: Participants indicated that the design of green alleys should prioritize utility, safety, cleanliness, and recreational opportunities for children. They were responsive to the idea of adding GSI. Awareness: The participants mentioned some benefits such as shading, cooling effect, aesthetics, room to sit, room for walking or cycling, limiting puddles and standing water, and stormwater infiltration.
Adkins et al., 2012 (Portland, US)	Survey among 748 people. One study area with “deluxe” green street facilities (planted basins with attractive plants and some trees), one with “basic” green street facilities (standard lawn-covered planting strips with trees), and two control areas.	Understand how two different types of green streets influence the attractiveness of walking. The measure of attractiveness was obtained by asking respondents to identify on a map on which segment they like to walk.	Mobility: The “deluxe” green streets were more attractive for walking than normal streets. However, the “basic” green streets were not significantly better than normal streets. The presence of an adjacent park to the street also significantly increased the attractiveness of walking. Separation of the sidewalks from the street by sidewalk setbacks or on-street parking also significantly increased the attractiveness of walking, but at a lower level than “deluxe” green streets and parks.
Shandas, 2015 (Portland, US)	A survey in 2009 (650 responses) and a follow-up survey in 2011 (132 responses). The study site includes six neighbourhoods where the city planned or had undergone construction of GSI and two control neighbourhoods.	Understand how the implementation of GSI (in the right-of-way) affects perceptions of neighbourhood quality and services and if demographic factors increase the likelihood of adopting stewardship behaviours to maintain the GSI.	Awareness and acceptability: Results suggested that people who received higher levels of outreach and education in the program are more likely to accept the implementation of new green facilities. Stewardship: People who rated their neighbourhood with higher average scores were more likely of stewarding a public stormwater facility. In the two neighbourhoods where facilities were installed, fewer people were interested in stewardship. There were differences in the variables that influence the likelihood of adopting stewardship behaviours when analyzing income groups. Being older was associated with a lower interest in stewardship.
Everett et al., 2015 (Portland, US)	Interviews with 45 residents living in a residential neighbourhood with bioswales in the right-of-way.	Understand attitudes, perceptions, and behaviours of people living near bioswales.	Mobility: Few respondents complained about losing parking spaces. Safety: Residents mentioned that people can fall into the bioswale, and tall vegetation can obstruct drivers’ sight. Aesthetics: Many complains were about mess and littering as many respondents found that there is a lot of waste in the bioswales. Some residents thought the bioswales were not well-maintained and some would like to change the plants or have the possibility of maintaining them themselves. People generally appreciated trees in the bioswale, but a small minority of people disliked them. Biodiversity: Some respondents complained about having more insects. Awareness and acceptability: Some respondents were not aware of benefits for floods and did not understand how bioswales can filter pollutants. Along with people who were happy with the bioswales, people environmentally engaged were more positive than others.

Table 3-4 Case studies analyzing the effects of green stormwater infrastructure (continued)

Study (locality)	Sample	Goal	Results – Potential co-benefits and barriers of implementing GSI
Mottaghi et al., 2021 (Malmö, Sweden)	Survey among 328 households near a park and observations of children's behaviour in the park.	Analyze the affordance of GSI (ponds, bioswale and paved canals connected to a large sunken lawn) installed in a park for younger children (3-6 years) and middle-aged children (7-10 years).	GSI preferences: People living with children used the sunken lawn more frequently than other GSI. Potential activities: The classification of the affordance of the GSI showed that there are meaningful action possibilities in the GSI for the children such as running, cycling or walking in the sunken lawn when it is dry, hiding in the vegetation, and using bio-waste such as woody debris as tools or treasures. Parental influence: Observations of children's behaviour and the different paths taken has shown that children's behaviour depends on their parents' use of space and on the time spent in the park.
Suppakittpaisarn et al., 2020 (photographs from US cities / 390 participants from US and Canada, and 37 not specified or from elsewhere)	Survey among 427 participants. It consists of 54 images based on six photographs of US cities. Using three levels of tree densities and three levels of bioretention planting densities, each photograph was manipulated to create nine different street configurations.	Analyze people's preferences of different GI by investigating perceived naturalness, safety and messiness of images showing different configurations of streets with different levels of tree density and bioretention density.	GI preferences: Respondents preferred, in order, the landscapes with many trees, few trees and no trees. They preferred landscapes with a lot of bioretentions to no bioretention. However, the difference between no or a little bioretention and little or a lot of bioretention was not significant. Naturalness, safety, and messiness: Results showed that as tree density increases from no tree to few trees to many trees, the perceived naturalness and safety scores also increased. There was no significant relation for perceived messiness. For bioretentions, the difference was significant only between no bioretention and a lot of bioretention. For an increase from no bioretention to a lot of bioretention, there was a small increase in perceived naturalness, safety, and messiness. However, the authors analyzed to what extent the perceived naturalness, safety and messiness can predict the preference. They found that only perceived naturalness and perceived safety were related to preference.
Suppakittpaisarn, Jiang, et al., 2019 (photographs from US cities / participants mostly from US)	Three surveys among 1473 participants. The responses analyzed are preference scores for 145 photographs with GI.	Evaluate preferences of different densities of vegetation for trees, understory, bioretentions and overall vegetation.	Preferences: A higher density of vegetation, either for total vegetation, trees, understory and bioretentions, was significantly associated with a higher preference. The study found that the combination of different types of vegetation was not affecting the relationship between preference and density of vegetation. For overall vegetation, trees and understory, the relation between density of vegetation and preference can be described by a power curve (at low levels of density, an increase of density leads to a high increase of preference, and then the increase in preference gradually attenuates for the same increase in density). The nature of the relationship could not be clearly defined for bioretention.
Suppakittpaisarn, Larsen, et al., 2019 (photographs from US cities / mostly from US)	Survey conducted among 497 laypeople and 117 designers. Analysis of preferences of 55 photographs showing GI, GSI, and barren urban landscape.	Evaluate preferences of different GI and GSI (messy bioretentions, neat bioretentions, lawns and retention ponds, green roofs, street trees, and flowers).	GI preferences: Landscapes with GSI are significantly preferred to landscapes with no GSI. Among all the studied GI and GSI, the preferred types were, in order of preference, flowers, trees, neat bioretentions, green roofs, lawns and retention ponds, messy bioretentions, and the barren category. Overall, the preferences were similar among laypeople and designers. However a t-statistic test revealed a small significant difference for messy and neat bioretention, lawns, and green roofs as designers showed stronger preference for green roofs and neat or messy bioretentions.

Table 3-4 Case studies analyzing the effects of green stormwater infrastructure (continued)

Study (locality)	Sample	Goal	Results – Potential co-benefits and barriers of implementing GSI
Ferreira et al., 2021 (Elvas and Faro cities, Portugal)	Survey conducted through 75 institutional stakeholders from two Portuguese cities (31 from Elvas and 44 from Faro).	Understand stakeholders' perceptions on implementing nature-based solutions (NBS), and understand what determines the respondents' perceptions of urban challenges, priority interventions, proposed NBSs, and potential benefits.	Mobility: The study showed a relationship between stakeholders who consider improving mobility as a priority and those who are concerned with high traffic levels and value cycle-pedestrian green paths. Health and air pollution: Air pollution, a main concern, was associated with concerns about heavy traffic. While stakeholders generally indicated that NBS provide health benefits, they also indicated that the benefits on air purification would be offset by increased traffic congestion due to an increase in green spaces. Conversely, cycle-pedestrians' green paths were associated with better health conditions. NBS preferences: Implementing urban trees was the most preferred NBS and there was a correlation between people preferring urban trees among other NBS and prioritization of having space for leisure and sports. Creating green shaded areas and riverbank rehabilitation were also highly valued.
Fischer & Gopal, 2021 (39 countries)	Survey conducted among 428 people from 39 countries.	Investigate how people have used green street corridors during COVID-19 partial and complete lockdowns.	Mobility: Participants were mostly willing to change their walking or cycling route to use green streets. GI preferences: When asked which type of GI they preferred between street trees, low landscaping (grasses, perennials, and wildflowers), both trees and low-landscaping, green walls/facades, water retention basins/rain gardens or other types, participants indicated preferring street trees with low-landscaping (72%) and street trees alone (15%).
Herivaux et al., 2021 (Lez Catchment, France)	Survey conducted among 400 households to understand preferences for different GI or GSI implementation.	Analyze people's perceptions of ecosystem benefits and negative effects provided by different levels of NBS.	Awareness and acceptability: Co-benefits commonly cited concerned landscape conservation, air quality, climate change mitigation, local temperature, and biodiversity. Overall, the average number of negative effects was much lower than the number of ecosystem services mentioned. Mobility: The most cited disadvantage regarding NBS concerned mobility issues, especially car travel.
Jakstis et al., 2022 (15 European countries)	Survey conducted among 584 European residents.	Analyze preferences for different green and water features. Investigate greenspace visit frequency and outdoor recreation frequency before and during the pandemic.	GI preferences: Among (1) Trees and bushes, (2) Low landscaping, (3) a combination of trees, bushes, and low landscaping, (4) natural habitat, and (5) none of the above, a combination of trees was preferred (3). Among (1) permanent lake or pond, (2) temporary water retention area, (3) natural or constructed wetland, (4) stream or river, and (5) none of the above, scenarios (1) and (4) were preferred. Mobility: Dominant type of neighbourhood greenspace (private, public or mix) and respondents' access to urban greenspace during the pandemic were significantly related to respondent's greenspace visit and outdoor recreation behaviour.

knowledge about the benefits and challenges of implementing NBS, such as GSI, can explain the mixed results found by Ferreira et al. (2021). Indeed, stakeholders indicated that NBS such as cycle-pedestrians' green paths can provide health benefits. However, they also mentioned that the implementation of green spaces would increase traffic congestion and offset the benefits on air purification initially provided by the NBS. These findings suggest that the benefits of GSI are not yet well understood by citizens and stakeholders. This can influence perceptions and, in turn, active mobility outcomes.

The studies also mentioned outcomes related to stewardship, biodiversity, and potential benefits for children, as shown in Table 3-4. The studies demonstrate that a particular attention needs to be paid to children, considering that in urban settings, GSI often occupy open spaces that could otherwise serve as playgrounds (Mottaghi et al., 2021). Mottaghi et al. (2021) raised the fact that to better meet the needs of children, it is necessary to understand the social and spatial aspects of children's behaviours. The analysis of focus groups conducted by Seymour et al. (2010) also highlighted that green alleys should prioritize the addition of recreational opportunities for children.

3.3.2.3 Examples of projects around the world – Identification of potential outcomes

In this section, we discuss seven studies identified in the article selection process that described a total of 22 GSI projects. These studies, summarized in Table 3-5, consisted mainly of thorough descriptions of projects, together with a discussion of potential outcomes. While the studies presented in the previous section are based on a comprehensive methodological framework to analyze the outcomes of GSI, the focus here lies on the description and discussion of the projects. Some authors support their ideas with quantitative data, such as vehicle speeds or crash rate analysis. These studies revealed that the goals of the projects were related to stormwater management, road safety, active mobility, and the development of high-density neighbourhoods. We focus here on the aspects related to road safety and active mobility.

First, the studies suggested that the implementation of GSI has the potential to increase safety by reducing the width of the road and serving as a traffic calming measure (Clemente, 2020; Greenberg, 2008; Polanski, 2015; Valente et al., 2021). Following the implementation of GSI in the right-of-way in projects in the United States, Polanski (2015) observed a reduction of traffic

Table 3-5 Examples of projects that implemented green stormwater infrastructure

Study	Description of the project	GSI implemented	Potential outcomes related to mobility
Greenberg (2008)	Ten projects in the United States and Canada: investigating the potential of sustainable projects to bring common benefits related to improvements of movement, ecology, and community concerns.	Infiltration basins and landscaped curb extensions, bioswales, rain gardens, street trees, permeable centre medians, permeable paving, and gravel storage trenches under the permeable paving.	- Improving pedestrian safety by reducing the width of the streets to be crossed, creating shelters in the centre of streets, or adding a physical separation between pedestrians and motor vehicles. - Reduction of vehicle speeds following the reallocation of spaces from motorized vehicles to GSI and active paths.
Girling (2010)	UniverCity, Vancouver, Canada: building a high-density neighbourhood while protecting downstream salmon habitat.	On parcel detention and infiltration, green streets with a variety of GSI, and large-scale detention and infiltration facilities such as ponds within green spaces.	- Reducing the impervious areas of the road network (i.e., reducing the space allocated to motorized vehicles). - The project aims to build a high-density neighbourhood with connected pedestrian and cycling networks and offering transportation choices.
Polanski (2015)	Three projects in the United States: improving stormwater management, securing the street and reallocating the spaces between all users. For all projects, a portion of the space allocated to motor vehicles was reallocated to pedestrians and GSI.	GSI were all implemented on the right-of-way. They include a channel creek as a centre median, street trees, vegetated tree pits, vegetated curbs at intersections, and vegetated chicanes.	- Most of the GSI implemented can serve as traffic calming measures. Reducing the width of the street and adding chicanes can reduce vehicle's speed. - Vegetated curbs at intersections reduce the crossing distance for pedestrians. - Street trees along the sidewalk and in the median centre reduce the optical width of the roadway. - Increasing the space allocated for pedestrians and cyclists.
Shafraay & Kim (2017)	Three walkable urban projects in Seoul, South Korea: the Cheonggyecheon project is a pedestrian walkway of 5.8 km along a water stream that was previously covered by a highway. The Seoulllo project is a pedestrian walkway of 983 m with green elements. The Yongdu Park is a pocket park.	Cheonggyecheon project: increase in plant species from 68 to 308 and implementation of waterfalls and fountains. Seoulllo project: 684 circular planters and 23,195 trees (215 types/50 families). Yongdu Park: small green space.	- Improving the aesthetic quality of the landscape. - The Seoulllo project has improved the connectivity of the pedestrian network by converting a highway to a pedestrian path. - The Cheonggyecheon project contributed to increasing public transit ridership. - The Yongdu Park meets the needs of residents and has the potential to improve landscape design and social interactions.
Clemente (2020)	Cycle networks integrating stormwater management developed in Boston, San Francisco, Zwolle and Copenhagen to prevent roads from flooding when underground drainage networks are saturated.	Boston: permeable pavement, rain garden channels between the street and the path, and tree trenches between the sidewalk and the bicycle path. San Francisco: a raised bicycle path that allows water to be dispersed into a backfill. Zwolle: a bicycle path with a hedge alongside and trees. Copenhagen: a bicycle path with a drainage system underneath.	- Moderating traffic by reducing road widths. - Implementing bicycle paths. - Trees that cover the bicycle path can create shade. - Increasing the safety and attractiveness of cycling paths.
Samuel et al. (2021)	Africa Avenue/Bole Street, Addis Ababa, Ethiopia: reconstruction of an arterial road with a higher width and addition of GI.	GI and GSI were implemented along the arterial road. The authors mentioned bioswales, planter boxes and trees.	The study suggests that developing projects that aim to maximize GI and GSI benefits can lead to more sustainable transport.
Valente et al. (2021)	The State Road 7 bis, Campania, Italy: restructuring the road by adding bicycle and pedestrian paths and implementing GSI to increase safety and mitigate flooding.	Street trees, tree pits, tree trenches, planters, swales, bioretention, green spaces and permeable paving.	- Improving comfort of cyclists and pedestrians by creating shading areas and reducing heat islands. - Some configurations allow cyclists to be isolated from vehicular traffic, which greatly improves the safety of cyclists. - For narrow streets, the proximity of buildings generally provides enough shade for pedestrians and cyclists. Smaller infrastructure such as permeable paving, tall trees, planters, and swales can be implemented.

speed in one project, and anecdotal observations supporting the reduction of speeds for two projects. Conversely, Samuel et al. (2021) observed an increase in pedestrian collisions after the reconstruction of an arterial road in Addis Ababa, Ethiopia, where they implemented GI and GSI, but also increased the width of the road.

Some studies suggested that the development of sustainable neighbourhoods with GSI can improve active mobility. Girling (2010) mentioned that the design of a high-density neighbourhood with green streets can improve the connectivity of the pedestrian and cycling networks. The implementation of GSI is also associated with the potential of reallocating space for active mobility (Clemente, 2020; Polanski, 2015; Shafray & Kim, 2017). For example, the Cheonggyecheon project and the Seoulo project in Seoul, South Korea, described by Shafray & Kim (2017) consisted in converting a space for cars, namely two highways, into pedestrian pathways with GI and GSI. These two projects were also studied by Kim, U. et al. (2021) who conducted a survey among pedestrians to understand their satisfaction and their perception of air quality when walking on those greenways compared to walking on a sidewalk path parallel to each greenway. Results showed that respondents who walked through a greenway had a better perception of air quality compared to sidewalk users for both projects. Pedestrians on the Seoulo greenway also reported higher satisfaction than sidewalk users, whereas the results were not significant for the Cheonggyecheon project. The studies by Shafray & Kim (2017) and Kim, U. et al. (2021) were included in our analysis because they address the synergy between water management and active mobility. Specifically, the authors describe the infrastructure as nature-based solutions with objectives encompassing water cleaning and flood prevention. These studies place significant emphasis on walkability aspects and provide examples of street redesigns that promote active transportation. However, most of the green features implemented could be described as GI rather than GSI. Additionally, the Cheonggyecheon project has faced several criticisms, notably the fact that the restored stream is artificially supplied with water from the Han River and an underground source (Jeon & Kang, 2019). These critiques challenge the relevance of this project in terms of water management. Overall, these studies suggest that the implementation of GSI in the right-of-way can promote active travel by improving safety, increasing the connectivity of cycling and walking networks, and developing new dedicated active paths. These studies also highlight that GSI is often implemented as part of a broader project that can bring other modifications that need to be considered when evaluating the design. These studies demonstrate that GSI design and implementation is often done with a concern for active mobility. They also raise the need for

more comprehensive empirical studies examining the complex interactions between GSI and active mobility.

3.4 Discussion

3.4.1 Measured and potential effects of GSI on active mobility

This comprehensive review of the literature identified several measured and potential effects of green features on active mobility in cities. The relationships resulting from this analysis are illustrated in Figure 3-3. Since very few studies have directly assessed the effects of GSI on active mobility, the relationships between GSI and GI are presented together with the relationships between the measured GI and the active mobility outcomes. More specifically, the links between GSI and measured GI illustrate how different types of GSI include various green features.

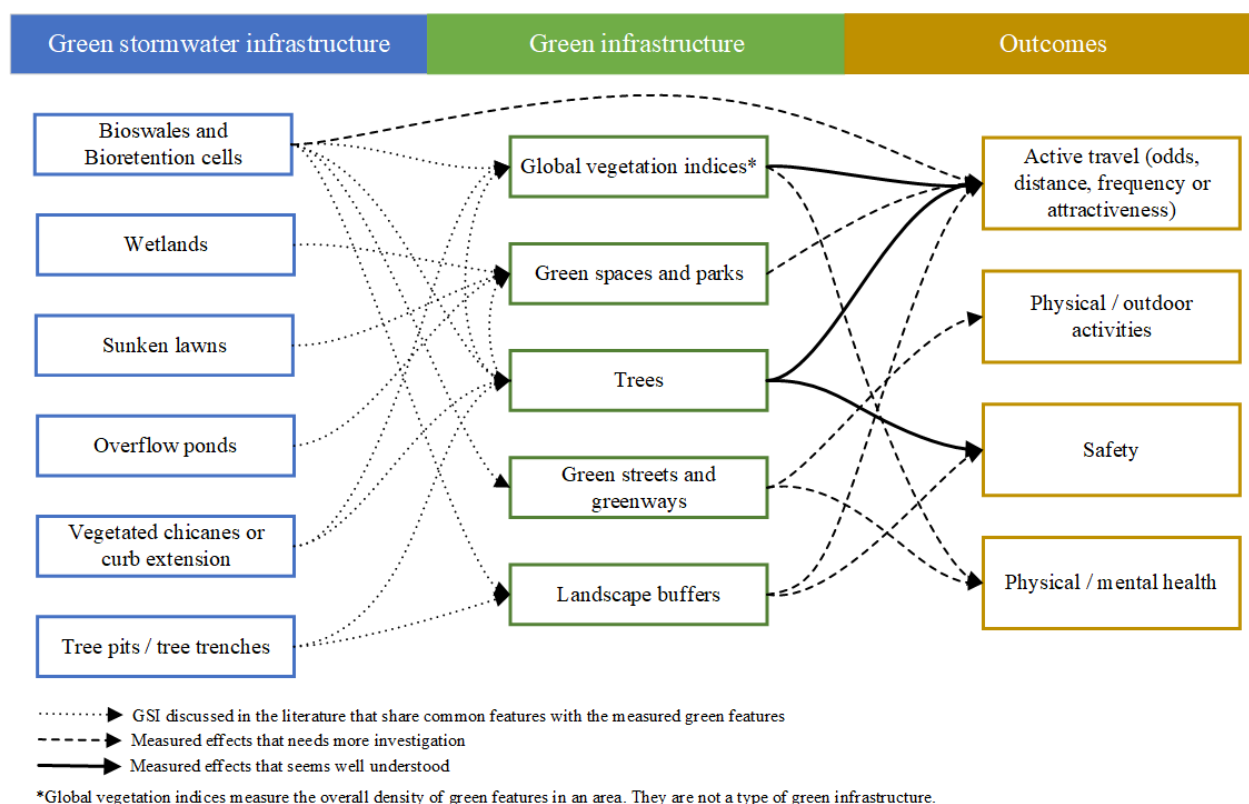


Figure 3-3 Potential and measured relationships between green stormwater infrastructure and active mobility

These links highlight the close relation between GSI and GI and their potential to lead to similar outcomes on active mobility. Bioswales and bioretention cells are the only GSI for which outcomes have directly been measured, showing that there is a need for more empirical studies directly assessing the effects of GSI on active mobility³.

3.4.1.1 Measured effects of green features on active mobility

The main greenery indicators that have been analyzed in the literature are global vegetation indices and number of trees or tree canopy. Overall, these types of vegetation are associated with positive effects on active mobility. As shown in Figure 3-3, the global vegetation indices and street trees have been directly associated with active travel, whereas green spaces and parks have been directly associated with physical activities. Furthermore, street trees have been found to be directly associated with road safety. Green spaces and parks have also been associated with positive outcomes for active travel; however, the relation is more complex as more studies found non-significant results.

The reviewed literature also mentioned some measured effects for bioswales/bioretention cells, landscape buffers, and greenways/green streets as shown in Figure 3-3. However, these effects have only been analyzed in a few studies, which limits the generalization of the results. Their understanding therefore requires further research.

Finally, most measured effects are between global vegetation indices or GI and the outcomes, while there is only one measured relation between GSI and active travel. Therefore, to understand the potential of GSI to promote active travel, the indirect links between the GSI and the outcomes are examined in the next section.

3.4.1.2 Potential effects of GSI on active mobility

As shown in Figure 3-3, the reviewed literature on GSI highlighted many links between GSI and the measured green features that are expected to lead to the same outcomes for active travel. Based on these results, we can establish a link between the measured benefits of GI and the benefits that GSI could bring through its common characteristics with GI. First, several GSI (vegetated chicanes,

³ Il est à noter que certains types d'IVGEP sont très récents et leur mise en place nécessite un espace considérable comparativement aux noues végétalisées ou aux biorétentions. Ces facteurs expliquent également pourquoi les effets de ce type d'infrastructure sur la mobilité active n'ont pas encore été quantifiés.

vegetated curb extensions, tree pits, tree trenches, bioswales, and bioretentions) are characterized by the presence of vegetation, whereas the overall density of vegetation visible from the street (measured through GVI) has been shown to support active mobility. Thus, the findings suggest that the implementation of GSI on the right-of-way, which increases the overall vegetation density, can promote active travel. In addition, as mentioned by Ferguson (2012), it is possible and even easier to plant trees in GSI such as rain gardens, since these types of infrastructure provide more rooting space for urban trees to grow and reach a higher canopy density. In this regard, Grey et al. (2018) demonstrated that tree pits with an underdrain can achieve twice the growth compared to conventional street trees (receiving a lower amount of rainwater). Furthermore, this study highlights the importance of proper drainage to prevent water saturation that hinders tree growth.

The implementation of GSI can also increase the density of street trees and lead to similar benefits as those illustrated in Figure 3-3 (increase in active travel and improved road safety). Trees can be planted in several types of GSI, such as bioretentions, vegetated chicanes, vegetated curb extensions, etc.

Moreover, the implementation of GSI is often done directly in the right-of-way, which leads to a change in the allocation of the urban space. This specific characteristic of GSI requires particular attention since it seems to bring benefits, but also raises concerns with respect to social acceptability. On the one hand, several studies mentioned that GSI can improve safety by reducing the width of the road and acting as traffic calming measures (Clemente, 2020; Greenberg, 2008; Polanski, 2015; Valente et al., 2021). For example, GSI, such as tree trenches and bioswales, can be implemented between the active path and the motorized path, thereby creating a physical barrier to protect pedestrians and cyclists from motorized vehicles. Studying the use of bicycle lanes to access urban parks, Niță et al. (2018) showed that illegally parked cars were an important factor influencing the use of bicycle lanes. This problem can be overcome by implementing GSI as a physical barrier between the road and the bicycle lane. Moreover, some types of GSI can be implemented as traffic calming measures such as vegetated chicanes or vegetated curb extensions. On the other hand, this reallocation of space also brings concerns within the population. Studies highlighted that there are concerns about car mobility, safety and aesthetics, and that there is a lack of awareness and acceptability for those projects (Everett et al., 2015; Ferreira et al., 2021). The analysis of the literature specific to GSI has raised several considerations, especially among car users that have had to adapt their behaviour to a new street configuration. This highlights the

challenges associated with the implementation of GSI. Indeed, the implementation of GSI on a space that was previously dedicated to motorized vehicles, such as implementing roadside bioswales, implies significant changes for users. Research is required to understand the specificities of GSI that challenge the social acceptability of these projects, notably its footprint, which is larger than GI.

Finally, as shown in Figure 3-3, several GSI such as sunken lawns and overflow ponds can be implemented in green spaces or parks. These features may be attractive for leisure active travel. The analyzed studies also mentioned the need to reduce impervious surfaces and reduce the risk of flooding by implementing GSI that allows water to infiltrate into the soil instead of using typical drains. By reducing the risk of road flooding, GSI can improve mobility for all users.

Overall, considering the benefits of green features, especially street trees, it seems that GSI can play a similar role and should promote active travel.

3.4.1.3 Social and contextual considerations

Through this review of the literature, heterogeneity in the relationship between vegetation, GI and active travel was found across age groups, gender, built environment characteristics and regions. Several studies found positive impacts of green features on the mobility and safety of elderly people. GSI can be implemented as a raised median that divides the street into two sections and serves as a refuge for the elderly who need to rest before crossing the second part of the road. When implemented as curb extensions, GSI can reduce the length to be crossed at the intersection. Regarding children, the reviewed studies have shown that GI (buffer landscape and shade-casting trees) can promote active travel, and GSI can promote recreational and educational activities. Moreover, several studies found differences between men and women (Akinci et al., 2021; Li & Ghosh, 2018). However, these differences should be further studied.

Finally, some results suggested that studies should pay attention to differences across regions (rural, urban and suburban), and across areas with different densities of the built environment. Indeed, the review suggests that in residential areas where there is a lot of greenery on private land, the effects of planting trees may not be as large as in dense urban areas where there is almost no vegetation. Conversely, the competition for space might be more intense in densely populated areas.

These findings revealed that age, gender, and the density of the built environment are important variables that may influence the effects of GI and GSI on active travel. These findings highlight the complexity of the relationship between GI, GSI and active mobility. Further studies should evaluate the effects of GSI in different regions, and across different population groups.

3.4.2 Research gaps and opportunities

This analysis of the literature on the potential synergy between GI visible in the right-of-way, GSI and active mobility has highlighted research gaps and opportunities relative to the: (i) indicators of green features, (ii) street design and context, (iii) heterogeneity in the population, (iv) distinction between cycling and walking, and (v) social acceptability.

First, the analysis of the indicators used to quantify green features revealed the existence of various indicators representing the same green feature. It is necessary to assess the relevance of different indicators depending on the context of the study and the analyzed outcomes. Although the use of a global index such as the GVI is relevant to understand the overall effects of vegetation (namely since it represents an eye-level view), this indicator does not differentiate the effects by types of vegetation, nor does it consider the surrounding environment. Moreover, the results of the literature search revealed that very few studies evaluated empirically the relation between GSI and active mobility. Thus, further studies should develop new methods for quantifying GSI, while considering the complexity of using a specific indicator.

Furthermore, research is needed to analyze how different street designs and context of the built environment can influence the effects of GI and GSI on active mobility. The analysis of articles on GSI revealed differences in the appreciation of different types of GI and GSI with respect to their specific characteristics (types of vegetation, size, location, etc.). For example, the appreciation of trees seems quite widespread, while the implementation of bioswales, which have a larger footprint, raised several concerns among citizens such as the loss of parking spaces. Moreover, a particular attention should be paid to the differences across regions⁴ (urban, suburban, and rural) since the literature review has shown that the perceptions may vary depending on the density and the built environment. As demonstrated by Wu, Jiayu et al. (2020), the effect of green features (assessed

⁴ Il serait également pertinent de comprendre si les variations de climat entre différentes régions et les variations de température selon les saisons influencent les effets de la végétation sur la mobilité active. De plus, les effets de la végétation varient selon la saison. Par exemple, Chun & Guldman (2018) ont démontré que la végétation (mesurée avec le NDVI) réduit la température en été, mais l'augmente en hiver dans la région centrale de Columbus, Ohio.

with the GVI) on walking and cycling varies depending on the type of road in which they are implemented. Thus, there is a need to further investigate the effects on different types of roads (local, collector and arterial).

In addition to these considerations, further studies should also investigate heterogeneity in the population. Differentiated results have been found across different socio-economic groups, emphasizing the importance of conducting segmented analysis. Among studies on GI, street trees, landscape buffers and raised medians were associated with an increase of road safety, especially for children and elderly people. The studies discussing GSI also revealed some potential to increase pedestrians and cyclists' safety while implementing GSI. Further studies should analyze how the implementation of GSI can benefit vulnerable populations.

Both in the studies on GI and GSI, there were few studies on cycling compared to walking, and the results of the literature review suggest that the effects of GI and GSI vary depending on the travel mode. The travel purpose might also influence the effects of GSI on behaviour and perceptions. Efforts are therefore warranted to make the distinction between walking and cycling activities.

Finally, the case studies on GSI revealed considerations on the social acceptance of projects involving its implementation. More studies are needed to understand the social acceptance of these projects across different population groups and road users (drivers, pedestrians, cyclists, etc.). The social acceptance of the reallocation of the space seems to be a challenge for car users. However, more case studies are needed to understand the perceptions of other users. Moreover, further studies should analyze how people's awareness of the benefits of GSI on the environment is influencing social acceptance.

Overall, the review of 70 scientific articles discussing both green features in general and GSI provided a clear picture of the actual knowledge on the effects of vegetation on active travel, while identifying relationships that remain poorly understood and that require further investigation. More research is certainly needed to understand the effects of different types of GI, and especially GSI, given its potential to achieve complementary objectives.

3.5 Conclusion

This comprehensive review of the literature contributes to the understanding of the existing knowledge on the relationship between GSI and active travel, highlighting the nuances in terms of

outcomes, and identifying relationships that need to be better understood. One of the main findings of this review is the limited number of scientific articles that directly address the relationships between GSI and active mobility. The review of the studies on GSI and active mobility revealed the potential to improve the attractiveness of walking and cycling, reallocate space for active paths and improve safety, through the implementation of GSI. Moreover, we identified some common characteristics between GSI and GI that positively influence active mobility. For instance, both for GI and GSI, some features are visible from the street and they often create a separation between the motorized and non-motorized modes. Through its common characteristics with GI, GSI has the potential to improve active travel, physical activity, road safety, and health.

To guide the design of future studies, we identified gaps in the literature and nuances that require more research. There is a need to develop indicators to identify and characterize different types of GI and GSI in the built environment. The wide variety of indicators used to measure GI demonstrated the need to better understand how to choose the proper indicator based on the purpose of the study. There is a need for more empirical studies investigating how the benefits of GSI materialize in different contexts, across population groups, depending on the travel mode (walking or cycling), and depending on the types and features of GSI. This scientific contribution will help researchers develop studies that will hopefully lead to evidence-based recommendations regarding the implementation of GSI. For now, the findings from our comprehensive review of the literature can support decision makers at the municipal level in better considering potential active travel benefits when planning the implementation of GSI.

3.6 Competing interests

The authors declare that they have no financial and non-financial competing interests.

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**CHAPITRE 4 ARTICLE 2 : GREEN STORMWATER
INFRASTRUCTURE AND ACTIVE MOBILITY: A CASE STUDY
INVESTIGATING THE EFFECTS OF BIOSWALES ON INDIVIDUALS’
PERCEPTIONS**

TRAVEL BEHAVIOUR AND SOCIETY, 21 AOÛT 2023

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Abstract

Cities are increasingly designing streets with green stormwater infrastructure (GSI) to improve urban drainage systems, while providing secondary socio-environmental benefits. Yet, the relationship between GSI and active mobility remains underexplored. This study addresses this gap

by conducting a case study analyzing the impact of GSI implementation on individuals' perceptions of walking and cycling infrastructure, while identifying associated challenges and opportunities. The case study focuses on the redesign of five residential streets with bioswales in a small Canadian city. Data was collected through: (i) an online and in-person survey with 296 residents, (ii) interviews with 12 city planners, residents, or workers, and (iii) two focus groups with children aged 10-11.

Findings indicate that implementing bioswales within the right-of-way contributes to enhanced satisfaction with street design for walking and cycling. Bioswales have the potential to improve the comfort and safety of active travellers by reallocating space for pedestrians and cyclists, while segregating non-motorized and motorized traffic. However, satisfaction with bioswales varies significantly among individuals, following personal characteristics and attitudes. Factors such as exhibiting eco-friendly behaviour, valuing the aesthetics of the neighbourhood, and recognizing the socio-environmental and active mobility benefits of bioswales positively contribute to satisfaction. Conversely, limiting factors stem from changes experienced by car drivers due to the new street configuration and limited agreement or awareness regarding the socio-environmental benefits they provide.

This paper is relevant to planners and researchers wishing to understand the challenges and opportunities associated with designing multifunctional streets to support sustainable urban drainage systems and active mobility.

Keywords

Active mobility, Walking, Cycling, Green stormwater infrastructure, Bioswale, Urban Design

Highlights

- Street designs with bioswales enhance satisfaction for walking and cycling
- Bioswales improve aesthetic, comfort, and safety for active travellers
- Concerns about bioswales are primarily related to car transportation
- Understanding street functions is key for sustainable urban design

4.1 Introduction and Literature Review

In the context of urban densification, space competition is becoming a real challenge. Urban planners are therefore striving to design the built environment in a way that addresses multiple needs within limited space. Furthermore, incorporating nature into urban areas has emerged as a crucial approach to mitigate climate change impacts and provide liveable communities. More specifically, studies have shown that urban vegetation has the potential to improve walking and cycling by creating a comfortable, safe, and attractive environment (Adkins et al., 2012; Kweon et al., 2021; Piselli et al., 2018; Seymour et al., 2010).

The literature has demonstrated that increasing the density of vegetation within an urban area can increase the odds, frequency, and distance of active travel (walking or cycling) (Ki & Lee, 2021; Lu et al., 2018; Yang et al., 2019). Moreover, vegetation contributes to active travel by providing shading areas, improving thermal comfort, and improving air quality (Detommaso et al., 2021; Jia et al., 2021; Sylliris et al., 2023). Studies on specific vegetation elements such as street trees or green spaces have shown that urban vegetation can facilitate and promote active travel (Nawrath et al., 2019; Ozbil et al., 2021; Sarkar et al., 2015; Vich et al., 2019). Street trees can increase both perceived and objective safety (Kim, D., 2019; Zhu et al., 2022). For instance, the presence of trees along the road can create a more enclosed streetscape which reduces the driver's field of sight (Harvey & Aultman-Hall, 2015; Harvey et al., 2015). This encourages more responsible driving behaviour, including driving at slower speeds (Naderi et al., 2008). Additionally, research has demonstrated that people feel safer when there is lateral separation between the sidewalk and the curb such as a grass strip (Kweon et al., 2021; Landis et al., 2001). Regarding objective safety, street trees have been associated with lower risk of collisions involving pedestrians (Kim, D., 2019; Zhu et al., 2022).

In recent years, cities have been implementing green stormwater infrastructure (GSI), a specific green feature designed to capture and infiltrate and/or treat runoff to increase the resilience of drainage systems (Casal-Campos et al., 2018). With its vegetation, GSI can offer similar socio-environmental benefits as other green features, e.g., improving air quality, thermal comfort, and mental health (Abhijith & Kumar, 2019; Maund et al., 2019; Shafique & Kim, 2017; Shaneyfelt et al., 2017). In addition, by minimizing the risk of urban flooding, it contributes to enhancing the safety of all road users (Moretti & Loprencipe, 2018). Due to its main goal of collecting runoff, the

implementation of GSI in the built environment significantly changes the allocation of the space. Its deployment is often opportunistic, taking advantage of the need to renew the road or underground drainage system (Kuller et al., 2018). GSI can be implemented directly in the right-of-way to collect runoff from the impermeable surface of the street (road lanes, sidewalks, and bike paths). It is typically installed along the street edge, thereby offering the potential to enhance active travel by creating a physical barrier between motorized and active pathways.

Several studies reviewing recent GSI projects in the right-of-way have highlighted that integrated urban projects have the potential to yield benefits for both active mobility and stormwater management (Lemieux, Charlotte et al., 2023). The implementation of GSI can improve safety by acting as traffic calming measure such as vegetated curb extension or by reducing the width of the motorized lanes (Clemente, 2020; Greenberg, 2008; Polanski, 2015; Valente et al., 2021). Some projects have taken advantage of the redesign to include more space for active modes and isolate the active path from the motorized path (Clemente, 2020; Polanski, 2015; Shafray & Kim, 2017). Moreover, Adkins et al. (2012) found that GSI increase the attractiveness of walking activities. Suppakittpaisarn, Larsen, et al. (2019) showed that people prefer landscapes with GSI compared to nothing.

It is worth noting that previous studies incorporating an analysis of individuals' perceptions (e.g., questionnaires, interviews, or focus groups) highlighted certain concerns regarding the implementation of GSI. These concerns were primarily related to the visual aesthetics of the infrastructure and the potential constraints it may impose on car mobility. Everett et al. (2015) found that participants expressed dissatisfaction with the aesthetics of bioswales and the choice of plants. They also reported that debris tends to accumulate into the depressions of the bioswales, which are designed to temporarily store rainwater. Moreover, other studies demonstrated that there was apprehension among certain individuals that the implementation of GSI could have negative impacts on car travel (Ferreira et al., 2021; Hérivaux & Coent, 2021). These concerns include potential reductions in the number of lanes, removal of parking spaces, or the narrowing of the street width, which could constrain vehicle maneuvers (Everett et al., 2015; Seymour et al., 2010). Additional concerns were raised regarding pedestrian safety, as there were worries that individuals might accidentally fall into the bioswales, or that tall vegetation could obstruct drivers' line of sight (Everett et al., 2015). To the best of our knowledge, Adkins et al. (2012) is the only quantitative study that specifically aimed to measure the effects of GSI on active mobility. However, several

qualitative studies have also explored this topic, including works by Everett et al. (2015); Polanski (2015); Seymour et al. (2010); Valente et al. (2021). The existing literature has highlighted the potential benefits that GSI can bring to active mobility, including improved safety, aesthetics, and comfort. Furthermore, analyses of residents' perceptions of GSI have revealed several concerns regarding its implementation.

To address the gap in understanding individuals' perceptions of active mobility (walking and cycling) following the implementation of GSI, we have chosen to investigate a recent project in the City of Saint-Charles-Borromée (Quebec, Canada) that has incorporated bioswales within the right-of-way. Given the limited existing research on this topic, a case study methodology was employed to gain a comprehensive understanding of the factors that influence people's perceptions. It is crucial to enhance our understanding of the relationship between GSI and active travel, given the close interaction between mobility infrastructure and water management infrastructure within the right-of-way. The findings will assist urban planners in designing multifunctional streets.

4.2 Data and Methods

The research design is based on a case study methodology (as described by Meyer (2001)), including a survey, interviews, and focus groups. A case study is an appropriate way to explore new concepts with limited existing literature, as it allows to tailor the study to a specific context (Meyer, 2001). It also gives a holistic view of the case by providing detailed information on several complementary aspects. Relationships that could not have been so well understood in a strictly quantitative study can emerge from this process (Meyer, 2001).

The reasons mentioned above apply to our research topic, considering the recent implementation of GSI in several cities around the world (Greenberg, 2008; Polanski, 2015; Shafray & Kim, 2017; Valente et al., 2021) and the limited scientific literature on individuals' perceptions regarding the synergy between active mobility and stormwater management (Lemieux, Charlotte et al., 2023). Using a mixed method approach (i.e., qualitative and quantitative analyses), we reached a diversity of actors (municipal stakeholders, citizens, and children). This approach enables us to capture diverse perspectives from a wide range of population groups, leading to comprehensive insights that reflect the needs of all stakeholders (Gagnon, 2012). The survey gathers opinions from numerous respondents to evaluate overall satisfaction with different street designs and identify divergent groups based on individuals' characteristics. Interviews with planners, residents, and

workers provide insights into stakeholders' perceptions before, during, and after the project. Finally, focus groups contributed to understanding the needs of young people. Combined, these methods provide an overview of the opportunities and challenges related to the implementation of bioswales in smaller municipalities and suburban areas. It makes it possible to analyze the preferences of the individual while underlining the factors which contribute to these preferences. Ethical approval was obtained from the Research Ethics Board at Polytechnique Montreal⁵.

4.2.1 Study Area

The project at the centre of our case study consists of the redesign of five street segments located in Saint-Charles-Borromée (Quebec, Canada), a small city with a population of 15,285 (Statistics Canada, 2023). The City took advantage of the necessity to replace the sewage system to implement GSI. This GSI initiative aligns with the City's vision of developing climate-resilient infrastructure, enhancing stormwater management, and adding greenery to the area. Additionally, the City highlighted the benefits for active mobility. Figure 4-1 shows a map of the municipality and study area, with the redesigned streets located at the southeastern end of the city. The study area is primarily residential, with a concentration of shops, restaurants and services on the main street, and a hospital located approximately 500 m from the redesigned streets.

Figure 4-2 provides examples of the infrastructure implemented. The segments were redesigned with bioswales placed at ad hoc intervals to accommodate parking spaces. In the intervention area, 70% of street parking spaces were removed; most citizens have access to private parking lots. As part of the project, 200 trees were planted, while 20 trees identified as harmful or diseased were felled. Additionally, two segments feature bidirectional bike paths isolated from the road by bioswales. Prior to the redesign, one of these segments included a conventional bike lane (designated with markings and signage), while the other segment did not have a bike lane. The construction phase began in July 2021 and was completed in July 2022. Planting took place after winter, in June 2022.

⁵ Project #CER-2223-21-D.

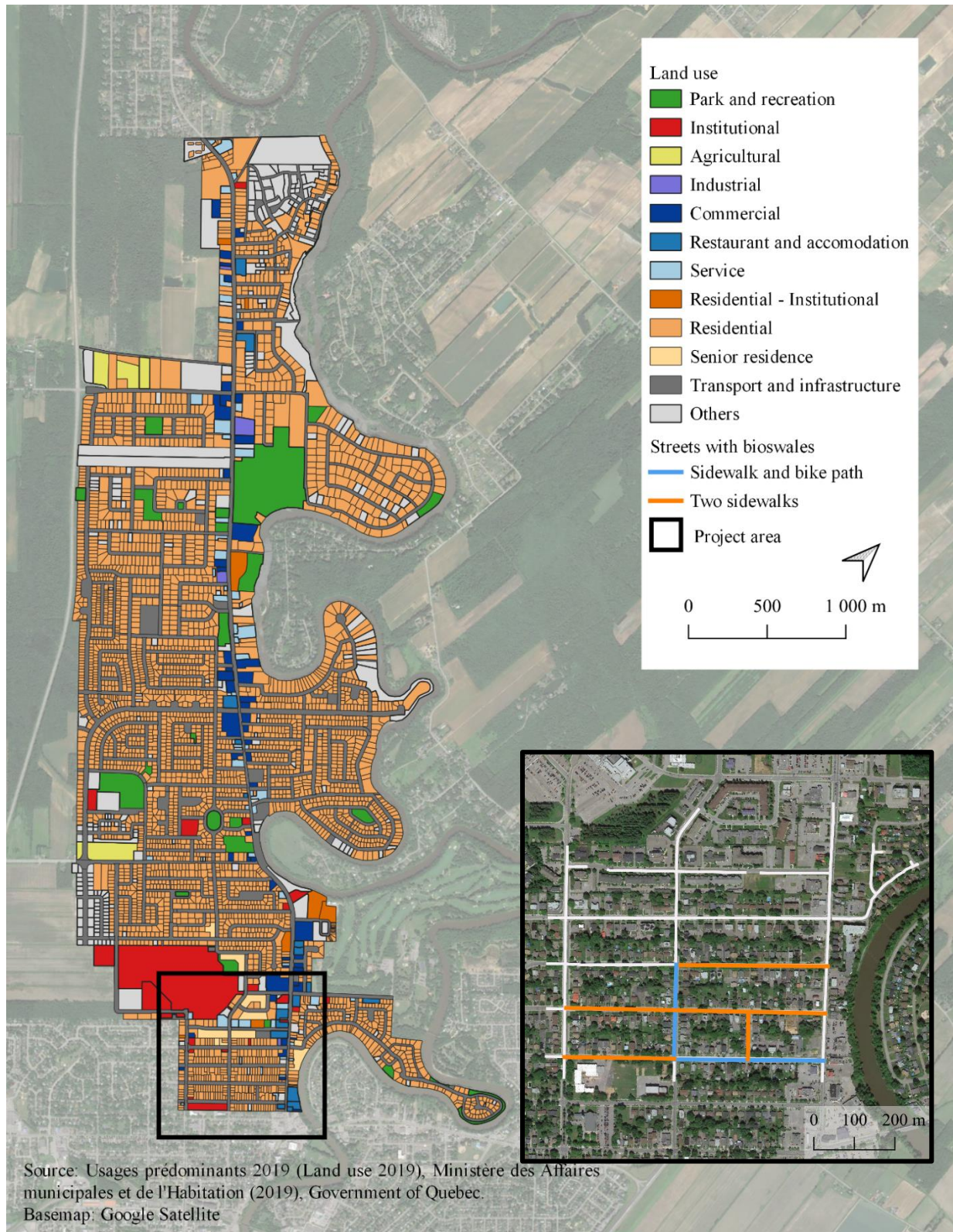


Figure 4-1 Study area and street segments with bioswales



Figure 4-2 Examples of bioswales implemented on five residential streets

4.2.2 Data Collection and Analysis

Data was collected from September 2022 to January 2023 through a survey with citizens ($N = 402$), interviews with various stakeholders ($N = 12$), and two focus groups with children aged 10-11 ($N = 13$). After excluding incomplete questionnaires ($N = 95$) and those where either age or questions used as dependent variables were not available ($N = 11$), the dataset consisted of 296 observations.

4.2.2.1 Quantitative Data Collection and Analysis

The survey was released online from September 21 to October 16, 2022, and all citizens aged 18 and above were eligible. The City of Saint-Charles-Borromée disseminated the survey through email and text message to 1677 individuals (66 City employees and 1611 residents) who subscribed to City communications. To ensure an adequate number of responses from individuals residing near the study area, researchers conducted door-to-door visits on all the redesigned streets. Residents had the option to either complete the survey online or fill out a paper form. A total of 25 paper surveys were collected alongside the online responses.

The survey included questions on socio-demographic characteristics, travel behaviour, respondents' attitudes towards their neighbourhood, and respondents' behaviour in their daily activities (recycling, composting, respecting speed limits while driving, etc.). The last section of the survey specifically focused on the satisfaction with the recently implemented bioswales. Photos showing the new infrastructure (Figure 4-2) allowed respondents not familiar with the project to have a better understanding of the project. As done in previous studies (Nawrath et al., 2019; Suppakittpaisarn et al., 2020), this section included a question to collect people's satisfaction level

on a scale of one (strongly dissatisfied) to seven (strongly satisfied) with three street configurations for walking and cycling (six scenarios in total). These scenarios are illustrated in Figure 4-3. To ensure consistency in terms of built environment, Adobe Photoshop was used to change the vegetation, while maintaining the same built environment in all scenarios for a specific mode (walking or cycling). The photos of bioswales used in the scenarios were obtained from a



Figure 4-3 Walking and cycling scenarios with different green levels (no vegetation, grass strip, and bioswale). Respondents were asked to indicate their level of satisfaction from one to seven for walking (or cycling) in three street configurations.

previous project conducted in 2013 in Granby (Quebec, Canada). This project was chosen as it provided bioswales of similar size to those in Saint-Charles-Borromée. These images aimed at

providing a realistic representation of how the bioswales would appear once the plants reached maturity. Additionally, a street with a comparable width to the redesigned streets was chosen.

Regression Analyses

To examine the relationship between satisfaction levels for different greening scenarios (Figure 4-3) and individuals' socio-demographic characteristics, exploratory linear regressions were conducted. There are two models for each mode (walking and cycling). For walking, the two scenarios compared are a bioswale versus a grey street ($Y_{bioswale-grey}$), and a bioswale versus a grass strip ($Y_{bioswale-grass}$). For cycling, the scenarios are the same, except that the sidewalk is replaced by a bike path.

For the sake of simplicity, regression equations are written in matricial form. The equation used in the regression models, both for walking and cycling scenarios, are **Equation 1** and **Equation 2**:

$$Y_{bioswale-grey} = \beta_0 + \beta_{SD}X_{socio-demographic} + \beta_{BA}X_{behaviours\ and\ attitudes} + \epsilon \quad (1)$$

$$Y_{bioswale-grass} = \beta_0 + \beta_{SD}X_{socio-demographic} + \beta_{BA}X_{behaviours\ and\ attitudes} + \epsilon \quad (2)$$

Where:

Y represents the difference in scores between two images with different levels of vegetation, ranging from minus six to six. For example, a score of 7 for a sidewalk isolated by a bioswale (c) versus a score of 4 for a sidewalk in a grey street (a) leads to a value of 3 for $Y_{bioswale-grey}$.

β_{SD} contains the regression coefficients associated with socio-demographic variables.

β_{BA} contains the coefficients associated with variables that accounts for respondents' attitudes towards their neighbourhood, and respondents' behaviour in their daily activities.

ϵ is the error term of the regression.

Several socio-demographic variables were included in the model as factor variables. Age, household income, occupation, and education levels were each categorized into three groups. Additionally, the presence of a child in the household indicated whether the respondent lived with at least one individual under 18 years old. As 97% of the sample reported having access to a car, we did not include that variable in the analysis. The respondent's home location was categorized into three groups: living less than 400 m away from the redesigned streets (0-399 m), equal to or farther than 400 m away, or unspecified (Unknown). We hypothesized that individuals' attitudes

towards their neighbourhood and behaviour in their daily activities could influence their satisfaction with different greening scenarios. Thus, we designed 13 questions with a 5-point Likert scale to evaluate individuals' attitudes and behaviours regarding these issues. Considering the limited size of our dataset and the inherent difficulty in directly interpreting the values of these variables, we used exploratory factor analysis (EFA). This allowed us to reduce the number of variables by identifying latent variables (factors) that could be utilized as independent variables in the regression analysis (Yong & Pearce, 2013). EFA accounts for common variance among the input variables (Suhr, 2005). It creates standardized latent variables (z-scores) that can be interpreted with the factor loadings. Three questions were excluded from the analysis as more than 5% of the sample did not respond, or a high percentage of participants provided identical scores (i.e., a score of 5 out of 5). We conducted EFA to group the ten remaining questions into descriptive categories (factors). The resulting latent variables were used as independent variables in the regression analysis.

To ensure the stability and validation of the results, we also performed ordered logistic regressions treating the dependent variable as an ordered categorical variable. The results were consistent with those of the linear regressions.

Cluster Analysis

To further explore the relationship between individuals' satisfaction of the different greening scenarios and individuals' characteristics, attitudes and behaviours, we conducted a k-means clustering analysis. Clustering is a technique used to group a set of observations into subsets based on the similarities among the values of several studied variables. The k-means algorithm aims to minimize the within-cluster sum of squares error (Hartigan & Wong, 1979). In other words, this approach minimizes the differences between observations within a same group. Using the k-means algorithm was advantageous considering our limited dataset ($N = 296$).

Six variables were used to group the individuals according to their level of satisfaction with different greening scenarios. As for the linear regressions, the variables used are the difference between the scores given to two scenarios. In total, three variables were created for each mode (walking and cycling) by comparing a bioswale versus a grey street, a bioswale versus a grass strip, and a grass strip versus a grey street. As all respondents were required to answer these questions,

we were able to include all observations in the clustering. To determine the optimal number of clusters, the elbow method and the average silhouette method were used.

Next, we analyzed the characteristics of the different clusters. The questionnaire included 12 questions directly related to the redesign of the streets with bioswales. These questions explored whether respondents agreed or disagreed (on a 5-point Likert scale) with the notion that bioswales can offer various benefits for the environment, walking, cycling, driving, etc. We examined the distribution of responses for each cluster to identify any trends among specific clusters. This analysis was conducted to assess whether clusters with a higher or lower satisfaction with bioswales agree or disagree with specific aspects related to the implementation of bioswales.

4.2.2.2 Qualitative Data Collection and Analysis

Interviews aimed to better understand the perceptions of different stakeholders. Semi-structured interviews were conducted with municipal stakeholders involved in the project (5) and citizens living or working in the area (7). The semi-structured approach is well suited to understand individuals' perceptions and enables participants to raise issues that are important to them (Galletta, 2013). Themes were designed based on issues identified in the literature and the research question. During interviews with municipal stakeholders, four main themes were investigated: (1) goals and effects of the project, (2) challenges and opportunities, (3) project planning, and (4) communication and citizen involvement. With the citizens, six main themes were investigated: (1) goals and effects of the project, (2) overall appreciation, (3) mobility, (4) safety, (5) environment, and (6) city communications. Interviews lasted an average of 28 minutes. Among the planners, there were two women and three men, while among the citizens, there were three women and four men.

We conducted two focus groups involving a total of 13 children aged 10-11 years (3 girls, 10 boys). The focus groups were held at a school located on one of the redesigned streets. A one-hour preliminary meeting was organized to establish initial contact with the children, followed by a second meeting for the focus groups. We first discussed the children's travel patterns and preferences. Subsequently, we delved into the safety aspects of the streets near the school, as well as the children's preferences concerning street design within their neighbourhood or near the school. Throughout the discussion, we incorporated questions on the redesigned streets. The last exercise involved showing side-by-side images of the redesigned streets before and after the project. The children were asked to identify the changes made, express their preferences, and

identify the safest configuration. Finally, we discussed the functioning and socio-environmental benefits of the bioswales.

Interviews and focus groups were transcribed manually and analyzed using MAXQDA software designed for qualitative research and mixed methods. The analysis followed an inductive approach, allowing themes to emerge from the data without predefining categories. The main themes were identified during the transcription phase. Using these main themes, an initial coding of the interviews and focus groups allowed the emergence of sub-themes. Then, two different authors coded an interview with a planner, an interview with a citizen, and a focus group to validate the choice of themes and sub-themes. The results were compared using MAXQDA's Inter-coder tool to assess the percentage of similarity between codes. The themes and sub-themes were adjusted to allow for consistent coding regardless of the coder.

4.3 Results

4.3.1 Quantitative Analysis

4.3.1.1 Level of Satisfaction of Bioswales for Walking and Cycling

Table 4-1 displays descriptive statistics of the sample compared to census data for people aged 20 and over living in Saint-Charles-Borromée. Nearly half of Saint-Charles-Borromée's population is 65 years or older. However, this age group represents only 22% of the sample. Overall, the subsample of respondents who live within 400 metres of the redesigned streets better represents the actual population. This is due to on-site survey collection.

Table 4-2 presents the rotated factor matrix of the factor analysis carried with the 10 questions on individuals' behaviours in their daily activities and perceptions regarding their neighbourhood. Based on the Guttman-Kaiser rule, three factors were retained. These factors account for 45.6% of the variance. The numbers in bold in the table are the highest value for each question (row). The three categories are: importance given to the neighbourhood aesthetic (four questions), environmental behaviour (four questions), and respect of traffic laws (two questions).

Table 4-1 Socio-demographic characteristics of the sample for linear regressions, with a comparison between residents living within 400 meters and those living 400 meters or beyond from the redesigned streets, compared to census data for the City of Saint-Charles-Borromée

	≥ 400 m		Survey < 400 m		Total		Census Profile 2021*
Observations (%)	186	(67%)	52	(19%)	278	(100%)	12855
Home location							
0-399 m	0	(0%)	52	(100%)	52	(19%)	-
≥ 400 m	186	(100%)	0	(0%)	186	(67%)	-
Unknown	0	(0%)	0	(0%)	40	(14%)	-
Age							
18-39	56	(30%)	11	(21%)	79	(28%)	(20%)
40-64	97	(52%)	30	(58%)	137	(49%)	(34%)
≥ 65	33	(18%)	11	(21%)	62	(22%)	(46%)
Gender - Female	115	(62%)	31	(60%)	173	(62%)	(56%)
Child in household	90	(48%)	18	(40%)	118	(42%)	-
Household income							
< 60K	39	(21%)	20	(38%)	67	(24%)	(49%)
60-125K	72	(39%)	20	(38%)	105	(38%)	(34%)
≥ 125K	54	(29%)	5	(10%)	66	(24%)	(17%)
Unknown	21	(11%)	7	(13%)	40	(14%)	(0%)
Occupation							
Full time	109	(59%)	26	(50%)	150	(54%)	-
Part time	14	(8%)	4	(8%)	20	(7%)	-
Retired	54	(29%)	15	(29%)	90	(32%)	-
Else	9	(5%)	7	(13%)	18	(6%)	-
Higher educational level							
High school	25	(13%)	11	(21%)	41	(15%)	(47%)
College	76	(41%)	21	(40%)	109	(39%)	(33%)
University	85	(46%)	20	(38%)	128	(46%)	(20%)

* Data extracted from the 2021 Census (Statistics Canada, 2023). The data presented includes the population aged 20 and over.

Table 4-2 Rotated factor matrix

Questions	Factor 1 Neighbourhood aesthetic	Factor 2 Environmental behaviour	Factor 3 Respect of traffic laws
It's important to me that my neighbourhood is pretty.	0.867	0.001	0.026
For me, it's important my neighbours take care of their property.	0.632	-0.129	0.240
I think the city should invest more in the aesthetics of the streets in my neighbourhood.	0.570	0.021	0.133
I'm concerned about the development of my neighbourhood.*	0.574	0.213	-0.067
I compost food scraps.	0.126	0.478	-0.181
I recycle the materials that go into the recycling box.	0.002	0.747	0.147
I try to limit my water consumption while cooking, washing the dishes, doing laundry, or showering.	0.003	0.672	0.148
I try to limit my water consumption for outdoor uses.	-0.016	0.596	0.071
When I drive, I respect speed limits.	0.069	0.075	0.459
When I cross an intersection with a pedestrian light, I always wait until the pedestrian light comes through.	0.131	0.055	0.825
Proportion of variance explained	0.185	0.167	0.105
Cumulative proportion of variance explained	0.185	0.351	0.456

* The question has been asked in the negative and reversed for factor analysis.
Highest value of each line is marked in bold.

The results of the linear regression models, controlling for socio-demographic characteristics and for the three latent variables identified in the previous factor analysis (neighbourhood aesthetic, environmental behaviour, and respect of traffic laws), are presented in Table 4-3. The dependent variables are the difference between the satisfaction level of two scenarios. Both for walking and cycling, there are two models: one for $Y_{bioswale-grey}$, and one for $Y_{bioswale-grass}$. We also conducted models comparing grass strips with no vegetation. However, we have decided not to present the results of these models due to their low explanatory power. Indeed, the adjusted R^2 values for walking and cycling were respectively 0.028 and 0.022.

For the socio-demographic variables, the results indicate that for all models, the home location and the age of the respondents are significantly associated with the satisfaction level between two scenarios. People living farther from the redesigned streets are more likely to prefer a street with more vegetation compared to people living near the redesigned streets. Both for walking and cycling scenarios, people living farther than 400 m from the redesigned streets prefer bioswales to no vegetation and bioswales to grass strips. These results, which may seem counterintuitive, are further investigated both in the cluster analysis and in the qualitative analysis. Also, being middle-aged is associated with lower preferences for bioswales compared to grey streets or grass strips.

Table 4-3 Results of linear regression models explaining the difference in the level of satisfaction between different greening scenarios

Dependent variable:	Walking		Biking	
Independent variables:	$Y_{bioswale-grey}$	$Y_{bioswale-grass}$	$Y_{bioswale-grey}$	$Y_{bioswale-grass}$
Home location (0-399 m = ref.)				
≥ 400 m	1.099*** (0.377)	0.533* (0.283)	1.203*** (0.356)	0.942*** (0.265)
Unknown	1.044** (0.504)	0.528 (0.379)	0.885* (0.477)	0.567 (0.355)
Age (18-39 = ref.)				
40-64	-0.994*** (0.350)	-0.556** (0.263)	-0.807** (0.331)	-0.502** (0.246)
≥ 65	-0.951 (0.602)	-0.516 (0.453)	-1.005* (0.569)	-0.532 (0.424)
Gender (Male = ref.)	0.129 (0.297)	-0.105 (0.224)	0.032 (0.281)	0.154 (0.209)
Child in household	-0.021 (0.349)	-0.446* (0.262)	-0.368 (0.330)	-0.125 (0.245)
Household income (< 60K = ref.)				
60-125K	0.219 (0.396)	0.275 (0.298)	0.362 (0.374)	-0.271 (0.279)
≥ 125K	0.258 (0.481)	0.511 (0.362)	0.163 (0.455)	-0.138 (0.339)
Unknown	0.088 (0.467)	-0.216 (0.351)	0.092 (0.441)	-0.328 (0.329)
Occupation (Full time = ref.)				
Part time	0.589 (0.559)	0.614 (0.420)	0.238 (0.557)	0.424 (0.415)
Retired	0.051 (0.508)	-0.098 (0.382)	-0.397 (0.528)	0.352 (0.393)
Else	0.217 (0.589)	0.078 (0.443)	0.247 (0.480)	0.133 (0.358)
Higher educational level (High school = ref.)				
College	0.227 (0.429)	-0.211 (0.322)	0.203 (0.405)	0.198 (0.302)
University	0.295 (0.453)	-0.071 (0.341)	0.659 (0.428)	0.481 (0.319)
Latent variables				
Neighbourhood aesthetic	0.668*** (0.158)	0.460*** (0.119)	0.488*** (0.150)	0.424*** (0.112)
Environmental behaviour	0.356** (0.157)	0.212* (0.118)	0.302** (0.149)	0.182 (0.111)
Respect of traffic laws	-0.218 (0.169)	-0.165 (0.127)	0.050 (0.158)	0.117 (0.118)
Observations	278	278	278	278
R ²	0.176	0.147	0.164	0.166
Adjusted R ²	0.122	0.091	0.109	0.112

Note: *p<0.1, **p<0.05, ***p<0.01
Standard deviations in brackets.

Results are significant for people aged 40 to 64 years old for all scenarios as well as people aged 65 years and over for the cycling scenario comparing bioswales to grey streets. Having a child living in the household is significantly associated with a lower preference for bioswales compared to grass strips. This result will be further investigated in the qualitative analysis. Finally, household income, occupation, and educational levels are not significantly associated with the satisfaction level between different greening scenarios.

Looking now at the latent variables, people valuing the aesthetic of their neighbourhood are significantly more likely to prefer bioswales to grey streets and grass strips, both for walking and cycling. Having environmentally conscious behaviour is also associated with higher satisfaction for bioswales compared to other walking scenarios. With respect to cycling scenarios, the results are only significant and positive for bioswales compared to grey streets. Lastly, respecting traffic laws is not significantly influencing satisfaction levels between different greenery scenarios. It is worth recalling that this latent variable was described with only two questions. This may explain why this variable is not significant.

4.3.1.2 Cluster Analysis of Respondents by Level of Satisfaction

Table 4-4 presents the cluster centres for the six comparisons of greening scenarios. Three clusters were selected for the analysis using both the elbow method and the average silhouette method.

Table 4-4 Cluster centres

	Cluster 1	Cluster 2	Cluster 3
Observations (%)	45 (15%)	148 (50%)	103 (35%)
Walking			
Bioswales - Grey	-2.822	1.230	3.631
Bioswales - Grass	-2.089	0.439	1.641
Grass - Grey	-0.733	0.791	1.990
Biking			
Bioswales - Grey	-2.067	0.818	3.476
Bioswales - Grass	-1.911	0.176	1.573
Grass - Grey	-0.156	0.642	1.903

Possible values are -6 to 6.

The negative values of all variables in Cluster 1 indicate that, on average, this group assigned lower ratings to images with more vegetation. On average, they prefer scenarios for walking and biking without vegetation (grey streets), followed by preferences for scenarios with grass strips and then bioswales. For further analysis, we will call this group the “Negative”. There are only 45 respondents in this group indicating that a minority of respondents are more satisfied with grey streets than green streets. Table 4-5 presents socio-demographic characteristics and average values for the three latent variables. Among the “Negative”, 47% are living less than 400 metres from the redesigned streets. This group has a higher proportion of individuals aged 65 and above, as well as retirees. It also has a larger proportion of individuals with lower education levels. In terms of income, there is a higher prevalence of low-income individuals in this group compared to the

overall sample. However, when compared to the population residing within 400 metres of the area (which accounts for 47% of this group), there is a lower prevalence of low-income individuals. The results of the linear regressions indicate that home location and age are influencing the level of satisfaction for bioswales compared to other scenarios. However, the household income level and educational level did not show significant effects in the regression models. Therefore, we cannot draw conclusions regarding the influence of these variables on satisfaction levels. Further research and analysis are needed to obtain a more comprehensive understanding of their impact. Lastly, the mean values of the neighbourhood aesthetic and the environmental behaviour are negative indicating that the “Negative” are giving less importance to the aesthetic of their neighbourhood

Table 4-5 Characteristics of the clusters

	Cluster 1		Cluster 2		Cluster 3		Overall sample	
	Negative		Moderately positive		Strongly positive		Home < 400 m	Total
Observations (N)	45	(15%)	148	(50%)	103	(35%)	63 (21%)	296 (100%)
Sociocultural background, N (% of the full sample)								
Home location								
0-399 m	21	(47%)	28	(19%)	14	(14%)	63 (100%)	63 (21%)
≥ 400 m	18	(40%)	97	(66%)	75	(73%)	0 (0%)	190 (64%)
Unknown	6	(13%)	23	(16%)	14	(14%)	0 (0%)	43 (15%)
Age								
18-39	6	(13%)	42	(28%)	37	(36%)	15 (24%)	85 (29%)
40-64	27	(60%)	75	(51%)	42	(41%)	34 (54%)	144 (49%)
≥ 65	12	(27%)	31	(21%)	24	(23%)	14 (22%)	67 (23%)
Gender (Female)	27	(60%)	97	(66%)	57	(55%)	36 (57%)	181 (61%)
Child in household	15	(33%)	65	(44%)	45	(44%)	22 (35%)	125 (42%)
Household income								
< 60K	14	(31%)	42	(28%)	15	(15%)	26 (41%)	71 (24%)
60-125K	19	(42%)	47	(32%)	45	(44%)	23 (37%)	111 (38%)
≥ 125K	3	(7%)	37	(25%)	28	(27%)	5 (8%)	68 (23%)
Unknown	9	(20%)	22	(15%)	15	(15%)	9 (14%)	46 (16%)
Occupation								
Full time	20	(44%)	85	(57%)	57	(55%)	33 (52%)	162 (55%)
Part time	4	(9%)	10	(7%)	5	(5%)	4 (6%)	19 (6%)
Retired	18	(40%)	43	(29%)	32	(31%)	17 (27%)	93 (31%)
Else	3	(7%)	10	(7%)	9	(9%)	9 (14%)	22 (7%)
Higher educational level								
High school	13	(29%)	24	(16%)	6	(6%)	14 (22%)	43 (15%)
College	21	(47%)	59	(40%)	37	(36%)	26 (41%)	117 (40%)
University	11	(24%)	63	(43%)	59	(57%)	21 (33%)	133 (45%)
Latent variables, Mean (S.D.)								
Neighbourhood aesthetic	-0.38	(1.02)	-0.09	(0.96)	0.31	(0.84)	-0.27 (1.10)	0.01 (0.96)
Environmental behaviour	-0.48	(1.16)	0.02	(0.94)	0.16	(0.84)	-0.06 (0.74)	0.00 (0.96)
Respect of traffic laws	0.15	(0.82)	-0.01	(0.88)	-0.07	(0.78)	0.12 (0.94)	-0.01 (0.84)

and indicate having a lower environmental behaviour compared to average values of other clusters. These results are consistent with the results of the linear regressions presented above.

Half the respondents are in cluster 2. On average, individuals in this cluster prefer bioswales, followed by grass strips, and grey streets. For cycling, there is almost no difference between bioswales and grass strips (mean of 0.176). This cluster can be described as the “Moderately positive”. The characteristic of this cluster in Table 4-5 shows that it represents the average population of the sample since almost all the variable distributions are extremely close to the overall sample distributions. The mean values of the three latent variables in this cluster are nearly zero, indicating a close correspondence between average values in this cluster compared to the overall sample.

The third cluster is characterized by a strong preference for greener scenarios. For both modes, respondents gave in average three more points (out of seven) to the scenarios with bioswales compared to grey streets. Moreover, they gave more than 1.5 points to the scenarios with bioswales compared to grass strips. Therefore, they can be described as the “Strongly positive”. As shown in Table 4-5, there are 103 respondents in that cluster. This group is characterized by a higher proportion of young adults (aged 18-39) and a high proportion of people with a university diploma (57%). As stated earlier, the educational level was not significant in the regression models. However, there appears to be an association between the level of education and the level of satisfaction with greener scenarios, as the proportion of people with a high level of education increases from the “Negative” to the “Strongly positive”. In contrast to the “Negative”, the mean of neighbourhood aesthetic variable is positive (0.31), and the mean of environmental behaviour variable is also positive but lower (0.16). This is consistent with the results of the regression models.

Figure 4-4 illustrates the level of agreement, measured on a 5-point Likert scale, for 12 questions related to the redesigned streets. Across all clusters, the "Negative" group exhibits the least agreement with the statements, while the "Strongly positive" group demonstrates the highest level of agreement. The initial four questions specifically address the socio-environmental benefits associated with bioswales. For all clusters, a high number of respondents have answered "Do not know" to these questions, with the "Negative" group displaying an even higher proportion. Additionally, the "Negative" group exhibits a higher percentage of disagreement or strong

disagreement regarding the contributions of bioswales to climate change mitigation and/or adaptation, improvement of biodiversity, improvement of stormwater management, and cost effectiveness. In contrast, the "Strongly positive" cluster demonstrates a higher proportion of agreement or strong agreement towards the socio-environmental benefits of bioswales. The "Moderately positive" group has a substantial proportion of individuals who hold neutral or agreeable views regarding these statements.

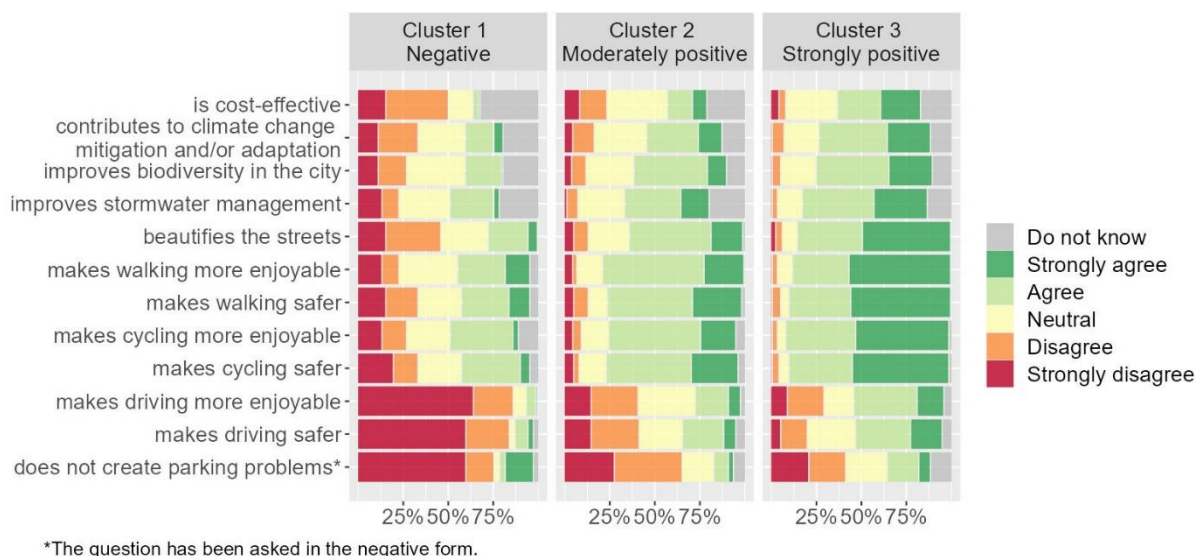


Figure 4-4 Levels of agreement with questions related to the redesigned streets with bioswales

The fifth question investigates whether individuals believe bioswales beautify the streets. The more a group prefers a higher level of vegetation, the more respondents in that group agree that bioswales beautify the streets. Then, four questions investigated whether bioswales make walking/cycling enjoyable or safer. Consistent with the previous results, the more a group prefers a higher level of vegetation, the more the respondents in that group agree that bioswales may improve active mobility. For all groups, including the "Negative", there is a greater number of individuals who agree rather than disagree with all the statements related to active mobility. Among the "Strongly positive", more than half of the respondents strongly agree with these statements.

Finally, three questions were asked to gauge perceptions regarding car travel. Among the "Negative", a majority strongly disagree that bioswales make driving more enjoyable and safer. Additionally, they believe that bioswales contribute to parking problems. In the "Moderately positive" group, there are more respondents who disagree rather than agree that bioswales could

have benefits for driving. For the "Strongly positive" group, the results are mixed, with a slightly higher number of individuals perceiving bioswales as advantageous for car travel. In general, respondents tend to agree that bioswales are beneficial for active modes of travel, such as walking and cycling, while displaying disagreement or neutrality regarding the benefits of bioswales for car travel.

4.3.2 Qualitative Analysis

Figure 4-5 presents the themes and sub-themes that emerged when coding the interviews and focus groups. Two main themes, directly related to individuals' perceptions of the bioswales implemented, emerged: advantages and disadvantages/shortcomings of bioswales. While expressing their opinions, the respondents often acknowledged both the advantages and disadvantages, understanding the other side of the coin. Thus, seven sub-themes were identified as common for these two main themes. In addition, the improvement of biodiversity and air quality are identified as advantages, while concerns about parking spaces are identified as a disadvantage/shortcoming of bioswales. Five sub-themes are secondary concerns that are either related to the project (but not related to the bioswales) or associated with the design of the neighbourhood on streets beyond the five segments that were redesigned. Finally, two sub-themes relate to the communication of the City throughout the project.

The following sections present the findings from the qualitative analysis. Certain sub-themes have been grouped together due to their close connection (e.g., road safety and active transport safety). We begin by analyzing the sub-themes directly linked to active travel, followed by the remaining sub-theme concerning perceptions of bioswale implementation. Finally, we discuss the main themes: "Secondary issues" and "Communication". The quotations included in the next sections have been translated from French.

Active Mode Infrastructure

The participants in the interviews and focus groups highlight the project's positive impact on active mobility infrastructure. Urban planners explain they took advantage of the refurbishment of the outdated infrastructure to renovate urban facilities and reallocate space between drivers, cyclists, and pedestrians. The aim is to reduce the space dedicated to cars and achieve a better balance between active modes and cars. The only shortcoming identified is the discontinuity of the cycle path. The addition of a bike lane on a single segment does not create a continuous cycle network.

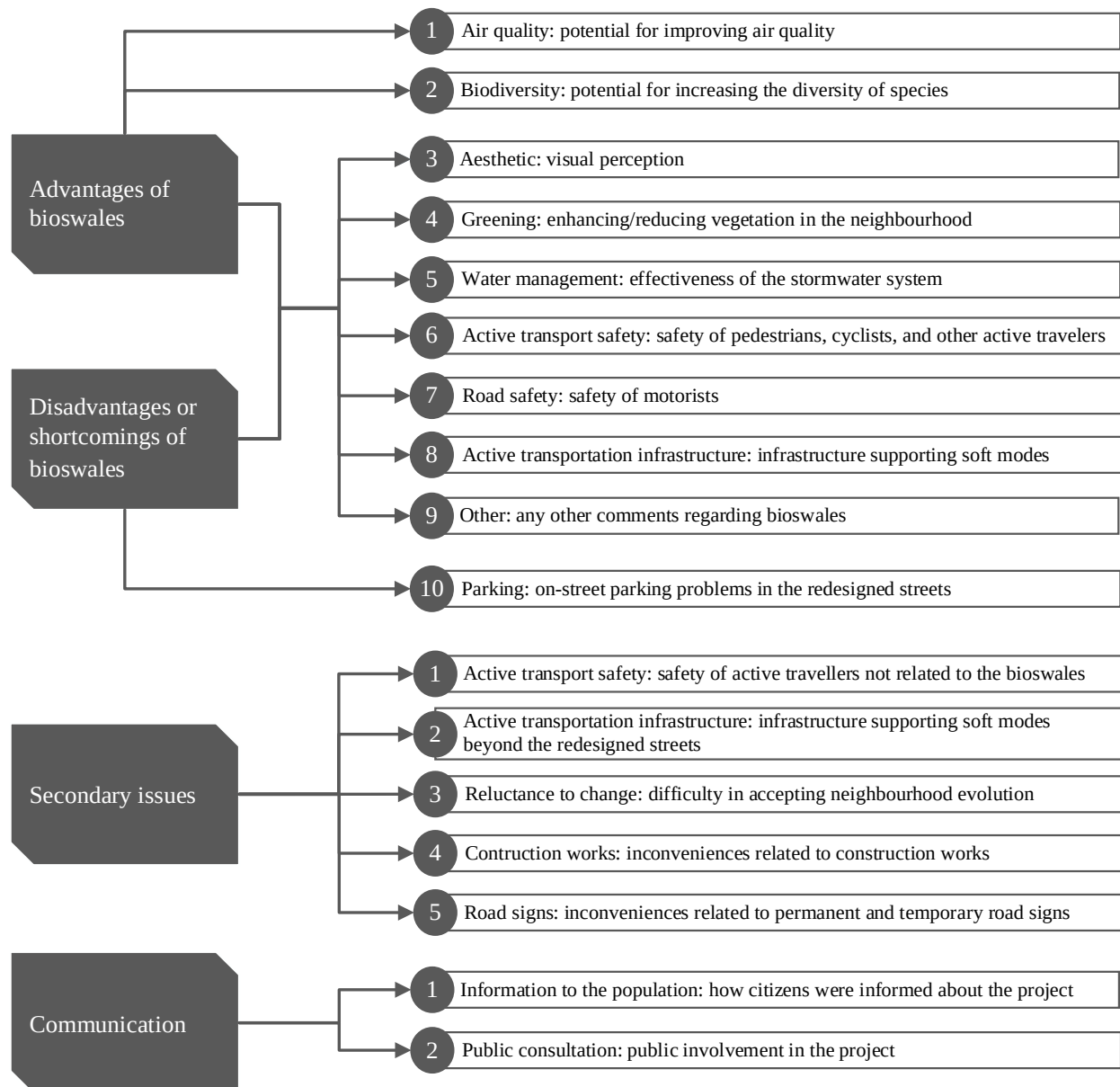


Figure 4-5 Main themes and sub-themes developed from coding interviews and focus groups

Overall, these results are consistent with the quantitative analysis, showing that most respondents believe that bioswales can facilitate active mobility.

Road Safety and Active Transport Safety

Some respondents, including planners, children, and residents, believe that the neighbourhood's safety has improved. Urban planners and residents explain that the vegetation creates a physical barrier between the carriageway and the active path (sidewalk or bike path), fostering a sense of

comfort and safety among active travellers. Moreover, the narrower streets help reduce vehicle speed and therefore improve pedestrian safety:

“The infrastructure is narrower. At intersections, people with wider vehicles encounter issues with vehicle crossings. They tell us that they no longer drive as they used to. But it's normal, they were driving 70 km/h on a 40 km/h -speed limit road. There is now much better compliance with traffic signs. It may not be well perceived by car users, but it benefits pedestrians.” (Planner 1)

Planners and citizens state that the new infrastructure enhances the safety of vulnerable users, including individuals with reduced mobility and children. Several mobility scooters have been observed on the bike paths by the respondents. Among the benefits mentioned are the implementation of smoother curb ramps and the physical separation provided by the bioswales. Contrastingly, we received several comments from elderly people during the door-to-door survey regarding the challenges of driving on the newly narrow streets. This issue seemed to pose more difficulties for this group. Similarly, several respondents mention the limited space for crossings at intersections and the reduction in road width. Other concerns are related to the height of the vegetation and the depth of the bioswales:

“I think it's safe as long as the vegetation is not too tall and if it's not obstructing the view. [...] A child can cross the street at any moment since it's a school neighbourhood.” (Citizen 1)

“There is a risk of falling into the bioswales.” (Child 1)

“During snowfall, especially during the first snowfalls, the bioswales blend in with the snow. People's cars can accidentally fall into the bioswales.” (Citizen 2)

Parking

The most frequently mentioned disadvantage during the interviews is the lack of parking spaces. The implementation of bioswales has resulted in a 70% reduction in on-street parking areas. For some citizens, this measure is problematic:

“At the beginning, there were numerous complaints from motorists as the lanes were narrowed down and parking spaces were eliminated.” (Planner 2)

“The machines [vehicles] are fighting! The delivery drivers, they come and park right in the middle of the street!” (Citizen 3)

“During snowstorms [during the snow clearing of private driveways], we can't even park cars on the street because there are no parking spaces available.” (Citizen 4)

According to the planners, there is an adequate number of parking spaces, especially considering that the project is located in a residential area with multiple private driveways.

Water Management

Planners are convinced that bioswales provide better stormwater management, allowing water to infiltrate into the soil. Citizens show familiarity with the basic stormwater management function of bioswales while the children have little knowledge on the infrastructure. Adult citizens all mention the benefits of bioswales for filtering and managing runoff. However, they were critical of their design. Some say they had experienced flooding in their basements during the heavy rains on September 13, 2022. Thus, they were not sure if the new infrastructure contributed to this phenomenon:

“Last month, we experienced flooding problems. We had never had flooding before, so we are questioning whether the infrastructure is functioning as effectively as it should be.” (Citizen 4)

Concerns raised include the potential for mulch to clog pipes connected to the storm drain, water accumulation in bioswales, and possible water overflow onto the street. According to the planners, during this rainfall event, the new infrastructure might have prevented the sector from being flooded since other sectors with no GSI such as a near-by hospital were severely affected. Citizens were the only group mentioning water management disadvantages. Overall, they do not seem convinced by the effectiveness of bioswales in their neighbourhood.

It is worth mentioning that during the interviews and on-site survey collection, several individuals discussed the rainfall events of September 13th. Using the rainfall intensity-duration frequency values for Norbert station (7015610), the nearest station from the study site, we can see that on September 13, 2022, 86.2 mm fell (56.6 mm in one hour). It corresponds to a 50 to 100-year return period (MELCCFP, 2022). Thus, this may explain that some citizens were flooded, especially considering that the groundwater level is high in this sector. Since this event occurred shortly before our data collection, both for qualitative and quantitative analysis, it may explain why many people doubted the effectiveness of the bioswales.

Aesthetic

Most of the respondents agreed that bioswales enhance the aesthetic of the area. Some participants mentioned it adds value to the neighbourhood. A few participants noted that the improvement

would be more apparent as the vegetation matures. Children were shown photos before and after the project. Out of the 13 children, 11 expressed a preference for the new configuration, while two stated that they would have preferred either no changes or grass. They say that grass is more practical for their activities.

Greening, Biodiversity, and the Environment

Many respondents highlight that bioswales contribute to the greening of the neighbourhood, although concerns arise, particularly regarding tree removal. Urban planners emphasize the advantages of replacing problematic tree species, namely, to reduce damage to drainage pipes and branch breakage. Planners also highlight the challenges faced in effectively communicating the necessity of tree removal to the local population:

“What was difficult initially in terms of communication was the tree removal. Even though we explained that they were silver maples that posed a threat to the houses because they have shallow roots underground. Moreover, they were pruned in a V-shape, and the branches would often fall.” *(Planner 3)*

Despite the discontentment regarding tree removal, most respondents believe that the project contributes to greening the neighbourhood:

"Nature has taken its rights back." (Child 2)

Only a few interviewees discuss the additional co-benefits, namely enhanced biodiversity and improved air quality:

"It does not only enable better water filtration, it also enables better air filtration." (Citizen 5)

"Flowers attract bees, which is great!" (Child 3)

Secondary Issues

Several concerns not directly related to bioswales have the potential to alter people's perception of bioswales. Many citizens express dissatisfaction with construction works, and changes in road signage. Many complaints are related to an intersection where two stop signs were removed as a raised intersection had been built. Some drivers were still making a stop even though it was no longer required, causing confusion among all users. This has led to conflicts among road users and insecurity for pedestrians, especially among children. Some citizens have also reported that vehicles are parking directly in the traffic lane instead of using designated parking spaces.

Subsequently, additional stop signs have been installed to restore the intersection to a four-way stop, and signage has been put in place explicitly prohibiting parking in traffic lanes. These irritants have likely negatively influenced the perception of residents in the area.

Furthermore, several concerns are related to active mobility, such as the lack of continuous bike lanes in the city and the perceived insecurity of active transportation. While most respondents are pleased with the city's implementation of a new bike lane, they lament the lack of infrastructure elsewhere in the neighbourhood and the city. According to them, people drive too fast in the neighbourhood. Both adults and children consider the streets to be unsafe for children. Although the implementation of bioswales has improved safety for active transportation, many feel that it is not sufficient especially in the street adjacent to the school.

Lastly, planners mention that citizens are resistant to change:

“Every change brings its share of resistance, but I believe that in the long run, people will get used to it, and eventually, they may not even react anymore. Right now, it's just that this type of installation is completely new.” (Planner 4)

During the focus groups, the majority of the children seemed very satisfied with bioswales. However, at the end of the meeting, we asked them if they would like to have bioswales in front of their houses, and most of them answered "no". Various reasons were mentioned, including the desire to have space to play and the desire to maintain the current configuration:

*"Not in my street because it would take away the space we use to play."
(Child 4)*

"I find my street already beautiful as it is." (Child 2)

The fact that the children appreciate the bioswales near the school but do not want them in their own street is reminiscent of the results obtained in the survey. Respondents living within 400 metres of the redesigned streets were less satisfied with the bioswales than those living more than 400 metres away.

Communication

The City of Saint-Charles-Borromée made efforts to clearly communicate the purpose of the project and its potential benefits to the citizens, with the goal of increasing the social acceptability:

"The information provided to citizens contributes to the success of the project. Explaining to citizens why we are doing this is important so that they understand better what is coming. Conversely, if there is less communication, there is less information. People do not understand and naturally, there can be more dissatisfaction." (Planner 4)

"Yes, we were informed about the construction works. There was already information available even before it started. There were models, drawings, sketches. They even took a photo (of the old street for their drawings). So, we could see the actual houses, the projected bike lane..." (Citizen 6)

Although citizens appear to have been well-informed about the construction works, many deplore the lack of prior consultation regarding the project. They would have appreciated being involved in the design phase of the project.

4.4 Discussion and Conclusions

4.4.1 Summary and Discussion of Findings

This paper assesses the effects of integrating GSI in the right-of-way on active mobility. A case study approach has been employed to investigate individuals' perceptions following the redesign of five streets in a North American suburban area, which involved the implementation of bioswales. Through the analysis of a survey, interviews with stakeholders, and focus groups with children, we have evaluated individuals' satisfaction with bioswales while comprehensively investigating the factors that enhance or limit this satisfaction.

The findings of this study indicate that the implementation of bioswales can positively impact active travel by enhancing aesthetic appeal, safety, and comfort. These findings align with existing scientific literature (Lemieux, Charlotte et al., 2023). Among the different greening scenarios (grey street, grass strip, and bioswale both for walking and cycling), the majority of participants expressed a preference for the bioswale, followed by the grass strip. This result is in line with previous studies that have demonstrated that people prefer street landscapes characterized by higher levels of greenery (Nawrath et al., 2019; Suppakittpaisarn, Larsen, et al., 2019), including landscapes with an abundance of bioretention cells as compared to those without bioretention cells (Suppakittpaisarn et al., 2020). Studies have also shown that among various green features, street trees emerged as the most favoured feature (Ferreira et al., 2021; Fischer & Gopal, 2021; Suppakittpaisarn et al., 2020). Flowers and bioretention have also received high appreciation (Fischer & Gopal, 2021; Suppakittpaisarn, Larsen, et al., 2019).

Our qualitative analysis demonstrated that trees are highly valued by all stakeholders. Respondents emphasized the benefits provided by trees in terms of aesthetics, greening, and air quality. Trees play multiple roles such as offering sidewalk shading and acting as a barrier against traffic noise (Engel-Yan et al., 2005). Furthermore, studies have shown that trees enhance safety for all users. By creating a more enclosed streetscape, trees reduce the optical width of the roadway (Harvey et al., 2015; Polanski, 2015), which in turn leads to a decrease in vehicle speeds (Naderi et al., 2008). The presence of street trees has been associated with a reduction in collision risks, particularly pedestrian-related collisions (Harvey & Aultman-Hall, 2015; Kim, D., 2019; Zhu et al., 2022). Moreover, GSI can provide more rooting space for tree growth (Ferguson, 2012). In light of our results and the scientific literature, it is highly relevant to integrate trees within bioswales to maximize their benefits for the community and the environment.

The results of this study also reveal insights on the needs of vulnerable groups. Our qualitative analysis clearly demonstrates that bioswales can enhance children's safety. Similarly, Kweon et al. (2021) found that parents feel safer for both their children and themselves when walking on a sidewalk isolated by a long-planted strip area (e.g., a grass strip). While implementing bioswales seems beneficial for children, our findings highlight the importance of allocating space for children's activities. As such, linear regression results suggest that individuals living with children prefer grass strips over bioswales. Supporting this result, Seymour et al. (2010) found that people value green street designs that create recreational opportunities for children. Another study has shown that among various GSI features in a park, such as ponds, bioswales, paved canals, and a large sunken lawn, the sunken lawn is the most frequently used feature by families and has a high affordance for children's activities (Mottaghi et al., 2021). A grass strip, similar to a sunken lawn, provides an open surface that can be utilized by children. Hence, we hypothesize that grass strips may be more suitable for children's activities compared to bioswales. It's worth noting that this space remains relatively small, which limits its use. In contrast, Mottaghi et al. (2021) also found that children are playing within the bioswale, using woody debris as tools or treasures. Another study indicated that people have concerns about the possibility of falling into bioswales (Everett et al., 2015), which could explain why individuals living with children might prefer grass strips to bioswales. Some parents and children interviewed in this study also mentioned the risk of falling into the bioswales. In light of these results, it is important to conduct further research into children's preferences regarding various types of GI and GSI.

The study highlighted some benefits for elderly people as participants believe their safety is improved by the separation of bike paths and sidewalks from the road. Additionally, Lee, S. et al. (2022) has shown that a higher density of the tree canopy is associated with a decrease in fall incidents among elderly pedestrians. This can be attributed to the shade provided by trees along sidewalks, which enhances thermal comfort and air quality. Furthermore, implementing bioswales at intersections can enhance safety by reducing the width that pedestrians need to cross (Greenberg, 2008; Polanski, 2015). It is worth noting that, according to people with motor disabilities, street trees stimulate physical activity despite their possible disservices, namely tiles bulging or falling branches (Wojnowska-Heciak et al., 2022).

On the one hand, this study reveals several factors contributing to higher satisfaction with bioswales. The results of the linear regression analysis indicate that individuals who exhibit eco-friendly behaviour and value the design of their neighbourhood are more likely to prefer a street configuration with bioswales over grass strips or grey street. Similarly, Everett et al. (2015) found that individuals who are environmentally engaged displayed a more positive attitude towards bioswales. The results of our cluster analysis are consistent with these findings. Among the three clusters (“Negative”, “Moderately positive”, and “Strongly positive”), the “positive” groups who expressed a strong satisfaction for greener scenarios, agree that bioswales provide socio-environmental and active mobility benefits. Lastly, linear regression results indicate that compliance with traffic laws, which can reflect safety-conscious behaviour, does not significantly influence satisfaction levels with different greening scenarios. Nonetheless, the qualitative analysis shows that people value bioswales for their potential to improve the safety of pedestrians and cyclists, especially children’s safety.

On the other hand, the results also reveal factors that limit satisfaction with bioswales. In the cluster analysis, we have identified a group that prefers scenarios with less vegetation. Within this group, 47% of the respondents (21 individuals) reside in the redesigned area. People in this group are less in agreement with the notion that bioswales enhance active mobility and provide socio-environmental benefits compared to other groups. An important finding for this group is that over 75% express disagreement or strong disagreement regarding the ability of bioswales to improve car mobility. They mostly believe that bioswales cause parking problems. These results align with the findings of the qualitative analysis. Indeed, the interviewed citizens were not convinced of the benefits that bioswales could provide for water management. Moreover, only a few citizens and

children mentioned co-benefits, such as improving air quality and biodiversity. Regarding car transportation, many interviewees expressed concerns about losing parking spaces and facing difficulties in maneuvering their vehicles due to narrow streets. As depicted in the interviews with citizens, it appears that for some residents, the constraints for cars outweigh the benefits for active modes of transportation and the environment. Other issues that could have affected the satisfaction of residents living within 400 metres of the bioswales are changes in traffic signage and construction work (from July 2021 to July 2022) that have disrupted their daily lives.

4.4.2 Design and Planning Recommendations

These results have significant implications in terms of urban design. Findings suggest that implementing GSI can facilitate and promote active travel. In contrast, bioswales do not appear to enhance car mobility, and some individuals even believe that bioswales negatively impact vehicle movement. The results from this study have led to several recommendations regarding the implementation of GSI to enhance active mobility, e.g.:

- 1) Take advantage of the reconstruction to prioritize active users by reallocating space and creating physical barriers between motorized and active paths.
- 2) Integrate trees within GSI to maximize their environmental, social and mobility benefits.
- 3) Ensure that vegetation does not obstruct the drivers' field of vision, especially near intersections.
- 4) Ensure that there are no risks of people or vehicles falling into the GSI if it is deep. It is possible to install a barrier to delineate the infrastructure, which can facilitate snow removal in cold-climate cities and prevent injuries.
- 5) Perform regular maintenance of the infrastructure to ensure its proper functioning and remove any debris that may accumulate within the depression.
- 6) Clearly indicate any changes in signage due to the new street configuration.

In addition, Polanski (2015) highlighted that reducing the distance to be crossed at intersections can enhance the safety of active travellers. Similarly, Kim, D. (2019) suggested that implementing GSI as a centre median provide a space that functions as a pedestrian refuge.

Furthermore, the implementation of GSI should consider all the functions of the streets, including those not related to mobility. Ferguson (2011) emphasizes the importance of considering all street activities in multifunctional street design, including buildings, vehicular and pedestrian movement,

and environmental processes. While GSI plays an important role in supporting environmental processes, it should not disrupt human activity. Balancing these factors ensures successful integration of GSI into street designs without compromising functionality.

To ensure public acceptance of the project, it is desirable to provide ample information to the population regarding the functioning of the bioswales and their multiple socio-environmental co-benefits. Specifically, it is important to explain that water may accumulate in the basins during heavy rainfall. Citizens have also expressed their desire to be involved in the decision-making process. Ensuring communication and collaboration with the community can contribute to the social acceptance of the project (Everett et al., 2015; Shandas, 2015).

4.4.3 Limitations

There are several limitations to this study. Firstly, the research was conducted in a small Canadian city, and further studies in different regions, including densely populated urban areas, are needed to determine if the findings are applicable elsewhere. As such, Lee, H. S. & Park (2015) found difference in the influence of vegetation on walking for urban compared to rural elderly women. Secondly, the survey data was not obtained through a random sampling, which could introduce bias and limit the broader applicability of the findings to Saint-Charles-Borromée's population or other contexts. Thirdly, data collection occurred only three months after the completion of the final construction phase. As depicted in the interviews, the construction had negatively influenced the perceptions of residents in the area. Additionally, perceptions may change as the vegetation matures and people become accustomed to the new street configuration. Regarding vegetation, it's important to acknowledge that the images employed to assess people's perceptions of bioswales can impact the outcomes. The images we utilized were intended to portray a design similar to the one in Saint-Charles-Borromée, when the vegetation will reach maturity. However, we omitted trees in the bioswales, which could also influence perception. Fourthly, it is important to note that both the quantitative and qualitative analyses in this study were constrained by small sample sizes. In the case of the quantitative analysis, this limitation restricted the inclusion of additional control variables. Notably, future studies should examine the effects of socio-demographic characteristics on perceptions and behaviours related to GSI implementation. Moreover, undertaking a study in a more diverse area and investigating the effects of vegetation, including GSI, within different built environments would offer valuable insights. It would help determine whether the inclusion of

vegetation yields comparable results across various settings, including densely populated urban areas, urban areas, and suburban areas. Lastly, this study examines the effects of bioswales implemented in a large area, including five street segments. Future research should investigate the distinct effects of various green features, considering their specific design characteristics. For instance, implementing a bioretention at an intersection (e.g., a curb extension) or along a street segment (e.g., a chicane) can result in different outcomes. The size of the infrastructure can also influence the outcomes. Studying specific characteristics of urban vegetation would allow for a more comprehensive understanding of the differentiated effects of green features.

Although this study has limitations, employing a mixed-method approach enabled us to compare and nuance the findings from each method, providing a comprehensive perspective on the active mobility challenges and opportunities associated with the implementation of bioswales. These findings suggest that GSI has the potential to enhance active travel by creating a safe, comfortable, and attractive environment. This research is relevant for planners and researchers seeking to design multifunctional streets that support sustainable urban drainage systems and active mobility.

4.5 Competing Interests

The authors declare that they have no financial and non-financial competing interests.

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4.7 Author Contributions

The authors confirm contributions to the paper as follows: study conception and design: C. Lemieux, F. Bichai, G. Boisjoly; data collection: C. Lemieux; quantitative analysis and interpretation: C. Lemieux, F. Bichai, F. Ciari, G. Boisjoly; qualitative analysis and interpretation: C. Lemieux, S. Lach Gar, F. Bichai, F. Ciari, G. Boisjoly; draft manuscript preparation: C. Lemieux. All authors reviewed the results and approved the final version of the manuscript.

CHAPITRE 5 DISCUSSION

Ce mémoire a contribué à l'avancement des connaissances quant aux bénéfices des IVGEP pour favoriser et faciliter les déplacements actifs (marche et vélo). Le chapitre 3 a permis de brosser un portrait clair de l'état des connaissances sur le sujet. En analysant la littérature portant sur les effets des IV et des IVGEP sur la mobilité active, il a été possible de démontrer quels sont les opportunités et défis liés à la mise en place des IVGEP dans l'emprise routière. Bien que plusieurs effets socio-environnementaux aient préalablement été documentés dans des revues de littérature, aucune étude ne s'était intéressée spécifiquement aux effets sur la mobilité active. De plus, le chapitre 3 a permis d'identifier les lacunes et opportunités de recherche qui pourront guider les chercheurs souhaitant mieux comprendre les relations entre les IVGEP et la mobilité active. Parmi les lacunes identifiées dans le chapitre 3, il y a le besoin de quantifier les effets des IVGEP sur la mobilité active, de distinguer ces effets selon le mode (marche ou vélo), le contexte et le type de population, et d'analyser les facteurs limitant l'acceptabilité sociale de tels projets.

L'étude de cas présenté dans le chapitre 4 a contribué à répondre à ces lacunes. En effet, cette étude a permis d'évaluer les effets des noues végétalisées, un type d'IVGEP souvent mis en place directement dans l'emprise routière, sur les perceptions des individus en lien avec la mobilité active. Cette étude distinguait les effets de différents types de végétation (aucune végétation, bande de gazon et noue végétalisée) sur la satisfaction des gens par rapport à des aménagements pour la marche et pour le vélo. D'abord, les relations entre la présence de noues végétalisées et le niveau de satisfaction par rapport aux infrastructures pour la marche et pour le vélo ont été quantifiées par le biais de régressions linéaires. Ensuite, l'analyse typologique des répondants a permis de révéler des facteurs associés à un niveau de satisfaction plus ou moins élevé pour les différentes configurations de rue. Enfin, l'analyse des entrevues et des groupes de discussion a fourni une compréhension approfondie des facteurs limitant ou favorisant l'appréciation des noues végétalisées.

Les résultats de l'étude de cas (chapitre 4) ont pu confirmer plusieurs hypothèses recensées dans la littérature scientifique (chapitre 3). Par exemple, plusieurs études présentant des cadres conceptuels ou discutant de récents projets ont mentionné que les IVGEP permettent de créer une barrière physique entre les modes motorisés et les modes non motorisés (Greenberg, 2008; Valente et al., 2021). Ces études ont également souligné la possibilité d'utiliser les IVGEP comme mesure

d'apaisement de la circulation (Clemente, 2020; Greenberg, 2008; Polanski, 2015). Les résultats de l'étude de cas soutiennent ces bénéfices. De plus, nombreuses études ont analysé la différence entre l'appréciation de configurations de rue avec différents niveaux de végétation. Ces études mentionnaient que les arbres sont hautement appréciés par les citoyens et qu'une augmentation de la densité de végétation est associée à une plus grande préférence (Ferreira et al., 2021; Fischer & Gopal, 2021; Suppakittpaisarn et al., 2020). Ces résultats sont conséquents avec les résultats du sondage qui ont montré que la majorité des citoyens sont plus satisfaits avec les configurations comprenant, en ordre, les noues végétalisées, les bandes de gazon et aucune végétation. L'analyse qualitative a également souligné l'importance accordée au maintien des arbres existant lors des travaux et à la plantation d'arbres dans les noues végétalisées.

Certaines préoccupations identifiées par Everett et al. (2015) ont pu être observées dans l'étude de cas. Notamment, la possibilité de tomber dans les noues végétalisées et l'accumulation de déchets dans les dépressions que forment ces infrastructures. Ces préoccupations ont également été soulignées dans l'enquête qualitative réalisée à Saint-Charles-Borromée. De plus, l'étude de cas a permis d'obtenir une meilleure compréhension des facteurs limitant l'acceptabilité sociale de tel projet, dont les préoccupations des citoyens pour les déplacements automobiles. En résumé, la mise en place des IVGEP dans l'emprise routière semble assez bénéfique pour la mobilité active, bien qu'elle puisse occasionner des désagréments au niveau des automobilistes.

Enfin, des recommandations quant à la construction des IVGEP dans l'emprise routière ont pu être faites grâce aux résultats combinés de l'étude de cas et de la revue de littérature scientifique. Ces recommandations, présentées dans le chapitre 4, découlent des résultats des chapitres 3 et 4. Ces recommandations sont les suivantes :

- 1) Profiter de la reconstruction d'une rue pour allouer plus d'espaces aux usagers actifs et créer une barrière physique entre les voies motorisées et les voies non motorisées.
- 2) Intégrer des arbres dans les IVGEP pour maximiser leurs avantages socio-environnementaux, dont ceux pour la mobilité active.
- 3) S'assurer que la végétation n'entrave pas le champ de vision des conducteurs.
- 4) Veiller à ce qu'il n'y ait pas de risques que des personnes ou des véhicules puissent tomber dans les fosses créées par les IVGEP. Il est possible d'installer une barrière pour

délimiter l'infrastructure, ce qui peut éviter les blessures et faciliter le déneigement dans les villes avec un climat froid.

- 5) Faire un entretien régulier des infrastructures afin d'assurer son fonctionnement et enlever les débris qui peuvent s'accumuler dans les dépressions.
- 6) Indiquer clairement tout changement de la signalisation routière dû à la mise en place des IVGEP.

CHAPITRE 6 CONCLUSION

Le présent chapitre résume les travaux de recherche réalisés et souligne les contributions de ce mémoire tout en détaillant les limites et perspectives de recherche.

6.1 Synthèse des travaux de recherche

Ce mémoire étudie les effets des IVGEP sur la mobilité active. La revue de littérature (article 1) souligne les lacunes et perspectives de recherche sur les relations entre les IV, les IVGEP et la mobilité active. Cette revue met en évidence les avantages potentiels de l'intégration des IVGEP directement dans l'emprise routière pour améliorer l'attractivité des déplacements actifs, réaménager les rues pour dédier un espace aux voies actives et améliorer la sécurité des piétons et cyclistes. Les similitudes entre les IVGEP et les IV sont également soulignées, notamment l'utilisation de ces infrastructures comme mesure d'apaisement de la circulation et l'augmentation de la densité de végétation totale. De par les caractéristiques communes des IVGEP avec les IV, les IVGEP ont le potentiel de favoriser les déplacements actifs, l'activité physique, la sécurité routière et la santé des populations. Les lacunes identifiées comprennent le besoin de développer des indicateurs pour caractériser les IV et IVGEP afin d'étudier comment les bénéfices des IVGEP se matérialisent selon leurs différentes caractéristiques. De plus, les études doivent distinguer les effets selon le contexte urbain, les caractéristiques sociodémographiques des individus et le mode de transport utilisé.

L'étude de cas (article 2) confirme les résultats de la revue de littérature en démontrant les effets positifs de l'intégration des IVGEP sur les perceptions des gens quant à la mobilité active. L'analyse du sondage révèle que les répondants sont plus satisfaits avec des configurations de rue pour la marche et le vélo qui comprennent des noues végétalisées par rapport aux configurations avec des bandes de gazon ou aucune végétation. Les avantages des noues végétalisées identifiés comprennent leur effet positif sur l'esthétisme des rues, la sécurité et le confort. Tant dans la revue de la littérature que dans l'étude de cas, les arbres sont hautement valorisés par les citoyens. De plus, les noues végétalisées sont perçues comme améliorant la sécurité des enfants et des personnes âgées en isolant les voies actives de la circulation routière. Cependant, certaines limites ont été identifiées, notamment les préoccupations liées aux stationnements et aux contraintes de manœuvre des véhicules.

6.2 Contributions

Cette recherche souligne le potentiel des IVGEP pour promouvoir la mobilité active. D’abord, la revue de littérature brosse un portrait de l’état des connaissances sur le sujet. La mise en commun de 70 articles traitant de la relation entre les IV, les IVGEP et la mobilité active permet de mieux comprendre les effets connus et potentiels de ce type d’infrastructure sur les déplacements actifs. En effet, plusieurs études n’abordent que sommairement la relation entre les IVGEP et la mobilité active, mais le recensement de ces résultats fournit un portrait plus clair de ces effets. De plus, l’analyse critique des lacunes et la proposition de recherches futures aideront les chercheurs à développer des études menant à des recommandations quant au design des IVGEP qui tient compte des besoins en termes de mobilité active.

À cet effet, l’étude de cas contribue à l’avancement des connaissances quant aux perceptions de la population à la suite de la mise en place de noues végétalisées dans l’emprise routière. Les résultats de cette recherche fournissent des orientations pour les urbanistes et les décideurs en matière de conception de rues multifonctionnelles qui soutiennent à la fois une gestion des eaux urbaines durable et la mobilité active. L’étude propose notamment des recommandations pratiques pour leur mise en œuvre. De plus, étant donné que cette étude a été réalisée dans une petite ville en région, elle permet de souligner des contraintes propres à ces villes, souvent moins étudiées que les grandes villes. Les résultats mettent en évidence la nécessité de tenir compte du contexte et des caractéristiques spécifiques des IVGEP pour maximiser leurs bénéfices pour les communautés et l’environnement.

6.3 Limites de l’étude

Bien que la réalisation de ces études ait mené à des recommandations quant à la construction des IVGEP pour améliorer la mobilité active, ces recommandations ne sont que préliminaires. En effet, davantage d’études sont nécessaires pour bien comprendre comment les effets des IVGEP se matérialisent dans différents contextes (urbain, suburbain et rural), selon les caractéristiques sociodémographiques et selon le type d’IVGEP.

Les résultats de l’étude de cas fournissent un avancement des connaissances dans ce domaine. Par ailleurs, cette étude comporte certaines limites. Tout d’abord, elle a été menée dans une petite ville canadienne située en région rurale, ce qui limite l’applicabilité des résultats en milieu plus dense

ou dans d'autres régions du monde. De plus, la collecte des données s'est déroulée seulement trois mois après la fin des travaux, affectant négativement les perceptions des résidents. Ensuite, les analyses quantitative et qualitative sont limitées à de petits échantillons. Pour l'analyse du sondage, ceci restreint l'inclusion de variables de contrôle (notamment sur les caractéristiques sociodémographiques et les caractéristiques de l'environnement bâti). De plus, les données du sondage ne sont pas issues d'un échantillonnage aléatoire, ce qui limite la généralisation des résultats à la population globale.

6.4 Perspectives de recherche

Afin d'étudier les effets des IVGEP sur la mobilité active en utilisant des bases de données existantes sur les déplacements, telles que les enquêtes origine-destination, il est nécessaire de développer de nouveaux indicateurs de la végétation. Ces indicateurs doivent prendre en compte différentes caractéristiques physiques de la végétation, telles que la hauteur des végétaux, la diversité des végétaux, l'emplacement de l'infrastructure, la présence d'une dépression, etc. Pour se faire, des défis se posent en matière de collecte de données, nécessitant de meilleurs recensement et diffusion des emplacements de ces infrastructures, ainsi que le développement de méthodes automatisées permettant de localiser et caractériser ces éléments de manière plus efficace. Les résultats de telles études permettront des recommandations claires quant au design des IV et IVGEP. De plus, l'utilisation de données sur les déplacements des personnes permettra d'étudier les effets sur les comportements de mobilité.

Comme mentionné dans les limites de l'étude, il est nécessaire d'étudier les effets des IVGEP dans différents contextes urbains et d'analyser si les effets varient pour différents groupes de la population ou selon les caractéristiques de l'environnement bâti. Il est aussi pertinent de mieux comprendre les répercussions sociales de la mise en place des IVGEP sur les populations locales. Les résultats du mémoire mettent en évidence le fait que les citoyens perçoivent que les IVGEP causent des contraintes pour les déplacements automobiles. Dans plusieurs contextes, il peut être avantageux de favoriser les déplacements actifs au détriment des déplacements automobiles. Par ailleurs, il serait pertinent de mieux comprendre qui bénéficie de la mise en place des IVGEP en termes de mobilité et de s'assurer que leur mise en place ne nuit pas à des groupes plus vulnérables, notamment dans un contexte où il y a très peu d'alternatives à la voiture. En conclusion, il est nécessaire de bien comprendre le contexte du projet afin d'optimiser les bénéfices des IVGEP.

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ANNEXE A QUESTIONNAIRE

Cette annexe contient la version papier du questionnaire distribué à Saint-Charles-Borromée. La version en ligne comprend exactement les mêmes questions.



Formulaire d'information et de consentement Participants au sondage

Titre de l'activité de recherche :

Questionnaire visant à comprendre les préoccupations et besoins des citoyens par rapport au projet de réaménagement du secteur sud de Saint-Charles-Borromée

Équipe de recherche :

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Polytechnique Montréal – Département des génies civil, géologique et des mines

Financement de l'activité de recherche :

La présente activité de recherche est financée par un organisme fédéral : le conseil de recherches en sciences naturelles et en génie du Canada (CRSNG) et des organismes provinciaux : le Fonds de recherche du Québec - Société et culture (FRQSC) et l'Union des municipalités du Québec (UMQ).

Conflits d'intérêts

L'équipe de recherche n'est pas en situation de conflit d'intérêts avec les organismes de financement mentionnés ci-haut, Polytechnique Montréal et la Ville de Saint-Charles-Borromée dans le contexte de la présente activité de recherche.

Préambule

Nous vous invitons à participer à ce sondage qui vise à mieux comprendre les préoccupations des citoyens par rapport au projet de réaménagement du secteur sud de Saint-Charles-Borromée.

Avant d'accepter de compléter le sondage, veuillez prendre le temps de lire l'information présentée.

Présentation générale du projet de recherche

L'objectif principal de cette recherche est d'étudier la relation entre la présence d'infrastructures vertes de gestion des eaux pluviales dans l'environnement bâti et les perceptions et comportements des individus lors de leurs déplacements.

Afin d'atteindre notre objectif, nous vous poserons des questions relatives à vos perceptions par rapport à différentes infrastructures, vos préférences et vos comportements de mobilité.

Dans le cadre de cette activité, nous cherchons des personnes qui habitent à Saint-Charles-Borromée ou dans le secteur nord de Joliette (au nord du chemin de fer du Canadien Pacifique). Les personnes doivent être âgées de 18 ans et plus.

Nature et durée de votre participation à l'activité de recherche

Votre participation dans le cadre de la présente activité consistera en une série de questions auxquelles il vous sera demandé de répondre. Il y aura des questions qui porteront sur les caractéristiques de votre ménage et votre code postal (qui nous aideront à mieux comprendre le contexte dans lequel vous habitez). Toutes les réponses que vous fournirez resteront confidentielles. Le questionnaire prendra environ 15 minutes.

Risques et inconvénients

La présente activité de recherche ne devrait pas entraîner des risques plus grands que ceux que vous rencontrez dans votre vie de tous les jours.

Avantages et bénéfices

Vous ne retirerez aucun bénéfice personnel de votre participation à la présente activité de recherche. Toutefois, votre participation contribuera à l'avancement des connaissances liées à la gestion intégrée des systèmes de transports et des infrastructures vertes.

Compensation financière

Vous ne recevrez pas de compensation financière pour votre participation.

Participation volontaire et possibilité de retrait

Votre participation à la présente activité de recherche est volontaire. Vous pouvez donc refuser d'y participer en ne répondant pas aux questions du sondage. À tout moment, vous pouvez cesser de répondre, peu importe la raison. Si vous ne complétez pas le sondage, votre questionnaire sera supprimé. Si vous voulez retirer vos réponses après avoir terminé le sondage, vous pouvez envoyer un courriel à gboisjoly@polymtl.ca avec votre code postal, âge et genre (pour identifier vos réponses) en demandant que vos réponses soient retirées. Dans ce cas, vos données seront complètement éliminées de l'analyse.

Confidentialité et protection de vos données

L'équipe de recherche recueillera et consignera toutes vos données de manière sécuritaire de façon à en protéger le caractère confidentiel par des réponses anonymes. Vous serez identifié uniquement par un numéro d'identification et l'équipe de recherche s'assurera de conserver la confidentialité de ces informations. Les données seront conservées avec mot de passe sur les ordinateurs des membres de l'équipe de recherche. Dans le cas de transfert de données, les données seront transférées par le biais du système sécurisé de gestion documentaire Alfresco. Le système Alfresco permet de donner accès à des documents à un nombre restreint d'utilisateurs qui peuvent consulter les documents par le biais de n'importe quel appareil. Les chercheurs auront chacun un code sécurisé pour accéder à la plateforme

L'équipe de recherche utilisera toutes les données pour les seuls objectifs du projet de recherche brièvement décrit ci-dessus. Les résultats du projet pourraient être publiés dans des articles scientifiques ou être partagés avec d'autres personnes lors de conférences scientifiques. Toutefois, aucune information pouvant conduire à votre identification ne sera contenue dans ces publications ou communications scientifiques.

À des fins de suivi ou de contrôle, votre dossier de recherche pourrait être consulté par une personne mandatée par le Comité d'éthique de la recherche de Polytechnique Montréal ou par une personne mandatée par les conseils de recherche. Toutes ces personnes adhèrent à des politiques de confidentialité strictes.

Les données recueillies seront conservées pendant une période de 7 ans, après quoi elles seront détruites.

Vous avez le droit de consulter votre dossier de recherche pour vérifier l'exactitude des renseignements recueillis aussi longtemps que l'équipe de recherche ou Polytechnique Montréal détiendront ces informations. Cependant, afin de préserver l'intégrité scientifique du projet de recherche, certaines informations seront accessibles seulement à la fin du projet de recherche.

Diffusion des résultats de la recherche

Les résultats de la recherche seront partagés aux citoyens dans un communiqué de presse diffusé sur le site web de la Ville de Saint-Charles-Borromée.

Indemnisation en cas de préjudice et droits des participant(e)s

Si vous deviez subir quelque préjudice que ce soit par suite de votre participation à cette activité de recherche, vous ne renoncez à aucun de vos droits ni ne libérez les chercheurs, l'organisme de financement, la Ville de Saint-Charles-Borromée ou Polytechnique Montréal de leurs responsabilités légales et professionnelles

Personnes-ressources

Si vous avez des questions sur les **aspects scientifiques** du projet de recherche ou pour vous **retirer de l'étude**, vous pouvez contacter Geneviève Boisjoly au (514) 340-4711, poste 4802 ou encore par courriel à gboisjoly@polymtl.ca.

Pour toute préoccupation sur vos droits ou sur les responsabilités de l'équipe de recherche concernant votre participation à ce projet, vous pouvez contacter le Comité d'éthique de la recherche de Polytechnique Montréal au (514) 340-4711, poste 4420 ou encore par courriel à ethique@polymtl.ca



Sondage sur les infrastructures vertes à Saint-Charles-Borromée

Consentement

1. J'ai pris connaissance du formulaire d'information et de consentement, décrivant la nature et le déroulement du projet de même que les risques et les inconvénients qui pourraient survenir.
2. Je comprends qu'en participant à ce projet de recherche, je ne renonce à aucun de mes droits ni ne dégage les chercheurs de leurs responsabilités.

☐ J'accepte de participer au sondage

☐ Je refuse de participer au sondage

Section 1 : Questions sur vos déplacements

Cette section vise à mieux comprendre vos habitudes de déplacement lors d'une semaine normale. Veuillez répondre au meilleur de vos connaissances.

1.1 Quels modes de transport utilisez-vous pour effectuer vos déplacements (pour le travail, les loisirs, le magasinage, les promenades, etc.) ?

❶ **Cochez la ou les réponses**

☐ Automobile

☐ Autobus

☐ Vélo (bicyclette)

☐ Marche

☐ Aide à la mobilité (fauteuil roulant, triporteur, quadriporteur, etc.)

☐ Autre (veuillez préciser) :

1.2 Pour chaque mode de transport **sélectionné à la question 1.1**, veuillez remplir les tableaux correspondants.

❶ **Aide à la mobilité** : Vous pouvez considérer que les déplacements réalisés uniquement avec un appareil d'aide à la mobilité sont des déplacements à la marche.

Automobile :

Au cours de la dernière semaine, **combien de jours** avez-vous fait au moins un déplacement en **automobile** pour chacun des motifs suivants ? Veuillez cocher la case correspondante pour chaque motif.

Motif	0 jour	1 jour	2 jours	3 jours	4 jours	5 jours	6 jours	7 jours
Travail* / Étude								
Magasinage								
Loisir								
Promenade / Balade								
Autre								

***EXCLURE** les déplacements effectués dans le cadre de votre travail comme des livraisons ou le service à domicile.

Autobus :

Au cours de la dernière semaine, **combien de jours** avez-vous fait au moins un déplacement en **autobus** pour chacun des motifs suivants ? Veuillez cocher la case correspondante pour chaque motif.

Motif	0 jour	1 jour	2 jours	3 jours	4 jours	5 jours	6 jours	7 jours
Travail* / Étude								
Magasinage								
Loisir								
Promenade / Balade								
Autre								

****EXCLURE** les déplacements effectués dans le cadre de votre travail comme des livraisons ou le service à domicile.*

Vélo :

Au cours de la dernière semaine, **combien de jours** avez-vous fait au moins un déplacement à **vélo** pour chacun des motifs suivants ? Veuillez cocher la case correspondante pour chaque motif.

Motif	0 jour	1 jour	2 jours	3 jours	4 jours	5 jours	6 jours	7 jours
Travail* / Étude								
Magasinage								
Loisir								
Promenade / Balade								
Autre								

****EXCLURE** les déplacements effectués dans le cadre de votre travail comme des livraisons ou le service à domicile.*

Marche :

Au cours de la dernière semaine, **combien de jours** avez-vous fait au moins un déplacement à la **marche** pour chacun des motifs suivants ? Veuillez cocher la case correspondante pour chaque motif.

Motif	0 jour	1 jour	2 jours	3 jours	4 jours	5 jours	6 jours	7 jours
Travail* / Étude								
Magasinage								
Loisir								
Promenade / Balade								
Autre								

****EXCLURE** les déplacements effectués dans le cadre de votre travail comme des livraisons ou le service à domicile.*

[illegible]

Section 3 : Questions sur vos habitudes dans votre vie quotidienne

Les questions suivantes visent à mieux comprendre le profil des participant(e)s.

3.1 Les énoncés suivants portent sur vos **comportements dans votre vie quotidienne**. Veuillez indiquer à quelle fréquence vous faites les différentes actions énoncées.

	Jamais	Rarement	Parfois	La plupart du temps	Toujours	Ne sais pas
Je composte les résidus de table.	☐	☐	☐	☐	☐	☐
Je recycle les matériaux (papier, carton, métal, verre et plastique) qui vont dans le bac de recyclage.	☐	☐	☐	☐	☐	☐
J'essaie de limiter ma consommation d'eau lorsque je cuisine, que je lave la vaisselle, que je fais du lavage ou que je me lave.	☐	☐	☐	☐	☐	☐
J'essaie de limiter ma consommation d'eau pour des usages extérieurs tels que l'arrosage d'une pelouse ou d'un jardin, le nettoyage de l'entrée et le lavage d'une voiture.	☐	☐	☐	☐	☐	☐
À l'épicerie, j'utilise des sacs en plastique pour emballer certains fruits ou légumes.	☐	☐	☐	☐	☐	☐
Lorsque je fais du vélo, je porte un casque.	☐	☐	☐	☐	☐	☐
Lorsque je suis passager(ère) à l'avant d'un véhicule, j'attache ma ceinture.	☐	☐	☐	☐	☐	☐
Lorsque je suis passager(ère) à l'arrière d'un véhicule, j'attache ma ceinture.	☐	☐	☐	☐	☐	☐
Lorsque je conduis, je respecte les limites de vitesse.	☐	☐	☐	☐	☐	☐
Lorsque je traverse à la marche une intersection avec un feu piéton, j'attends toujours que le feu piéton soit allumé pour traverser.	☐	☐	☐	☐	☐	☐

Section 4 : Questions sur le projet de réaménagement du secteur sud de Saint-Charles-Borromée

Les énoncés suivants portent sur les travaux de réaménagement faits dans le secteur sud de Saint-Charles-Borromée à l'été 2021.

 Vue d'une cellule de biorétention implantée sur la rue Boucher	 Vue des aménagements implantés le long de la piste cyclable sur la rue Boucher
---	---

4.1 J'ai vu ou j'ai entendu parler du projet de réaménagement du secteur sud avant aujourd'hui.

❗ *Veillez sélectionner une réponse ci-dessous*

- ☐ Oui
- ☐ Non
- ☐ Je ne suis pas certain(e)
- ☐ Je préfère ne pas répondre

4.2 Si vous avez répondu « Oui » à la question précédente, veuillez indiquer comment vous avez entendu parler du projet de réaménagement du secteur sud.

❗ *Cochez la ou les réponses*

- ☐ Sur le site web de la Ville de Saint-Charles-Borromée.
- ☐ Dans le magazine Vivre SCB.
- ☐ Lors de consultations publiques.
- ☐ Sur les réseaux sociaux.
- ☐ Par des amis, des collègues, etc. (bouche-à-oreille).
- ☐ En passant par là.
- ☐ Je préfère ne pas répondre
- ☐ Autre (veuillez préciser) : _____

4.3 Veuillez indiquer votre **niveau d'accord** avec les énoncés suivants qui portent sur les infrastructures qui ont été mises en place dans le **secteur sud de Saint-Charles-Borromée**. Répondez au meilleur de vos connaissances.

❶ Si vous ne connaissez pas le projet, vous pouvez répondre en vous basant sur les images présentées à la page précédente. Ces images montrent les infrastructures sur la rue Boucher à Saint-Charles-Borromée.

[illegible]

	Fortement en désaccord	En désaccord	Neutre	En accord	Fortement en accord	Ne sais pas
Selon moi, l'implantation de ce type d'infrastructures contribue à la lutte et/ou à l'adaptation aux changements climatiques.	☐	☐	☐	☐	☐	☐
Selon moi, ces infrastructures vont permettre une meilleure gestion des eaux pluviales.	☐	☐	☐	☐	☐	☐
Selon moi, ces infrastructures vont permettre d'accroître la biodiversité dans la ville.	☐	☐	☐	☐	☐	☐
Selon moi, l'implantation de ces infrastructures est rentable.	☐	☐	☐	☐	☐	☐

Section 5 : Questions sur votre appréciation des infrastructures vertes

Cette section vise à évaluer votre **niveau d'appréciation de différents types d'aménagement** de rue pour **la marche ou le vélo**. Les images présentées visent à montrer un exemple pour trois types d'aménagement, soit un aménagement traditionnel, un aménagement avec une bande de gazon ainsi qu'un aménagement incluant une infrastructure avec des végétaux qui permet l'infiltration de l'eau de pluie. Vous répondrez d'abord à des questions sur vos déplacements à la marche, puis les mêmes questions seront posées pour vos déplacements à vélo.

5.1 Veuillez évaluer votre niveau de satisfaction par rapport à ces **trois différentes configurations** de rue pour la **marche**.

❶ *Encerclez une valeur de 1 à 7*

1) Trottoir

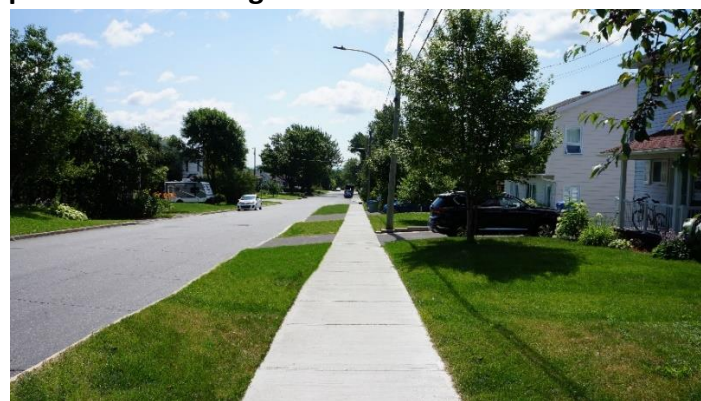


Très insatisfait(e)

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Très satisfait(e)

2) Trottoir isolé par une bande de gazon

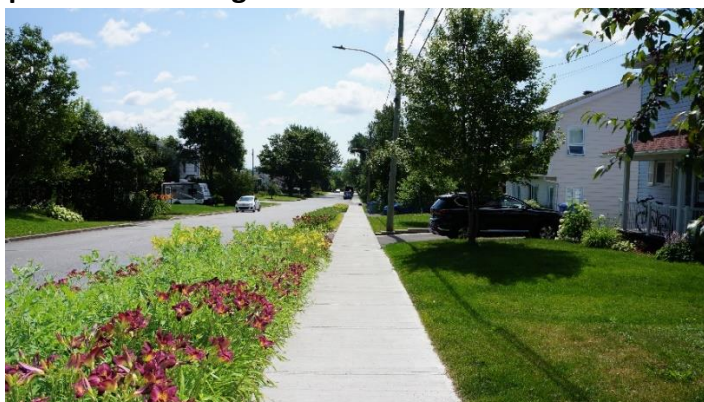


Très insatisfait(e)

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Très satisfait(e)

3) Trottoir isolé par des noues végétalisées



Très insatisfait(e)

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Très satisfait(e)

5.2 Veuillez évaluer votre niveau de satisfaction par rapport à ces **trois différentes configurations** de rue pour le **vélo**.

❶ *Encerclez une valeur de 1 à 7*

1) Piste cyclable bidirectionnelle surélevée



Très insatisfait(e)

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Très satisfait(e)

2) Piste cyclable bidirectionnelle isolée par une bande de gazon

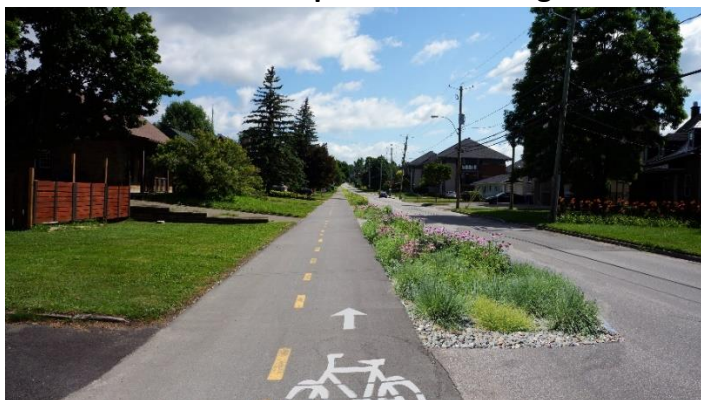


Très insatisfait(e)

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Très satisfait(e)

3) Piste cyclable bidirectionnelle isolée par des noues végétalisées



Très insatisfait(e)

1	2	3	4	5	6	7
---	---	---	---	---	---	---

Très satisfait(e)

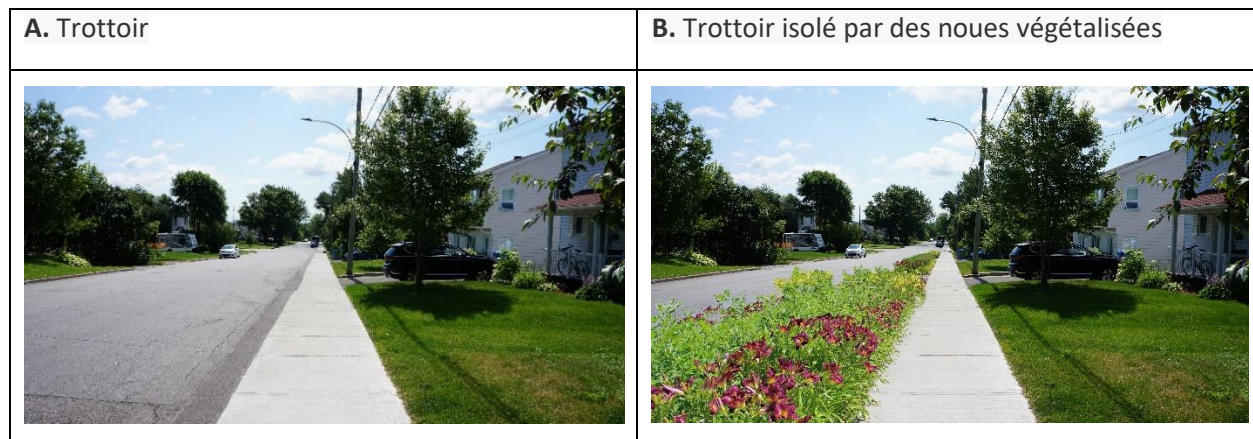
Section 5 : Question sur votre appréciation des infrastructures vertes (suite)

Les questions qui suivent visent à comprendre **vos comportements de mobilité** par rapport à **différentes configurations de rue**. Certaines questions portent sur vos **déplacements utilitaires**

(par exemple, se rendre au travail, magasiner, faire un loisir, etc.) alors que d'autres questions portent sur vos **déplacements récréatifs** comme des promenades/des balades ou de la course à pied. Vous répondrez d'abord à des questions sur vos déplacements à la marche, puis les mêmes questions seront posées pour vos déplacements à vélo.

Questions sur la marche

Les trois questions suivantes portent sur les images A et B ci-dessous.



5.3 Lors d'un **déplacement utilitaire à la marche** (par exemple, pour se rendre au travail, magasiner, faire un loisir, etc.), seriez-vous prêt(e) à **changer votre itinéraire** pour emprunter la rue **B** plutôt que la rue **A** ?

- ☐ Non, je ne changerais pas mon itinéraire.
- ☐ Oui, mais seulement si ça ne change pas la durée et la distance de mon déplacement.
- ☐ Oui, je serais prêt(e) à allonger un peu mon trajet.
- ☐ Oui, je serais prêt(e) à allonger considérablement mon trajet.
- ☐ Ne sais pas / Ne s'applique pas.

5.4 Pensez-vous que **vous feriez plus de déplacements utilitaires à la marche** (par exemple, pour se rendre au travail, magasiner, faire un loisir, etc.) dans votre quartier si les rues étaient aménagées comme celle sur l'image **B** plutôt que celle sur l'image **A** ?

- ☐ Très peu probable.
- ☐ Peu probable.
- ☐ Neutre.
- ☐ Probable.
- ☐ Très probable.
- ☐ Ne sais pas / Ne s'applique pas.

5.5 Lors d'une **promenade/balade à la marche ou d'une course à pied**, seriez-vous prêt(e) à **changer votre itinéraire** pour emprunter la rue **B** plutôt que la rue **A** ?

- ☐ Non, je ne changerais pas mon itinéraire.
- ☐ Oui, mais seulement si ça ne change pas la durée et la distance de mon déplacement.
- ☐ Oui, je serais prêt(e) à allonger un peu mon trajet.
- ☐ Oui, je serais prêt(e) à allonger considérablement mon trajet.
- ☐ Ne sais pas / Ne s'applique pas.

Question sur le vélo

Les trois questions suivantes portent sur les images C et D ci-dessous.

C. Piste cyclable bidirectionnelle surélevée	D. Piste cyclable bidirectionnelle isolée par des noues végétalisées
	

5.6 Lors d'un **déplacement utilitaire à vélo** (par exemple, pour se rendre au travail, magasiner, faire un loisir, etc.), seriez-vous prêt(e) à **changer votre itinéraire** pour emprunter la rue **D** plutôt que la rue **C** ?

- ☐ Non, je ne changerais pas mon itinéraire.
- ☐ Oui, mais seulement si ça ne change pas la durée et la distance de mon déplacement.
- ☐ Oui, je serais prêt(e) à allonger un peu mon trajet.
- ☐ Oui, je serais prêt(e) à allonger considérablement mon trajet.
- ☐ Ne sais pas / Ne s'applique pas.

5.7 Pensez-vous que **vous feriez plus de déplacements utilitaires à la vélo** (par exemple, pour se rendre au travail, magasiner, faire un loisir, etc.) dans votre quartier si les rues étaient aménagées comme celle sur l'image **D** plutôt que celle sur l'image **C** ?

- ☐ Très peu probable.
- ☐ Peu probable.
- ☐ Neutre.
- ☐ Probable.
- ☐ Très probable.
- ☐ Ne sais pas / Ne s'applique pas.

5.8 Lors d'une **promenade/balade à vélo**, seriez-vous prêt(e) à **changer votre itinéraire** pour emprunter la rue D plutôt que la rue C ?

- ☐ Non, je ne changerais pas mon itinéraire.
- ☐ Oui, mais seulement si ça ne change pas la durée et la distance de mon déplacement.
- ☐ Oui, je serais prêt(e) à allonger un peu mon trajet.
- ☐ Oui, je serais prêt(e) à allonger considérablement mon trajet.
- ☐ Ne sais pas / Ne s'applique pas.

Section 6 : Profil général

6.1 Quel âge avez-vous ?

_____ ans

6.2 Êtes-vous...

- ☐ Une femme
- ☐ Un homme
- ☐ Genderqueer ou non binaire
- ☐ Autre (veuillez préciser) : _____
- ☐ Je préfère ne pas répondre

6.3 Quelle est votre occupation principale ?

- ☐ Au travail à temps plein
- ☐ Au travail à temps partiel
- ☐ Étudiant(e) à temps plein
- ☐ Étudiant(e) à temps partiel
- ☐ En arrêt de travail / congé de maternité ou de paternité
- ☐ À la recherche d'un emploi
- ☐ Retraité(e)
- ☐ À la maison
- ☐ Autre
- ☐ Je préfère ne pas répondre

6.4 Quel est le revenu de votre ménage avant impôt ?

- ☐ < 20 000\$
- ☐ Entre 20 000\$ et 40 000\$
- ☐ Entre 40 000\$ et 60 000\$
- ☐ Entre 60 000\$ et 80 000\$
- ☐ Entre 80 000\$ et 100 000\$
- ☐ Entre 100 000\$ et 125 000\$
- ☐ Entre 125 000\$ et 150 000\$
- ☐ Entre 150 000\$ et 200 000\$
- ☐ > 200 000\$
- ☐ Je préfère ne pas répondre

6.5 Combien d'enfants y a-t-il dans votre ménage ?

❗ Vous pouvez inscrire « 0 » si votre ménage ne comprend pas d'enfant pour un groupe d'âge.

Groupe d'âge	Nombre d'enfant(s)
De 0 à 5 ans	
De 6 à 11 ans	
De 12 à 17 ans	

- ☐ Je préfère ne pas répondre

6.6 Pour nous aider à connaître votre contexte de vie, veuillez inscrire votre code postal ou le nom des rues d'une intersection à proximité de votre domicile.

Veuillez écrire votre code postal de la façon suivante : X1XS2S

Code postal : _____

Ou

Nom de l'intersection : _____

☐ Je préfère ne pas répondre

6.7 Depuis combien d'années vivez-vous à votre lieu de résidence actuel ?

☐ Moins d'un an

☐ 1 à 2 ans

☐ Plus de 2 ans

☐ Je préfère ne pas répondre

6.8 Avez-vous accès à une voiture pour vos déplacements quotidiens ?

☐ Oui

☐ Non

☐ Je préfère ne pas répondre

6.9 Quel est le plus haut niveau de scolarité que vous avez complété ?

☐ Aucune scolarité formelle

☐ École primaire

☐ École secondaire

☐ Diplôme d'études collégiales (CÉGEP/D.E.P)

☐ Certificat universitaire ou baccalauréat

☐ Diplôme d'études supérieures

☐ Autre : _____

☐ Je préfère ne pas répondre

6.10 Vous considérez-vous comme une personne à mobilité réduite (difficulté à se déplacer et/ou autonomie de déplacement limitée) ?

☐ Oui

☐ Oui, mais temporairement

☐ Non

☐ Je préfère ne pas répondre

Section 7 : Commentaires

Avez-vous d'autres commentaires ou suggestions concernant le projet de réaménagement du secteur sud de Saint-Charles-Borromée ?

ANNEXE B GUIDE D'ENTREVUE POUR LES CITOYENS

Cette annexe contient le guide d'entrevue utilisé pour les entrevues avec les personnes qui habitent ou travaillent à proximité des rues réaménagées.

Synergie entre les infrastructures vertes de gestion des eaux pluviales et la mobilité active :
les perspectives des citoyens
Guide d'entrevue

Entrevues d'environ 30 minutes avec des citoyens.

Matériel : Téléphone intelligent pour enregistrer la discussion

1. Introduction

- Description du projet
- Objectif : comprendre quels sont les points de vue des citoyens par rapport au réaménagement du secteur sud de Saint-Charles-Borromée avec l'implantation d'infrastructures vertes pour la gestion des eaux pluviales
- Thèmes :
 - o Connaissance des infrastructures
 - o Appréciation et acceptabilité
 - o Mobilité
 - o Sécurité
 - o Environnement
 - o Communications
 - o Projet de rues à sens unique
 - o Profil général

2. Connaissance des infrastructures

- 2.1. Est-ce que vous avez remarqué les nouvelles infrastructures mises en place sur les rues Bousquet, Gouin, Longpré, Juge-Guibault et Boucher ?
- 2.2. Quels sont les avantages et désavantages de ces infrastructures selon vous?
- 2.3. Selon vous, pourquoi la ville a-t-elle implanté ces infrastructures ?

3. Appréciation et acceptabilité

- 3.1. Est-ce que vous appréciez les infrastructures? Pourquoi ?
- 3.2. Trouvez-vous que la ville devrait en implanter plus ou moins ? Pourquoi ?
- 3.3. Trouvez-vous que les infrastructures sont utiles ? Pourquoi ?

4. Mobilité

- 4.1. Avez-vous ou songez-vous à changer vos habitudes de mobilité depuis que les infrastructures ont été implantées ? Est-ce que vous marchez ou faites du vélo plus ou moins ? Est-ce que vous utilisez la piste multifonctionnelle ?
- 4.2. Avez-vous remarqué des changements dans les habitudes de mobilité de vos voisins ?
- 4.3. Avez-vous remarqué si les enfants utilisent les infrastructures pour se déplacer ou pour jouer ?

5. Sécurité

- 5.1. Trouvez-vous que les nouvelles infrastructures sont sécuritaires ? Pourquoi ?
- 5.2. Avez-vous remarqué si les automobilistes roulent moins vite ?
- 5.3. Pensez-vous que les infrastructures sont sécuritaires pour les personnes à mobilité réduite ?

6. Environnement

- 6.1. Pensez-vous que l'implantation d'infrastructures de gestion des eaux pluviales est une bonne solution pour que les villes soient mieux adaptées à faire face à des événements climatiques majeurs comme de fortes pluies ? Pourquoi ?
- 6.2. Quels sont, selon vous, les bénéfices sur l'environnement de l'implantation d'infrastructures pour la gestion des eaux pluviales ?

7. Communications

- 7.1. Selon vous, est-ce que les communications faites par la Ville ont permis de mieux informer et sensibiliser les citoyens par rapport au projet ?
- 7.2. Selon vous, est-ce que les citoyens ont été impliqués dans le projet ?

8. Profil de l'individu

- 8.1. Avez-vous des enfants ?
- 8.2. Quels modes de déplacement utilisez-vous ?
- 8.3. Quels sont les motifs de vos déplacements ?

ANNEXE C GUIDE D'ENTREVUE POUR LES PLANIFICATEURS

Cette annexe contient le guide d'entrevue utilisé pour les entrevues avec les planificateurs.

**Synergie entre les infrastructures vertes de gestion des eaux pluviales et la mobilité active :
les perspectives des planificateurs**
Guide d'entrevue

Entrevues d'environ 30 minutes avec des planificateurs.

Matériel : Ordinateur pour enregistrer la discussion

1. Introduction

- Description du projet
- Objectif : comprendre quels ont été les défis et opportunités au niveau de la planification urbaine du projet de réaménagement du secteur Sud de Saint-Charles-Borromée
- Thèmes :
 - Objectifs
 - Défis et opportunités
 - Planification
 - Participation citoyenne

2. Objectifs et impacts

- 2.1. Selon vous, quel est l'objectif principal du projet de réaménagement du secteur Sud de Saint-Charles-Borromée ? Quels sont les objectifs secondaires ?
- 2.2. Pensez-vous que le projet tel que construit répond bien à ces objectifs ? Pourquoi ?
- 2.3. Quelle est, selon vous, la plus grande force du projet ?
- 2.4. Selon vous, quels sont les impacts du projet sur la mobilité ?

3. Défis et opportunités

- 3.1. Selon vous, qu'est-ce qui a contribué au succès du projet de réaménagement du secteur Sud de Saint-Charles-Borromée ? Qu'est-ce qui a été plus difficile dans le projet ?
- 3.2. Pensez-vous que d'autres villes devraient faire des projets similaires ? Pourquoi ?
- 3.3. Quels conseils donneriez-vous à une autre ville qui voudrait implanter des infrastructures vertes ?

4. Planification

- 4.1. Comment avez-vous fait pour réussir à coordonner le projet entre les différentes parties prenantes ?
- 4.2. Avez-vous priorisé certains aspects du projet ?
- 4.3. Lors de la conception des infrastructures, quels sont les principaux enjeux que vous avez considérés ?

5. Participation citoyenne

- 5.1. Quels étaient vos objectifs avec la participation citoyenne ? Pourquoi avez-vous inclus les citoyens ?
- 5.2. Quels moyens avez-vous mis en œuvre pour informer ou impliquer les citoyens dans le projet ?
- 5.3. Quels mécanismes vous ont permis de prendre connaissance des préoccupations des citoyens (avant, pendant, après le projet) ?
- 5.4. Quelles sont les principales préoccupations des citoyens par rapport au projet ?
- 5.5. Avez-vous fait des ajustements au projet pour répondre aux préoccupations des citoyens ?
- 5.6. Maintenant que le projet est construit, envisagez-vous des moyens d'informer ou d'impliquer les citoyens concernant l'entretien des infrastructures ?

ANNEXE D GUIDE POUR LES GROUPES DE DISCUSSION

Cette annexe contient le guide utilisé lors des groupes de discussion avec les jeunes.

Synergie entre les infrastructures vertes de gestion des eaux pluviales et la mobilité active :
les perspectives des jeunes
 Guide pour les groupes de discussion

Matériel : table, chaises, magnétophone et projecteur

Début de l'activité : tour de table pour que chaque enfant dise son nom, son âge et qu'il identifie sur une carte à l'aide d'un post-it dans quelle zone il habite (au nord-ouest ou au sud-est de l'école).

Déplacements

- Cette semaine, comment est-ce que vous vous êtes déplacé pour venir à l'école ? Pourquoi ?
- Au début de l'année, en septembre, comment est-ce que vous vous déplaçiez pour venir à l'école ? Pourquoi ?
- Est-ce que vous avez le droit de vous déplacer seul à vélo ? À la marche ? Pourquoi ?
- Si vous aviez le choix et qu'il faisait beau, quel moyen de transport préféreriez-vous utiliser pour venir à l'école (proposer marche, vélo, trottinette, auto et autobus) ? Pourquoi ?
- Est-ce que votre préférence est différente l'été par rapport à l'hiver ?
- Qu'est-ce qui rend faciles ou difficiles vos déplacements ?
- Qu'est-ce que vous appréciez le plus quand vous vous déplacez (à la marche ou à vélo) ?

Sécurité

- Est-ce que vous trouvez que les rues près de votre école sont sécuritaires pour les jeunes ? Pourquoi ?
- Qu'est-ce que vous proposeriez pour rendre les rues plus sécuritaires ?

Environnement

- Est-ce que vous avez remarqué des changements dans votre quartier depuis l'année passée ?
- Qu'est-ce que vous aimez dans votre quartier ou le quartier de l'école ?
- Qu'est-ce que vous n'aimez pas dans votre quartier ou le quartier de l'école ?
- Qu'est-ce que vous aimeriez changer dans la rue où vous habitez ?

Noues végétalisées

Des images seront projetées (2-3 images à la fois) et les jeunes seront amenés à commenter les différentes images. Voici les différentes questions qui seront posées :

- Qu'est-ce qui est différent sur les deux images ?
- Quelle rue préféreriez-vous utiliser pour venir à l'école (à la marche, à vélo) ? Pourquoi ?
- Selon vous, quels sont les avantages et désavantages de chacune des rues ?
- Quelle rue est plus sécuritaire ? Pourquoi ?
- Êtes-vous capable de m'expliquer à quoi servent ces infrastructures [l'image montre une noue végétalisée] ?

Explication courte et simple du fonctionnement d'une noue végétalisée.

- Quels sont les avantages et les désavantages selon vous de mettre des infrastructures comme celles-ci dans votre quartier ?
- Pouvez-vous nommer des avantages pour l'environnement ?
- Est-ce que vous aimeriez avoir ces infrastructures devant votre maison ? Pourquoi ?