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Green stormwater infrastructure and active mobility: A case study investigating the effects of bioswales on individuals' perceptions☆

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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 were collected through: (i) an online and in-person survey with 296 residents, (ii) interviews with 12 municipal stakeholders, 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.

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 and 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, 2019; Zhu et al., 2022). For instance, the

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presence of trees along the road can create a more enclosed streetscape which reduces the driver's field of sight (Harvey and 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, 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 and Kumar, 2019; Maund et al., 2019; Shafique and 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 and 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 the 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, as found in the review by Lemieux 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 and Kim, 2017). Moreover, Adkins et al. (2012) found that GSI increase the attractiveness of walking activities. Suppakittpaisarn 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 are 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 express 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 is apprehension among certain individuals that the implementation of GSI could have negative impacts on car travel (Ferreira et al., 2021; Hérivaux and 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 are worries that individuals might accidentally fall into the bioswales, or that tall vegetation could obstruct the 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), and 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. Conversely, 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 investigate a recent project in the city of Saint-Charles-Borromée (Quebec, Canada) that incorporated bioswales within the right-of-way. Given the limited existing research on this topic, a case study methodology is 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 offer insights into how the implementation of bioswales can be optimized to enhance active transportation. Moreover, this study underscores the need for planners to embrace integrated urban design, acknowledging the interactions between various street features.

2. Theory and methodology

2.1. Conceptual framework

This study aims to provide insights into the effects of bioswales on individuals' perceptions and satisfaction with streets specifically designed for walking and cycling, to shed light on how GSI can support active travel. As illustrated in Fig. 1, the literature suggests that satisfaction and travel behaviour are closely intertwined, where increased satisfaction with pedestrian and cycling environments is likely to lead to more walking and cycling (De Vos et al., 2019). In turn, individuals' satisfaction is largely influenced by the way individuals perceive the street. Furthermore, personal characteristics are key determinants of individuals' perceptions and satisfaction (Gao et al., 2017; Susilo and Cats, 2014) In line with this, the implementation of bioswales in the right-of-way has been shown to influence individuals' perceptions, and satisfaction, and the literature review uncovered a diversity of perspectives regarding bioswales among the population, which vary based on personal characteristics as well as street design. This section describes the hypothesized relationships between perceived street attributes, personal characteristics, satisfaction with street design for walking and cycling, and active travel behaviour, in the context of implementing bioswales in the right-of-way.

First, most studies evaluating the effects of a given intervention on walking and cycling focus on travel behaviour. For instance, studies have shown that implementing traffic calming measures (Bayomi et al., 2024; Gitelman et al., 2017; Huang and Cynecki, 2000), bicycle facilities (Duthie et al., 2010), and vegetation (Ki and Lee, 2021; Yang et al., 2019) can influence road user behaviour. Bioswales are expected to offer similar benefits to traffic calming measures, along with additional benefits provided by vegetation.

However, there are various mechanisms through which a particular street design can influence travel behaviour, and understanding those mechanisms can be very informative regarding specific design recommendations. Notably, the role of travel satisfaction and personal characteristics in explaining travel behaviour is important. In their conceptual paper on the role of travel satisfaction, De Vos and Witlox (2017) put forward the bidirectional relationships that exist between these elements. More specifically, De Vos (2019) argued that travel satisfaction is a predictor of travel mode choice. If someone has a positive experience with a specific mode while traveling, that person is likely to choose the same mode again. Thus, it is expected that if individuals are more satisfied with a given street design for walking and cycling, they are more likely to use these modes.

As shown in the conceptual framework, this paper focuses on understanding the influence of bioswales on travel satisfaction. By looking at satisfaction instead of behaviour, we aim to better understand the mechanisms through which bioswales could potentially increase active travel behaviour. Since little is known regarding the relationship between bioswales and active mobility, exploring these complex

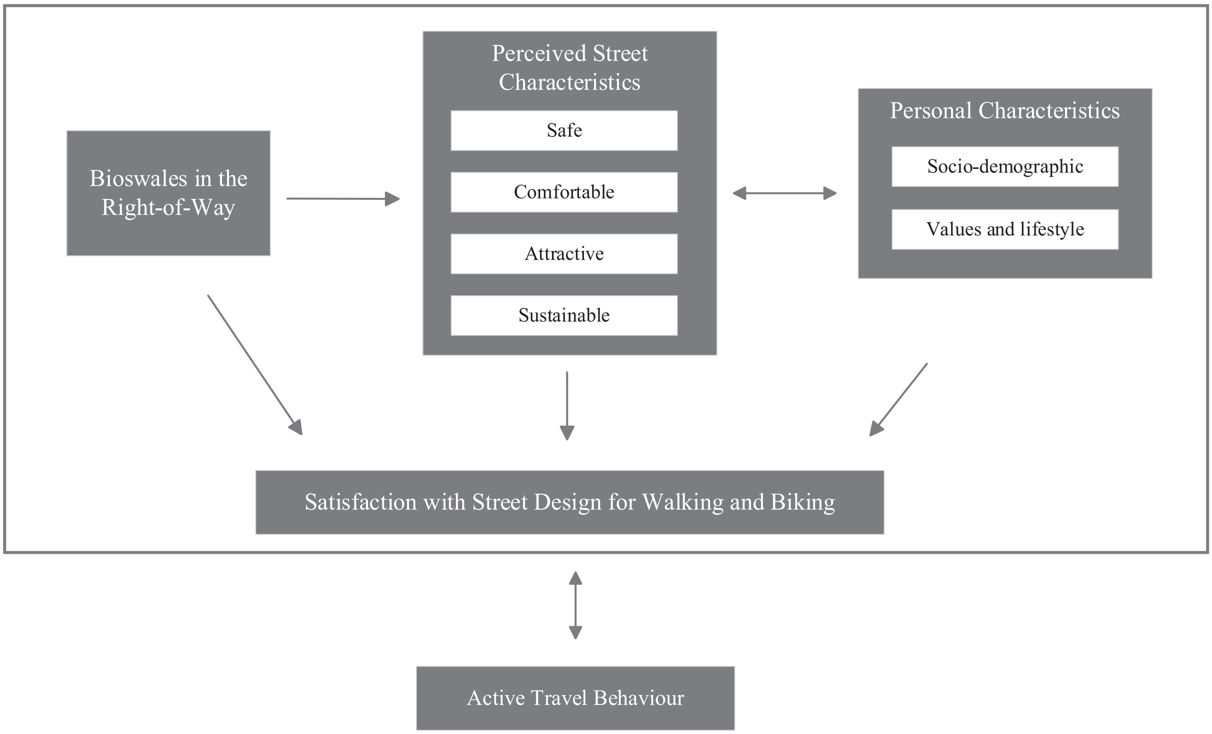

Fig. 1. Conceptual framework.

mechanisms will offer a more comprehensive understanding of the underlying processes rather than solely focusing on the final outcome (i.e., behaviour). This choice is also based on the particular case being examined. The case will be explained in more detail later, but it pertains to a situation where very few people engage in active transportation due to their reliance on cars. This context makes it difficult to study changes in active travel behaviour. Additionally, bioswales have only recently been introduced, so it is unlikely that people's behaviour has already changed.

To investigate the impact of bioswales on travel satisfaction, it is crucial to consider the various determinants of trip satisfaction. Weather, mode-specific attributes (cost, trip duration, etc.), personal characteristics (socio-demographic and attitudes), and route characteristics (slope, presence of bicycle paths, surrounding landscape, etc.) are all important elements that can affect trip satisfaction (Manaugh and El-Geneidy, 2013; Ory and Mokhtarian, 2005; St-Louis et al., 2014; Willis et al., 2013). Here, as we delve into the effects of a specific intervention, our focus lies on understanding how the intervention impacts the perceived characteristics of the street. Due to the novelty of the intervention, gaining knowledge about the effects of the different characteristics of the bioswales and street design will help inform how to improve the design to maximize the benefits of bioswales. Additionally, we aim to examine the personal characteristics that may influence this relationship.

As illustrated in the conceptual framework, four street characteristics are studied: perceived safety, comfort, attractiveness, and sustainability. As mentioned in the literature review, the implementation of bioswales in the right-of-way has the potential to influence perceived safety, aesthetics, and comfort. However, this relationship has yet to be clearly demonstrated (Lemieux et al., 2023). Moreover, since GSI is praised for its environmental benefits, it is expected that some people will recognize and value the environmental contribution of bioswales, which might affect their satisfaction with the design. While it is expected that, overall, bioswales should enhance these four street characteristics, some specific characteristics of bioswales might lead to negative impacts on perceptions. For instance, the accumulation of debris in bioswales can negatively impact the aesthetic appeal of the street. An in-depth analysis will provide insights regarding these nuanced outcomes.

As mentioned earlier, personal characteristics (i.e., socio-demographic characteristics, values, and lifestyles) can also influence satisfaction levels. For values and lifestyle, this study focuses on characteristics expected to influence the relationship between bioswale implementation and satisfaction with walking and cycling street design. For example, some studies have shown that people who value the environment are more satisfied with their walking trips (Manaugh and El-Geneidy, 2013; Ory and Mokhtarian, 2005). Manaugh and El-Geneidy (2013) explain that individuals who walk due to financial constraints will perceive elements of their trip differently compared to those who intentionally adopt walking as part of an active and pro-environment lifestyle. Similarly, we hypothesize that individuals who prioritize neighbourhood development, engage in composting, recycling, etc., will perceive the implementation of bioswales differently than those who do not prioritize these elements. The latter group may not perceive or appreciate the environmental and aesthetic benefits offered by bioswales. Thus, we hypothesize that personal characteristics and perceived street characteristics are interrelated.

Overall, this conceptual framework shows how implementing bioswales in the right-of-way can influence individuals' satisfaction with walking and cycling street designs and, in turn, affect active travel behaviour. The next section describes the methodology used to investigate these complex relationships between perceived street characteristics, personal characteristics, and satisfaction with street design.

2.2. *Case study methodology*

The research design is based on a case study methodology as described by Meyer (2001). 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). These reasons are relevant in the context of our research, considering the recent implementation of GSI in several cities around the world (Greenberg, 2008; Polanski, 2015; Shafray and Kim, 2017; Valente et al., 2021) and the limited scientific literature on individuals' perceptions regarding the synergy between active mobility and stormwater management (Lemieux et al., 2023).

Using a mixed method approach (i.e., qualitative and quantitative analyses), we reach 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). Indeed, the effects of bioswales on street design satisfaction are not uniform across the entire population. For instance, Adkins et al. (2012) found that GSI increases the attractiveness of walking, while Everett et al. (2015) revealed that some individuals do not find bioswales attractive. Furthermore, Ferreira et al. (2021) showed that among stakeholders interested in GSI implementation, there is a diversity of perceptions regarding the role GSI can play in overcoming urban challenges. These results support the need to involve a diversity of participants in the present study in order to capture a wide range of viewpoints.

As shown in Fig. 2, this mixed method approach includes a survey for quantitative analysis, and interviews and focus groups for qualitative analysis. The survey gathers opinions from numerous respondents to analyze the satisfaction levels with bioswales for walking and cycling compared to other scenarios, while investigating how personal characteristics and perceived street characteristics influence this relationship. The survey's analysis involves regressions and cluster analysis. First, regressions assess the statistical relationship between bioswale implementation and satisfaction with street design for walking and cycling, while controlling for personal characteristics. Then, cluster analysis complements the regressions' results by exploring how perceived street attributes relate to satisfaction levels. The role of personal characteristics is also assessed in the cluster analysis and compared with the results obtained in the regressions. These two survey analysis methods aim to explore, from a broad perspective, the full range of relationships depicted within the rectangular box of the conceptual framework (Fig. 1).

Subsequently, a qualitative analysis of interviews with planners, residents, and workers, along with focus groups with children, aim to provide an in-depth understanding of how bioswale implementation influences perceived street characteristics. Additionally, it explores whether other factors (not investigated in the survey) have influenced individuals' satisfaction, such as the novelty of the infrastructure or the communication during the project. Finally, the focus groups also incorporate the perspective of younger demographics who are not included in the survey. Given the presence of a school in the study area, we consider it essential to involve children's perspectives. Different data collection methods are used for adults and children to account for the different needs of these two groups.

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 individuals' preferences while underlining the factors which contribute to these preferences. The mixed method provides both a broad and in-depth analysis of the relationships depicted in the conceptual framework. The data collection processes for the survey, interviews, and focus groups are further explained in section 2.4. The methodological choices for each analysis (regression analyses and cluster analysis of the survey data, and qualitative analysis of the interviews and focus groups) are further detailed in section 3 along with the presentation of the results. Ethical approval was obtained from the Research Ethics Board at Polytechnique Montreal.[2]

[2] Project #CER-2223–21-D.

2.3. 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. Fig. 3 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.

Fig. 4 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.

2.4. Data collection

Data were 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. The sample size was constrained by the small population of Saint-Charles-Borromée and by the limited resources for data collection. However, because the study is exploratory in its nature and does not require high precision in its findings, a smaller sample size is sufficient {Daniel, 2012 #152}.

2.4.1. Survey

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. This additional data collection was essential to ensure reaching a sufficient number of respondents residing near the redesigned street (in the sample, there are 63 individuals living within 400 m of the redesigned streets).

The survey included questions on socio-demographic characteristics, travel behaviour, respondents' values and lifestyles (valuing their neighbourhood, composting, recycling, etc.). The last section of the survey specifically focused on the satisfaction with the recently implemented bioswales. Photos showing the new infrastructure (Fig. 4) 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 Fig. 5. To ensure consistency in terms of built environment, Adobe

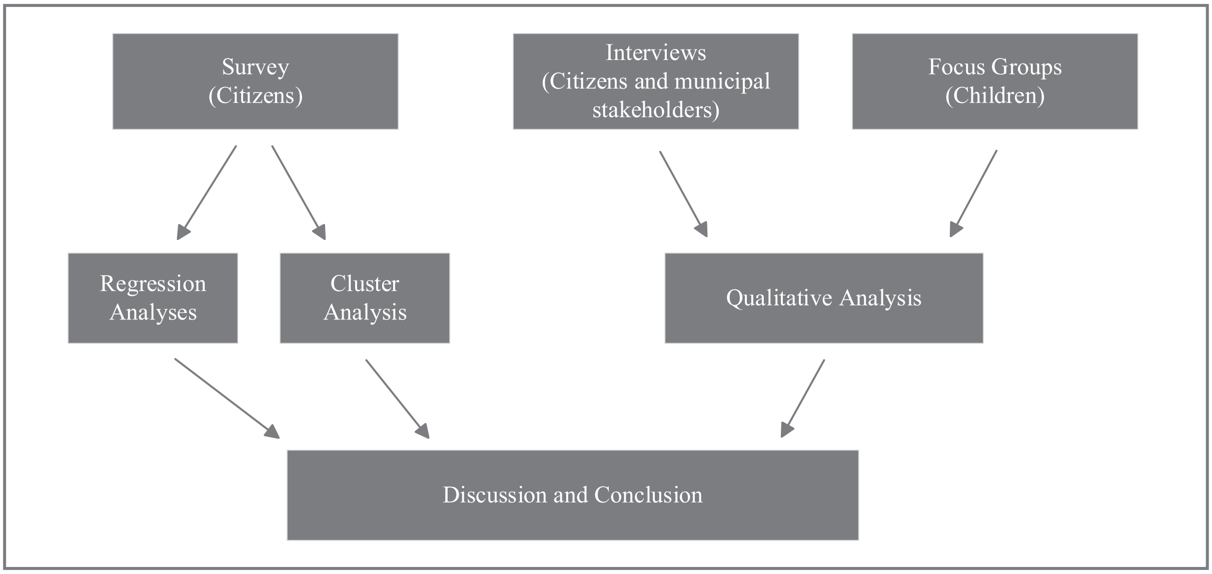

Fig. 2. Case study methods and analyses.

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 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.

2.4.2. *Interviews*

The selection of participants for the qualitative analysis aimed to obtain an overview of diverse perceptions regarding the implementation of bioswales. Rather than aiming to generalize the results, the goal is to understand the factors and processes that explain varying levels of satisfaction with bioswales and the benefits that bioswales can bring to active mobility. Semi-structured interviews were conducted with municipal stakeholders involved in the project (5) and citizens living or working in the area (7). Since the project was carried out in a small city with a constrained staff, the five municipal stakeholders selected (an engineer, an urban planner, two communication officers, and one municipal elected official) represented all municipal employees directly involved in the project or possessing significant knowledge about it. For the selection of citizens, we aimed to include respondents with diverse backgrounds to provide a wide range of perspectives. Among the seven citizens were three women and four men, including three workers, one retired individual, and three parents. Although this does not make the sample representative by any means, by including a diverse group of stakeholders, we aimed to obtain a comprehensive overview of the processes at play.

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 objective. 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. Given that they are not experts, the themes were tailored to be more specific for citizens to ensure consideration of impacts on safety, mobility, and the environment. Interviews lasted an average of 28 min. Among the municipal stakeholders, there were two women and three men.

2.4.3. *Focus groups*

We conducted two focus groups involving a total of 13 children aged 10–11 years (3 girls, 10 boys). We chose focus groups over interviews for the children's activity because participating in a group discussion allows children to interact with their peers and express their thoughts in a familiar context replicating their classroom environment (Mauthner, 1997). This familiar context also helps mitigate potential power imbalances that could arise in a face-to-face interview with an unfamiliar researcher (Greene and Hill, 2005).

The focus groups were held at the 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 which configuration they perceived as the safest. Finally, we discussed the functioning and socio-environmental benefits of the bioswales.

3. Analyses and results

3.1. *Survey – Regression analyses*

At first, exploratory linear regressions are conducted to evaluate if there is a statistical relationship between the implementation of bioswales in the right-of-way and satisfaction with street design for walking and cycling. To analyze this relationship, the scenarios presented in Fig. 5 are used to compare how respondents rate different street designs. The dependent variable represents the difference in ratings for the street scenarios showing bioswales compared to grass strips or grey streets (streets without vegetation). Thus, as presented in the conceptual framework, these analyses focus on the direct relationship between bioswales in the right-of-way and satisfaction with street design for walking and cycling. Variables representing personal characteristics (socio-demographics, values, and lifestyles) are included as independent

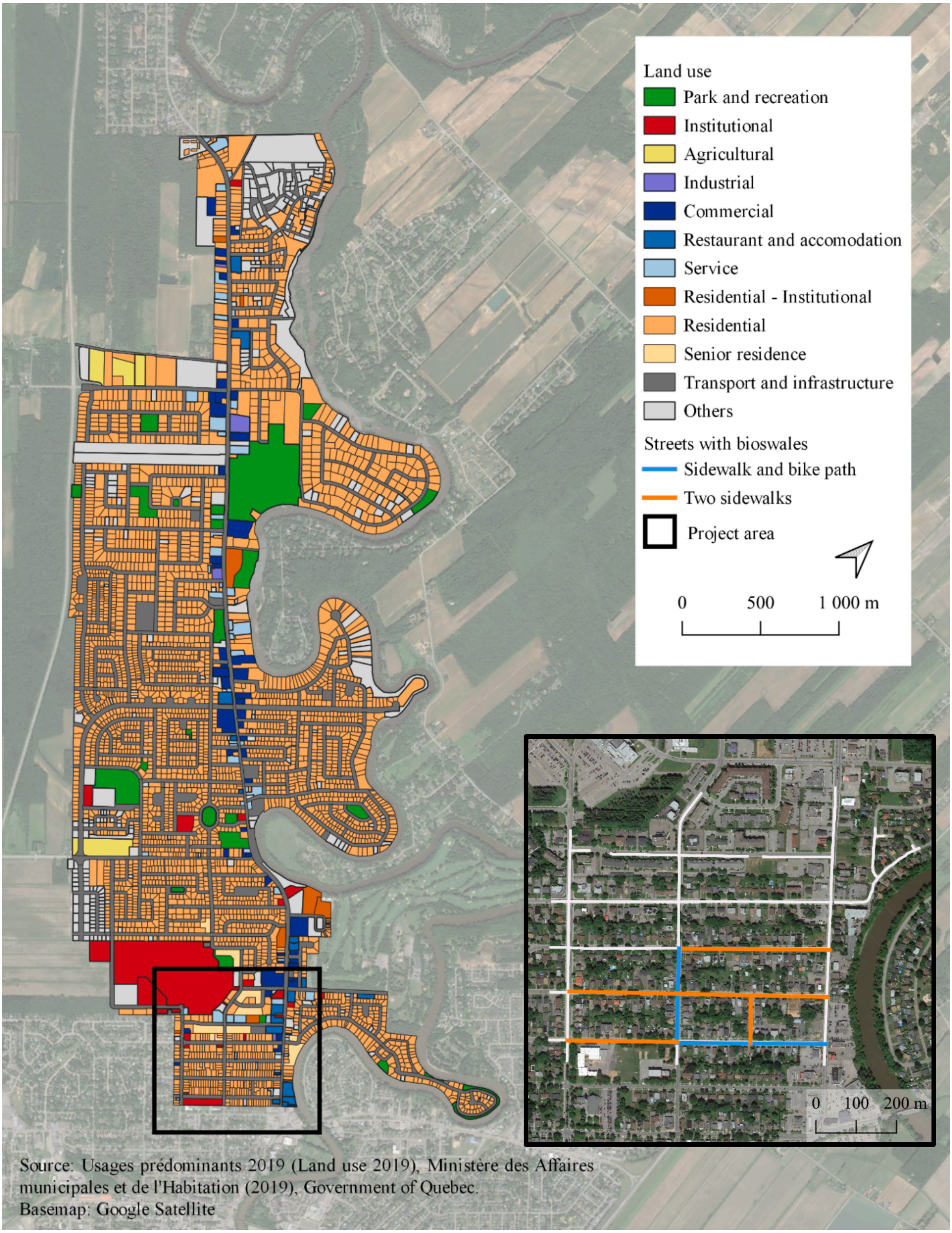

Fig. 3. Study area and street segments with bioswales.

variables. 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 Eqs. (1) and (2):

$$Y_{bioswale-grey} = \beta_0 + \beta_{SD}X_{socio-demographic} + \beta_A X_{values\ and\ lifestyles} + \epsilon \qquad (1)$$

Fig. 4. Examples of bioswales implemented on five residential streets.

Fig. 5. 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. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

$$Y_{bioswale-grass} = \beta_0 + \beta_{SD} X_{socio-demographic} + \beta_{VL} X_{values\ and\ lifestyles} + \epsilon \quad (2)$$

Where:

Y represents the difference in scores between two images with different levels of vegetation, ranging from minus −6 to 6. For example, a score of 7 for a sidewalk isolated by a bioswale (scenario c) versus a score of 4 for a sidewalk in a grey street (scenario a) leads to a value of 3 for $Y_{bioswale-grey}$.

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

β_{VL} contains the coefficients associated with variables that account for respondents' values and lifestyles.

ϵ is the error term of the regression.

Several socio-demographic variables are included in the model as factor variables. Age, household income, occupation, and education levels are each categorized into three groups. Additionally, the presence of a child in the household indicates 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 do not include that variable in the analysis. The respondent's home location is 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). The descriptive statistics of the sample are presented in the Supplementary Material.

We hypothesize that individuals' values and lifestyles can influence their satisfaction with different greening scenarios. Thus, three latent variables are included in the model to represent individuals' attitudes toward the aesthetic of their neighbourhood, their environmental behaviour, and their compliance with traffic laws. These variables were obtained from an exploratory factor analysis involving 10 questions. This analysis is described in the Supplementary Material. The results of the linear regression models, controlling for socio-demographic characteristics and for the three latent variables are presented in

Table 1. 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 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. This result, which may seem counterintuitive, is 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. For people aged 65 years and over, results indicating lower preference for bioswales are significant only 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 is 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. This may be explained by the fact that this latent variable is described with only two questions in the factor analysis.

Table 1
Results of linear regression models explaining the difference in the level of satisfaction between different greening scenarios.

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

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.

3.2. Survey – Cluster analysis

To explore the relationship between individuals' satisfaction of the different greening scenarios and individuals' characteristics and perceived street attributes, a k-means clustering analysis is conducted using the survey data. This analysis explores similar aspects as the linear regressions presented above. While linear regressions assess the significance of relationships statistically, clustering does not provide this evaluation. However, the cluster analysis offers insights into the perceived street attributes influencing individuals' satisfaction levels. Specifically, within the conceptual framework outlined in Fig. 1, this analysis aims to investigate the relationships between perceived street attributes (safety, comfort, attractiveness, and sustainability) and satisfaction with street design for walking and cycling.

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 and Wong, 1979). In other words, this approach minimizes the differences between observations within a same group. Using the k-means algorithm is advantageous considering our limited dataset (N = 296).

Six variables are 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 are 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, the clustering includes all observations from the survey. Based on the elbow and average silhouette methods, the optimal number of clusters is three. Table 2 presents the cluster centres for the six comparisons of greening scenarios.

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 cycling without vegetation (grey streets), followed by grass strips and bioswales. For further analyses, we refer to this group as 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. Subsequently, 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". Finally, 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 2, there are 103 respondents in that cluster.

Next, we analyze the characteristics of the different clusters. In addition to the socio-demographic characteristics and the three latent variables derived from the factor analysis discussed in the previous section, the distribution for 12 questions directly related to the redesign of the streets with bioswales are analyzed. These questions explore 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 examine the distribution of responses for each cluster to identify any trends among specific clusters. This analysis is conducted to assess whether clusters with a higher or lower satisfaction with bioswales agree or disagree that different street characteristics are improved by the implementation of bioswales.

Table 2
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
Cycling			
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.

Table 3 presents the socio-demographic characteristics and average values for the three latent variables. The "Moderately positive" group represents the average population of the sample since almost all the variable distributions are extremely close to the overall sample distributions as shown in Table 3. The "Negative" and the "Strongly positive" groups have more distinct characteristics. Among the "Negative", 47 % are living less than 400 m 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, this might be due to a higher proportion of low-income individuals among respondents residing within 400 m of the area (which accounts for 47 % of this group). In contrast, the "Strongly positive" group is characterized by a high proportion of young adults (aged 18–39) and a high proportion of people with a university diploma (57 %).

Consistently, the results of the linear regressions indicate that home location and age are influencing the level of satisfaction for bioswales compared to other scenarios. Based on the cluster analysis, 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". However, the 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. The household income level was not significant in the regression models, and drawing conclusions from the cluster analysis remains challenging. Indeed, the distribution of household income levels differs significantly for individuals residing near the redesigned streets (overrepresented in the "Negative" group) compared to the overall sample.

Lastly, Table 3 presents the mean values for the latent variables. For the "Negative" group, the neighbourhood aesthetic and the environmental behaviour variables are negative, indicating that this group is giving less importance to the aesthetic of their neighbourhood and indicate having a lower environmental behaviour compared to the average values of other clusters. These results are consistent with the results of the linear regressions presented above. In contrast to the "Negative", the "Strongly positive" group exhibits positive values for both the mean of the neighbourhood aesthetic variable and the mean of the environmental behaviour variable. This is consistent with the results of the regression models. Consistent with previous results, all the mean values of the latent variables for the "Moderately positive" group are close to zero, indicating that this group represents the average population of the sample.

Fig. 6 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 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.

The fifth question investigates whether individuals believe bioswales beautify the streets. The more a group prefers a higher level of

Table 3
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										
< 60 K	14	(31 %)	42	(28 %)	15	(15 %)	26	(41 %)	71	(24 %)
60–125 K	19	(42 %)	47	(32 %)	45	(44 %)	23	(37 %)	111	(38 %)
≥ 125 K	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)

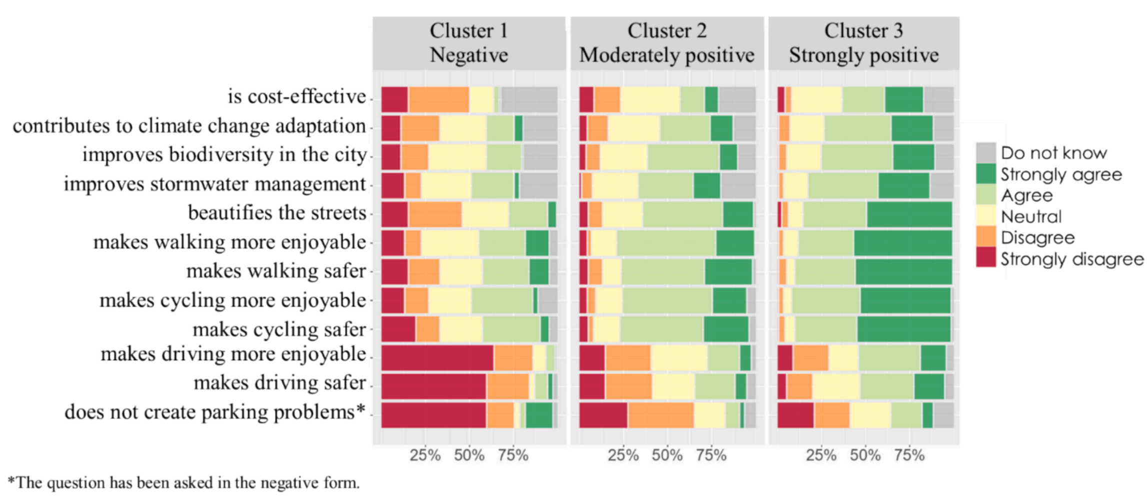

Fig. 6. Levels of agreement with questions related to the redesigned streets with bioswales.

vegetation, the more respondents in that group agree that bioswales beautify the streets. Then, four questions investigate whether bioswales make walking/cycling enjoyable or safer. 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.

Finally, three questions 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, namely walking and cycling, while displaying disagreement or neutrality regarding the benefits for car travel.

3.3. Focus groups and interviews – Qualitative analysis

The interviews and focus groups aim to complement the regression and cluster analyses by providing an in-depth analysis of specific relationships outlined in the conceptual framework. The primary objective is to gain a deeper understanding of how the implementation of bioswales influences perceived street attributes (safety, comfort, attractiveness, and sustainability). Furthermore, this analysis is not limited to a predefined set of questions, as is the case in a survey, allowing participants to bring up any factors that may impact satisfaction with bioswale implementation. The quantitative analysis gives us an overall view of factors affecting satisfaction, while the qualitative analysis helps us understand in more detail why people are satisfied or dissatisfied with bioswales. This analysis also helps uncover differences between the vision and understanding of municipal stakeholders and citizens. Finally, focus groups with children provide important insights regarding the children's needs and their own experiences as street users.

Interviews and focus groups were transcribed manually and analyzed using MAXQDA software designed for qualitative research and mixed methods. The analysis follows 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 municipal stakeholder, 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.

The analysis identified two primary aspects directly related to bioswale implementation, focusing on transportation outcomes as well as aesthetic and environmental outcomes. Several themes are related to transportation, including safety, comfort, and parking. Other themes address bioswales' aesthetic and environmental benefits, such as water management, greening, air quality, and biodiversity. The following analysis provides an in-depth examination of these themes, focussing specifically on the direct relationship between bioswales and transportation. Additional themes were raised during the interviews and focus groups; however, they are not directly linked to the implementation of bioswales and are only briefly assessed at the end of the analysis. Although these factors may have influenced individuals' satisfaction with the project, they are not specific to bioswale implementation. Some relate to other neighbourhood issues, while others pertain to broader outcomes that could have arisen from any road reconfiguration. These themes include a lack of infrastructure supporting active mobility in the city, inconveniences due to changes in road signage, disruptions from construction work, and the communication and public consultation process surrounding the project. The quotations included in the next sections have been translated from French.

3.3.1. Transportation outcomes

This section presents themes and sub-themes related to the relationship between bioswales and transportation, focusing on safety, comfort, and parking. Both municipal stakeholders and adult citizens emphasize the project's positive impact on active mobility infrastructure. In addition to the benefits associated with replacing old infrastructure, some advantages directly linked to implementing bioswales are noted. The most significant benefit is the physical separation between motorized and active modes. Most citizens and municipal stakeholders believe this separation enhances the safety and comfort of active travellers, especially children:

> *"I find that for pedestrians and cyclists, it's safer than it was before. […] I think the bike lanes are much safer now than when it was just a street with small bollards separating the bike lane. […] Everything feels safer. When cars pass by, it's less scary because the bike lane acts as a barrier. It creates a barrier, whereas before, you were right on the edge of the road. You don't need to be as cautious now." (Citizen 6)*
>
> *"We converted an on-street bike lane into an off-street one on Juge Guilbault Street, separated by a median with trees. This also improves the safety of active transportation. It promotes active transportation by increasing the sense of security for young people." (Municipal Stakeholder 5)*

Additionally, specific groups are acknowledged as particularly benefiting from the infrastructure, including parents with strollers, seniors, and individuals with disabilities:

> *"Regarding the widening of the space, meaning adding vegetation next to the sidewalk, I think it's good for protecting children." (Citizen 5)*
>
> *"There are people with walkers, people with canes, people who walk slowly, and mothers with strollers. […] There are people who want to stay active, who want to walk, but want to do so while feeling safe. This is the case in the southern area [study area], where people feel safe during their trips because the vegetation creates a protective buffer. Among the vulnerable users are also children who walk to school. […] We can also talk about cyclists, people on rollerblades… That's what I would say about vulnerable users." (*Municipal Stakeholder *3)*

Respondents observed several mobility scooters using the bicycle paths. Some explained that the proximity to schools and the high number of senior residences in the neighbourhood further underscore the need for safe pedestrian infrastructure. However, despite the necessity of ensuring safe travel for children, one respondent point out that there is too much traffic in the area for children to play in the streets:

> *"Whether it was before or after the construction, children have never played in the street. We are not in a neighbourhood where people play in the street much because we're close to the hospital, and cars still drive fairly fast. People play in their backyards. It's too busy, and even with the street narrowing, some have told me the city did that to reduce speed." (Citizen 2)*

Despite this comment, neither citizens nor municipal stakeholders significantly addressed the concept of the street as a space for playing, and the role of bioswales in that regard.

Most respondents believe the narrowing of street lanes due to bioswale implementation contributes to lowering vehicle speeds and traffic volume:

> *"There may be slightly less traffic because the narrower streets make it harder to enter or exit. On Rue de la Visitation, the street isn't wide enough, so drivers are often forced onto the opposite side, making it difficult or tighter to pass when another car is coming. In my opinion, that discourages some people from driving through. We benefit because they no longer pass by the start of the street, so there are fewer people here. But yes, overall, there's probably less traffic." (Citizen 3)*
>
> *"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." (*Municipal Stakeholder *4)*

While respondents highlighted several benefits of reallocating space for vegetation and promoting active mobility, many citizens have raised concerns about the challenges this creates for motorized vehicle drivers. Residents report difficulties maneuvering their vehicles on narrow streets, particularly at intersections, and highlight the additional challenges for larger vehicles, such as delivery trucks:

> *"They could have removed those features [the bioswales] or only installed them on one side to maintain a more reasonable street width. When you arrive at an intersection, you have to be careful of others arriving at the same stop, because you might hit them. […] When people come with large vehicles, like delivery vehicles, it's even tighter." (Citizen 1)*
>
> *"It's very difficult to turn around on the street. These are challenges people face in Montreal [dense urban city]. Normally, when you live here, you don't encounter that." (Citizen 2)*
>
> *"If a car is parked too far forward [near the intersection], it causes a problem. If it's shifted to the other side, it's because the intersections are*

narrower. I know they wanted to do that so the kids have a shorter distance to cross the street. They just need a slightly wider section." (Citizen 7)

Feedback from older adults, collected through door-to-door surveys, indicate that navigating these newly narrow streets posed specific challenges for their group. Municipal stakeholders acknowledge the difficulties for trucks and buses:

*"The small issue we've had is that by narrowing the streets, it's difficult for school buses and trucks to pass. We have to keep in mind that there's a school nearby, and a school bus isn't a bicycle, so it needs enough space to get through." (*Municipal Stakeholder *2)*

However, as mentioned in a previous quote, they also emphasize the advantages of reduced vehicle speeds. Moreover, besides citizens expressing frustration with these changes, their responses suggest they adapt their driving behaviour by making frequent stops and slowing down when encountering other vehicles. While drivers view these adjustments negatively, they align with the project's goals as outlined by municipal stakeholders. Overall, planners emphasize the benefits in terms of reduced vehicle speed while citizens focus on the inconvenience associated with the reallocation of space.

The narrowed lanes also raise an issue for some active travellers, such as skaters or people cycling. This is particularly problematic on streets featuring bioswales and sidewalks on both sides (without bicycle lanes). In that configuration, there is no dedicated space for cyclists or other micro-mobility users, which forces them to share the narrower lanes with motorized vehicles:

"There's no space on my street for cyclists. For a cyclist to ride on the street, it's very dangerous. People drive fast, and there's no space. To pass a cyclist, you have to completely change lanes." (Citizen 2)

Citizens raise other concerns regarding the design of bioswales. The height of the vegetation creates safety concerns mostly expressed by citizens, such as tripping hazards and visibility issues:

"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 5)

Citizens emphasize the importance of proper maintenance to ensure the vegetation does not grow too tall. While this issue has not yet arisen in Saint-Charles-Borromée due to the vegetation still being immature, Fig. 7 shows a comparison between the bioswales in Saint-Charles-Borromée in June 2023 and a similar installation in Granby, QC, taken in July 2022 after 10 years of growth. Although the vegetation in Saint-Charles-Borromée may differ and could be maintained differently, the comparison effectively illustrates the concern raised by citizens. In contrast, municipal stakeholders primarily focused on maintaining the vegetation to encourage healthy growth, given that the planting had only recently occurred.

Additional concerns have been raised regarding the depth of the bioswales. Some citizens worry that individuals may fall into the bioswale depressions if they are not paying attention while walking:

"The new vegetation [bioswales] is lower than the sidewalk, which means people could trip if they're a bit distracted. That's the main disadvantage I see for now." (Citizen 2)

They would prefer the vegetation to be level with the sidewalk. However, it's important to note that the depression is part of the bioswales' design for managing stormwater, which typically requires a specific depth and slope. Additionally, the depth of the bioswales creates challenges during winter, as their boundaries can become less visible, as illustrated in Fig. 8, and expressed by respondents:

"During snowfall, especially during the first snowfalls, the bioswales blend in with the snow. People's cars can accidentally fall into the bioswales." (Citizen 3)

While municipal stakeholders have not received any complaints or reported safety issues related to vegetation height or the risk of pedestrians falling into the bioswales, they do recognize that adapting the design for winter conditions, particularly concerning snow removal, is an area for ongoing improvement:

"We had to go through a lot of trial and error since this is a new project. Regarding the mistakes, there's snow removal. If we ask the citizens whether snow removal in the sector has been a success, they will respond "no". We needed to adapt the machines for the new infrastructure, and I don't think the snow removal operators are there yet. [...] I think we still have a lot to learn about snow removal to make it optimal and ensure that even in winter, people feel safe." (Municipal Stakeholder 3)

"When the snowplow comes, it's clear that it doesn't clean as thoroughly because it has to maneuver around trees, lampposts, and all that. So, we had to hire a private snow removal service to come by after we'd already cleared the snow once. They take care of removing the remaining snow. I think that solved the issue. We just needed to adapt, but overall it works well." (Municipal Stakeholder *5)*

Despite all the benefits mentioned above, the most frequently cited issue during the interviews, and almost always identified as the most critical concern for citizens, is the loss of parking spaces. The implementation of bioswales led to a 70 % reduction in on-street parking. For residents, this reduction is particularly problematic when hosting visitors or during snow clearing of private driveways:

Fig. 7. The image on the left shows the bioswales implemented in Granby in 2013, where the sidewalk is almost entirely obscured by mature vegetation. This picture was taken in July 2022. In contrast, the image on the right displays the bioswales in Saint-Charles-Borromée, installed in 2022. Here, the vegetation is still immature, and the sidewalk and bicycle path are clearly visible from the road. This picture was taken in June 2023.

Fig. 8. A bioswale covered by snow on Gouin Street. The picture was taken in January 2023. Location: 46°02′07.8″N 73°26′57.8″W.

> *"The machines [vehicles] are fighting! The delivery drivers, they come and park right in the middle of the street!" (Citizen 1)*
> *"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. […] I think the city could provide more green spaces with its new infrastructure without putting all the green spaces into bioswales. They took away parking spots, supposedly because we're in a neighbourhood with houses [with driveways], but they didn't think about snow removal. There are two apartment buildings next to my place, and when there are snowstorms, cars can't even get out onto the street because there's no parking." (Citizen 2)*

Municipal stakeholders acknowledge the frustration expressed by citizens and attribute it to the suburban context, where car dependency leads to a strong attachment to parking spaces:

> *"At the beginning, there were numerous complaints from motorists as […] parking spaces were eliminated." […] During celebrations like Father's Day, Mother's Day, or Christmas, visitors are forced to park much farther away. […] By narrowing the streets, we reduced on-street parking by 70 %. So, we need to find a solution for visitor parking." (*Municipal Stakeholder *2)*
> *"It's true that we received some criticism, mostly related to parking. People felt like the parking space in front of their house belonged to them. So, it involved a lot of change for them. Some people even came to the City Council to voice their complaints." (*Municipal Stakeholder *3)*

However, most municipal stakeholders believe there is still an adequate number of parking spaces, especially given that the project is located in a residential area with numerous private driveways. They also note that some green spaces initially planned for the project were removed to accommodate more parking spaces:

> *"Here, we are in a more rural suburb. Cars play a major role, so the infrastructure had to accommodate vehicles. This led to numerous debates about parking. We were lucky, but along the way, we had to sacrifice some green spaces to add a few parking spots here and there." (*Municipal Stakeholder *5)*

Fig. 9 summarizes the key themes related to transportation. The grey rectangles represent themes where citizens and municipal stakeholders

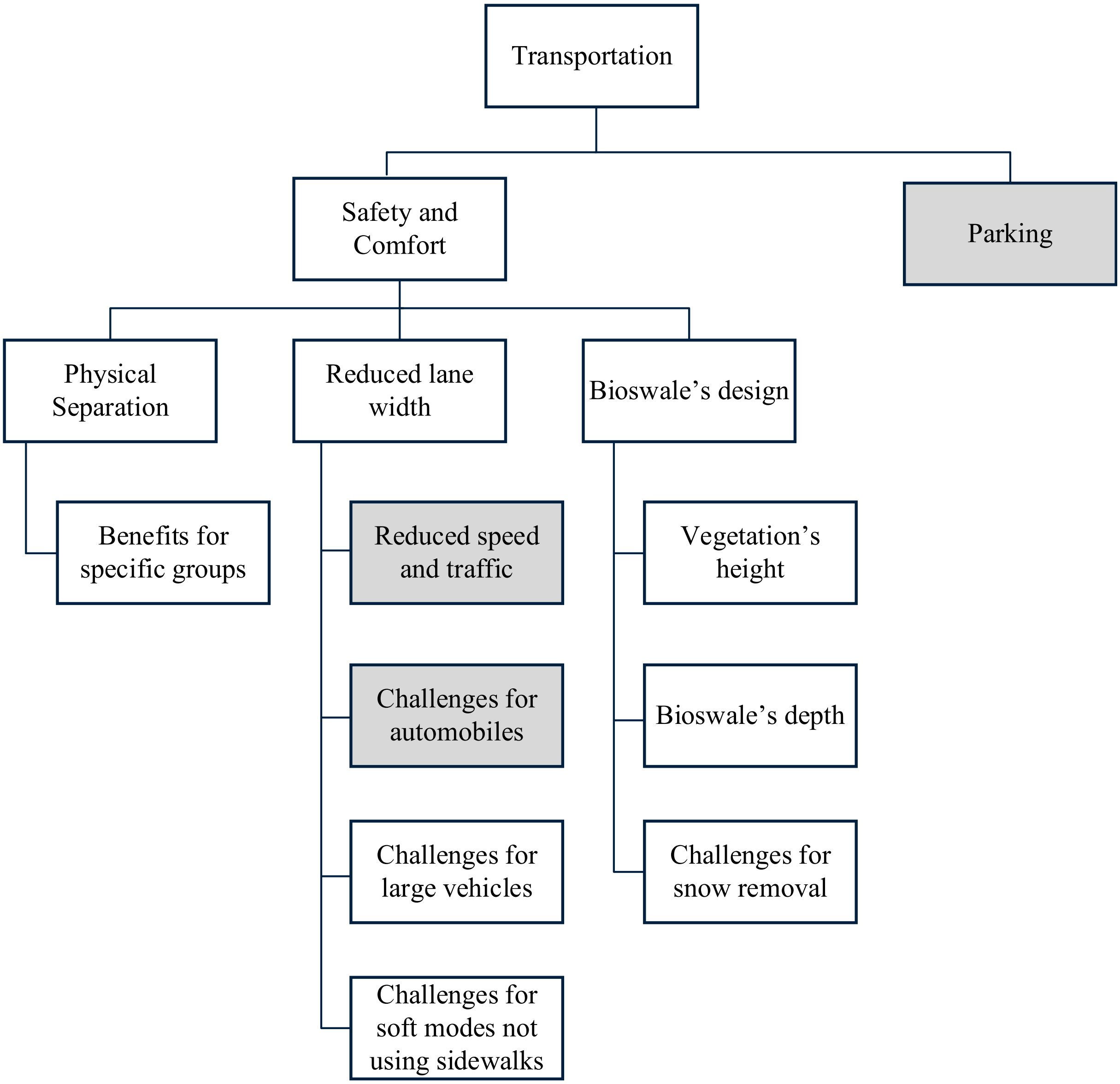

Fig. 9. Emergent themes and sub-themes from interviews related to transportation outcomes. Grey rectangle indicates themes where citizens and municipal stakeholders have divergent opinions.

have divergent opinions. Almost all respondents mention the physical separation between the carriageway and the sidewalk or bicycle path as one of the most positive benefits. The reduced lane width, mainly due to the addition of bioswales, is seen as offering both advantages and disadvantages. The impacts on motorized vehicles are a source of debate among citizens, as well as between citizens and municipal stakeholders. Municipal stakeholders are primarily concerned about safety and vehicle speed, while citizens are focused on the reduced space allocated to cars and the restricted car movement due to the presence of bioswales. The same observation applies to the removal of parking spaces, with citizens expressing a need for more parking spaces. At the same time, most municipal stakeholders believe they have effectively balanced the various elements on the street, allocating more space for vegetation and active travellers at the expense of parking spaces. Finally, a few comments pertain to the design of bioswales. These elements could likely be improved with minor design adjustments and are not a source of debate among respondents.

3.3.2. *Aesthetic and environmental outcomes*

Several themes relate to bioswales' aesthetic and environmental outcomes, including water management, air quality, biodiversity, and greening. All municipal stakeholders believe that bioswales improve stormwater management, for example:

> *"The greatest strength of the project is the renewal of infrastructure for better water management."* (Municipal Stakeholder *2)*
> *"The main objective was to refurbish outdated infrastructure, particularly the underground pipes and sewers. As for the secondary objectives, they include providing a better living environment for residents, optimizing stormwater management, taking the opportunity to ensure proper sustainable stormwater management, enhancing the area's aesthetics, adding greenery, reducing impermeable surfaces, incorporating more vegetation, and so on."* (Municipal Stakeholder *5)*

Citizens generally understand bioswales' primary stormwater management function, with all adult citizens mentioning their benefits for filtering and managing runoff, for example:

> *"It enables better water filtration." (Citizen 6)*

"Rainwater can now nourish the groundwater instead of going into storm drains, so the groundwater levels can remain high. It's a good thing." (Citizen 2)

However, they are critical of the design, and some reported basement flooding during the heavy rains on September 13, 2022, leading to doubts about whether the new infrastructure contributed to the issue:

"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. […] When there is heavy rain, the water drains down into the soil. But a city worker explained to me that if the water level gets too high [in the bioswale], there's a pipe at the street level with a filter. It's designed to collect the water and direct it into a storm drain. But it seems like it didn't work during the last big rainfall. I was told this because I was concerned. With the heavy spring rains, there was always water. It was always full of water, and I thought to myself, my goodness, it's not draining well. I wondered if it was properly connected, or if something was blocking it, like a piece of concrete, that was causing it not to drain well. […] But I was assured [by city staff] that it can't get blocked." (Citizen 2)
"I know that the mulch clogged the pipes once. I think the floating mulch gets into the pipe and blocks everything. I don't think it was a success. They [the bioswales] filled up with all the rain we had. The mulch overflows, spreads everywhere, and we end up with mulch all over the street. They [the City] are looking into replacing mulch by another material." (Citizen 7)

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 municipal stakeholders, during this rainfall event, the new infrastructure might have prevented the sector from being flooded since other sectors with no GSI such as a nearby hospital were severely affected:

*"It has never been a problematic area [for flooding]. But recently, there were 90 mm of rain in the span of two hours. The project may have had a positive impact because there was no overflow on those streets, whereas there was elsewhere." (*Municipal Stakeholder *2)*

Interestingly, only citizens raised concerns about water management disadvantages, and many remain unconvinced about bioswales' effectiveness in their neighbourhood. Citizens' doubts may arise from a general unfamiliarity with the bioswale system. As such, municipal stakeholders noted that they had to engage in extensive communication efforts to explain how bioswales function:

*"For stormwater management, we had to explain the bioswale system. It's an unknown term, so we had to explain and re-explain it several times. We needed to clarify that it's not just for aesthetics when we plant certain types of plants. There's an intention behind it regarding soil permeability and water runoff. […] I wouldn't say people were necessarily questioning it, but even within our project team, we could feel it wasn't well understood. We sensed a need to further explain things." (*Municipal Stakeholder *3)*
*"If I look back at the communications we released, yes, it was explained [how bioswales contribute to managing stormwater runoff]. We provided information about it, but I don't know to what extent people really grasped the idea. In the release, we discussed it, explaining its purpose. That's what I saw. And if I check the website, there are old press releases that we shared, and it was explained there too. But those are from a while back." (*Municipal Stakeholder *1)*

It is worth mentioning that during the interviews and on-site survey collection, several individuals discuss 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 why 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 doubt the effectiveness of the bioswales.

This illustrates a phenomenon affecting satisfaction with GSI in the context of climate change. As cities experience more frequent extreme rainfall, citizens may misattribute such events to changes in infrastructure, as seen here. Unfortunately, the timing of this extreme rainfall event shortly after the bioswale installation appears to have negatively impacted residents' perceptions, fostering doubts. The novelty of this type of infrastructure, combined with the rare event, has led to misunderstandings, with citizens questioning the efficacy of the bioswales.

Only a few citizens—and no municipal stakeholders—mention the benefits related to biodiversity and air quality. Few citizens mentioned that mixed vegetation in bioswales provides habitat for species:

"There's a wide variety of plants. I think there are milkweeds, so that's great. It attracts butterflies." (Citizen 3)
"I think it's better for the wildlife that develops there. […] I think all the flowers, bees… it's good. […] It's also very beneficial for biodiversity development." (Citizen 6)

Few citizens mention that vegetation in the bioswales, especially trees, is improving air filtration:

"Well, of course, trees help with oxygen." (Citizen 5)
"It also enables better air filtration." (Citizen 6)

The limited interest given to these co-benefits might be because interviewees were asked general questions about environmental benefits rather than being prompted to discuss specific types, which could explain why these elements are overlooked. However, this suggests that the co-benefits of bioswales are not widely recognized or valued.

In contrast, many respondents highlight that bioswales contribute to the greening of the neighbourhood. The presence of trees in the bioswales is highly valued by all stakeholders:

"The presence of vegetation strengthens the soil, it provides anchoring. It's also good for heart pollution—well, I mean for mental health. Moreover, it helps with education and behaviour. When people see a beautiful place, they tend to behave better." (Citizen 5)
"We took the opportunity to enhance the urban environment by implementing more progressive designs that address current needs, in contrast to the car-centric streets of the 1950s and 1960s. We aimed to create a more human-scale atmosphere by increasing greenery." (Municipal Stakeholder 4)

Although there is an overall benefit for greening, citizens express significant frustration and confusion regarding the removal of trees in their neighbourhood. Municipal stakeholders attempted to clarify the reasons for removing some trees. They emphasize the advantages of replacing problematic tree species, namely, to reduce damage to drainage pipes and branch breakage. They also note challenges in effectively communicating the reasons for 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." *(Municipal Stakeholder 3)*.

While these efforts have convinced some citizens, a lingering skepticism remains among others. Many do not fully trust the City's explanations, leading to ongoing discontent about the situation.

"We have beautiful century-old maples on the street. Unfortunately, they have been partially uprooted to make space for [wider] sidewalks. […]. It was fine before, except perhaps for the roots lifting the sidewalk. But now, [by changing the street configuration], they have broken the tree roots.

[…] I think it's obvious that a century-old tree that is partially uprooted is at high risk of disease. They claimed to do this [the whole project] for the environment (sarcastic tone). I was disappointed to see this." (Citizen 2)

"Yes, they cut down trees at the beginning, and people were outraged. However, those trees had roots that likely caused damage to the underground infrastructure. At some point, this must have had negative impacts, especially concerning the aqueducts and sewers." (Citizen 4)

Most of the respondents agree that bioswales enhance the aesthetics of the area:

"Pedestrians and cyclists find it beautiful. It's true that it's beautiful." (MS2)

"I find it beautiful, there's no problem with that. We can say it's beautiful, and it will be even more so when the trees grow." (Citizen 3)

Some participants mention that it adds value to the neighbourhood. They note that this beautification could encourage residents to engage more in active transportation and prioritize their well-being. Some citizens and municipal stakeholders believe that enhancing the visual appeal of the urban environment not only beautifies the area but also encourages residents to take greater pride in their surroundings and behave more respectfully:

"In general, I find it beautiful. I like when it's beautiful. I feel that when a city becomes more attractive, it encourages people to take better care of their environment and behave better." (Citizen 5)

"The fact that the neighbourhood is more attractive encourages more people to go out for a walk rather than take their car." (Municipal Stakeholder 3)

A few participants suggest that these improvements will become more noticeable as the vegetation matures. Citizens find that the newly planted vegetation appears unappealing until it matures:

"They may have wanted to beautify it as well. It will probably look nicer when the trees are mature." (Citizen 7)

"I can't wait to see what the plants in the bioswales will look like in a few years. If the plants grow and it looks beautiful, it will definitely create a pleasant environment." (Citizen 6)

Fig. 10 summarizes the key themes related to environmental and aesthetic outcomes. Once again, the grey rectangles represent themes where citizens and municipal stakeholders have divergent opinions. Overall, respondents recognized aesthetic and environmental benefits from the bioswales, mainly due to improved stormwater management and neighbourhood greening. However, a notable gap exists between citizens' and municipal stakeholders' views, as some citizens disagree with certain municipal decisions or doubt that the infrastructure truly provides the benefits claimed by officials. Shortly after the project's completion, heavy rainfall likely eroded citizens' trust and negatively impacted satisfaction with the bioswales. Similarly, some citizens are unconvinced that the tree removal was appropriate. They doubt the reasons stated by municipal stakeholders and believe that more efforts should have been made to preserve mature trees. Other themes, including benefits for air quality, biodiversity, and aesthetics, were less discussed and did not seem to catalyze debates among respondents, although the appearance of vegetation in bioswales was mentioned regularly.

3.3.3. Insights from children

Children's perspectives on the new bioswale infrastructure highlight concerns distinct from those of adults. They focus on benefits for the safety of active travellers and are not as concerned with car-related issues, likely due to their own experiences and the fact that they are not driving. Their perspectives align more closely with the needs of active travellers. Some children voice apprehension over the high number of cars in the neighbourhood, associating them with noise and danger. For instance, one child notes the threat posed by parked cars while talking about the benefits of replacing parking spaces with bioswales:

"There's no need for parking all along the street. If someone opens their door while you're in the bike lane, you could get doored." (Child 1)

Similar to adults, children value the physical protection offered by bioswales. In contrast to adults' perspectives on the negative impact of narrower intersections for drivers, children said they must avoid certain intersections (without bioswales) because they are too wide and difficult to cross safely. Thus, they perceive the narrowing of crosswalks with bioswale implementation as a positive change.

As for the risk of falling into the bioswales, some children believe that falling into a bioswale would be safer than falling directly onto the street. However, not all children share this view. One child, who skateboards, prefers grass strips, which he feels would be less painful to fall into. This child also complains that the narrower streets make skateboarding challenging, even with a bicycle path. Since he fears falling into the bioswales while skateboarding on the bicycle lane, he prefers to use the street. However, sharing the road with motorized vehicles on the narrowed street increases his discomfort, echoing comments from one of the adults interviewed.

Children's need for spaces to play also informs their views. While

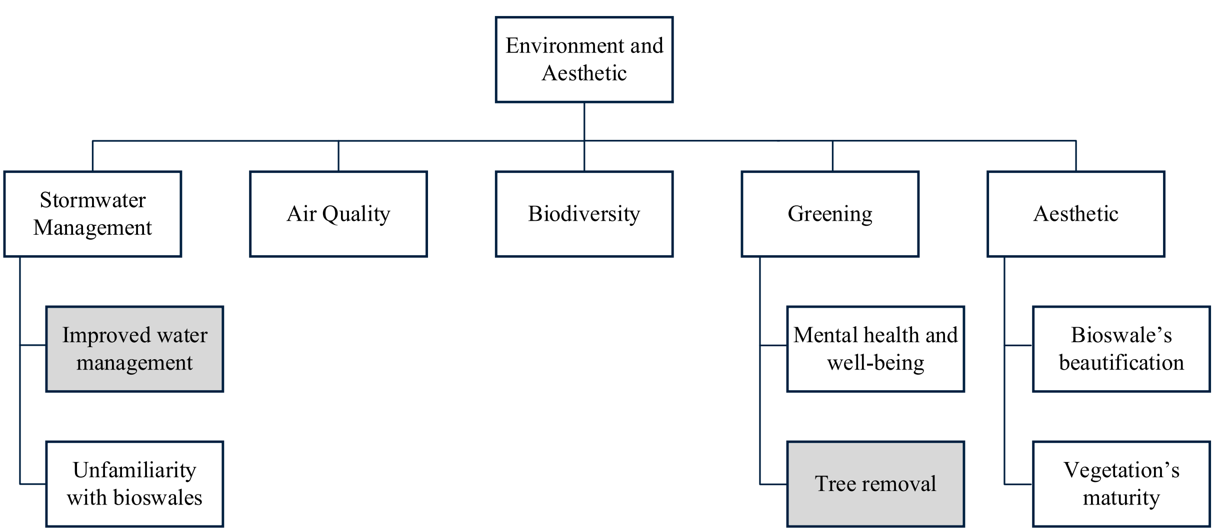

Fig. 10. Emergent themes and sub-themes from interviews related to environmental and aesthetic outcomes. Grey rectangle indicates themes where citizens and municipal stakeholders have divergent opinions.

most enjoy walking along streets with bioswales, they do not perceive the infrastructure as suitable for play. In particular, most children do not want bioswales on their own streets because they prefer to use that space for playing. While creating playing spaces was not part of the goals mentioned by municipal stakeholders, other GSI types might better support children's activities.

Children appreciate bioswales' aesthetic and environmental benefits, especially the greening they bring to the neighbourhood. Out of the 13 children, 11 express a preference for the new configuration after seeing before-and-after photos, while two state that they would have preferred either no changes or grass. These two children say that grass is more practical for their activities. Others express their appreciation for trees and flowers. Like adults, children mention that the vegetation in the bioswales was not particularly attractive at the moment, which one child emphasize by saying:

"They should put flowers instead of dead flowers." (Child 2)

This reinforces the time needed for vegetation to mature before people can really appreciate the appearance of bioswales. Regarding environmental benefits, children demonstrate limited knowledge but still mention some aspects related to air quality, biodiversity, and stormwater management.

3.3.4. Secondary issues

Several concerns not directly related to bioswales can potentially alter people's perception of bioswales. Many citizens express dissatisfaction with construction works and changes in road signage. Some adjustments were made to overcome any confusion regarding road signage, but these irritants have likely negatively influenced residents' perceptions. Furthermore, several concerns are related to active mobility, such as the lack of continuous bike lanes in the city and the general perceived insecurity of active transportation in the city. 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. Although the implementation of bioswales has improved safety for active transportation, many feel that it is insufficient, especially in the street adjacent to the school.

Other concerns are related to resistance to change and communication of the project. Municipal stakeholders mention that citizens are resistant to change and that it can take time before they appreciate the new infrastructure. 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 social acceptability. 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. The consultation and communication of the project, especially considering the novelty of this project, have likely influenced individuals' satisfaction.

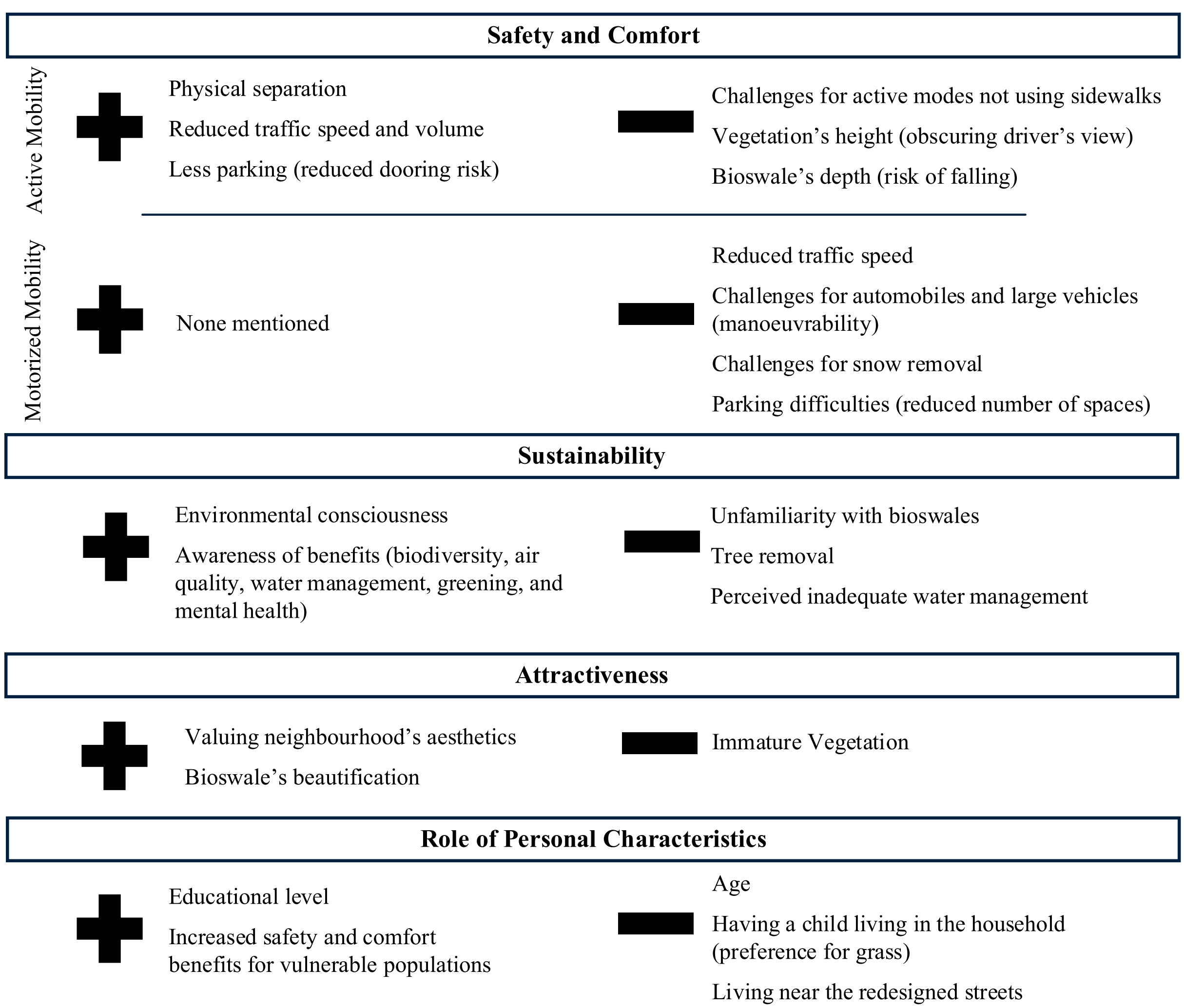

Fig. 11. Factors explaining varying satisfaction levels with bioswales among adult citizens, children, and municipal stakeholders derived from regression, cluster, and qualitative analyses.

4. Discussion and conclusion

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 was employed to investigate individuals' perceptions following the redesign of five streets in a North American suburban area, which involved the implementation of bioswales. The relationships between bioswales and satisfaction levels with walking and cycling street designs, as displayed in the conceptual framework, have been investigated through a combination of analyses (linear regressions, cluster analysis, and qualitative analysis). The combination of these three methods provided nuanced insights into the underlying factors influencing satisfaction levels.

Besides describing the general impact of bioswales on active mobility, this study provides an in-depth analysis of the factors affecting individuals' satisfaction. Fig. 11 summarizes the identified factors explaining varying satisfaction levels with bioswales. These factors are derived from the regressions, cluster, and qualitative analyses. Thus, they are mainly based on the residents' perceptions (adults and children), while also nuanced through the eyes of municipal stakeholders. As shown in Fig. 11, the factors are divided into four broad aspects: safety and comfort, sustainability, attractiveness, and personal characteristics.

Regarding safety and comfort, having a safety-conscious behaviour was not found to significantly influence satisfaction levels with bioswales in the regressions. Nonetheless, the cluster analysis showed that most respondents believe bioswale makes walking and cycling more enjoyable and safer. In line with that, the qualitative analysis showed that the increased sense of safety can be primarily attributed to two main factors: the physical barrier created by bioswales between active and motorized modes, and the reduced speed and traffic volume resulting from the narrowed motorized lanes (due to bioswales' implementation). Moreover, interviewees mentioned increased safety benefits for children, older adults, and people with disabilities. Specifically, the qualitative analysis demonstrated that bioswales can enhance children's perceived safety and adults' perception of the street as safe for children. 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).

Despite the overall benefits for active mobility, the qualitative analysis allowed to pinpoint specific design elements of bioswales that could be improved for active travellers. These include ensuring that the vegetation's height does not obstruct drivers' view, ensuring that the bioswale's depth does not pose a risk of falling into the swale, and challenges for active travellers who need to share the narrowed carriageway with motorized vehicles on streets featuring only sidewalks and bioswales (without bicycle lanes).

While safety and comfort seem beneficial for active mobility, findings suggest that bioswales' implementation is perceived as challenging for motorized vehicles, as all identified factors decrease satisfaction, as shown in Fig. 11. Among the "Negative" cluster, over 75 % of individuals expressed disagreement or strong disagreement regarding the ability of bioswales to improve car mobility. They mostly believe that driving on the streets with bioswales is not enjoyable or safe and that bioswales cause parking problems. These car-related factors also had a higher proportion of disagreement among the positive clusters. These results align with the findings of the qualitative analysis. Adult citizens report that it is hard to maneuver their vehicles in the narrowed lanes and intersections and that the reduced number of parking spaces is insufficient for their needs. While municipal stakeholders understand those perceived challenges, they believe that they have considered those elements in the design. As depicted in the interviews with citizens and clusters, it appears that for some residents, the constraints for cars outweigh the benefits for active modes of transportation.

Many factors influencing satisfaction with bioswales are related to their environmental or sustainable component. The results of the regression analyses indicated that individuals who exhibit eco-friendly behaviours are more likely to prefer a street configuration with bioswales over grass strips or grey street. Similarly, Everett et al. (2015) found that environmentally engaged individuals displayed a more positive attitude towards bioswales. The results of the cluster analysis were consistent with these findings. Among the three clusters ("Negative", "Moderately positive", and "Strongly positive"), the positive groups who expressed a strong satisfaction with greener scenarios, agreed that bioswales provide environmental benefits, including improving stormwater management, increasing biodiversity, and contributing to climate change mitigation and adaptation. Some of these benefits were also mentioned in the interviews and focus groups, while the focus was on water management and greening.

Our qualitative analysis demonstrated that trees are highly valued by all stakeholders. Interviewees 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). Moreover, GSI can provide more rooting space for tree growth (Ferguson, 2012). Furthermore, while not related to environmental benefits, studies have shown that trees can also enhance safety by creating a more enclosed streetscape, reducing vehicle speeds and risk of collisions {Harvey, 2015 #11; Polanski, 2015 #85; Naderi, 2008 #80; Kim, 2019 #9; Niţă, 2018 #81; Zhu, 2022 #8}. In light of our results and the scientific literature, it appears highly relevant to integrate trees within bioswales to maximize their benefits for the community and the environment.

Interestingly, the qualitative analysis revealed a notable gap between adult citizens' and municipal stakeholders' views regarding the environmental benefits of bioswales. The interviewed citizens were not convinced of the benefits that bioswales could provide for water management. The interviewees highlighted that the extreme rainfall event that occurred a week before the start of data collection may have negatively influenced residents' perceptions, as some residents attributed flooding issues to the bioswales. Similarly to the doubts regarding stormwater management, some citizens are unconvinced that the tree removal was appropriate. These misunderstandings or doubts of citizens regarding municipal stakeholders' decisions and explanations might have been strengthened by the general unfamiliarity with bioswales. The results from the cluster analysis also revealed that many citizens do not know if bioswales provide socio-environmental benefits, especially among the "Negative" cluster.

Several factors related to the attractiveness of bioswales can influence individuals' satisfaction. The results of the linear regression analysis indicated that individuals who value the design of their neighbourhood are more likely to prefer a street configuration with bioswales over grass strips or grey streets. The results of our cluster analysis were consistent with these findings. Among the three clusters, the positive groups (who expressed strong satisfaction with greener scenarios) agreed that bioswale beautifies the streets. Most interviewees believe that bioswales enhance the neighbourhood's aesthetics. However, some noted that the time required for the vegetation to mature affects the bioswales' immediate aesthetic appeal. These findings align with existing scientific literature (Lemieux 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 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 and Gopal, 2021; Suppakittpaisarn et al., 2020). Flowers and bioretention have also received high appreciation (Fischer and Gopal, 2021; Suppakittpaisarn et al., 2019).

Finally, personal characteristics can also explain different satisfaction levels with bioswales. While most socio-demographic characteristics tested in the regressions were not significant, further studies, perhaps with a larger sample size, should delve deeper into that. From the analyses of the survey and the qualitative results, people of different age groups seem to respond differently to bioswales' implementation. While implementing bioswales seems beneficial for children, linear regression results suggested that individuals living with children prefer grass strips over bioswales. This contrasts with the preference for bioswales expressed by most children in the focus groups. Supporting the regression results, 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 parents might perceive grass strips as more practical for children's activities compared to bioswales. It is 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 also explain why individuals living with children might prefer grass strips to bioswales. Some parents and children interviewed in this study 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 potential benefits for elderly people as some interviewees believe their safety is improved by the separation of bike paths and sidewalks from the road. Additionally, Lee et al. (2022) have 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).

Finally, our regression analysis indicates that people living near the redesigned streets are less likely to prefer bioswales. There was also a higher proportion of these residents falling into the "Negative" cluster. As highlighted in the interviews, this sentiment may be partly due to secondary issues such as recent construction work, changes in road signage, or project-related communication. Additionally, these residents were more directly impacted by the project, which may have intensified their negative perceptions, particularly regarding perceived challenges for motorized vehicles.

As reflected in this discussion, each method complements and corroborates one another. While regressions assessed statistical significance, clusters provided nuanced insights into the underlying factors influencing satisfaction levels. The qualitative analysis provided further understanding of the factors affecting the respondents' satisfaction levels with bioswales. These are mostly related to safety, comfort, attractiveness, and sustainability. The qualitative analysis emphasizes critical aspects of bioswale design that require more attention. Additionally, this analysis helped to identify secondary issues that could have affected individuals' satisfaction with the different street scenarios. Finally, the focus groups with children provide important insights and nuances regarding the impact of bioswale's implementation on children's mobility and activities.

4.2. Design and planning recommendations

This case study demonstrates that the implementation of bioswales in the right-of-way has implications for mobility. The results indicate that implementing bioswales in the right-of-way can enhance overall satisfaction with street design for walking and cycling. As emphasized in the conceptual framework, enhancing individuals' satisfaction with their walking and cycling trips can increase the likelihood of using these modes. As a result, our findings suggest that implementing bioswales is an effective policy to promote active mobility.

While bioswales are commonly implemented and designed for stormwater management, it is crucial to also consider their implications for transportation. Practitioners should consider integrating GSI and transportation planning to maximize the benefits provided by these types of infrastructure. For example, this research indicates that, in general, citizens perceive the benefits of bioswales for active mobility but also perceive adverse effects for motorized mobility. The design should consider the restrictions imposed on motorized traffic and their impact on individuals' perceptions, along with the goal of the redesign and the particular context in which it is implemented. Being aware of how citizens might perceive bioswale implementation can help planners understand the social acceptability of such projects. Concerns related to motorized mobility could negatively impact social acceptability, particularly in car-dependent areas. Therefore, planners should carefully consider these multifaceted effects. Simple retrofits can help mitigate negative impacts. For example, installing bollards to clearly mark bioswale boundaries during winter can prevent vehicles from inadvertently driving into the bioswale. As such, the results from this case study lead to several recommendations regarding the implementation of GSI to enhance active mobility, e.g.:

- Take advantage of the reconstruction to prioritize active users by reallocating space and creating physical barriers between motorized and active paths.
- Integrate trees within GSI to maximize their perceived environmental, social and mobility benefits.
- Ensure that vegetation does not obstruct the drivers' field of vision, especially near intersections.
- 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.
- Perform regular maintenance of the infrastructure to ensure its proper functioning and remove any debris that may accumulate within the depression.

In addition, Polanski (2015) highlighted that reducing the distance to be crossed at intersections can enhance the safety of active travellers. Similarly, Kim (2019) suggested that implementing GSI as a centre median provides 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). 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 the street design 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).

4.3. Limitations

There are several specificities to this study that can compromise the broader applicability of its findings. 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 and Park (2015) found a difference in the influence of vegetation on walking for urban compared to rural elderly women. Nonetheless, as most studies focus on large urban settings, this study contributes to the literature by covering an underexplored research context.

Secondly, the survey data were 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. The online survey was disseminated to people who had subscribed to City communications, a group that might not be representative of the entire population. Nevertheless, this study aims to be exploratory due to the novelty of the topic. It initiates research on the effects of GSI on active mobility by highlighting several factors that may influence individuals' perceptions of bioswales, raising concerns specific to green stormwater infrastructure (as opposed to traditional greenery).

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 is 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 on five different street segments with slightly varying street designs. 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. Additionally, it can be challenging to generalize results from projects analyzing a specific type of GSI due to variations in their designs across different sites. In the case of this project, even within the same project, there are variations in the design elements of bioswales (e.g., the width, length, spacing between basins, presence of trees, etc.). These variations could potentially influence individuals' perceptions. Therefore, it would be valuable to explore these distinctions in future research to provide 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 study demonstrates the need to further explore the relationship between GSI and active mobility by identifying specific factors (related to safety, comfort, sustainability, and aesthetics) influencing satisfaction with bioswales. It is essential to understand that GSI has unique characteristics that differ from traditional greenery, such as trees. Future research could focus on specific design elements to provide clear recommendations for traffic engineers and urban planners. This research is relevant for planners and researchers seeking to design multifunctional streets that support sustainable urban drainage systems and active mobility.

CRediT authorship contribution statement

Charlotte Lemieux: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Sara Lach Gar:** Formal analysis. **Françoise Bichai:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Francesco Ciari:** Writing – review & editing, Supervision, Methodology. **Geneviève Boisjoly:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of Competing Interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tbs.2025.101042.

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