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Innovative Applications of O.R.

Where to plan shared streets: Development and application of a multicriteria spatial decision support tool

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ABSTRACT

In response to the growing recognition of the vital role played by streets as public spaces in enhancing the vibrancy of urban life, various concepts aiming at creating greener and more inclusive streets have gained popularity in recent years, especially in North America. Shared streets are one example of such concepts that have attracted the attention of citizens and of urban and transportation planning professionals alike. This was the case in the city of Sherbrooke (Quebec, Canada) where, in response to numerous citizens' requests, a need was identified to develop decision aid tools to help evaluate and rank street segments based on their potential to become shared streets. To achieve this, an action-research project was initiated in which we conducted a socio-technical process based on MACBETH, a multicriteria evaluation method. The project led to the development of a spatial decision support tool, operationally used today by the city professionals. This tool ensures a more informed and transparent decision-making process and supports shared streets planning policy. The methods developed are generalizable and can be adapted to other cities facing similar planning problems.

1. Introduction

In a world increasingly aiming for sustainable development and human-sized livable environments, many cities worldwide are confronted with the consequences of past choices that have made them very car-dependent, to the point of profoundly shaping their land use patterns (Saeidizand, Fransen & Boussauw, 2022). As a consequence, it has become essential to rethink road infrastructure in terms of safety, accessibility, and sustainability, in line with the efforts undertaken for the decarbonization of western lifestyles (Foletta & Henderson, 2016) and in connection with the objective of sustainable mobility for all, defined in the Sustainable Development Goals (SDGs), especially SDG 11 of making "cities and human settlements inclusive, safe, resilient and sustainable" (United Nations, 2016). In order to achieve these sustainable development goals, cities look for guidance from organizations such as the National Association of City Transportation Officials (Livable City (2021; NACTO, 2021)), or Center for active transportation (2021).

In North America, shared streets have been receiving increased attention over the last years (Kaparias, Bell, Biagioli, Bellezza & Mount, 2015). The concept of a shared street is inspired by the Dutch *Woonerf*[1] (Karndacharuk, Wilson & Dunn, 2013a), which appeared in the 1970s. The functions of such streets are to prioritize more vulnerable users by promoting their full ownership of the street while modifying motorists' behaviour towards safer and more vigilant driving (Polus & Craus, 1988). Other similar street concepts include Play Streets (Esmonde et al., 2022) and Complete Streets (Marleau Donais, Abi-Zeid, Waygood & Lavoie, 2019).

Shared streets can be seen as an approach to transform urban spaces into more livable and human-sized environments (Al-Mashaykhi, Hammam, Wahab, Rani & Jasimin, 2020), thereby contributing to the conversation about the car's place in the public space (Babb, 2021), a conversation notably accelerated by the COVID-19 pandemic that has profoundly transformed living habits and individual and collective mobility (Corazza, Moretti, Forestieri & Galiano, 2021; Mouratidis, 2021). Although there is no unique definition of shared streets (Kaparias et al., 2013), authors agree on several common characteristics

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[1] Woonerf translates as "residential ground" or "living yard.

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(Al-Mashaykhi et al., 2020), including the reduction (or absence) of physical segregation between transportation modes on the roadway (Hamilton-Baillie, 2008), the presence of less signage, and the placement of obstacles in the lane to modify the visual environment and encourage drivers to reduce their speed (Karndacharuk, Wilson & Tse, 2011). The presence of landscaping and street furniture, which reinforces the identity of the street as a pleasant public space suitable for various users' activities, is also among their main features (Ranmalsingha, Kaushal, Mark & Nuwan, 2018). Shared streets are thereby promoted as a place for recreation, meeting and socialization, in addition to their mobility and accessibility functions (Karndacharuk, Wilson & Dunn, 2013b). They encourage the presence of cyclists and pedestrians who are expected not only to move around, but also to stay around and use the street as a public place (Jiang, Massimiliano, Maffeia, Meng & Vorländerb, 2018; Jones, Marshall & Boujenko, 2008).

One of the first questions that need to be addressed by cities wishing to implement shared streets is that of choosing the candidate streets that are the most conducive for this concept. Which factors should be considered? How can a wide range of criteria, qualitative and quantitative, be taken into account and aggregated? How can transparency and social acceptability be ensured? And how can the various viewpoints and perspectives of different stakeholders, including citizens, be considered? The current scientific literature provides little help for answering these questions with a rare exception in Marleau Donais et al. (2019), who developed a multicriteria evaluation model for Complete Streets.

In order to fill the gap in the literature and in practice, we developed and applied a rigorous multicriteria evaluation approach to assess the potential of streets to be redesigned as shared streets. We implemented the results in a spatial decision support tool that subsequently was used operationally.

In this paper, we present our socio-technical process to develop the model and its application to the city of Sherbrooke located in the province of Quebec, Canada. The rest of the text is organized as follows: Section 2 presents the methods developed and the city used as a case study. Section 3 describes the model construction process, while Section 4 contains the results. A discussion of the results is provided in Section 5, and we conclude in Section 6.

2. Methods and application

We adopted a multi-method approach (Franco & Lord, 2011) based on conceptual maps, Multicriteria Decision Aiding (MCDA) and geographic information systems (GIS). Conceptual maps can be defined as graphic representations of people's beliefs, ideas, point of views and/or concerns about a specific situation or problem (Axelrod, 2015). They are especially useful to support brainstorming during the structuring phase of an MCDA process (Marttunen, Lienert & Belton, 2017).

MCDA consists of a family of methods to support decision making and planning that allows for structured and rigorous evaluations of elements (often called alternatives) in contexts characterized by conflicting objectives. It is particularly suited when quantitative and qualitative information, as well as stakeholders' preferences, must be integrated (Roy, 2016). For spatial problems, MCDA can be combined with GIS (Chakhar & Martel, 2004) to build spatial decision support systems (Dell'Ovo, Capolongo & Oppio, 2018; Demesouka, Vavatsikos & Anagnostopoulos, 2016; Malczewski & Rinner, 2015; Marleau-Donais, Abi-Zeid & Lavoie, 2017). A facilitator team is often necessary to help a group of participants in the construction of a multicriteria model that reflects its values and preferences. Group facilitation can be defined as a "goal-orientated dynamic process, in which participants work together in an atmosphere of genuine mutual respect, in order to learn through critical reflection" (Burrows, 1997, p. 401). Socio-technical MCDA processes, where an MCDA model is co-constructed in a social setting with various participants, promote dialogue, transparency and increase acceptance since they are conducted in the context of organizational and environmental considerations (Phillips & Bana e Costa, 2007).

MCDA has been applied in various domains such as healthcare, nature conservation, environmental science, transportation, and land use planning, to name a few (Adem Esmail & Geneletti, 2018; Boggia et al., 2018; Cegan, Filion, Keisler & Linkov, 2017; Diaby, Campbell & Goeree, 2013; Keller, Fournier & Fox, 2015; Lavoie, Florent, Vansnick & Rodriguez, 2015; Marleau Donais et al., 2019; Singh, Jha & Chowdary, 2017). In urban planning, some examples of MCDA applications include the evaluation of sustainable transport scenarios (Hickman, Saxena, Banister & Ashiru, 2012); the identification of suitable locations for rural roads (Castro & Vistan, 2020); the evaluation of walking environments (Lee, Lee, Son & Joo, 2013); the selection of bike projects (Barfod, 2012); the assessment of nature tourism potential (Rocchi, Cortina, Paolotti & Boggia, 2020); and the evaluation of urban infrastructure locations (Caprioli & Bottero, 2021).

The multi-criteria evaluation model was built using the MACBETH method (Bana E Costa, De Corte & Vansnick, 2012) which provides, using a weighted sum, a global score for each evaluated alternative. There are several reasons for selecting MACBETH. First, we opted for the simplest and most familiar model, namely the additive aggregation model (weighted sum). However, although simple to use in practice, the weighted sum often leads to methodological problems due to the incorrect use of scales that are not cardinal and due to the incorrect interpretation of the weights as importance scales. In fact, cardinal scales are required for computing a weighted sum since adding ordinal values is mathematically incorrect. Furthermore, to ask the question "what is the relative importance of a criterion" is meaningless in a weighted sum. Weights cannot be evaluated by directly comparing criteria without considering the ranges of measures on the criteria. This is a mistake encountered in several popular weighting procedures and is the most common and critical mistake in weighted sums (Keeney, 2002). By allowing the construction of cardinal scales and of scaling constants (commonly called weights), in a methodologically correct fashion, MACBETH avoids the main traps associated with a weighted sum (Bana E Costa et al., 2012). It does so by requiring as input not only ordinal preference information but also interval preference information. Moreover, MACBETH allows the alternatives to be assessed based both on qualitative and quantitative information. Furthermore, it is relatively simple to use in a facilitated setting with participants who have little or no experience in multi-criteria decision analysis (Lavoie et al., 2015). Finally, MACBETH has its own supporting computer software (M-MACBETH) that allows simple and effective recording of the information provided by participants. In addition to enabling the construction of a real-time decision analysis model, this software identifies potential inconsistencies in the judgments expressed by participants and proposes, if necessary, alternative solutions (Carnero & Gomez, 2016). As for the spatial aspects of the project, we developed new software for automatic data processing and transfer between the M-MACBETH software and ESRI's ArcMAP10.7[2] (Marleau-Donais et al., 2017). This new software was recently expanded into an application called Othello, available as open source on Github.[3] During the project, we also used depthMapX, a visual and spatial network analysis software (UCL Space Syntax, 2022).

2.1. Case study

The model was applied in the city of Sherbrooke (Fig. 1), one of the largest cities in the province of Quebec with 175,000 inhabitants (Institut de la statistique du Québec, 2022) over an area of 366 km^2 (Ministère des Affaires municipales et de l'Habitation, 2010). For several years, the municipal administration had been considering implementing shared streets, notably through the adoption of a

[2] https://www.esri.com/en-us/home.

[3] https://github.com/ulaval-rs/othello.

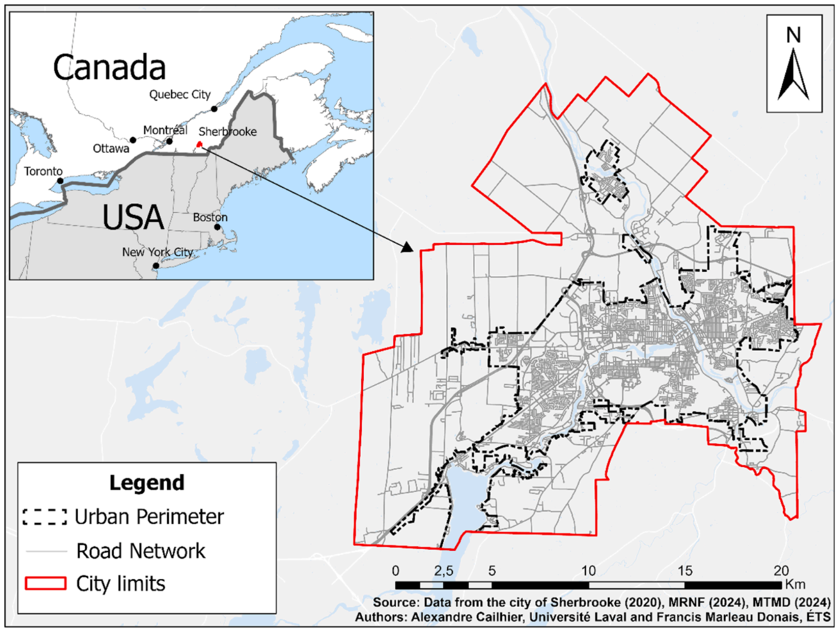

Fig. 1. Case study. city of sherbrooke, province of québec, Canada.

Sustainable Mobility Plan 2012–2021 (City of Sherbrooke, 2012) and an Active Transportation Master Plan in 2016 (City of Sherbrooke, 2016). In 2020, motivated by repeated requests from citizens and recurrent media coverage, the city of Sherbrooke contacted our research team, which led to this action research project. Action research is a research strategy that goes beyond the description and explanation of a phenomenon. It combines theory and practice in order to develop solutions that make it possible to act on problems observed in the field.

During the course of the project, we conducted nine workshops of three hours each, distributed over a six-month period, with a group of 13 participants from Sherbrooke City's administration (three directors, two division chiefs, two project managers, two landscape architects, two engineers, one urbanist and one geomatic analyst). The participants had been identified jointly with one of the project managers. As facilitators, we followed the principles of decision conferencing, a social process where key actors are engaged in the modeling process, thereby ensuring their ownership of the developed artefacts and their subsequent implementation (Phillips, 2007). We adopted a constructivist view where the produced knowledge resulted from the interaction between subjects (group and our research team) and a problem. All the workshops were recorded. This allowed us to revisit discussions between the workshops and helped us to organize the information and produce the conceptual maps.

At the end of the first workshop, we asked the participants to give us their impressions regarding the meeting, the positive and less positive points, whether the meeting met their expectations and points to improve in the following meeting. Overall, the response was that they greatly appreciated the first meeting, particularly because the many professionals present around the table made it possible to share several different points of view. Some participants, however, indicated that it would have been great to have a better definition of the concept of the shared street and some examples to better guide reflections, which we therefore prepared for the subsequent meetings. At the beginning of each following meeting, we revisited what had been accomplished in the previous one and made sure that we had agreement concerning the design decisions that were made.

3. The model construction process

The model construction process consisted of two main phases adapted from Abi-Zeid, Marleau Donais and Cerutti (2023), namely problem structuring and criteria construction followed by the development of the MACBETH evaluation model.

3.1. Problem structuring and criteria construction

In order to structure the problem and construct a set of evaluation criteria to help assess the potential of a street to be redesigned as a shared street, we followed a value-focused thinking approach, which helps a group to articulate the core values that guide its decisions (Keeney, 2007). This first phase required three workshops, during which the vision of the group and the priorities of the City were discussed. This resulted in several conceptual maps, an example of which is presented on Fig. 2. The workshops revealed 67 elements that could influence the choice of a street to be redesigned as a shared street. These elements covered a wide range of topics such as land uses, criminality, proximity services, density, social deprivation, and heat islands. These were finally grouped in four dimensions: security, accessibility, environmental and social and led to the construction of 9 evaluation criteria out of the four dimensions (5 qualitative and 4 quantitative) described below. Furthermore, a total of 3325 local street segments were retained for evaluation on the 9 criteria.

3.2. Security dimension - Criterion: visibility

The objective of this qualitative criterion is to prioritize the implementation of shared streets on segments with the safest geometries in terms of visibility. Visibility is negatively impacted by the presence of slopes or curves. A segment can have one of the following four performances in increasing order of potential (Fig. 3). The performances' ranking of this criterion, like for all criteria, was obtained based on consensus with the participants. Based on this criterion alone, a street A, that for example has a no sloping topography and is linear, has a higher shared street potential than a street B, that has a sloping topography and curve(s).

3.3. Security dimension - Criterion: connectivity

The objective of this quantitative criterion is to prioritize, for safety reasons, the implementation of shared streets on street segments with

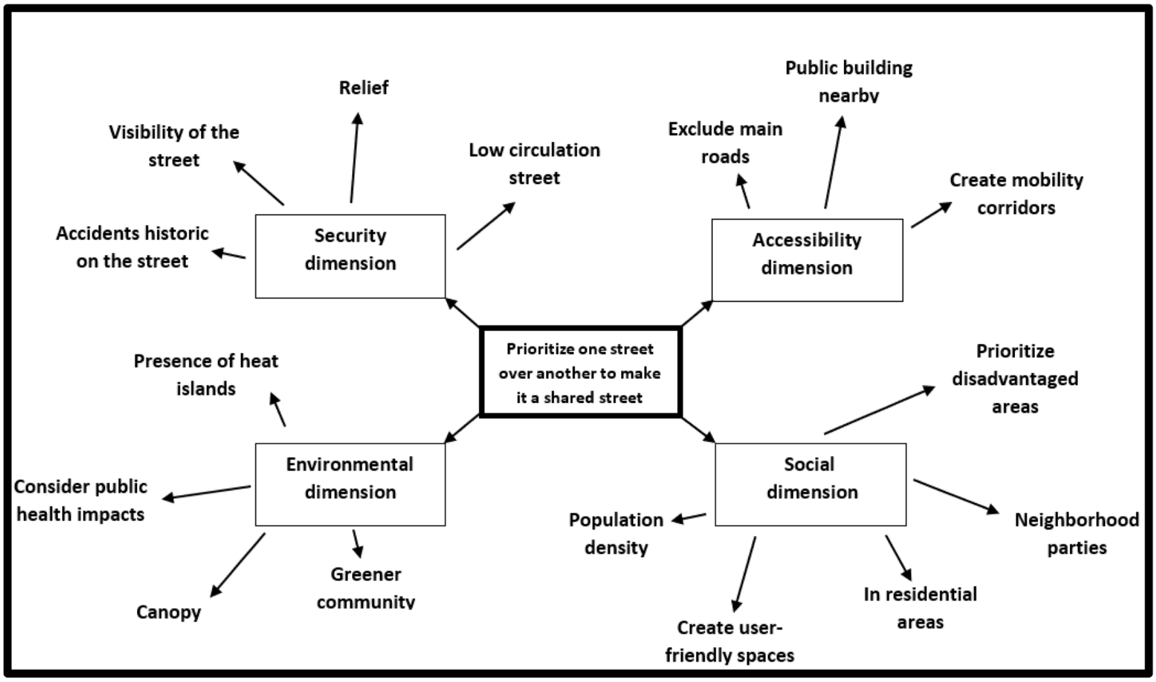

Fig. 2. Conceptual map illustrating a sample of the elements that could influence the choice of a street to be redesigned as a shared street.

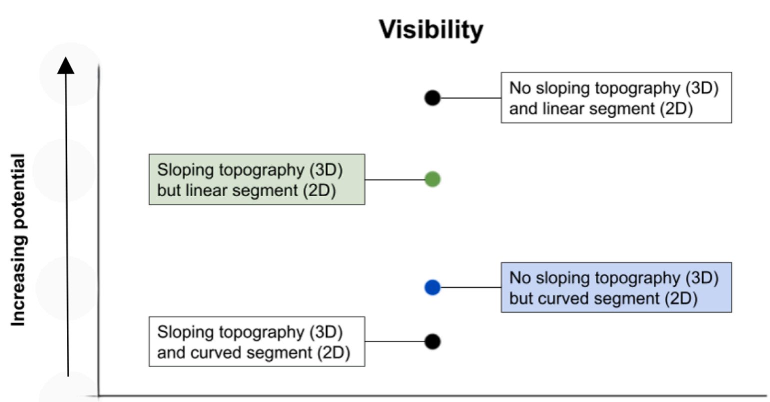

Fig. 3. Performances on the criterion Visibility - The distance between the performances reflects the difference in the potential.

low connectivity. It is calculated using the Space Syntax approach and the DepthmapX software to measure the normalized angular choice, a measurement unit specific to Space Syntax (UCL Space Syntax, 2022). A segment can have a connectivity index (between 0 and 1.55), which measures of its potential to be used as part of the shortest path from a segment to every other segment within a radius of 1200 m (Hillier, Yang & Turner, 2012). A segment with a high connectivity is more likely to be used by cars and is therefore less safe. Based on this criterion alone, a street A with, for example, a connectivity index of 0.25, has a higher shared street potential than a street B with a 1.25 connectivity index. This criterion is used as a proxy for security.

3.3.1. Accessibility dimension - Criterion: proximity to public buildings and/or contiguity to a green area

The objective of this qualitative criterion is to prioritize the implementation of shared streets on street segments located near public buildings and green areas in the city. Proximity is measured by the number of buildings (community, cultural, commercial, institutional and public) located within a 500 m radius of a street segment. The contiguity of a street segment to a green area within the city was also taken into account to increase its potential. A segment can have one of the 10 performances in increasing potential as presented on Fig. 4. Based on this criterion alone, a street A for example, located near 20 public buildings and contiguous to a green area, has a higher shared street potential than a street B located near 5 public buildings and not contiguous to a green area.

3.3.2. Accessibility dimension - Criterion: proximity to public transit stops

The objective of this quantitative criterion is to prioritize the implementation of shared streets on street segments located near transit stops in the city. Proximity is here measured by the number of Sherbrooke Transportation Society transit stops located within a 500 m radius of a street segment. A segment can have a performance of 0 to 70. Based on this criterion alone, a street A for example located near 15 transit stops, has a higher shared street potential than a street B located near 5 transit stops.

3.4. Accessibility dimension - Criterion: active transportation

The objective of this qualitative criterion is to prioritize the implementation of shared streets on street segments that could improve accessibility to active mobility networks and where there is already

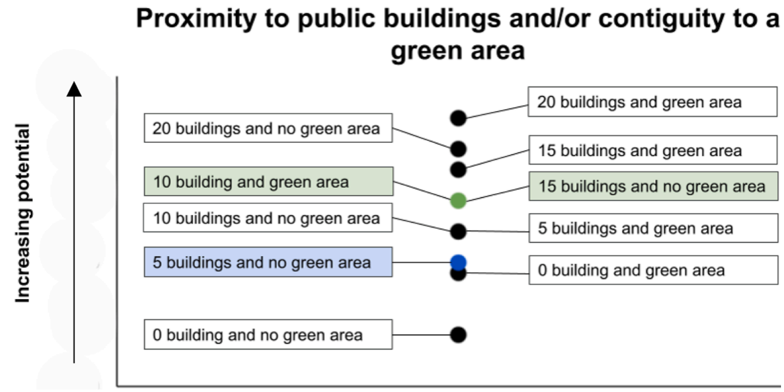

Fig. 4. Performances on the criterion Proximity - The distance between the performances reflects the difference in the potential.

evidence of pedestrian and bicycle use. A street segment can have one of the following four performances in increasing order of potential: (1) no bicycle network and no pedestrian network, (2) a bicycle network but no pedestrian network, (3) no bicycle network but a pedestrian network, and (4) a bicycle network and a pedestrian network. Based on this criterion alone, a street A with a bicycle and pedestrian network, has a higher shared street potential than a street B without a bicycle nor a pedestrian network.

3.5. Environmental dimension - Criterion: canopy index

The objective of this quantitative criterion is to prioritize the implementation of shared streets on street segments with a low canopy, since their redesign could contribute to greening areas characterized by a low vegetation cover. Canopy can be defined as the portion of trees and vegetation above ground and directly exposed to the sun (City of Montreal, 2020). Using LiDAR data, it is measured here as the ratio (0 to 100 %) of the area of the ground projection of the sun-exposed trees to the total area of a street segment with a 20 m buffer zone. Based on this criterion alone, a street A for example, with a canopy percentage of 10 % has a higher shared street potential than a street B with a canopy percentage of 35 %.

3.6. Social dimension - Criterion: housing density

The objective of this quantitative criterion is to prioritize the implementation of shared streets on street segments where they could benefit the greatest number of citizens. To measure performances on this criterion, we computed for each segment the number of housing units per 100 linear meters within a buffer of 20 m (the results ranging from 0 to 928 housing units per 100 linear meters). Based on this criterion alone, a street A for example, with 30 housing units per 100 linear meters has a higher shared street potential than a street B with 15 housing units per 100 linear meters.

3.7. Social dimension - Criterion: material and social deprivation index

The objective of this qualitative criterion is to prioritize the implementation of shared streets in the most deprived areas of the city. It uses the Quebec material and social deprivation index, computed every five years (Institut national de santé publique du Québec, 2020), at the dissemination area scale, the smallest geographic unit for which Canadian Census data is published. The index identifies the quintile (Q1 to Q5) for social deprivation and that for economic deprivation. We constructed the criterion such that a segment can be assigned one of five performances as in Fig. 5. For example, if it is in an area that rated Q1 on the social or economic dimension and not Q3 nor Q4 on the other dimension, then it is considered very privileged (1). Conversely, if it is in an area rated Q5 on the social or economic dimension and not Q1 nor Q2 on the other dimension, then it is considered very deprived (5). The other three performance levels are combinations of quintiles on the two dimensions as seen in Table 1. Based on this criterion alone, a segment A for example, that is in a dissemination area deemed materially and socially very deprived has a higher shared street potential than a street B located in a dissemination area that is materially and socially very privileged.

3.8. Social dimension - criterion: citizen engagement

The objective of this qualitative criterion is to prioritize the implementation of shared streets on segments where a strong citizen engagement has been observed. To measure this criterion, the presence

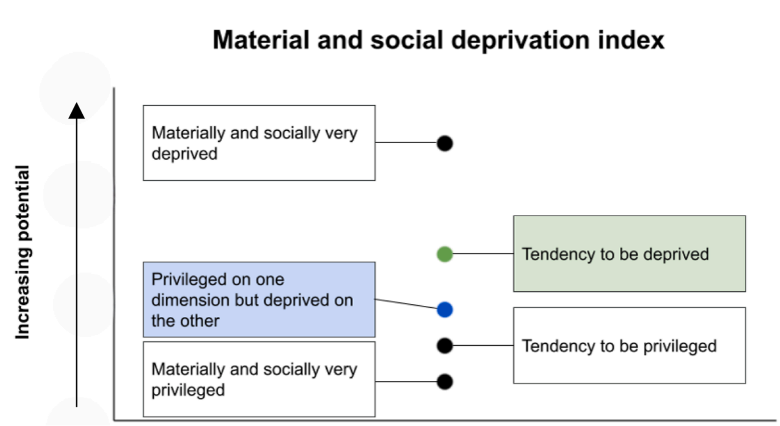

Fig. 5. Performances on the social deprivation criterion. - The distance between the performances reflects the difference in the potential.

Table 1
The social deprivation criterion.

		Social deprivation				
		Q1	Q2	Q3	Q4	Q5
Material deprivation	Q1	1	1	1	2	3
	Q2	1	2	2	3	4
	Q3	1	2	3	4	5
	Q4	2	3	4	4	5
	Q5	3	4	5	5	5

or absence of neighborhood party(s) during the project's previous year and the presence or absence of organizations related to recreation and community life are used as proxies. A segment can have one of four performance levels of increasing potential: (1) a street segment that had no neighborhood party in 2019 and has no social organization, (2) a street segment that had no neighborhood party in 2019 but has social organization(s), (3) a segment that had neighborhood party(ies) in 2019 but has no social organization, and (4) a street segment that had neighborhood party(ies) in 2019 and has social organization(s). Based on this criterion alone, a Street A for example, that hosted a neighborhood party during the previous year and has a social organization has a higher shared street potential than a street B with no neighbourhood party during the previous year and a social organization.

3.9. Development of the MACBETH evaluation model

MACBETH uses semantic information provided by the participants to build cardinal value functions for each criterion. These functions translate the performance on each criterion, whether qualitative or quantitative, to a value reflecting the preferences of the participants, called attractiveness. In our context, the alternatives are the street segments, and the attractiveness scores represent the potential of a segment to be redesigned as a shared street. There are three main steps in the MACBETH method: (1) setting reference levels in order to define a criterion's unit of attractiveness; (2) constructing the cardinal value function for each criterion and (3) deriving the scaling constant (weight).

First, a "neutral" performance and a "good" performance are specified for each criterion, to which attractiveness values of 0 and 100 are assigned respectively. However, other values could be used without changing the end results. The built attractiveness scales are open and thus, performances can be worse than neutral and better than good. As a comparison, the Celsius temperature scale is a constructed interval scale where 0 was chosen to represent the water freezing point and 100 the water boiling point. Therefore, a unit on this scale (a Celsius degree) is 1/100th of the difference between the freezing temperature and the boiling temperature. In MACBETH, the "neutral (0)" reference corresponds to a performance A, that participants consider acceptable for designing a shared street from the perspective of the given criterion, while the "good (100)" reference is a performance B, that is considered fully satisfactory and with which they are totally happy to start designing a shared street. Consider for example the canopy criterion, the neutral reference point was set to 25 % and the good reference point to 20 %. In other words, all other things being equal, segments with a canopy percentage of 25 % *could* be considered for redesign while all street segments with a canopy percentage of 20 % or less should definitely be considered for redesign as shared streets. Note that the neutral level is not necessarily the minimal level required. It is possible that a segment having a canopy performance of more than 25 % could still be redesigned as a shared street because the attractiveness of its performances on the other criteria is high.

The second step is to obtain from the participants the perceived difference of attractiveness between pairs of performance levels according to seven semantic categories: null, very low, low, moderate, strong, very strong and extreme. This information allows MACBETH to propose an interval scale that is compatible with the answers provided. Fig. 6 presents a table of judgments comparing the attractiveness of various canopy values provided by participants. This table is translated in the software M-Macbeth and provides the attractiveness scale in Fig. 7, obtained from a linear mathematical program (Bana E Costa et al., 2012). We note that the scale is not linear, and it is rarely the case in practice. For example, the attractiveness of a canopy index of 40 or more represents the same potential for designing a shared street from the perspective of this criterion.

The third step is to construct the scaling constants (weights) that will be used to compute the global score of an alternative. For this purpose, n fictitious alternatives (street segments) are defined, where n is the number of criteria, such that each alternative has a "good" performance level on one criterion (different for each option), and neutral performances on all the other criteria. In addition, an all neutral fictitious segment is defined. Participants are then asked to identify, for each pair of fictitious segments, which of the two has a higher potential and to qualify the difference in potential according to the same seven semantic categories used to construct the cardinal attractiveness scales. To illustrate the process, Fig. 8 shows the case where a fictitious segment A with a higher reference performance on the criterion Housing Density and lower references on all other criteria is compared to segment B with a higher reference performance on the criterion Proximity to Public Transit stops and lower references on all other criteria. Participants have judged that A has a higher potential and the difference of potential of A and B is weak. Based on this type of information for all pairs of fictitious segments, the software provides a set of weights consistent with the judgment expressed. These weights are scaling constants and reflect the relative importance of moving from a zero value (lower reference) to a 100 (higher reference) on one criterion compared to move from a zero value to a 100 on another criterion. In the case of these two criteria, the weight of Housing Density was computed to be 13,85 % and that of Proximity to Bus Stops to be 9,2 %. The scaling constants can be interpreted as follows: The relative importance of moving from a lower reference to a higher reference on the criterion Housing Density is 1,5 times more important than moving from a lower reference to a higher reference on the criterion Proximity to Bus Stops (13,85/9,2). Again, we would like to emphasize here that weights in the weighted sum are not the relative importance of the criteria but rather scaling constants.

	0%	10%	15%	20%	25%	30%	35%	40% and more	Current scale	Extreme
0%	Null	Modera.	Positive	Positive	Positive	Strong	Positive	Positive	525	V. strong
10%		Null	Weak	Positive	Strong	Positive	Strong	Positive	350	Strong
15%			Null	Weak	Positive	Positive	Positive	Positive	225	Moderate
20%				Null	Weak	Modera.	Modera.	Positive	100	Weak
25%					Null	Weak	Positive	Positive	0	V. weak
30%						Null	Weak	Modera.	-100	Null
35%							Null	Weak	-200	
40% and more								Null	-300	

Fig. 6. Table of judgments in M-MACBETH for the canopy criterion.

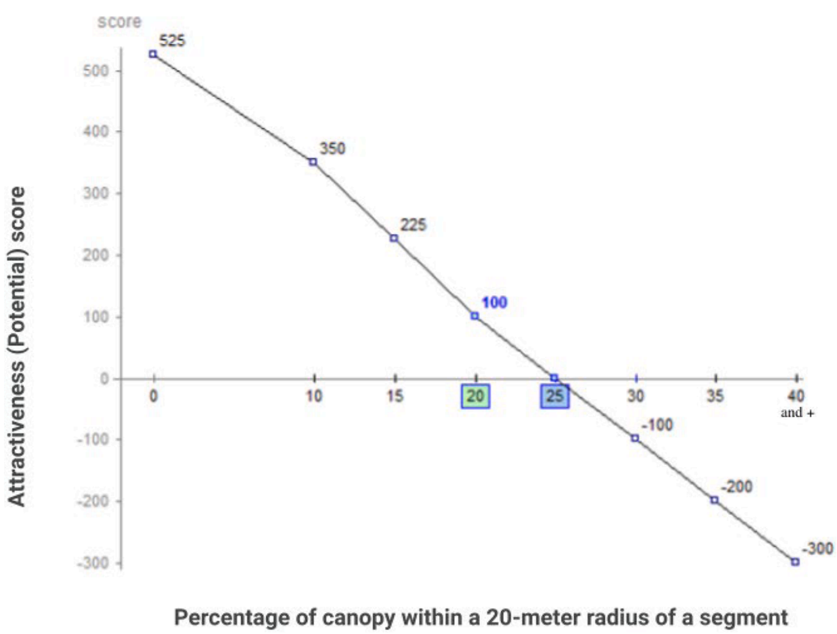

Fig. 7. Attractiveness (Potential) scale of the canopy criterion.

4. Results, validation and post-project evaluation

Table 2 presents the criteria constructed along with their weights while Appendix 1 presents the attractiveness interval scales for each criterion. After having constructed the attractiveness scales and the scaling constants, a global score reflecting the overall attractiveness (potential) of a segment to be redesigned as a shared street was computed, as a weighted average, for each of the 3325 segments.

Five categories with different colors corresponding to the quintiles of a segment's score were then defined: Very high (1st quintile of global scores), high, moderate, low, very low (5th quintile). Initially, the results were displayed using quintiles defined at the city level. Not surprisingly, many segments in the central areas had a high potential while that of segments in the periphery was much lower. This would have led to investments only in the central area and was not equitable. In fact, each neighborhood has its own internal dynamics that makes it unique, and difficult to compare with other neighbourhoods. Consequently, the quintiles were computed for the 33 neighborhoods and the results were presented at the neighborhood level, thus promoting a more equitable distribution of resources. Fig. 9 presents the results for one of the neighbourhoods. 33 such maps were produced and implemented in ArcMAP.

4.1. Validation of the results and implementation in a decision support tool

To ensure that the model results are consistent with the participants' vision and values, a sample of 20 street segments, located in different neighborhoods and with different overall attractiveness scores, were presented to the participants. The participants were asked to assign, according to their knowledge of the territory and the road network, each of the 20 segments to one of the five shared street potential categories. The set of anonymous alternatives was representative of a wide variety of contexts, i.e., streets which potential to be redesigned as a shared

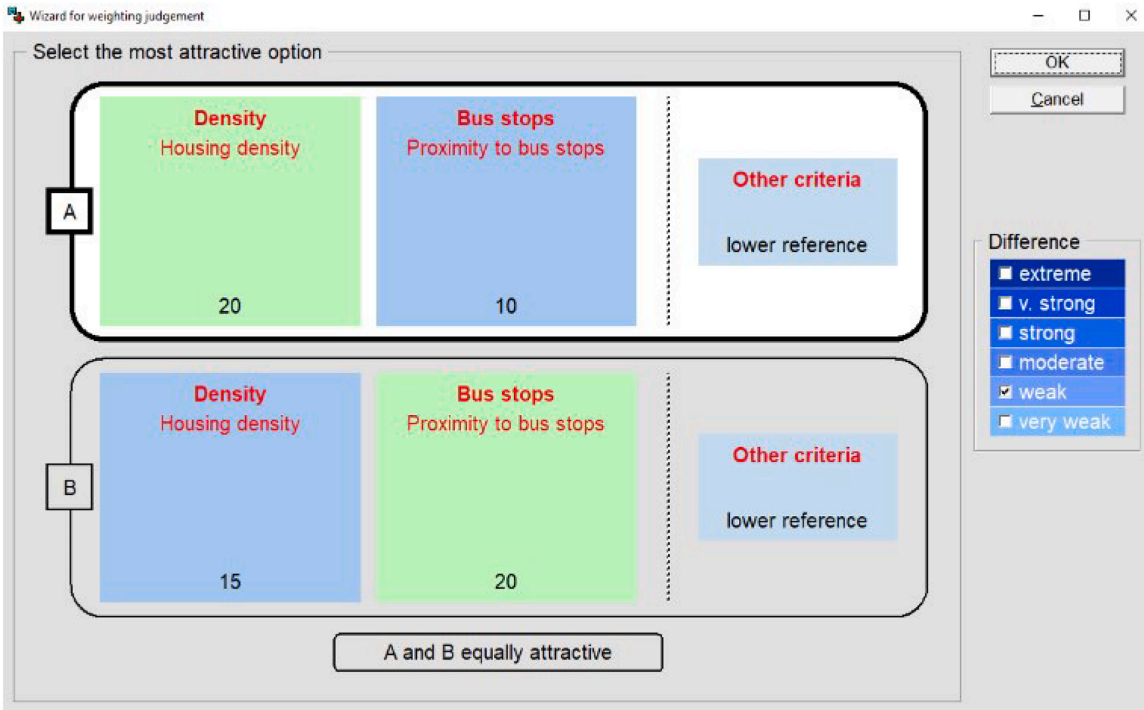

Fig. 8. Example of comparing two fictitious alternatives.

street ranged from a very low potential to a very high potential with a variety of high or low performances on different criteria.

Our objective was to compare, qualitatively, the results of the model with those of the participants. In this first validation exercise, there was a discrepancy with four segments. This led to a discussion with the participants that highlighted the need to modify a criterion. In fact, the proximity to public buildings and green areas criterion was initially computed only for proximity to public buildings without consideration of green areas. Following discussions with the participants and the first validation results, we modified this criterion to include the green area element, re-constructed its attractiveness scales and recomputed the global attractiveness scores. The modified model was then consistent with the evaluation of the participants for 19 of the 20 segments. This was deemed satisfactory by the participants and the model, and its results were finalized. The model results, implemented in ArcMap, was delivered to the city of Sherbrooke as an operational tool for spatial decision support (SDS) along with a final report.

4.2. Post-project evaluation

Four months after the project, we conducted an informal post-project evaluation and one year later, we requested a letter from the project manager concerning the impact that the project had on the organization. Several key elements can be addressed in an MCDA a posteriori: the process, its outcomes, and its adoption by the participants (Marleau Donais, Abi-Zeid, Waygood & Lavoie, 2021). We chose to evaluate the process to understand how it was perceived by the participants, thereby gaining insights into how we can improve our future practices. The following questions were asked:

- What aspects did you like best and what aspects did you like least in the process of building the decision support tool? Why?
- What do you consider to be the strengths and weaknesses of the decision support tool construction process in which you participated? Why?
- What aspects of the decision tool construction process did you find most challenging? Why?
- How did you perceive the transition from face-to-face to virtual meetings (due to the pandemic)? What type of meetings did you prefer and why?
- If you had to do the project over again, are there any aspects of the process that you would do differently? If so, which ones and why?

The answers revealed that the general perception of the process was positive. In particular, the participants appreciated the group meetings that allowed different perspectives and a wide range of views to be taken into consideration. The methodological rigour of the process, the presence of facilitators at the meetings and the acquisition of new knowledge were also mentioned as strengths of our approach. Finally, they emphasized the relevance of building a spatial decision support tool that specifically reflects their values and objectives, rather than proceeding via a turnkey approach proposed by external experts. Nonetheless, the participants also mentioned some challenges: the difficulty in maintaining a clear direction during group discussions at times, the feeling that too much time was sometimes spent on certain aspects and the impression that they occasionally experienced an information overload. The complexity of certain MCDA notions was also raised, emphasizing the importance of having MCDA experts as facilitators. These findings are consistent with other findings in the literature (Marleau Donais et al., 2021).

5. Discussion

This project was a first experience for the city of Sherbrooke and its professionals in applying MCDA to support urban planning decisions. The process helped them build a common value system and reach a consensus around a shared vision and communicate it to the citizens by making the results available online. Shortly after the end of this research, a pilot project, that received a positive reaction from the public, was implemented on a street segment. The implementation of other shared streets throughout the city are expected to follow. Furthermore, the city’s commission for security and social development as well as the commission for the environment and mobility has adopted a Shared Streets strategy in 2023.

Table 2
A summary of the criteria constructed.

Criteria	Objective	Unit of measure	Neutral reference (0)	Good reference (100)	Criteria weight
Security dimension					
Visibility	Prioritize the implementation of shared streets on street segments with the safest geometries in terms of visibility	Qualitative scale (4 levels)	A street segment having a non hilly topography (3D) but being curved (2D)	A street segment having a hilly topography (3D) but is linear (2D)	10,77 %
Connectivity	Prioritize the implementation of shared streets on street segments with low connectivity	Standardized choice index for a radius of 1200 m (quantitative scale from 0 to 1.55)	0 (a dead end street) or 1	0.75	6,92 %
Accessibility dimension					
Public buildings and green area	Prioritize the implementation of shared streets on street segments located near public buildings and green areas in the city	Qualitative scale (10 levels)	5 public buildings nearby but not contiguous to a green area	10 public buildings nearby and contiguous to a green area or 15 public buildings nearby but not contiguous to a green area	19,23 %
Public transit stops	Prioritize the implementation of shared streets on street segments located near transit stops in the city	Number of stops within a radius of 500 m (quantitative scale from 0 to 70)	10	20	9,23 %
Active transportation	Prioritize the implementation of shared streets on street segments where they could improve accessibility to active mobility networks and where there is already evidence of pedestrian and bicycle use	Qualitative scale (4 levels)	Segment with a bicycle infrastructure but no pedestrian infrastructure	Segment with no bicycle infrastructure but with a pedestrian infrastructure	12,31 %
Environmental dimension					
Canopy index	Prioritize the implementation of shared streets on street segments with a low canopy, so that their redesign could contribute to greening areas with low vegetation cover	Percentage (quantitative scale from 0 % to 100 %)	25	20	8,46 %
Social dimension					
Housing density	Prioritize the implementation of shared streets on street segments where they could serve the greatest number of citizens	Number of housing units per 100 linear meters (quantitative scale from 0 to 928)	15	20	13,85 %
Material and social deprivation	Prioritize the implementation of shared streets in the most deprived areas of the city	Qualitative scale (5 levels)	Segment located in a diffusion area favoured on one dimension but deprived on the other	Segment located in a diffusion area with a tendency to deprivation	15,38 %
Citizen engagement	Prioritize the implementation of shared streets on street segments with strong citizens engagement	Qualitative scale (4 levels)	Segment with no neighborhood event in the previous years and hosting no social organization	Segment with no neighborhood event in the previous year but hosting social organization(s)	3,85 %

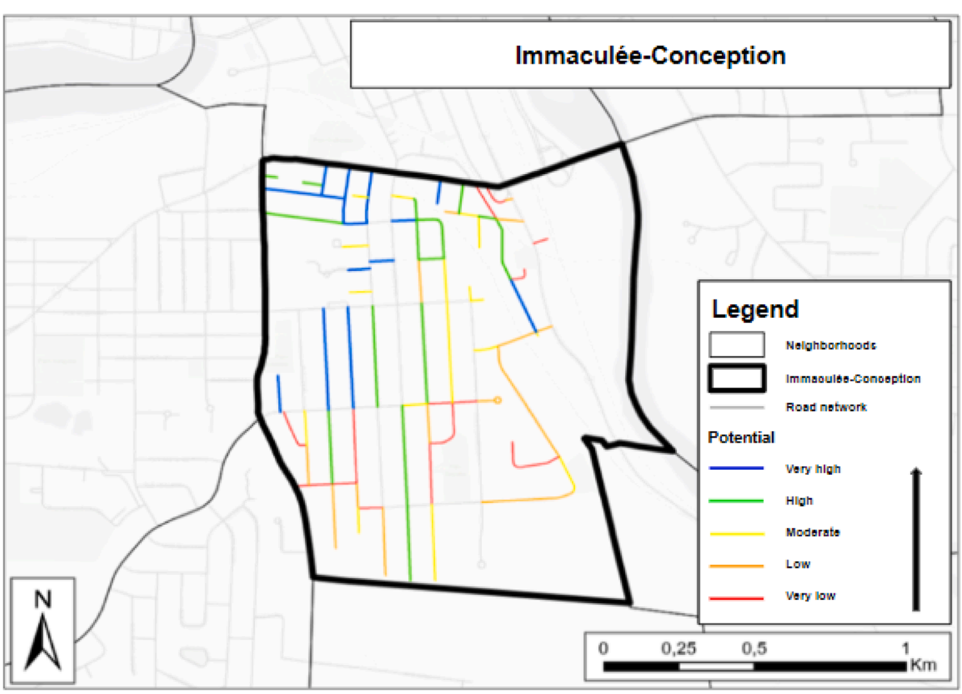

Fig. 9. An example of a neighborhood final map representing the potential of segments to be redesigned as shared streets.

To describe the impact of our project, the words of the project manager are quite informative: “The support you have provided and the analyses you have produced have enabled us to take a fresh look at the relationship between the city’s road network and the spatial organization of its territory. The contribution is twofold: First, the marriage of engineering data with social, economic, real estate and environmental data has not only enabled us to define a theoretical model that responded to our concerns and to those of the general public, but also to illustrate in a concrete way to colleagues from a variety of backgrounds the importance of a cross-disciplinary analysis to the challenges we face. Second, this has been a success since it is a first within the municipal apparatus. In addition, the care you have taken to include methodological details in the final report makes it an invaluable tool that will stand the test of time, allowing us to improve the theoretical model as our context evolves, and even to adapt it to respond to related issues” .[4]

As can be expected, the project has limitations. First, it was not possible to include some criteria due to the unavailability of data. For example, there was no data on the number of accidents as a function of the average pedestrian flow on a segment. This was also the case for the percentage of mineralized surface around a segment and heat islands’ location. However, the percentage of mineralized surface around a was replaced by the canopy criterion, which also gives a good overview of the places characterized by a strong mineralized surface.

Second, the model developed represents the values, concerns, and objectives of the city’s professionals who participated in its development. Thus, if these values or objectives evolve over time, the model may no longer reflect the city’s vision. An update of the criteria as well as the scales and weights may be necessary to adapt the model to new realities that may emerge.

Third, the health crisis of Covid-19 changed the course of the project along the way. This had three main impacts: migration from face-to-face meetings to virtual meetings, continuation of the process with a smaller group of professionals and spacing of the meetings. The transition to a virtual mode strongly influenced the meetings’ environment. On one hand, it was more difficult for the facilitators to observe the group dynamic and adapt the approach accordingly. On the other hand, the number of city representatives participating in the meetings decreased from about ten individuals to only a few professionals (from two to four) as of the third meeting. This situation certainly influenced the results of the study in some ways as the knowledge and expertise of professionals who did not attend the meetings until the end of the project could not be included as expected. However, this situation was offset to some extent by the consideration, to the best of their knowledge, of the multiple issues that could be associated with the implementation of streets shared by the few professionals who attended the meetings until the end of the project. The situation created by the health crisis also affected the duration of the project since it was extended by four months. The delay between meetings was significant at times, which made it difficult for the professionals to recall the discussions and progress made during the previous meetings.

6. Conclusion

The project presented in this paper is an original contribution to the literature on informed decision-making for the transformation of urban environments, road networks and shared streets through the combination of MCDA, geographic information systems and group facilitation. Our results contribute further empirical evidence related to the benefits of MCDA in urban and land use planning. It fills a gap in the literature since to our knowledge, the only study that addressed the issue of shared streets with MCDA had a different scope and did not aim at evaluating the shared streets design potential (Karndacharuk et al., 2013b). Furthermore, this action-research project has highlighted the usefulness of group facilitation and participatory decision-making for the development of an MCDA model in urban planning. Knowledge transfer between the participants and the facilitator team as well as within the participants was continuous during the whole intervention.

The benefits of the artefacts developed in this project are numerous. First, the City of Sherbrooke is now able to make more informed choices around investments and explain these choices in a more transparent manner. In addition, this tool allows the city to be more proactive rather than simply reacting to citizens’ pressure on an ad hoc basis. Knowing which street segments have the highest potential for redesign as shared streets is an excellent decision aid in the planning process. In addition to its operational value for the users, the tool facilitates communication among professionals such as urban planners, elected officials and most importantly, citizens, thereby increasing social acceptability of the decisions made.

The approach presented here is generalizable to other similar contexts. Some criteria in other cities may differ, but the same methodological process could be applied to develop similar spatial decision support tools. As for future research, it could be interesting to broaden the scope of the participants in the process, by including, for example, elected officials or representatives of the civilian population. Professionals often have a technical vision of a situation according to their fields of expertise. The involvement of citizens could bring different perspectives and thus enrich the reflection process. Moreover, the inclusion of citizens at all stages of the process could increase the trust level in the process and its results, thereby reinforcing the acceptance and legitimacy of decisions.

CRediT authorship contribution statement

Alexandre Cailhier: Writing – original draft, Visualization, Validation, Software, Formal analysis, Data curation. **Irène Abi-Zeid:** Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Roxane Lavoie:** Writing – review & editing, Supervision, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Francis Marleau-Donais:** Writing – review & editing, Data curation. **Jérôme Cerutti:** Writing – review & editing.

Declaration of competing interest

The authors declare no conflict of interest and no use of generative AI in writing the text

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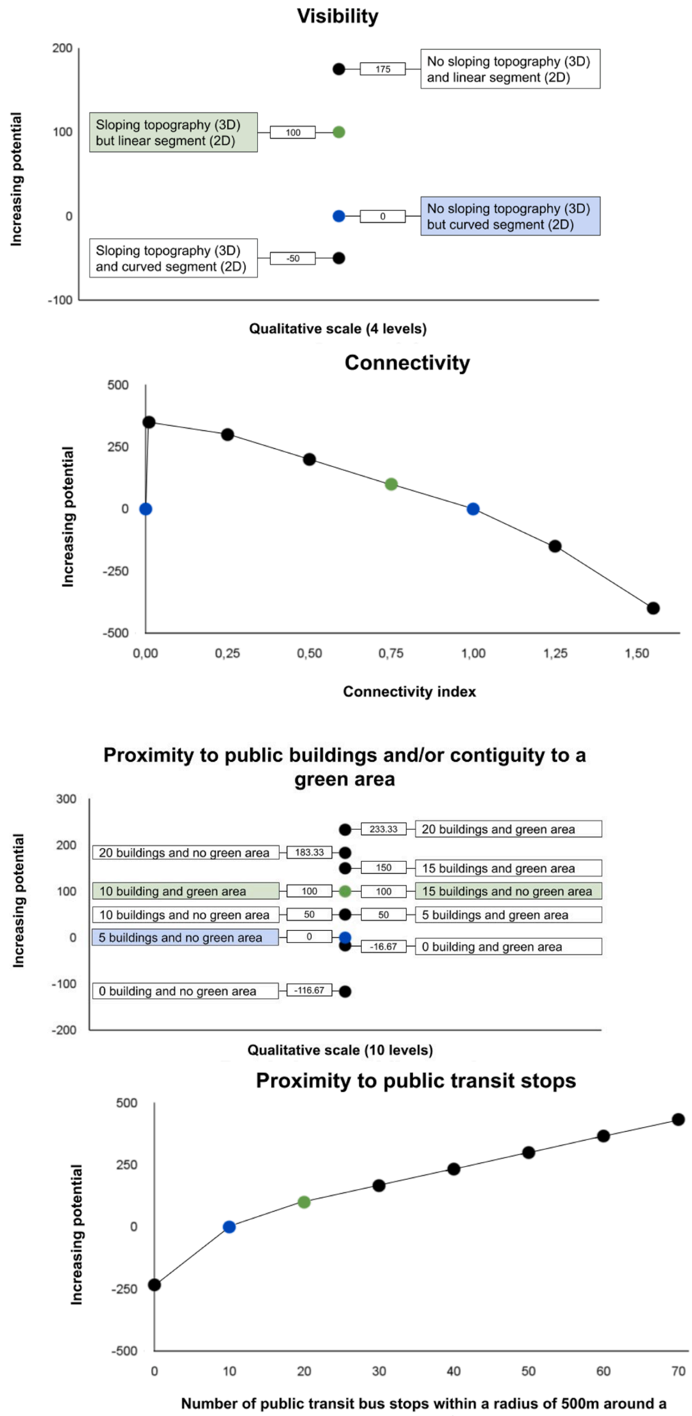
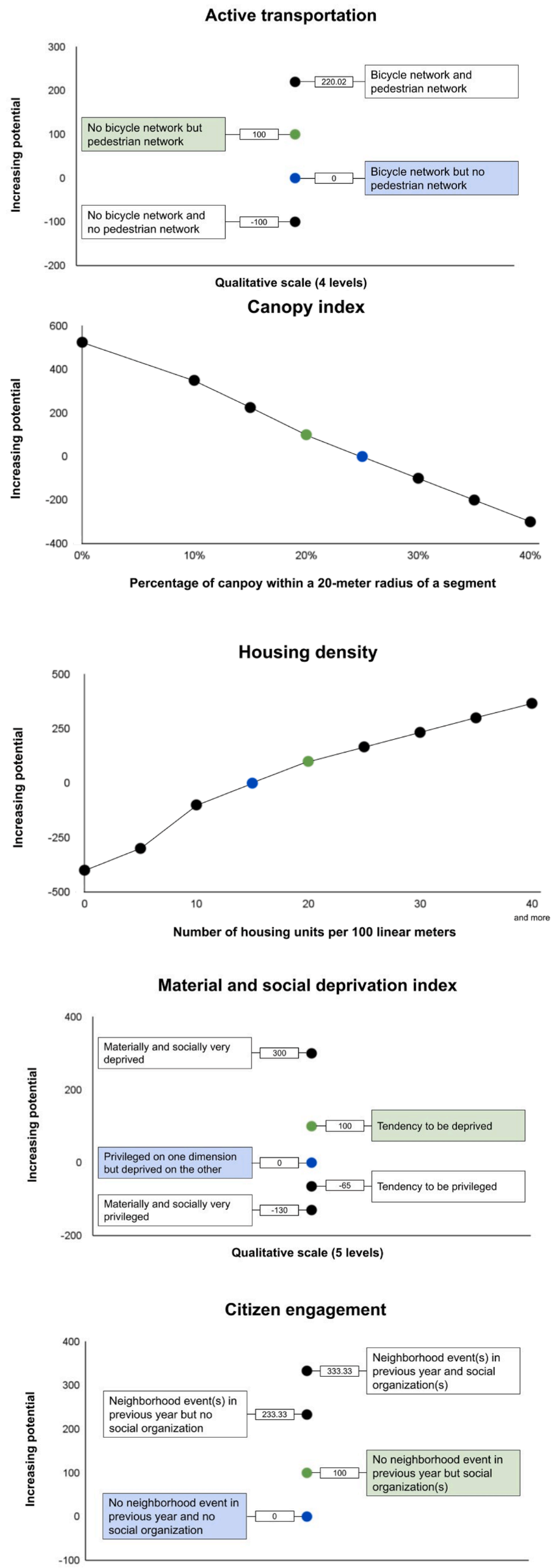
Appendix 1 Criteria attractiveness (potential to be redesigned as shared street) scales

The blue dots represent the « neutral » reference point and the green dots represent the « good» reference point.

[4] Translation from French of the partial content of a letter signed by the councillor for special projects – mobility division in Sherbrooke.


Visibility
Increasing potential
200
100
0
-100
175
No sloping topography (3D) and linear segment (2D)
Sloping topography (3D) but linear segment (2D)
100
0
No sloping topography (3D) but curved segment (2D)
Sloping topography (3D) and curved segment (2D)
-50
Qualitative scale (4 levels)
Connectivity
Increasing potential
500
250
0
-250
-500
0,00
0,25
0,50
0,75
1,00
1,25
1,50
Connectivity index
Proximity to public buildings and/or contiguity to a green area
Increasing potential
300
200
100
0
-100
-200
233.33
20 buildings and green area
20 buildings and no green area
183.33
150
15 buildings and green area
10 building and green area
100
100
15 buildings and no green area
10 buildings and no green area
50
50
5 buildings and green area
5 buildings and no green area
0
-16.67
0 building and green area
0 building and no green area
-116.67
Qualitative scale (10 levels)
Proximity to public transit stops
Increasing potential
500
250
0
-250
-500
0
10
20
30
40
50
60
70
Number of public transit bus stops within a radius of 500m around a segment


Active transportation
Increasing potential
300
200
100
0
-100
-200
220.02
Bicycle network and pedestrian network
No bicycle network but pedestrian network
100
0
Bicycle network but no pedestrian network
No bicycle network and no pedestrian network
-100
Qualitative scale (4 levels)
Canopy index
Increasing potential
600
400
200
0
-200
-400
0%
10%
20%
30%
40%
Percentage of canpoy within a 20-meter radius of a segment
Housing density
Increasing potential
500
250
0
-250
-500
0
10
20
30
40
and more
Number of housing units per 100 linear meters
Material and social deprivation index
Increasing potential
400
200
0
-200
Materially and socially very deprived
300
100
Tendency to be deprived
Privileged on one dimension but deprived on the other
0
-65
Tendency to be privileged
Materially and socially very privileged
-130
Qualitative scale (5 levels)
Citizen engagement
Increasing potential
400
300
200
100
0
-100
333.33
Neighborhood event(s) in previous year and social organization(s)
Neighborhood event(s) in previous year but no social organization
233.33
100
No neighborhood event in previous year but social organization(s)
No neighborhood event in previous year and no social organization
0
Qualitative scale (4 levels)

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