Design of Parking Interventions and Evaluation Methodology in Housing Area Estates

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Abstract

This paper provides an overview of the current challenges that occur within the design of the urban mobility concept and urban development concept. These challenges are discussed in view of the unique ELABORATOR project, which brings together different approaches and measures in a total of 12 European cities to improve micro mobility and sustainability and prove a concept toward climate-neutral cities. The main goal of the paper is to clearly describe the current state of mobility in the city of Liberec in the Rochlice housing estate area with the main objective focused on parking availability and identification of undesirable phenomena (incorrect parking, exhausted parking capacity, difficult passage for rescue services etc.). Therefore, the definition of ongoing problems is described from default to design and propose strategic interventions towards efficient parking supporting local mobility needs. Parallelly, the evaluation methodology is defined according to the requirements of strategically defined goals in sustainable urban mobility plans and the goals of the project. The proposed methodology reflects in situ measurement, identification of large-scale impacts based on quantitative analysis, and qualitative feedback collection from public events and applied interviews with city residents, and last but not least, the use of shared experiences of cities within the ELABORATOR project. This complex solution is defined to improve parking availability and to measure the real impact of proposed interventions on traffic on dedicated housing estates.

Keywords: *Elaborator, Evaluation, Intervention, Micro mobility, Urban mobility, Parking, Videodetection*

1. Introduction

Nowadays, city development and transportation within cities face a wide range of various challenges. It's climate neutrality, demographic changes, or even raising obesity rates and many other aspects [1]. Therefore, these are becoming more relevant and considered within the definition of strategic goals and the development of the city. One of the approaches to overcome these challenges is to develop sufficient environment and provide sufficient infrastructure considering the support of micromobility.

In recent years, multiple projects and subsidies have been launched with funding at the national or international level of regional or city development. Even the European Union (EU) performed activities that led to the definition of strategies and action plans towards zero pollutions, climate neutrality, decarbonization, etc. Five main missions have been defined under Horizon Europe, which are focused on the way to achieve concrete solutions delivered by 2030. One of the missions is focused on the importance of climate-neutral and smart cities. This mission involves local authorities, citizens, businesses, investors, as well as regional and national authorities, to deliver 100 climate-neutral and smart cities by 2030. These cities were selected as pioneers of experimentation and to develop innovation centers enabling dissemination and exchange of experiences with other cities in the coming years [2].

Although these projects are primarily aimed at cities and their centers, there are also the outskirts of cities and housing estates where most residents live. Therefore, these places should also be considered and also play an important role. From the perspective of transportation, these areas could be a resource of potential problems in city centers, whether it is about parking capacity, traffic load on the infrastructure or even travel times compared to other mobility modes. Commuting could have a large-scale impact on

all modes of transportation within the city.

To make cities climate neutral and smart throughout mobility requires attention to city development and its regional relations. It could be affected by the application of micro mobility solutions as well as effective planning; however, it is also about capacity building and allocation of public space. It requires the support of public transport and enhancement to ensure balanced modal splits. However, a human-centered approach is even more essential, especially if just new seating or suitable forms of greenery could even contribute to a sustainable increase in quality of life [3].

This paper provides an overview of strategic interventions to be applied in housing area estates to optimize parking resources that could positively affect micro mobility, commuting, city logistics, and serviceability of the area to prove enhancement of mobility solutions in the line of the ELABORATOR approach.

2. Elaborator Approach Towards Climate Neutrality

"One of the EU funded projects is the ELABORATOR performing complex European living laboratories on designing sustainable urban mobility towards climate neutral cities. The project aims at multimodality, safety, public space allocation, micro mobility improvements, vehicle restriction in city centers by applying appropriate interventions. The main objective is to provide enough data and knowledge exchange from different pilots and application of similar solution in a different environment to appropriately implement the twinning approach, leading to the complex evaluation of designed interventions in 12 pilots in various European cities, see Table 1.

Tab. 1. The list of ELABORATOR pilots.

City	Country	100 climate-neutral and smart cities [4]
Milan	Italy	✓
Copenhagen	Denmark	✓
Helsinki	Finland	✓
Issy-les-Moulineaux	France	✗
Zaragoza	Spain	✓
Trikala	Greece	✓
Lund	Sweden	✓
Liberec	Czech Republic	✓
Velenje	Slovenia	✓
Split	Croatia	✗
Krusevac	Serbia	✗
Ioannina	Greece	✓

The interventions consist of smart enforcement tools, dynamic re-design of spaces and allocation, shared services, and integration of active and green modes of transportation. They are specifically co-designed and co-created with user groups identified 'vulnerable to exclusion', local authorities and relevant stakeholders [5]. Interventions are appropriately implemented according to the needs and requirements of particular pilots in different cities. The ELABORATOR consists of 12 living labs/cities and other 36 stakeholders such as universities, public, and private companies from various European countries. Living laboratories are developed to ensure data acquisition is used for the appropriate validation and assessment of interventions' impacts. Living laboratories should be deployed before the intervention is applied to measure initial conditions, progress during implementation, and final evaluation with impact assessment. All data are stored locally in living labs, but the main goal of the ELABORATOR is to provide a unique platform for the exchange of data, knowledge, and the impact of applied interventions [6]; generalized diagram of the platform is below, see Figure 1.

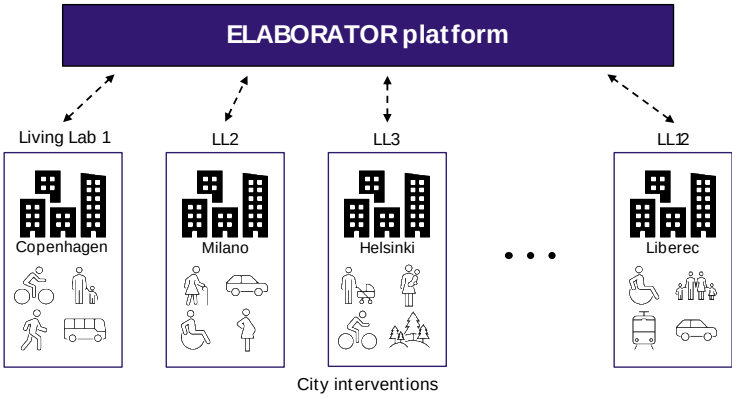

Fig. 1. Data and knowledge exchange through the ELABORATOR platform in pilot cities.

Since the project is in its initial stage, in which interventions are currently designed to be implemented, various interventions are to be applied in different cities. However, in upcoming stages of the project the twinning approach would be performed to validate whether one strategic and efficient intervention e.g. from Helsinki could be applied with the same positive impact in other cities such as Liberec. The twinning approach would lead to complex evaluation of strategic interventions according to the specific area, environment, or other specifics of the pilot city, which are to be evaluated by qualitative and quantitative measurements to ensure precise in situ data evaluation, large-scale impacts, or even perception of residents and its satisfaction.

The city interventions are focused on wide range of city challenges, but mainly on multimodality, safety, public space allocation, micromobility, and measures to improve mobility in city centers. One of the goals is also to improve the quality of operation in the housing area estates that would be applied in the city of Liberec. In Liberec, the proposed interventions would be applied to the Rochlice housing estate, where several problems are currently to be solved. Therefore, this article provides an overview of how to perform enhancements in these pilots according to the ELABORATOR methodology considering particular stages of the project, including complex evaluation and impact assessment.

3. Definition of strategic interventions

According to the described ELABORATOR project, the city of Liberec, like other cities, is solving the fundamental question of how to reduce the negative impact of traffic while maintaining the necessary level of sustainable mobility. Conceptually, this question is looking into the Sustainable Urban Mobility Plan (SUMP), which covers all basic measures of mutual optimal requirements. The City of Liberec has a Sustainable Mobility Plan 2021-2030 [7]. Our research is in compliance with the suggestions part of this document. At the same time, the city has the Strategic Development Plan of the Statutory City of Liberec 2021 document [8], in which a list of strategic measures can be found in the field of transport.

Due to the complexity of sustainable mobility issues, the methodology was approached using Checkland's soft systems methodology [9]. Through state-of-the-art analysis and brainstorming, an unstructured problem situation was expressed as a "rich picture." At this stage, several European cities were considered. Subsequently, a narrower specification of specific problems within the defined part of the city of Liberec-Rochlice was made, focusing on problems in the area of quiet traffic (parking). For these problems, the research then proposed specific strategic measures to help solve the defined problems. The aim is to find a balanced solution for sustainable mobility, i.e. to improve the quality of life of the citizens of Liberec while efficiently dealing with transport.

3.1 Existing problems

The defined area of the Liberec-Rochlice housing estate is a local part of the city where parking is not yet regulated in any way. Due to this fact, combined with the limited street space and dense development within the estate, the area has typical problems, which are:

- lack of parking places in the street area;
- problems caused by parking larger vehicle (van, lorry/truck etc...);
- problematic use of reserved parking spaces;
- vehicles parked for long periods that take up parking spaces;
- violating regulation (vehicle parked in a place that is not used to park for a given type of vehicles);
- breach of payment discipline (in the case of paid parking);
- reduced pedestrian safety due to unsuitable parking;
- reduced safety of vehicle traffic due to unsuitable designed parking;
- excess traffic caused by the search for free capacity (vehicles circle while they are looking for a parking place);
- difficult passage through the street space due to the number of parked vehicles (a problem especially for the rescue and emergency services);
- complicated supplying and other traffic services;
- lack of motivation for people to choose a mode of transport other than the car (e.g. bicycles, public transport, micromobility, etc.);
- increased emissions and noise from traffic;
- reduced attractiveness of the area (claim on valuable public spaces);
- limited resources on implementation of new approaches such as MAAS or autonomous shuttle;
- limited accessibility with impact on social issues (elderly people, mothers with small children, etc.);
- lack of support for micromobility.

An illustration of the selected problems that exist in housing estates can be found in Figure 2 below.

Fig. 2. Identified parking problems in the housing estate areas

Generally, there could be even more issues that are related to inclusivity, safety, exclusion groups, gender, and social issues that are not observable efficiently at the first glance, but that has to be identified by appropriate evaluation strategies [10].

3.2 Proposed interventions

In the parking area, the following general measures can be taken into account for the long term in the selected part of Liberec-Rochlice based on the available documents [7, 8].

Analysis of the mobility and micromobility in a selected (problematic) part of the city - Knowledge of the behavior of road users in a selected area over time is very important in assessing the effectiveness of the introduction of any measure below, and also serves as an important basis for policy support for the measures being introduced. There are two complementary basic ways of conducting the analysis, namely, interviewing road users through a questionnaire survey and direct observation of selected aspects of road user behavior. Large vehicles (lorries, larger vans) are often a problem when passing through densely populated areas and complicating the mobility of local residents.

Optimizing the number of parking spaces in locations with a predominant residential development. In areas with a predominant residential development, parking areas occupy a significant part of the total area of the transport infrastructure and public space, which can be undesirable. The goal is to efficiently use traffic space while maintaining the quality of life of citizens of the local part of the city of Liberec.

Checking and evaluating the appropriate way of monitoring the occupancy of parking spaces. In general, there are two basic methods of measuring occupancy, namely the balance method and measuring the occupancy of individual parking spaces. In the balance method, detection focuses on entry and exit to/from a parking zone or area. The condition for using this method is a limited number of entrances and exits within the assessed area. Occupancy detection of each parking space consists of installing detectors on each individual space (magnetic, ultrasonic), or you can monitor an entire area (a group of parking spaces) and detect the occupancy of individual spaces from the image, or you can use camcar. These detection methods make it possible to provide reliable information on the occupancy of the area even in situations of individual sensor failure. However, the cost associated with equipping larger areas increases with the high number of sensors required. The detection of individual parking spaces is suitable for determining occupied and free (according to traffic regulations) parking spaces in the area. Vehicles that are located outside these parking spaces cannot be detected, or additional detectors must be installed, which also detect the area of unauthorized parking, or other places.

Proposal to expand the system of measuring the occupancy of specific parking areas and places After checking the possibility of a suitable way of monitoring parking areas in the area, the general recommendation is to expand the system of measuring the occupancy of specific parking areas and places. In particular, these are exposed parking spaces that we monitor in order to find out whether the goal of their use is being met, where it is essentially necessary to distinguish between expedient long-term parking, where lower parking turnover (P+R, larger parking areas) and expedient short-term parking is preferred, where a higher turnover rate is preferred (K+R, dealing with matters at the office, shopping, delivery of services, etc.). The Living Lab principle can be fully utilized for this measure.

As part of the investigation, the above list of possible long-term measures was discussed with municipality stakeholders in Liberec to define a concrete feasible test plan in the local part of Liberec-Rochlice. Within the local part, the following traffic measures will be targeted:

Introduction of a ban on the entry of vans and trucks into the local part (estate) of Liberec-Rochlice - The aim of the measure is to eliminate unnecessary passage and parking of this category of vehicles in the local part with dense built-up areas. As part of the measure, monitoring of the traffic situation before and after the implementation of the measure is a prerequisite. Similar measures are already being implemented in the Czech Republic, for example, in the cities of Olomouc, Ostrava-Poruba, and Otrokovice.

Introduction of reserved places for short-term parking in front of selected entrances to apartment buildings - The aim of the measure is to set up a functional system for efficient short-term parking with a high turnover of vehicles. As part of the measure, it is assumed that the occupancy and turnover rate of the parking areas in front of the selected entrances will be monitored over time before and after the introduction of this measure in order to assess the effectiveness of the measure. Similar measures that are currently being implemented concern the reservation of certain strategic locations for efficient supply within the concept of City logistics.

Continuous monitoring of the use of reserved parking spaces - Some spaces are already reserved (reserved) in the Liberec-Rochlice area, e.g. for users with physical disabilities. The number of reserved spaces usually follows from technical regulations and standards and may or may not realistically correspond to user needs in the area. Sometimes reserved spaces remain empty while drivers park in the area in unauthorized places. The aim of the measure of continuous monitoring of existing and in the future newly built reserved places is to evaluate the effectiveness of their quantity. Generally found publications deal with continuous monitoring, e.g. article [11] deals with the issue of monitoring the possible abuse of reserved places, but does not address their effective use.

4. Evaluation procedure considering various impacts of interventions

Measurement of the real benefits of the proposed interventions is key to the overall assessment of their impact. With regard to the type of interventions chosen, a balanced approach has been chosen between qualitative and quantitative ways of measuring real impacts. This is also evident from the fact that the sub measures are both area-based and local in character. It is not realistic to achieve a quantitative assessment of the whole extent of the defined area in sufficient detail of the necessary parameters. Conversely, a qualitative assessment using precise measurements is not realistic in the entire size of the study area. The measurements that are expected to be carried out can be divided into the following groups:

- measurement of traffic parameters to assess the effect of the intervention over the whole area;
- detailed local measurements at the location of the intervention;
- an area-wide investigation of the impact of the measures based on satisfaction and preference surveys of local users.

The evaluation procedure would be using new approach of Living Lab, that integrates all the captured data from detection systems, and therefore, it would be possible to share accurate information about the specifics and events in a given location leads to future automated elements of parking services, when not only the driver of the vehicle will receive reliable information for parking in the destination location, but also for future use in autonomous mobility or shared vehicles, the introduction of such progressive new approaches is highly desirable [12].

4.1 In-situ detection and counting measures

The goal is to validate all measures through continuous data collection. Interventions are designed so that their effect and impact can be demonstrated with data. In coordination with this, appropriate technologies must be selected that can realistically be installed in the area. For each measure, the proposals for the implementation of parameter detection for the subsequent evaluation of their benefits are described below. The table then shows the basic parameters of the proposed measurements. The schematic diagram of the area specifies the expected location of the technologies for the implementation of the necessary data measurements, see Figure 3.

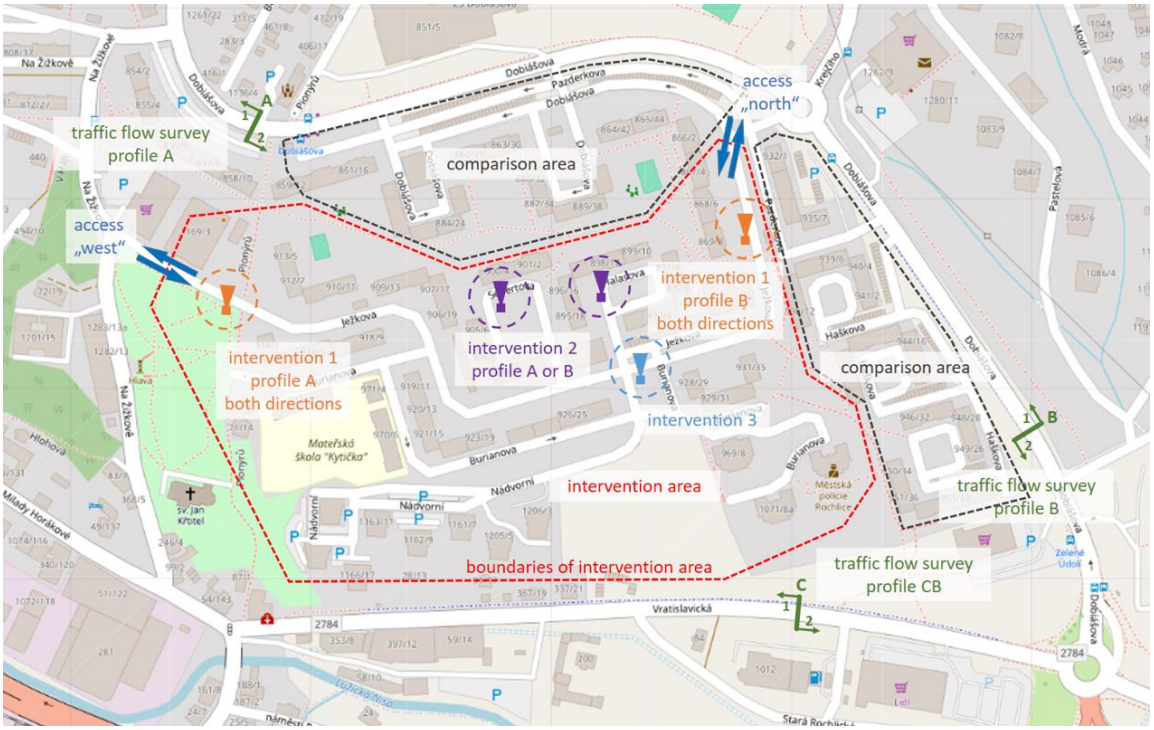

Fig. 3. Map of the whole area with the locations of the designed surveys.

Intervention 1 concerns the restriction of entry and parking of vans and trucks in the study area. The assessment of the impact of the measure is mainly based on the detection of vehicles and their types in the area. This will be carried out in two ways, always for a period of at least one month before and an equal period after the implementation of the intervention. The monitored area was also chosen for its compactness, with only two entrances. At both of them, the passing vehicle structure will be monitored both in the incoming and outgoing direction. Based on the evaluation of the data from both inputs, the number of vehicles in the area according to their types will be further evaluated using a balance method. For this measurement, image processing technology will be used, where the desired parameters will be detected by cameras/sensors appropriately placed in both profiles. The second method of verification is a manual survey of the types of parked vehicles at two different times before and after the implementation of the measure. For this measurement, an automated LP and vehicle type recognition method will be used from off-line video recordings. Both types of measurements will make it possible to evaluate whether the number of occurrences of vans and platoons has decreased after the implementation of the measure and to quantify this real change.

Intervention 2 will allow residents to park their vehicles for short-term periods in marked parking spaces near their home. This will allow them to conveniently load/unload their vehicle and then park in a standard space. The purpose of the measurement is to demonstrate the functionality of this intervention, namely that it is used by multiple users over time for the necessary period of time and not for long-term vehicle parking. The measurement will take place after the implementation of the measure and will use image processing technology with recognition of vehicle parking. Both reserved parking spaces and surrounding standard parking spaces will be monitored. Data will be used to evaluate occupancy and turnover rates, as well as the length of parking of individual vehicles. The data will be compared between the marked and standard spaces.

Intervention 3 aims to verify the real use of specific parking spaces reserved for users with physical disabilities. The principle of the proposed measurement is similar to that of the intervention number 2. Using video detection, the use of reserved spaces and surrounding standard spaces will be measured, especially in terms of occupancy, turnover, and length of parking by vehicle type. The data will be used to assess whether the use of the spaces is in line with their purpose.

All of these data measurement methods will be accompanied by short-term sub-surveys to verify the quality and reliability of all detection equipment and technologies used. These data will also be evaluated accordingly. Parameters that would be used for further evaluation are mentioned below, see Table 2.

Tab. 2. Principles and parameterizations of in situ detections and measures.

Intervention	Survey principle	Survey scope	Measured parameters
(1) Prohibited entry for vans and trucks	Detection of vehicle types entering the area. (videodection)	Both accesses to the area for at least 1 month before and after the implementation of the intervention.	-Number and percentage of vehicles of different types in each access over time. -Number of vehicles of different types in the entire area over time.
	Detection of number and types of vehicles parked in the area. (manual survey using LPR from videorecordings)	The entire defined area in two terms before and after the implementation of the intervention.	-Percentage of vehicles parked in the area by type. -Occupancy of parking in the area. -Comparison with the number according to the balance method.
(2) short-term parking	Number of vehicles of different types in the whole area over time.	A group of 2-3 spaces after their implementation in a proper part of the area and another 5-10 standard neighboring parking spaces.	For each parking space: - occupancy over time - turnover - length of time parking - type of vehicles
(3) reserved parking	Detection of number and types of vehicles parked in the area.	One group of 1-2 reserved spaces after their implementation in a proper part of the area and another 5-10 standard neighbouuring parking spaces.	For each parking space: - occupancy over time - turnover over time - length of parking - type of vehicles

As described, advanced image recognition matrices will be used for key measurements. This technology was chosen for several reasons. Based on advanced image processing techniques and the detection of various objects, their trajectories, and other detailed parameters, a wide range of facts can be measured with a single detector, including, for example, vehicle types that may be problematic for other types of detection. Another advantage is that they are compact and can be safely installed for longer surveys with less risk of damage to the equipment. In particular, the negative effect of degraded visual conditions, whether by weather or time of day, can be problematic. However, with regard to public lighting in the study area, this influence is eliminated.

The requirements for the final selection of the appropriate technology and the final determination of the survey locations are as follows:

- possible detection of moving and stationary vehicles and their categories
- possible placement on a lighting pole including energy recharging
- availability of data even under standard night lighting conditions
- real-time provision of measured data
- ensuring privacy (no video recording or sharing is required)
- easy handling, installation and calibration of the device

The figure shows an example of the possible available systems, devices and their operational characteristics, see Figure 4.

Fig. 4. Examples of advanced solutions using image recognition methods [13, 14, 15]

4.2 Data driven impacts at the large scale

To verify the real impact of the implemented interventions, additional measurements are proposed that are not directly focused on the location of the implementation. These are complementary surveys, but they have the ambition to significantly support the final evaluation of the measures.

The first type of measurement proposed will measure traffic flow parameters on the roads that bring traffic into the study area. Video detectors or alternatively other mobile equipment (microwave radar) or short-term manual surveys will be used. The objective is to monitor the correlation between traffic in the vicinity and in the study area. In addition, parking surveys will be carried out in the neighboring area in order to assess any other impacts.

The second type of survey is a targeted survey of users (residents) of the study area. The aim is to use a sufficient sample of respondents to assess their attitudes, experiences, opinions, and satisfaction related to parking issues in the area. This research will be carried out on two dates before and after the implementation of the measures. A summary of these measures is given in Table 3.

Tab. 3. Principles and parameters of large-scale surveys.

Intervention	Survey principle	Survey scope	Measured parameters
(1, 2, 3) All interventions	Traffic flow parameters detection surrounding of the intervention area.	During the time of measurement for intervention 1 (or shorter but at least 24 hours in a row).	- traffic density over time. - vehicle types - correlation with traffic and modal split in the intervention area
	Detection of number and types of vehicles parked in another area. (manual survey using LPR from video recordings)	Comparison area in terms before and after the implementation of the interventions.	- percentage of vehicles parked in the area by type - occupancy of parking - correlation with the results from intervention area
	Collecting users' opinions and experiences with parking in the area. (survey)	Group of 100 respondents before and after the implementation of the measures.	Evaluation of the parking situation in the area. Description of user behaviour with regard to parking. Knowledge of planned/implemented interventions. Rating of interest/experience in implemented interventions.

4.3 Interviews, polls, and public events

The preceding text describes the measurement of traffic data, which allows to assess the measurable effects of the implemented measures on the basis of objective traffic engineering information. Another possible direction of the evaluation is the assessment of the subjective impressions of the people who are affected by the implemented measures. This assessment is not less important, especially because the area selected for the introduction of measures is a populated area of the city, specifically a part of the Liberec-Rochlice district.

When implementing any (not only) traffic measures in cities that have a direct impact on the lives of local residents or other users of public space, it is very important to communicate these measures and changes to citizens and all other interested parties. The effort is to gain an overview of the needs, preferences, and problems of citizens and all parties concerned. Based on this, it is then possible to better plan and target measures so that, in addition to fulfilling the city's strategic goals (e.g. in the area of reducing negative effects on the environment), the needs of the city's residents and visitors are also met. At the same time, it is very appropriate to focus on obtaining a subjective evaluation of the measures already in place, to determine the degree of their acceptance by the affected groups of people, to determine the degree of satisfaction with the dream state, and to determine any perceived shortcomings or even deterioration compared to the original state. Subjective assessment can be obtained in public debates, discussions with affected persons, using questionnaire surveys, either online or in paper form, or, for example, using controlled interviews and oral questionnaire surveys. It is always necessary to ensure the representation of all relevant groups of people, in terms of age representation, economic status, family status, relationship to the locality, and other parameters according to the specific measures being implemented.

All the measures selected for the introduction of the local part of Liberec-Rochlice affect the residents of the selected area, in particular. An important goal of all these interventions is to increase the quality of life of local residents and improve the satisfaction of their parking needs.

The evaluation of the subjective impacts of the selected measures will take place in the form of public discussion meetings, at which the measures will be presented in more detail to the public and especially to local citizens. Furthermore, in order to find the opinions of all relevant groups, a questionnaire survey will be carried out in the form of oral questionnaire surveys of the polling area and also in the form of an online questionnaire. The combination of these several different methods will ensure a wider range of respondents and will make it possible to balance the possible disadvantages and limitations of individual methods.

As for public discussion meetings, a great benefit of this method of obtaining feedback is the possibility of free discussion by the participants, the explanation of the purpose of the introduced measures, and the possibility of a detailed analysis of the perception of the measures and the reasons that lead the participants to their opinions. The disadvantage here is the relatively narrow range of people involved, which will probably be limited to people who are actively interested in the given issue.

Oral questionnaire surveys carried out on the street will allow for quick feedback from a wider range of respondents. Another advantage is that the respondents can have the traffic measures in question directly in front of them when answering the questions. The disadvantage here is primarily the limited time for obtaining answers, as many respondents will only have a limited amount of time to participate in the survey.

An online questionnaire is a widely available option for conducting a questionnaire survey, as it is a form that is very friendly and easy to fill out for a wide range of respondents. Respondents can choose the time they will take the questionnaire and do not have to adjust their daily schedule. They don't need anything other than their mobile phone or computer to participate. Therefore, there is the potential to obtain a high number of responses from a wide range of respondent groups. However, to ensure this, it is necessary to choose a suitable distribution channel for the questionnaire so that some groups of respondents are not excluded by an inappropriate distribution. The risk of respondents being singled out is particularly high among older generations, who generally use less modern technology.

5. Conclusion

The paper summarizes, on a particular example of a city of Liberec, measures how to improve traffic - life balance in the public space in a residential area, where parking problems not only deteriorate traffic situation but also lead to the insufficient use of dedicated public space due to incorrect parking [16]. The interventions were designed according to the sustainable urban mobility plans and discussion with representatives of the municipalities. The paper not only proposes several measures but emphasizes the necessity of proper evaluation of these measures, following the procedures of the ELABORATOR project, that focuses on the transferability of the measures among different European locations to speed up the way to smart and sustainable European cities.

The project will continue with the implementation of the proposed measures and their evaluation in a clear and transparent way that will enable the twinning approach with other cities involved in the project.

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