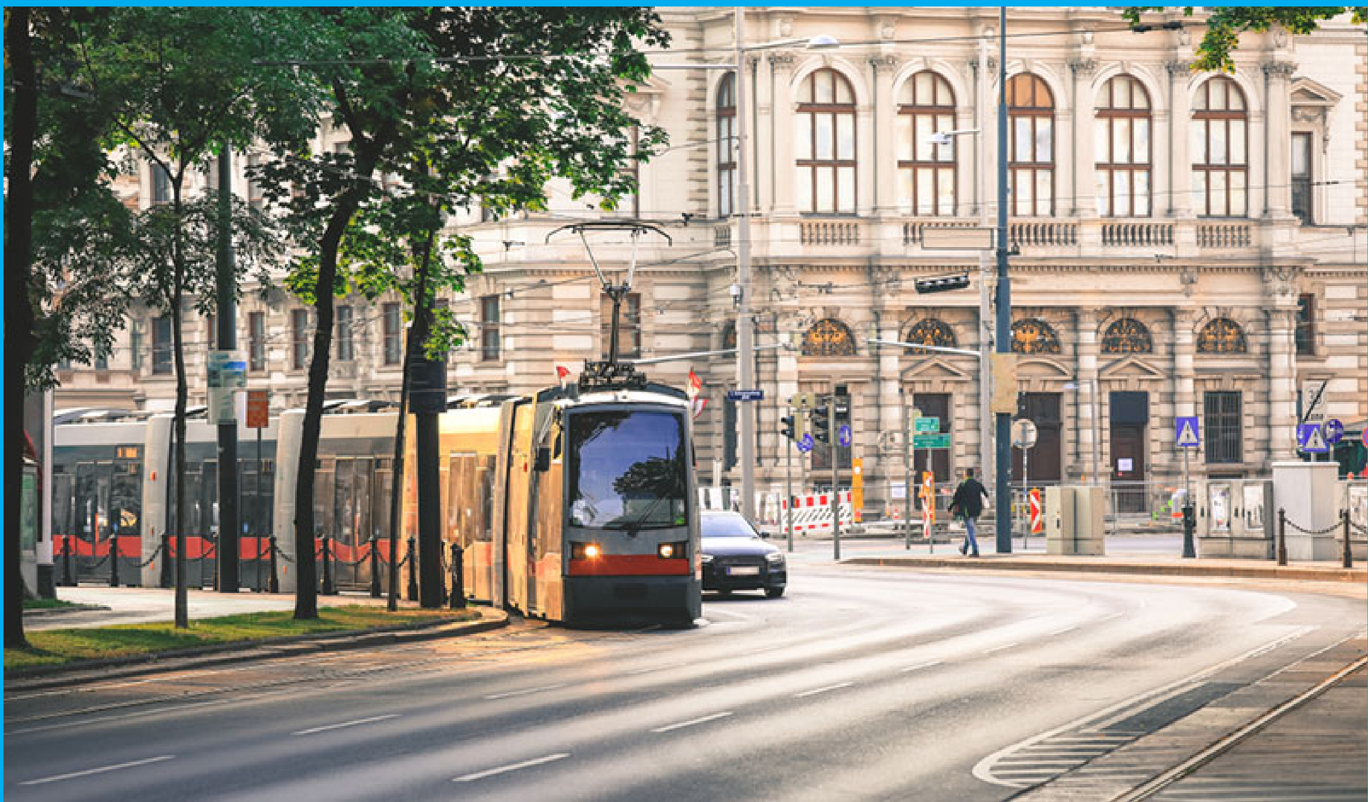
CIE5050-09 Additional Research Project

Urban Livability Research and a Pollution Emission Case Study in Delft



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1. Introduction

At present, many studies have begun to focus on evaluating urban accessibility and livability, which can be a series of great guidance for future urban planning considering residents' personal perceptions of various living aspects. It can be observed from the existing literature that urban accessibility has a mature evaluation system, considering travel distance, trip purpose, travel time, individual's perceived utility, and other constraints. However, the existing studies review urban livability from many very different directions, and no consolidated concept is proposed or concluded. This makes the evaluation of urban livability hardly provide a comprehensive understanding of the concept of urban livability. In this case, this additional research aims to propose a general framework describing the urban livability concept and its connotation. Besides, several indicators shall be selected from this framework to be quantified and calculated so that there could be a specific quantitative method for evaluating urban livability based on this framework.

Section 2 of this report is the literature review regarding urban accessibility and livability evaluation. Section 3 introduces the methodology used in this research to establish the conceptual framework of urban livability, and how indicators for quantitative evaluation are selected and calculated. Section 4 presents the results obtained by applying the methodology demonstrated in Section 3. Section 5 illustrates the analysis process based on the obtained results. Section 6 provides the final conclusions of this research. Section 7 summarizes some shortcomings of the current research and points out in which direction this research should be further improved. And Section 8 is the personal reflections on the process of this additional research of the author.

2. Literature review

The literature review of this research is to get a general picture of urban accessibility and livability's evaluation ideas and methodologies and provides inspiration for establishing the methodology that will be used in this research.

The literature review begins with looking up research on urban accessibility evaluation. Bhat et al. 2000 wrote a literature review on the development process of urban accessibility index, which categorized urban accessibility index into five different types, including graph theory and spatial separation, cumulative opportunities, gravity measure, utility measure, time-space measure. Graph theory and spatial separation represent a series of simplest accessibility measures, in which the only dimension used for the evaluation is distance. The most general network accessibility measure computes the weighted average of the travel times to all other zones under consideration. The cumulative opportunities represent a series of simplest accessibility measures that take account of both distance and the objective of a trip. This kind of measure defines a travel time or distance threshold and uses the number of potential activities within that threshold as the accessibility for that spatial unit. The gravity measure includes an attraction factor as well as a separation factor. It uses a continuous measure that is used to discount opportunities with increasing time or distance from the origin. Therefore, this type of measure follows a reverse order of counting accessibility from the previous two schemes. The utility measure is based on individual's perceived utility for different travel choices, so for each individual, accessibility is the value of the maximum of his/her utilities over a certain set of alternative destinations. The benefits brought by this method are that accessibility will not decrease when alternative destinations increase, and it will also not decrease when the utility of one of the alternative destinations increases. The time-space measure adds another dimension to urban accessibility's evaluation. It considers the time constraints of individuals. Since individuals have only limited time periods during which to conduct activities. Then under this circumstance, the travel time could affect the time span they can use to undertake their activities. If take all such time constraints into account, the constraints can be divided into three categories. The first is capability constraint, which is the limit of human performance (e.g., people need to sleep every day). The second is the coupling constraint, which tells that an individual must be at a specific location at a specific time (e.g., a human must work). The last one is the authority constraint, which is closely related to government policies (e.g., the curfews during the COVID pandemic). Besides, like dynamic traffic assignment (DTA), this type of measure also considers the constraint brought by common resources within one household. For example, if one member in a household will use the only car for his/her travels, the accessibility of other household members will be affected. In addition of the work of Bhat et al., some studies also process their research from a perspective of environmental cost. Vasconcelos and Farias 2012 proposed a method to estimate urban accessibility considering types of transport, travel distances, travel time, and environmental costs. The environmental costs mainly consist of fuel consumption and local pollution emission. The methodology was used to consider six neighborhoods in Lisbon, and for each neighborhood, the best traffic mode, and corresponding destinations were derived concerning accessibility. Ahuja and Tiwari 2021 thought that there could be many missing links in the accessibility indicator development, planning process, implementation, and related policy-making, so they proposed some requirements for improved accessibility-related policies, developing realistic measures based on gaps they identified. Dinand Ekkel and de Vries focused their research on the accessibility of green spaces. The result of this research showed that comparing results across different studies was difficult, so function-oriented approach was needed now, solving the problem such as how people's contact with nature impacts their health, and what type and qualities are relevant in this regard?

As for urban livability, Mouratidis 2020 evaluated it from three perspectives: commute satisfaction, neighborhood satisfaction, and housing satisfaction. Some specific aspects of three types of satisfaction were also proposed. Commuting satisfaction was considered depending on a wide range of factors such as travel mode, trip duration, safety, comfort, and cleanliness, etc. Neighborhood satisfaction consists of two aspects: objective and perceived characteristics. Objective characteristics include the presence of and accessibility to facilities as well as the location of the neighborhood within the city. Perceived characteristics are perceived safety and fear of crime, place attachment, perceptions of accessibility, neighborhood social cohesion, attractiveness, and quietness. Factors associated with housing satisfaction include the construction quality, plan, and design of the dwelling, the dwelling size, the adequacy of interior space, the housing amenities, and the price of the dwelling. His research showed that commute satisfaction was linked to subjective well-being indirectly. Neighborhood satisfaction was found to be related to subjective well-being directly. Housing satisfaction was found to have a significant direct association with subjective well-being. All these findings implied that they were suitable indicators for evaluating urban livability. In this research, the satisfaction level was obtained by designing and spreading questionnaires to ask participants to give scores. This kind of scoring method through spreading questionnaires was also widely used in other urban-livability-related studies. Paul and Sen 2018 assessed urban livability within a metropolis based on the impact of integrated urban geographic factors (IUGFs) in urban centers of Kolkata. Some experts' opinions were asked and taken as the guidance of ascertaining the most important IUGFs among a complete set. On this basis, the livability variations of constituent urban centers were assessed by dividing the Kolkata Metropolitan Area (KMA) into K clusters. Residents' personal opinions were also collected by letting them participate in a questionnaire survey. Cao et al. established an agent-based simulation, assessment, and interpretation for the case of Futian District, Shenzhen. An indicator system was designed for measuring urban livability, which included aspects of safety, health, convenience, comfort, and inclusiveness (about social disadvantage groups, gender equity, and urban innovation capabilities). The final livability score was obtained by adding up by weights of five indicators.

To sum up the literature study, many studies have conducted research on evaluating urban accessibility considering different aspects Existing methodologies have already been able to deal with thoughts on travel time, travel distance, trip purpose, and time constraints. Therefore, urban accessibility can be evaluated depending on what aspects one wants to focus on and select suitable methods for calculations. However, there has not been such a mature evaluation system for urban livability. Very different aspects were considered and they naturally brought different indicators, thus totally different methodologies. A general conceptual framework can help a lot for future studies on urban livability, and make the evaluation more integrated and comprehensive. On the basis of this framework, it is expected to be simpler and more reasonable to select indicators that are suitable for quantitative evaluation and generalize the real level of a city's livability condition.

3. Methodology

The work of this research is divided into three steps: establishing the general conceptual framework of urban livability, selecting and quantifying urban livability indicators, and conducting a case study within the range of Delft city.

3.1 Establish the general conceptual framework of urban livability

To establish this general conceptual framework of urban livability, it is important to clearly understand what aspects people concern most in their life. One effective way to discover these living aspects is to spread questionnaires, as has been done in many studies. However, as mentioned in the literature review of this research, many studies determined several aspects based on researchers' personal ideas, and then asked participants to score their satisfaction levels on these aspects. Participants then had no chance to think about other aspects that were not mentioned in the given questionnaire under this circumstance. In order to let participants freely express their true feelings, this research does not intend to design questions pointing toward any pre-defined living aspects. Since pre-defined living aspects can influence participants' thinking logics and make them miss some critical points in their daily life, which is a situation that is not expected in this survey, so, the only question is "*What living aspects do you think play the most important roles in your daily life?*" And no other questions will be proposed in this survey. By asking this question, it is expected that participants can feedback on their true feelings in their daily life. It is also expected that participants will give feedback from different dimensions or levels (e.g., from a macroscopic or microscopic level). For example, some of them might mention their household income, and others may talk something about the general economic condition of the city. All these answers can help researchers to better understand the concept of urban livability and establish the final framework.

The only requirement for this question is that it must be spread to people of different age groups because people of different ages might have totally different living demands in their daily life, which means that they will pay attention to very separate living aspects. On this basis, four age groups are used in this questionnaire survey: 1) 6-18 years old, 2) 19-30 years old, 3) 31-50 years old, and 4) over 50 years old. Age group 1) mainly includes students who have not entered universities or found a job. For this age group, it is expected that they will mainly have some common feelings on education-related factors. For age group 2), it includes people who tend to have strong demands for getting a satisfying job and preparing for raising the family. Therefore, it is likely for them to feedback something about the high-level education and economic conditions. Age group 3) includes people who have relatively stable living conditions, so they may pay attention to various fields in their lives, concerning different topics, and have different feelings and demands. It is expected to obtain the most abundant feedback from this age group. Most people included by age group 4) are close to their retirement or have already retired. They are more vulnerable physically and economically compared to people of other age groups. They are likely to propose something about the care for elderly, urban facilities/spatial design for vulnerable people, etc.

Based on the feedback obtained from these participants, several living aspects will be extracted and concluded. For each living aspect, it will be followed by some factors, representing some specific fields in this aspect. Finally, some indicators that might can be quantified corresponding to these factors will be proposed for the later selection process.

3.2 Select and quantify urban livability indicators

To select suitable indicators for quantitatively describing urban livability among all possible candidates, two selection principles are set here:

- The selected indicators should be able to cover most people's concerns about their life, which means that the most frequently mentioned aspects in the survey should be considered while selecting indicators.

- The selected indicators should be easy to quantify, and no subjective evaluation is expected, which means that the indicators should can be directly calculated using certain formulas, instead of letting people give discrete scores.

3.3 Case study

With the selected indicators and determined calculation methods, a case study shall be conducted. In the later section, it will be explained that the selected indicators are from economic, transport, and environmental aspects, along with reasons for choosing them. Therefore, in this sub-section, the logic, process, and methodology of this case study based on the selected indicators will be illustrated.

The case study will be based on a simulation program built by Koen de Clercq, which simulates the process that agents traveling between different zones using different modes in Delft city. These agents will be generated during the simulation, along with their origins and destinations, paths, travel distances, final positions in the simulation, travel times, (generalized) travel costs, travel speeds, and traffic modes used. In addition, some statistical data such as the standard deviation/median of travel distance/time of each agent will also be calculated during the simulation. The traffic network of Delft has also been built in the simulation program, consisting of several layers which represent networks of different traffic modes. Therefore, it can be seen that this simulation has already included some indicators from aspects of economics and transport. The economic part is included by calculating the generalized costs of traveling, and the transport part is included by calculating the travel distance, travel time, and travel path. Although these pre-determined calculations in the simulation can be different from the calculation strategies proposed later in this research on economic and transport indicators, in this research, calculations of these two parts will remain the same so that the original output of this simulation will not be affected, so no modifications will be made for them, and the simulation output obtained from the current algorithm will be directly used to derive other indicators in this case study. On this basis, this research will only add environment-related indicators to the existing simulation.

According to the information and data published by Dutch National Institute for Public Health and Environment, there are five types of pollutants in the consideration of traffic pollution emissions: CO_2, NO_2, NO_x, PM_{10}, and $PM_{2.5}$. Along with these five pollutants, the expected unit pollution emissions of different vehicle types, under different road conditions (e.g., congested or not, road types, etc.) are also provided. However, this dataset does not include the impact on the pollution emission of different traffic modes. Besides, the unit pollution emissions of all vehicle types are based on the travel distance (km) also according to the dataset published by Dutch National Institute for Public Health and Environment, so the unit pollution emission is the quantity of pollutants emitted by a certain type of vehicle per kilometer it travels.

In the established simulation, there are in total five traffic modes included: car, carpool, transit, bicycle, and walk, in which car and carpool are considered to emit above-mentioned pollutants and other modes are environmentally-friendly in this case study, so the pollution emissions are only calculated for car and carpool. Since there is no difference made between car and carpool in the unit pollution emission dataset, the same unit pollution emission value will be applied for both modes.

In addition, the diffusion effect of these pollutants will also be taken into account. The pollutants will not stay at the source point where it is emitted, especially for gas pollutants. They are easy to be spread outward from their emission source. Therefore, it is necessary to think about how far the pollutants will spread and how much urban space will be affected by them. A distance-decay function will be implemented for such calculations because it matches well with the spreading condition of pollutants in the air. In this case study, the distance-decay function used is cited from the formula describing the noise diffusion effect proposed by Lin (2010):

$$\Delta P(r) = 10 \cdot \log\left(\frac{1}{4}\pi r^2\right)$$

$$P(r) = P_{source} - \Delta P(r)$$

Where, r is the distance away from the emission source point of pollutants. ΔP is the decay quantity of pollutants at distance r away from the emission source point. $P(r)$ is the real quantity of pollutants at distance r away from the emission source point. P_{source} is the pollution emission at source point. These two formulas are applied for all five pollutants in this case study.

The entire calculation of this case study will be totally based on the data output by the established simulation, including data of traveling agents' ids, modes used, travel distances, OD information, paths, final positions, etc.

The calculation process can be summarized into four steps:

- Step 1: Find agents who use cars and carpools for their traveling, and extract them and corresponding trip data, including source nodes, destinations, next nodes to go, and travel distances from the simulation output to a new dataset for later use.

- Step 2: Determine the unit quantity (per km) for each kind of pollutant emitted by agents using car and carpool. And calculate the emission of each kind of pollutant of each agent.

- Step 3: Use the pre-determined distance-decay function to calculate the diffusion effect of these pollutants. Take discrete distances, and calculate the quantities of pollutants at these distances.

- Step 4: Visualize the calculation results on the map.

4. Results

This section will show the results got by applying the methodologies explained in Section 3, and will still be divided into three sub-sections, corresponding to three steps in Section 3.

4.1 General conceptual framework of urban livability

In total, there were 25 participants for the designed survey. Among them, 4 are from group 1), 10 are from group 2), 7 are from group 3), and the last 4 are from group 4). All 25 participants gave their feedback on the given question. As expected, answers were very different from each other, so it is hard to make a general summary for the feedback because many answers were of totally different dimensions and levels. For example, some participants said that they thought safety, transport, and goods price were very important evaluation standards for urban livability but did not specifically point out which parts of safety and transport were of great concern. And it is obvious that goods price is not at the same dimension as safety and transport. It is one of the factors in the economic aspect. Therefore, the researcher must conclude and categorize these answers to unify factors of different levels.

Besides, there was a great difference between the concerns of elder people (over 50 years old) and people from other age groups. People over 50 years old are close to their retirement or have already retired. The most frequently-mentioned living aspects were social equity and economic condition. Some specifically-mentioned points include the number of nursing homes for elder people, green spaces, government subsidies for elder people, and the pension policy, etc. Some elder people who have trouble walking and running also mentioned that they expected the urban design could be more friendly to them, for example, adding some auxiliary facilities while boarding the bus, train, tram, and other vehicles.

As for people who are to find a job or having a job (mostly are people from 19-50 years old), they care more about the economic condition of the city. For those who are young and preparing for finding a job, they pay more attention to the number of opportunities in the job market. They also concern a lot for the culture, the environment, and surrounding neighborhoods in the city. This may be because that young people’s demand for spiritual aspects is relatively higher than people of other age groups. For middle-aged people who have a job at present, they expect that the current job could be steady if it is satisfying, or to seek another better-paid job in the job market if it is disappointing, so still an intensive demand for a good job market condition. Besides, they also care about the distribution of social resources such as education and medical care, and safety level, including crime rate, traffic safety, food safety, and energy safety because most middle-aged people have children to raise and the elderly to support. They always have to support the entire family to live, so it is natural for them to care so many different aspects in their life.

Among all the living aspects mentioned by participants, transport is a topic that is commonly paid attention to. No matter what age group people belong to, they all look forward to higher connectivity between different areas in the city, a better public transport system, and lower generalized costs for traveling.

Based on the above analyses on participants' feedback on the given question, the general conceptual framework is built and shown in the figure below:

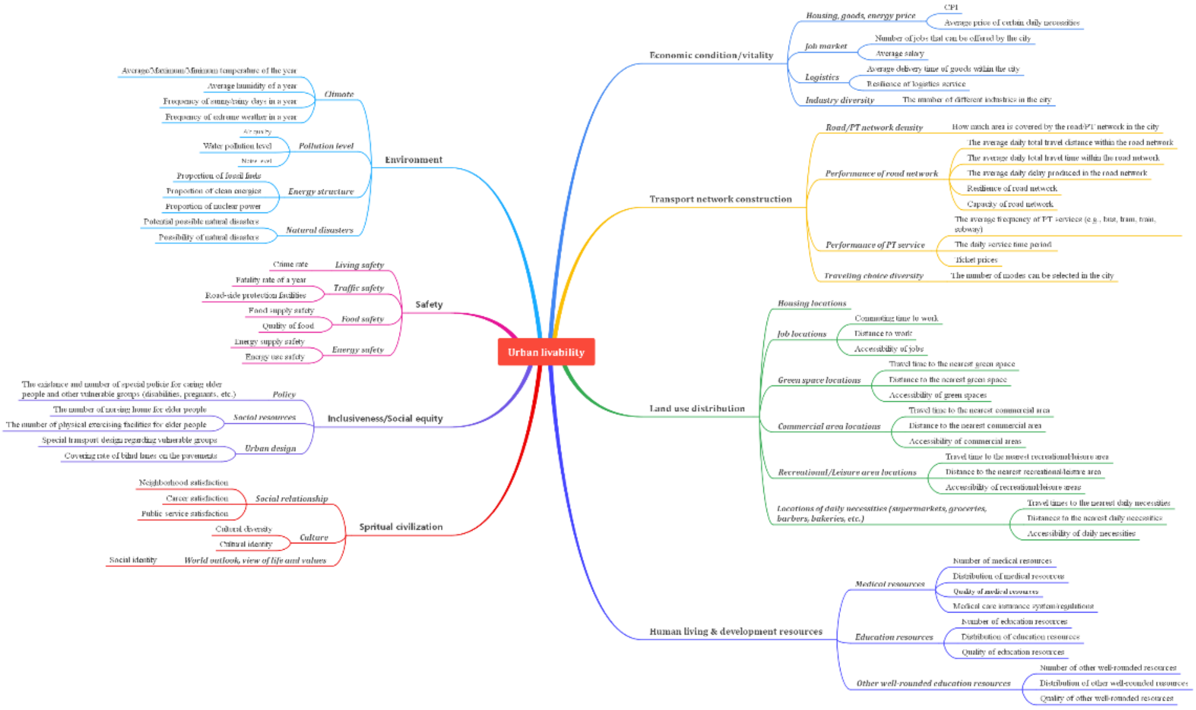


Fig 1. The general conceptual framework of urban livability

Finally, eight aspects are proposed in the conceptual framework, including economic condition, transport network construction, land use distribution, human living & development resources, environment, safety, inclusiveness/social equity, and spiritual civilization. For each of the eight living aspects, several factors are also listed. For example, the economic condition contains factors such as housing, goods, energy price, job market condition, logistics condition, and industry diversity. Regarding the selection and quantification of the indicators in the later step, some specific indexes are listed as well, for example, the housing, goods, and energy price can be evaluated using CPI and the average price of some certain daily necessities.

For the transport network construction, road and PT network density, performance of road/PT network/service, and traveling choice diversity are of consideration. Land use distribution contains factors of housing locations, job locations, green space locations, commercial area locations, recreational locations, and locations of other daily necessities including supermarkets, groceries, barbers, bakeries, etc. Human living & development resources mainly consider medical care, education (in schools), and other well-rounded education resources. As for the environment, climate condition, pollution level, energy structure of the city, and natural disasters are four critical elements. Safety issues cover the safety of living (crime rate), traffic safety, food safety, and energy safety. The social equity can be divided into three perspectives: government policy, social resources, and urban design. The spiritual civilization describes the spiritual demands of residents, which considers the social relationship, culture, and world outlook, view of life and values.

It can be observed that these aspects are not completely independent from each other. Some elements of one aspect could also be a part of another aspect. For example, the medical insurance is mentioned in the aspect of human living & development resources, but it could also be a factor in city's economic condition.

4.2 Indicator selection and quantification

According to the selection principles set in section 3.2, indicators from three aspects: economic, transport, and environment are finally selected because almost all participants mentioned something about these aspects. Then in sub-section 4.2.1, 4.2.2, 4.2.3, specific indicators and corresponding quantitative calculation strategies are explained. Sub-section 4.2.4 proposes a general evaluation method for the urban livability, describing city's livability level from a integrated view.

4.2.1 Economic indicators

Jahyeong Koo et al. (1997) proposed an ***expenditure function*** is used to express the economic condition of a city:

$$e(p^r, u) = \min_{q_r} \sum_{i=1}^{N} p_i^r q_i^r : U(q^r) \geq u$$

Where $p_i^r\,(q_i^r)$ denotes the price (quantity) of the i-th good or service consumed at region r. The expenditure function gives the minimum cost to the representative individual of attaining some specified level of utility, u, when faced with a set of prices for the goods and services that enter that individual's utility function. And a ***true cost-of-living index*** is used to compare the goods price in the target city and the base city:

$$\frac{e(p^c, u^*)}{e(p^b, u^*)}$$

Where p^c and p^b denote the prices faced by the individual in the comparison and base regions respectively. The true cost-of-living index is the comparison of the cost of purchasing the goods and services which provide the same utility in both a comparison area and a base area.

Household income is also an important indicator:

$$HI = I_a \cdot HS$$

Where HI is the household income, I_a is the average individual income in the city, and HS is the household size (the number of family members who work).

4.2.2 Transport indicators

The ***average daily total travel distance (in a month)*** is the first indicator selected for transport system of a city:

$$td_{ai} = \frac{\sum_d \sum_i td_{di}}{\sum_d q_d}$$

Where td_{ai} is the average daily total travel distance of individual i in a month. td_{di} is the travel distance of individual i on day d. q_d is the total flow on day d.

Then is the ***average daily total travel time (in a month)***:

$$tt_{ai} = \frac{\sum_d \sum_i tt_{di}}{\sum_d q_d}$$

Where tt_{ai} is the average daily total travel time of individual i in a month. tt_{di} is the travel time of individual i on day d. q_d is the total flow on day d.

The ***average total delay (in a month)*** can tell the congestion level of the traffic network:

$$d_{ai} = tt_{ai} - tt_{ar}$$

Where d_{ai} is the average daily delay of individual i in the road network, tt_{ar} is the reference total travel time.

In addition of transport network indicators, other indicators showing the accessibilities of different land uses should also be included. The ***job accessibility*** could be calculated using the algorithm created by McKenzie (1984):

$$A_{abs} = \int_0^T E(T)\, dt$$

$$A_{(p)} = {A_{abs}}\Big/{\sum_j E_j}$$

Where A_{abs} is the absolute accessibility index for zone i. E is the number of relevant employment opportunities that can be reached. t is the travel time by mode of interest. T is the critical travel time threshold. $A_{(p)}$ is the relative accessibility index for zone i. E_j is the number of relevant employment opportunities in the region j.

Then comes the ***accessibility of green spaces, commercial areas, and recreational areas***:

$$A_i = \frac{E_j^{g,c,r}}{\exp{(bt_{ij})}}$$

Where $E_j^{g,c,r}$ is the number of green spaces, commercial areas, and recreational/leisure areas in zone i. t_{ij} is the average intrazonal travel time. b is the distance-decay parameter. i is the original household. j is the destination area.

<u>*4.2.3 Environment indicators*</u>

The existing literature shows few indicators that directly express how good/bad the environment of the city is. The most popular way to measure the environment condition is to detect the concentration of harmful gas such as PM particles, SO_x, NO_x, CO, etc., in the air, and compare them to the limits set by the national government or international organizations.

<u>*4.2.4 General evaluation*</u>

The utility function can be used to express the general urban livability regarding above three aspects as the attributes of the city.

$$v_i = \beta_0 + \beta_{1i}x_{1i} + \beta_{2i}x_{2i} + \beta_{3i}x_{3i} + \varepsilon$$

Where v_i is the utility for a household choosing city i to live. x_{1i}, x_{2i}, and x_{3i} represent the economic, traveling and environment condition of city i. β_{1i}, β_{2i}, and β_{3i} are the coefficients of three city attributes. β_0 is a constant, representing the utility for other characteristics of the city which are not included in the three attributes. ε is the error term.

4.3 Case study

As introduced in section 3.3, pollution emissions of agents using cars and carpools are calculated. The unit emission of each type of pollutant is listed in the table below:

Table 1. Unit emission of each type of pollutant per km

Pollutant	*Unit emission per km*
CO	3.799
NO_2	0.065
NO_x	0.264
PM_{10}	0.031
$PM_{2.5}$	0.009

Then to find out the diffusion effects of these pollutants, three distance ranges from the source point of emission are determined to be 0.1 km, 0.2 km, and 0.3 km, respectively.

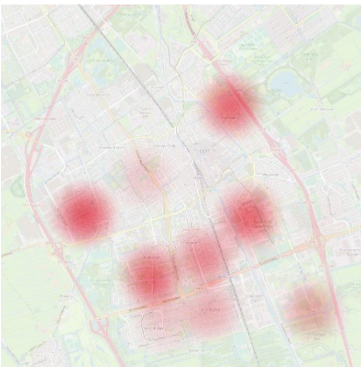
Part of the calculation results are shown in the table below as examples:

Table 2. Calculation results of pollution emissions (part)

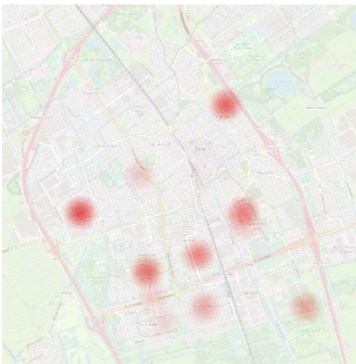
Agent ID	*Pos x*	*Pos y*	*CO*	*CO r1*	*CO r2*	*CO r3*
515	83911.83	450269.3	9.00363	8.99578	8.97221	8.93294
4	85765.03	446286.4	8.92765	8.91980	8.89623	8.85696
518	84266.36	445797.3	10.6372	10.6294	10.6058	10.5665
10	84412.02	447745.7	7.56001	7.55216	7.52859	7.48932
527	83931.38	445680.4	9.00363	8.99578	8.97221	8.93294

Pos x and *Pos y* are the coordinate data of the agent. *CO* is the pollution emission at its source point. *CO r1*, *r2*, and *r3* are the pollutant diffused to distance *r1*, *r2*, and *r3* away from the source point. It can be observed that agent 515 and 527 have exactly the same pollution emissions since they have the same travel distance. Some calculation results that are not shown here in this table exhibit negative values at distance *r2* or *r3*, which means that their corresponding pollutants would not spread so far away.

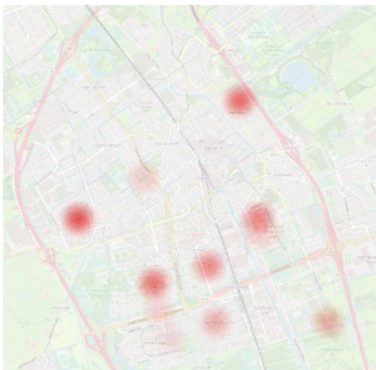
Based on the coordinate data of agents, the calculation results are visualized on the map of Delft with a form of heat maps, which are shown in figures below. Each type of pollutant has a corresponding heat map.



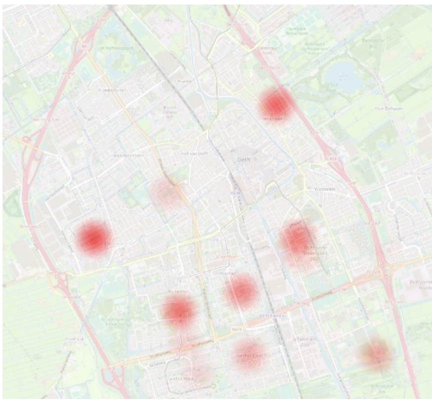
CO

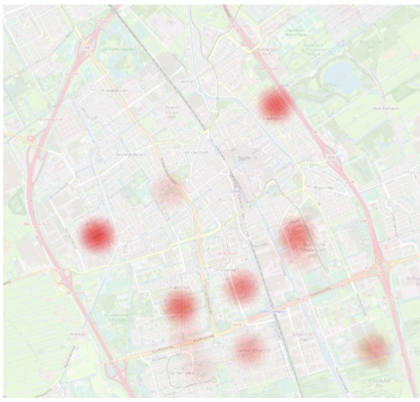


NO_2



NO_x





PM_{10} *$PM_{2.5}$*

Fig 2. Pollution emissions visualization

It can be directly observed from the above heat maps that CO emission is much more serious than other pollutants. Since the unit emissions of NO2, NOx, PM10, and PM2.5 per km are very close, it is hard to find obvious differences between their heat maps.

5. Discussions

For the results that have been exhibited in Section 4, there are some supplementary discussions that have to be made in this section.

The conceptual framework of urban livability established in this research has covered a wide range of aspects that are frequently concerned by people of different age groups. This could provide a solid basis for later research on urban livability. And it is more possible for researchers to have a comprehensive picture while considering livability problems. Some links between different living aspects that can be missed before are easier to be taken into account with such a clear framework. However, this framework does not show those overlaps between different aspects or factors. Like mentioned in Section 4.1, some indicators of factors can also belong to different aspects. Besides, this framework is established based on 25 survey participants' feedback. Although they cover a wide range of age groups, the sample size is still small. Therefore, there can still be something missed by this framework, for example, the survey question was not sent to vulnerable groups other than elderly, so opinions from such as disabled people, pregnancies, parents of small babies are not collected and analyzed. And people from different countries can also provide different feedbacks since the culture and social environment are very different.

As for the indicator selection and quantification, clear selection principles and concrete calculation strategies have been determined, which make the evaluation standard of urban livability clearer and more reasonable compared to previous research and able to eliminate some subjective factors (e.g., scoring satisfaction levels), thus avoiding imprecise results. Meanwhile, on the other hand, these selection principles and calculation strategies also abandon aspects that are hard to be quantified such as safety (food, energy safety in particular), and human living & development resources distribution. Even if these aspects are not as popularly thought of as selected living aspects, they still play certain roles in urban livability evaluation, and should not be entirely ignored.

The case study is based on an existing simulation program, and at the end of it, all types of pollution emissions are successfully calculated, and the obtained results are further visualized on the map using QGIS. In addition, the diffusion effect of pollutants is also computed in the study, which gives a picture of how pollutants will spread and affect the air quality in different zones of the city. However, there are also shortcomings in the current algorithm. The calculation assumes that each agent emits pollution at its final position during the simulation, but the reality is that it keeps emitting pollution along its path, so this process has not been calculated yet. Besides, there is no difference between the unit emission value of mode car and mode carpool, and the emission quantity under congested situation has not been considered.

6. Conclusions

This research mainly contributes to the establishment of a general conceptual framework of urban livability, which covers a wide range of living aspects concerned by people of different ages, reflecting what they expect and demand for in their daily life. Specific indicators from living aspects of economic, transport, and environment are selected from the established framework for building up a clear quantitative evaluation standard for urban livability, and concrete calculation strategies are determined. A case study is conducted based on an existing simulation set up by Koen de Clercq to explore the quantity of pollutants emitted during people's traveling, as well as the diffusion effects of these pollutants. The results of the case study show that CO has the biggest impact on city's environment condition since its corresponding unit emission quantity is the biggest among five types of pollutants, and it is expected to have the farthest spread distance.

7. Recommendations for future research

In Section 5, shortcomings in each step of the research have been discussed. In this section, recommendations for future research on this topic will be given on the basis of those shortcomings detected.

The first recommendation is to enlarge the sample size of the survey, letting more people join the discussion. In particular, the survey should not only include people from different ages, but also should care about people of different occupancies and nationalities. This is helpful for enriching the contents of the conceptual framework.

The second is to further develop the indicator selection and quantification strategies. More living aspects should be covered in the evaluation standard. A mature evaluation system should weigh every relevant aspect and give a comment on the general livability level of the city, and at the same time, could also be able to express the level of each aspect.

The third is to further enhance the calculation algorithm used in the case study. The pollution calculation should consider the real traffic condition (congested or not). The unit pollution emission should be distinguished by different modes, instead of using the same value for both modes. This could help discover how much could carpool mode improve the traffic pollution emission situation. Besides, it is better to explore the pollution emission along each agent's travel path, instead of assuming all the pollutions are emitted at agents' final destinations and this is not realistic.

The last thing is about the distance-decay function used in this research for calculating the pollutant diffusion effects. The current distance-decay function used in the experiment is inspired by the noise diffusion formula. It could be replaced by some advanced models which are specifically for calculating the diffusion effects of pollutants, and they also include underlying data. One example is Urban Strategy Models, and it could be applied for the calculations in relevant research in the future.

The last small point is to let the coordinate data of each agent better fit the real longitude and latitude data. This is to better do the visualization, avoiding showing points at wrong places.

8. Personal reflections

This section will summarize some lessons the author learned during this research. These lessons will be in the order of work steps of the research.

The first part of reflections is about preparing for potential risks. The author realized that the actual process of the research (e.g., methodologies finally applied, workload of each step, etc.) could be very different from expectations at the beginning, so potential risks and corresponding mitigation methods should be pre-determined so that much time can be saved in case of unpredictable difficulties, which also guarantee that the problem met will be solved in a reasonable logic.

The second part of reflections is about improving the efficiency of literature study. It is important to make the goal of literature study clear, for example, what is the current research trend/progress of a certain field? Or what methodologies have been proposed to solve a certain kind of problems? A clear goal helps find proper literature for reading so that there will not be much time spent on papers which only offer limited help and inspirations.

The third part is about being more flexible on applying research methodologies. For each step in the research, there can be a varies of ways to reach the goal. It is better to think about different alternative methods and start with the most direct/simplest one, instead of keeping wondering around one single method. It is inefficient that researcher only thinks about one method first and turn to another when the method cannot lead to a satisfying result.

The last part is to double-check the results of all steps in the research. Sometimes there can be mistakes that are hard to be realized and found in the applied method. For example, the author made mistakes in data processing step, but only when the obtained data was used in the next step, did author realize that there were problems with data. Therefore, one should always remember to re-think about the process of each step in the method and make sure that later work will not be affected.

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