# Fuzzy Logic Framework for Local Accessibility Assessment based on Built Environment Characteristics

Fatima Hanani[1], Aziz Soulhi[2]
[1]Laboratory LASTIMI, CEDOC EMI, Mohamed V University, Rabat, Morocco
[2]National Higher School of Mines, Rabat, Morocco

Keywords: Built environment, Fuzzy Logic, Land use, Local Accessibility.

Abstract: Researchers and decision-makers are increasingly interested in assessing the impacts of urban design and transportation planning on local accessibility. The used accessibility measures present several issues and limitations, namely: lack of understanding of accessibility concepts and technical and computational complexity. In this paper, we present a new method to measure local accessibility. In this method, we use the fuzzy logic approach. Our proposed method will measure local accessibility according to the three urban characteristics, i.e., activity density, land use mix, and street design. This work has confirmed that accessibility is an issue of urban design. In particular, it has shown that the combination of two urban characteristics, namely activity density, and land use mix, is very determinant for accessibility. This work can serve as a helpful tool for policymakers to understand and capture the interactions between accessibility, land use, and travel behaviour.

## 1 INTRODUCTION

The global urban transition that has been underway for several decades is phenomenal. It has put cities and governments in front of unprecedented challenges to provide urban infrastructure and services, such as education, energy, transport and water. In addition, climate change, environmental constraints and resource scarcity have added more stresses to cities.

Transportation is one of the most essential services as it connects the different city areas and allows people to access opportunities. According to (The Global Mobility Report, 2017), the proposed principles for sustainable transport have four goals, efficiency, green mobility, safety, and universal access. These objectives are also associated with land-use planning, and their successful implementation depends on the integration of transport and urban planning. In this perspective, the concept of accessibility is supposed to provide a basic framework for this integration (Saghapour et al., 2018). In (Zhang et al., 2015), accessibility is defined by the spatial distribution of potential destinations, the ease of reaching each one, and the extent, quality, and character of the activities found there. Recently, accessibility has gained ground in city institutions that can use it most effectively as a planning tool (Páez et al. 2012) and also as a tool to evaluate (Saghapour et al., 2018) the effectiveness of policies for land-use and transport planning.

To transform the concept of accessibility into a measure used by decision-makers, an extensive literature on accessibility measures exists. According to (Miller, 2020), there are three categories of accessibility measures: cumulative opportunities measures, gravity-based measures, and utility-based measures. These methods have several limitations. Furthermore, despite the extensive literature on the impact of the built environment on travel behavior, there was relatively little evidence on the relationship between accessibility and the built environment. Therefore, we believe that writing accessibility in terms of the characteristics of the built environment shows the importance of integrating land use and transport.

For this purpose, we will propose, in this work, a new method based on fuzzy logic that allows to assess the local accessibility (at street level) according to the surrounding urban characteristics. As described in (Ewing et al., 2010), the built environment has five attributes, namely: density, diversity, design, destination accessibility, and distance to transportation. In this paper, we chose to study the



Hanani, F. and Soulhi, A.
Fuzzy Logic Framework for Local Accessibility Assessment based on Built Environment Characteristics.
DOI: 10.5220/0010730800003101
In *Proceedings of the 2nd International Conference on Big Data, Modelling and Machine Learning (BML 2021)*, pages 187-195
ISBN: 978-989-758-559-3
Copyright © 2022 by SCITEPRESS – Science and Technology Publications, Lda. All rights reserved

following characteristics: density, diversity, and design. This paper will answer the following questions: Can sustainable accessibility (active transport) be achieved through urban design? To what extent can this opportunity serve city managers to fulfill sustainable transport requirements?

This paper will be organized as follows. First of all, we introduce the concept of accessibility and the different methods used to measure it. After discussing the limitations of existing accessibility measurement methods, we will present our new measurement method based on the fuzzy logic approach. Then, we give a brief review of the literature (related works) covering the impact of the built environment on accessibility and travel behaviour. Besides, we discuss the result of our method. Finally, we conclude our paper by citing some perspectives for this work.

# 2 ACCESSIBILITY MEASURES

Accessibility has been the subject of much work among researchers and actors (planners, decision-makers, transportation, development). Despite several years of active discussions, this concern is still more present in the debate on spatial planning and transport planning issues.

## 2.1 Local Accessibility Definition

Accessibility is a significant feature of urban areas and often represents transport and land-use objectives. Several scientific fields such as transport planning, urban planning, and geography use this concept, which plays an essential role in policymaking (Karst et al., 2004). It can be a practical tool for planning and evaluating transport and land use planning (Saghapour et al., 2018).

There are several definitions of accessibility. We quote some of them in the following. Firstly, in (Páez et al. 2012), the author defines accessibility as the possibility to reach opportunities (desired services and activities) distributed in space and time. Secondly, in (Zhang et al., 2015), the author describes accessibility by the spatial distribution of potential destinations, the ease of access (cost and time savings, variety of transportation modes) to each destination, and the extent (quality, diversity, and character) of activities. Finally, according to (Karst et al., 2004), accessibility is the extent to which land use and transport systems enable (groups of) individuals to reach activities or destinations using (a combination of) transport mode(s).

In the light of the last definition, we can define local accessibility as the extent to which land-use planning allows (groups of) individuals to reach activities or destinations utilizing active modes of transport (walking and cycling). In this case, accessibility can measure the impact of land use on the city's sustainability and individuals by offering them the possibility to access activities by walking or cycling.

## 2.2 Existing Accessibility Measures

Accessibility measures generally consist of two essential elements (Páez et al. 2012): the traveller' cost (determined by the spatial distribution of travellers and opportunities) and the quality/quantity of opportunities. According to the accessibility literature, there are three methods, which identify three broad categories of indicators.

*Cumulative opportunities*: this measure counts the number of opportunities reached within a given access threshold (isochrone). This type of measure focuses on the number of potential destinations or opportunities rather than their distance and indicates the choices available to residents (Karst et al., 2004).

*Gravity-based measures*: this measure relies on the evidence that destinations become progressively less attractive and less accessible as the cost (travel time, effort, cost) increases. This phenomenon can be considered by weighting each destination according to a decay factor (gravity function) representing its distance from the origin (McCahill et al., 2015).

*Utility-based measures*: this method refers to the random utility theory. According to this, the probability that an individual will make a particular choice (e.g., destination, mode of transport) depends on the utility of that choice relative to the utility of all others (Zondag et al., 2015). This measure corresponds to the log-sum of discrete choice models applied to destination choice analysis (Páez et al. 2012).

## 2.3 Built-environment-based Measure

According to (Miller, 2020), the accessibility measurement methods mentioned above present several issues and limitations, namely: lack of understanding of accessibility concepts (among politicians, the public and non-modellers), technical complexity, computational complexity, and lack of standardized software availability and data. Imprecision is another limitation of the different methods of measuring accessibility. Thus, in the case of arbitrary selection of the isochron, the imprecision concerns the absence of differentiation between the possibilities adjacent to the origin and those just inside or outside the isochron. For the other methods, as mentioned in (Handy et al. 1997), the parameters of the impedance function have to be selected or estimated. However, these parameters, which reflect the relative importance of travel impedance in the choice of destination, are based on aggregate travel patterns rather than individual travel decisions. Indeed, the individual in their evaluation of accessibility uses quantitative and qualitative information, making the underlying travel cost (impedance) different from one individual to another (Páez et al. 2012). In addition, as stated in (Zondag et al., 2015), accessibility is seen as the main effect of the transport system. Therefore, all methods presented above calculate accessibility as a function of transport system parameters (cost, travel time, distance).

This work aims to highlight the fact that accessibility is also an outcome of urban design. Therefore, we present a new method, based on fuzzy logic, to assess the accessibility according to the urban characteristics of the area. We call it built-environment-based accessibly measure. The use of fuzzy logic seems relevant to us, given the limitations mentioned above. Indeed, it is difficult to set up a measure of accessibility with precise variables and intervals. Furthermore, city managers need to read, understand, and modify the rules of the accessibility calculation model easily. Moreover, with fuzzy logic, the accessibility measure is easy to understand and interpret thanks to linguistic variables and human reasoning.

# 3 BUILT-ENVIRONMENT AND ACCESSIBILITY: RELATED WORK

The substantial increase of the urban population, urban sprawl and the distance from activities have created a great need for travel that cannot be satisfied by existing infrastructures and even by the construction of others. This situation has led to the high use of the private car. Consequently, cities face recurrent congestion, pollution, social inequality, road accidents, and increasing consumption of gasoline (Toward Sustainable Mobility, 2019) (The Global Mobility Report, 2017). As a result, contemporary transportation focuses on changing travel behaviour to reduce car travel and encourage alternative modes, such as public transport, walking, and cycling (Saghapour et al., 2018). In recent decades, many studies have investigated and analysed the interactions between urban form and traveller behaviour. These studies have shown that travel behaviour is impacted by socio-economic characteristics (of the household) and built-environment characteristics (of the surrounding area). The latter is represented by the so-called 5D (density, diversity, design, destination accessibility and distance to transport) variables (Ewing et al., 2010). In fact, the built environment impacts travel behaviour through the degree of ease, the possibilities offered to reach destinations, and the quality of opportunities made available and accessible. Therefore, accessibility, as defined above, is at the heart of any change in travel behaviour.

Depending on the context, different studies on the relationships between land use (5D variables) and travel behaviour have focused on different transport and travel parameters (trip frequency, distance travelled, travel mode choices or total vehicle kilometres travelled). However, we chose to limit our research to these three characteristics (density, diversity, design) considered by the scientific literature to be the key factors that most influence active transportation modes (at the local level) (Oakes et al., 2007).

## 3.1 The Density of Activities

Density refers to the number of people, housing units, jobs or floor area per unit area (Ewing et al., 2016). A high density (residential, employment, other activities, service, and leisure facilities) in a city will reduce travel distances between residences, workplaces and service facilities (Choi et al., 2020) (Saghapour et al., 2016) on the one hand. On the other hand, the complementary grouping of different activities will help to better link different travel objectives (Xia et al., 2020). Consequently, it will limit energy consumption and vehicle emissions (Yang et al., 2017) by creating walkable environments and promoting public transport (Naess, 2012). As a result, residents of dense cities, with a higher proportion of destinations within good walking or cycling distance, can be expected to make shorter daily trips on average than their counterparts in less dense cities (Stevens, 2017). Therefore, this can generate independence aims at the use of the private car (Newman et al., 2006).

However, as discussed in (Deepty et al., 2019), population or job density or even the aggregate provide only a partial understanding and do not fully capture the impact of the density of the set of available activities on travel behaviour. Therefore, it would be wise to consider using a more comprehensive variable to provide information on the density of all activities in the area.

### 3.2 The Land Use Mix

Land use mix refers to the degree of concentration of workplaces, shops, public administrations, cultural events and recreational facilities (Song et al 2013). As summarised by (Manaugh et al., 2013), since with a single use of space, occupants will be obliged to use motorized modes to get to their destinations, mixed-use with complementarity will do the opposite. It will allow the residents to walk or cycle to their destination. According to several studies, the land-use mix has several benefits to transportation, health, economics and the environment (Manaugh et al., 2013) (Hirt, 2016).

There are several methods for measuring land-use mix (Song et al 2013). They all implicitly or explicitly contain two concepts: distance and quantity. The author in (Song et al 2013) surveyed the different methods and classified them into two categories: 'Integral' and 'Divisional'. The first category of measures, generally applied to small areas, tends to reflect the balance of land use. However, the second category, often applied to large geographic areas, tends to reflect uniformity of land use.

### 3.3 Street Design and Network Connectivity

As argued in (Brown et al., 2007), local urban design principles, such as street configuration, availability of sidewalks and bike lanes, and neighbourhood aesthetic qualities, can influence the attractiveness of non-motorised travel modes. In addition, the author of (Ozbil et al., 2011) found that street network layout is the leading independent variable affecting pedestrian flow on streets. Furthermore, he argued that shorter distances between intersections, smaller block sizes and more direct paths encourage walking and cycling. Indeed, according to (Ozbil et al., 2011), the configuration of streets (connectivity) is considered vital because it affects both the directness of travel (making travel more or less efficient) and the number of alternative routes, which has implications for interest and safety. In other words, better network connectivity can reduce travel distances for all modes, including walking and cycling, and it can provide more choices of routes. It should be mentioned that there is essential literature dealing with the measurement of connectivity. In (Dill et al., 2004), the author evaluated several methods of measuring connectivity (Block length, Block size, Block density, Intersection density, Street density, Connected Intersection Ratio, Percent four-way intersections and Link-Node Ratio). In (Frank et al., 2005), the author used the intersection density as a measure of connectivity in his study at Atlanta. He considered that areas with more than 30 intersections per square kilometre are more walkable than other areas. The author in (Litman, 2021) used Link-Node Ratio as a connectivity indicator suggests that a link-node ratio of 1.4 may be a good target for network planning. Others found that values between 1.2 and 1.4 are good targets (Dill et al., 2004).

We have noted that the most used measures in the literature are intersection density, street density, connected node ratio and per cent four-way intersection. In addition, the author in (Dill et al., 2004) found a strong correlation between the first three measures and suggested that Pedestrian Route Directness (PRD) is the best measure to evaluate the potential to encourage walking and cycling.

## 4 METHODOLOGY OF LOCAL-ACCESSIBILITY MEASUREMENT

### 4.1 Presentation of Fuzzy Logic

Fuzzy logic proposes a mathematical environment built on the theory of fuzzy sets introduced in 1965 by Professor Lotfi A. Zadeh (University of California, Berkeley). This approach attempts to simulate human reasoning and allows the integration of imperfect data in a decision process. As explained in (Hanani et al., 2021), and described in figure 1, the basic characteristics of fuzzy logic are the linguistic variables, the universe of discourse, the function of membership, and the fuzzy subset.

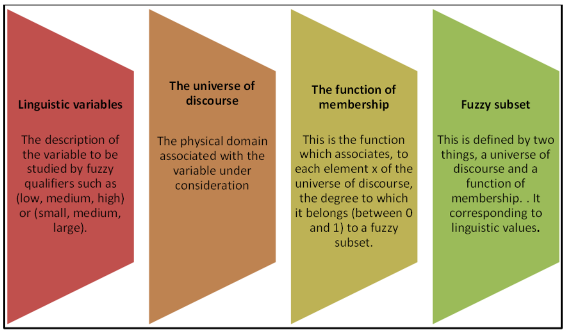


Figure 1: Fuzzy logic characteristics (Hanani et al., 2021)

Moreover, as presented in figure 2, the operating principle of a fuzzy logic system includes three phases. Namely: fuzzification, fuzzy inference engine, and defuzzification.

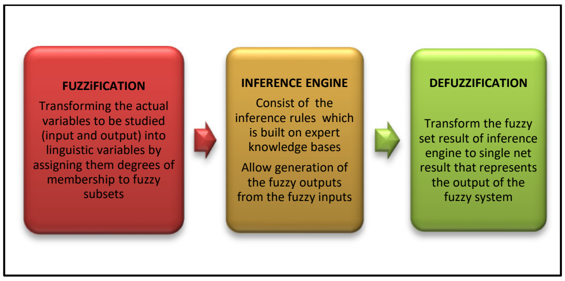


Figure 2: fuzzy logic phases (Hanani et al., 2021)

## 4.2 Accessibility Assessment by Fuzzy Logic

We suggest a new method for measuring local accessibility that allows a significant level of spatial disaggregation since we are interested in measuring accessibility at the street level. Indeed, we will describe local accessibility (output) as a function of the three urban characteristics described above (inputs), i. e., activity density, land-use mix and street design. For this purpose, we follow the steps illustrated in figure 3.

**a) Fuzzification:** we start by defining fuzzy subsets and membership functions for each variable of our fuzzy system (Input and Output). Then we translate the different variables into fuzzy language.

**b) Fuzzy inference**: this is where we apply human reasoning. This phase consists of two steps. The first step is to build decision rules and find the membership rule of the conclusion for each of them. The second step consists of the aggregation of the conclusions. For this phase, we use the Mamdani inference mechanism.

**c) Defuzzification**: this final phase extracts a real value from the fuzzy subset resulting from the previous step. We chose to use the centre of gravity method because it considers the entire final membership function when calculating the final result.

### 4.2.1 Definition of Linguistic Variables

To model our system to evaluate local accessibility, we have defined the four variables. For each variable, we determine the fuzzy subset and the membership functions.

**a) Activity density index**

As we pointed out above, it would be more relevant to think about using a more exhaustive variable to evaluate the influence of activity density on local accessibility. In this regard, we have chosen to assess the density exhaustively, considering all the existing activities in the studied area (residential, jobs, other activities, services, leisure facilities). Theoretically, we cannot define the optimal distribution of each type of activity that would lead to the ideal density (of activities) in an area. Therefore, we will introduce a reference area where the activity density is optimal. Inspired by (Song et al 2013), and to have a normalized variable, we have introduced a new measure that will inform us about the degree of dispersion of our study area compared to the reference area. We call it the activity density index (ADI). We assume that R is the reference area and k is the number of activity types present in this area. For each activity type i (from 1 to k), the density percentage of each activity type i is $r_i$ with $\sum r_i = 1$.

For a zone X with density percentages of each type of activity $x_i$ ($\sum x_i = 1$), we determine ADI by measuring the dispersion of the density of X to R (the average deviation from the reference). The ADI tells us how much the activity density of area X deviates from our reference area. We can calculate the activity density index (ADI) of area X as follows:

$$ADI_X^R = 1 - \sum_{i=1}^{k} r_i |x_i - r_i| \qquad (1)$$

In case of a wide deviation from the reference, the value $|x_i - r_i|$ is close to 1. Therefore, the activity density index is close to 0. Assuming a density close to the reference, the value $|x_i - r_i|$ is close to 0. Therefore, the activity density index is close to 1. For this variable, we choose the following subset:

- ✓ High activity density: when $ADI$ is high than 0,8
- ✓ Medium activity density: when the $ADI$ is amount 0,6
- ✓ Low activity density: when the $ADI$ is less than 0,4

**b) Land Use Mix**

Based on (Song et al 2013), we choose to use the entropy index, which is the most used measure to evaluate the land use mix. Its formula is as follows:

$$LUM = -\left[\sum_{j=1}^{K} P_j \ln(P_j)\right] \Big/ \ln(k) \qquad (2)$$

Where $P_j$ the percentage of each land-use type j in the area, and $k$ is the number of land-use types (categories of interest). The Entropy Index varies from 0 (least mixed area) to 1 (most mixed area)

(Litman, 2021). According to (Litman, 2020), we choose the following subset:

- ✓ High Land use mix: when $LUM$ is high than 0,7
- ✓ Medium Land use mix: when the $LUM$ is between 0,5 and 0,7
- ✓ Low Land use mix: when the $LUM$ is around 0,3

**c) Street Design and Connectivity**

For our study, since our objective is to see how the built environment can improve local accessibility and encourage active modes of transportation, we chose to use Pedestrian Route Directness (PRD) to measure street connectivity. As said above, it may be a better measure that can inform the promotion of cycling and walking than other measures. The PRD is obtained by the ratio between the shortest Route distance ($D_R$) and the Straight-line distance ($D_S$) for two selected points.

$$PRD = \frac{D_R}{D_S} \qquad (3)$$

The lowest possible value is 1, where the shortest Route distance ($D_R$) is the same distance as the Straight-line distance ($D_S$). Values further than one (1) are not recommended because it indicates that the route is not direct and there are several changes of direction to reach the destination.

Based on (Dill et al., 2004), we define our subset for connectivity index as follows:

- ✓ High Street design & network connectivity: when $PRD$ is less than 1,5
- ✓ Medium Street design & network connectivity: when the $PRD$ is between 1,5 and 1,8
- ✓ Low Street design & network connectivity: when the $PRD$ is higher than 1,8

**d) Local Accessibility**

We have noticed that there is no standard for assessing local accessibility. Indeed, we can state whether one area is more accessible than another by comparing accessibility (regardless of the method used for the calculation). But we certainly cannot determine the perfect accessibility level for an area. Therefore, we will introduce a reference area where accessibility is optimal. We use the accessibility value of this area as a baseline to assess the accessibility of any studied zone.

We will assume that the accessibility of the reference area is $A_R$, and the accessibility of the studied area is $A_Z$. We define a local accessibility index (LAI) as the ratio between $A_Z$ and $A_R$.

$$LAI = \frac{A_Z}{A_R} \qquad (4)$$

The highest possible value of LAI is 1, where the accessibility of the studied area ($A_Z$) is the same as the reference zone ($A_R$). Small values than one (1) are not recommended because it indicates that the studied area is not well accessible. We define our subset for local accessibility index as follows:

- ✓ High accessibility when $LAI$ is high than 0,7
- ✓ Medium accessibility when $LAI$ is between 0,5 and 0,7
- ✓ Low accessibility when $LAI$ is less than 0,5

### 4.2.2 Membership Functions and Inference Rules

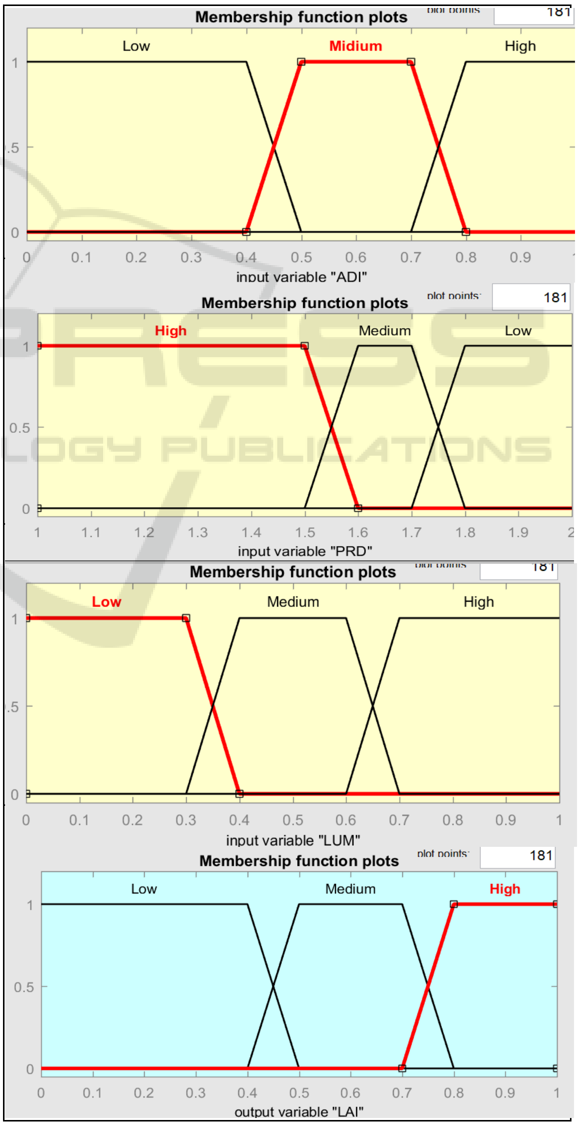


Figure 3: Membership Functions.

SCITEPRESS SCIENCE AND TECHNOLOGY PUBLICATIONS

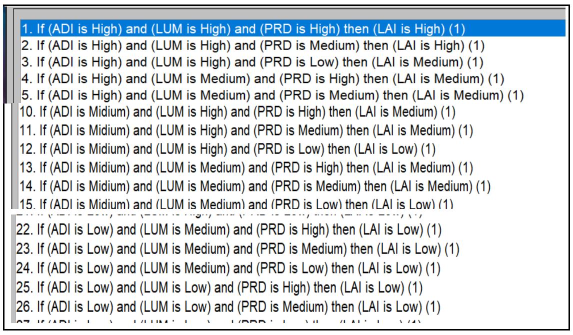
1. If (ADI is High) and (LUM is High) and (PRD is High) then (LAI is High) (1)
2. If (ADI is High) and (LUM is High) and (PRD is Medium) then (LAI is High) (1)
3. If (ADI is High) and (LUM is High) and (PRD is Low) then (LAI is Medium) (1)
4. If (ADI is High) and (LUM is Medium) and (PRD is High) then (LAI is Medium) (1)
5. If (ADI is High) and (LUM is Medium) and (PRD is Medium) then (LAI is Medium) (1)
10. If (ADI is Midium) and (LUM is High) and (PRD is High) then (LAI is Medium) (1)
11. If (ADI is Midium) and (LUM is High) and (PRD is Medium) then (LAI is Medium) (1)
12. If (ADI is Midium) and (LUM is High) and (PRD is Low) then (LAI is Low) (1)
13. If (ADI is Midium) and (LUM is Medium) and (PRD is High) then (LAI is Medium) (1)
14. If (ADI is Midium) and (LUM is Medium) and (PRD is Medium) then (LAI is Medium) (1)
15. If (ADI is Midium) and (LUM is Medium) and (PRD is Low) then (LAI is Low) (1)
22. If (ADI is Low) and (LUM is Medium) and (PRD is High) then (LAI is Low) (1)
23. If (ADI is Low) and (LUM is Medium) and (PRD is Medium) then (LAI is Low) (1)
24. If (ADI is Low) and (LUM is Medium) and (PRD is Low) then (LAI is Low) (1)
25. If (ADI is Low) and (LUM is Low) and (PRD is High) then (LAI is Low) (1)
26. If (ADI is Low) and (LUM is Low) and (PRD is Medium) then (LAI is Low) (1)

Figure 4: Example of Inference Rules.

Through the above section, we have built our fuzzy system that measures accessibility in regards to three variables, i. e. activity density, land-use mix and street design. We define the universe of discourse, the fuzzy subset (High, Medium and Low) and the membership functions for each variable.

Figures 3 and 4 give an overview of our fuzzy system for built-environment accessibility measurement.

# 5 DISCUSSION

## 5.1 Result Interpretation

After the previous steps, our fuzzy system for evaluating the local accessibility is now ready. We proceed to the analysis and interpretation of the defuzzification results. To do that, we will analyse the surface graphs for three cases.

### 5.1.1 Case 1: Fixed ADI in an Average Value

In this case, we set the density to an average value (0.6), and we see how our system reacts.

We can see in Figure 5 that when the density is medium, we can only expect a medium value of accessibility. Therefore, when the PRD is low, accessibility remains low whatever the value of the LUM variable. This result shows that it is crucial to consider ease of access when studying and plaining local accessibility.

### 5.1.2 Case 2: Fixed LUM in an Average Value

As per figure 6, when we set the LUM to a medium value (0,5), we notice that this case presents the same result as the previous one. The maximum accessibility value we can expect is medium. Therefore, when the PRD is low, accessibility remains low whatever the value of the ADI variable, which confirms the link between accessibility and the ease of reaching a destination.

According to case 1 and case 2, we conclude that the land-use mix has the same impact as the activity density on local accessibility.

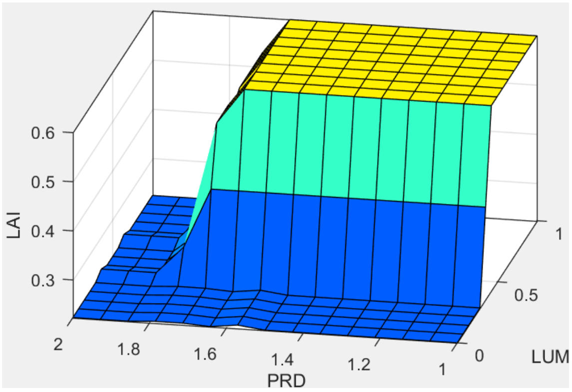


Figure 5: Surface View for the case N°1.

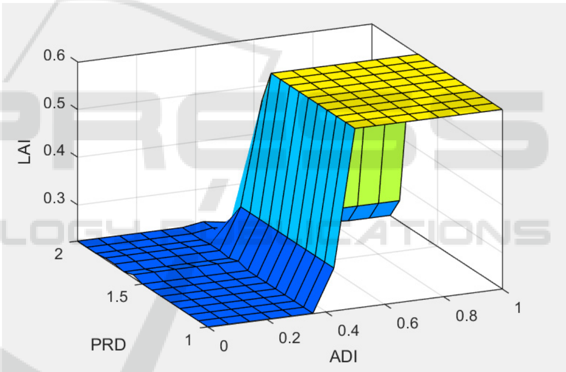


Figure 6: Surface View for the case N°2

### 5.1.3 Case 3: PRD Fixed in an Average Value

As we can see in figure 7, in contrast to the two previous cases, the most important remark is that accessibility can reach high values but with one crucial condition: both ADI and LUM must be increased. In addition, this graph shows two main findings:

- Local accessibility can be medium when at least one of the two has a medium value;
- Local accessibility is low when at least one of the two has a low value.

This result is consistent because when the density is low, there is no reason to talk about the land-use mix. Moreover, when the density is high, and the land use mix is down, we conclude that the area is mono-activity. In both cases, the accessibility remains low, except when PRD become high. In this case, accessibility takes a medium value (figure 8). Furthermore, we can conclude that a combination of ADI and LUM characteristics are crucial and relevant to achieve high local accessibility.

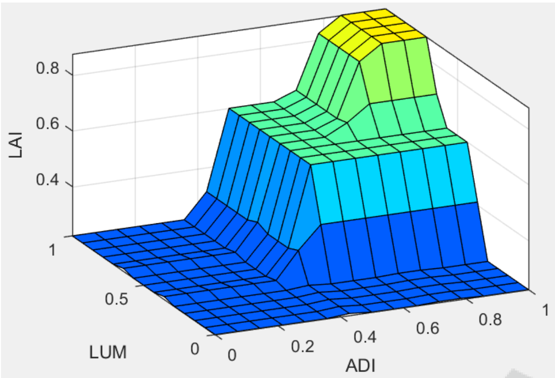


Figure 7: Surface View for the case N°3

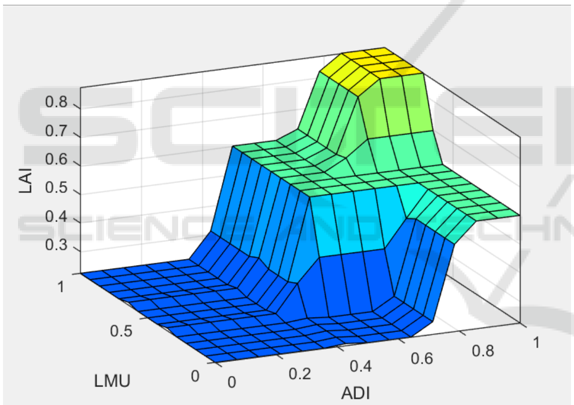


Figure 8: Surface View for PRD high value

## 5.2 Contributions and Limitations

Although the commonly used method for measuring local accessibility is the cumulative opportunity method. In this paper, we chose to extend the scope by considering the surrounding land use environment. We decided to evaluate local accessibility using the principles of the gravity method, incorporating an impedance function capturing the access conditions to each opportunity (PRD). This method allowed us to consider the two main components of accessibility (Karst et al., 2004): the ease of walking (or cycling) to reach a destination and the quantity and spatial distribution of opportunities. The first component is represented, in our model, by the characteristic 'Street Design and Connectivity' (PRD), and the second by the combination of the two other urban characteristics, i.e., Activity Density Index and the Mixed-Use Index. We have suggested a model that allows a high level of disaggregation to capture small-scale design features (street scale), also evaluate non-motorized trips. Therefore, our model can help city decision-makers predict the full impacts of land use management strategies on improving local accessibility. Namely, densification of activities, mixing activities and bringing them closer together by improving walking and cycling conditions and pedestrian-friendly environments.

To be relevant and practical, a model must be exhaustive and consider all the factors and elements that can influence accessibility. However, although our model considers the two main components of accessibility (opportunity and ease of access), it does not consider how these two components are perceived and used by individuals with different characteristics (Páez et al. 2012). Therefore, our model deals only with local accessibility, and it does not consider regional accessibility. It only concerns active modes of transport and not others.

## 6 CONCLUSIONS

It is widely recognised that accessibility is one of the main effects of the transport system (Zondag et al., 2015). However, this paper shows that accessibility is also a matter of urban planning. In particular, we have found that local accessibility can be defined by three urban characteristics, i.e., activity's density, land-use mix and street design.

This paper presents a conceptual framework and a new method to measure local accessibility. Based on one of the tools of artificial intelligence, which is fuzzy logic. This method is easy to understand and interpret thanks to the use of linguistic variables and human reasoning. It also showed that accessibility is more affected by the two main characteristics, namely activity density and land-use mix.

Furthermore, through this work, our objective is to participate in the collective effort of researchers to propose a model that allows transportation and land use planners in cities to predict how their policies and decisions can improve local (active) accessibility and sustainable development.

In the perspectives, and to complete this work, we intend to extend our model to treat the question of accessibility globally and to consider the regional dimension. Also, our work can be improved by testing it with actual data to calibrate it.

## REFERENCES

Brown, B.B., Werner, C.M., Amburgey, J.W. and Szalay, C., 2007. Walkable route perceptions and physical features: Converging evidence for en route walking experiences Environment and Behavior Vol 39(1), pages 34–61.

Choi, S., Choo, S. and Kim, S., 2020. Exploring the influences of compact development on zone-based travel patterns: a case study of the Seoul metropolitan area, Transportation Letters, 12:5, 316-328,

Chris McCahill, Mary Ebeling, 2015. Tools for measuring accessibility in an equity framework, Congress for the New Urbanism 23rd Annual Meeting Dallas, Texas April 29 – May 2.

Deepty. J, Geetam. T., 2019. Measuring density and diversity to model travel behaviour in Indian context, Land Use Policy, Volume 88, 104-199.

Dill, J., 2004, Measuring Network Connectivity for Bicycling and Walking, TRB Annual Meeting.

Ewing, R. and Cervero, R., 2010. Meta Analyse: Travel and the built environment, Journal of the American Planning Association, Vol. 76, No. 3, pp. 265-294

Ewing. R., Hamidi. S. and Grace. JB., 2016. Compact Development and VMT—Environmental Determinism, Self-Selection, or Some of Both? Environment and Planning B: Planning and Design, Vol 43, pp. 737-755

Frank, L.D., Schmid, T.L., Sallis, J.F., Chapman, J., Saelens, B.E., 2005. Linking objectively measured physical activity with objectively measured urban form: Findings from SMARTRAQ, American Journal of Preventive Medicine, 28 (2 SUPPL. 2), pp. 117-125

Global Mobility Report, 2017. https://sustainabledevelopment.un.org/content/documents/2643Global_Mobility_Report_2017.pdf, 15/04/2021 22h30

Hanani, F., Soulhi, A., 2021 improving traffic congestion assessment by using fuzzy logic approach. Journal of Theoretical and Applied Information Technology, Vol.99. No 3 pp 625-638.

Handy, S L, Niemeier, D A, 1997. Measuring accessibility_ an exploration of issues and alternatives, Environment and Planning A, volume 29, pages 1175-1194.

Hirt, S. A., 2016. Rooting out mixed use: Revisiting the original rationales, Land Use Policy, Volume 50, Pages 134-147,

Karst T. Geurs, Bert van Wee, 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. Journal of Transport Geography, Volume 12, Issue 2, Pages 127-140,

Litman, T., 2020. Evaluating Accessibility for Transport Planning. https://www.vtpi.org/access.pdf, 23/04/2021, 13h30

Litman, T., 2021. Land Use Impacts on Transport, https://www.vtpi.org/landtravel.pdf, 26/04/2021 15h30.

Manaugh, K., & Kreider, T., 2013. What is mixed use? Presenting an interaction method for measuring land use mix. Journal of Transport and Land Use, 6(1), 63-72.

Miller, E., 2020, "Measuring Accessibility: Methods and Issues", International Transport Forum Discussion Papers, No. 2020/25, OECD Publishing, Paris.

Naess, P., 2012. Urban form and travel behaviour: experience from a Nordic context. Journal of Transport and Land Use, 5(2)

Newman. P. W. G. and Kenworthy. J. R., 2006. Urban Design to Reduce Automobile Dependence", Opolis: An International Journal of Suburban and Metropolitan Studies, Vol. 2, No. 1, 2006, pp. 35-52.

Oakes JM, Forsyth A, Schmitz KH., 2007. The effects of neighborhood density and street connectivity on walking behavior: The Twin Cities walking study. Epidemiol Perspect Innov.;4:16.

Ozbil. A., Peponis. J. and Stone. B., 2011. Understanding the link between street connectivity, land use and pedestrian flows, urban design International, vol 16}, pp 125-141

Páez, A, Scott, D. M., Morency, C, 2012. Measuring accessibility: positive and normative implementations of various accessibility indicators, Journal of Transport Geography,Volume 25 , Pages 141-153,

Saghapour, T, Moridpour, S. & Thompson, R, 2016. Public transport accessibility in metropolitan areas: A new approach incorporating population density, Journal of Transport Geography, Volume 54, Pages 273-285,

Saghapour, T, Moridpour, S. & Thompson, R, 2018. Sustainable transport in neighbourhoods: effect of accessibility on walking and bicycling. Transportmetrica A: Transport Science

Song, Y., Merlin, L., Rodriguez, D., 2013. Comparing measures of urban land use mix, Computers, Environment and Urban Systems, Volume 42, Pages 1-13,

Stevens, M. R., 2017. Does Compact Development Make People Drive Less? Journal of the American Planning Association, 83:1, 7-18,

Toward Sustainable Mobility, 2019. https://www.sum4all.org/data/files/gra-globalroadmapofaction-press.pdf, 10/04/2021, 12h20

Xia, C., Gar-On Yeh, A., Zhang, A. 2020. Analysing spatial relationships between urban land use intensity and urban vitality at street block level: A case study of five Chinese megacities, Landscape and Urban Planning, Volume 193, 103669,

Yang, B., Xu, T., Shi, L. 2017. Analysis on sustainable urban development levels and trends in China's cities, Journal of Cleaner Production, Volume 141, Pages 868-880,

Zhang, C., Man, J., 2015. Examining Job Accessibility of the Urban Poor by Urban Metro and Bus: A Case Study of Beijing. Urban Rail Transit 1, 183–193.

Zondag, B., De Bok, M., Geurs, K. T., Molenwijk, E., 2015. Accessibility modeling and evaluation: The TIGRIS XL land-use and transport interaction model for the Netherlands, Computers, Environment and Urban Systems, Volume 49, Pages 115-125.