Mobility (In)Justice Atlas of Tunis: Transferring perspectives from Global North to Global South

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Abstract

Who has access to basic needs? How are mobility resources distributed? Who is exposed to the externalities of transporation? Mobility justice focuses on these questions to understand how fair our mobility is. In this context, the Technical University of Munich, TUM, designed an Atlas to study mobility injustice in Munich. This innovative approach maps out areas with pronounced social and mobility disadvantages. It studies the dynamics between social groups and mobility structure to reveal patterns of injustice and to provide policy recommendations.

This paper builds upon the Mobility Injustice Atlas of Munich and designs a four-phase framework to transfer the mobility injustice atlas concept to other cities. The first step of the framework relies on collaborating with local stakeholders to understand their needs and the mobility structure of the studied area. Secondly, the atlas designer reviews the available databases and calculates the relevant social and mobility variables. The next step is to analyse the variables to identify situations of mobility injustice. Finally the last step consist on providing outputs of this study for decision-makers. This framework not only guides the designer in creating a mobility injustice atlas but also offers adaptation options based on the data availability and the studied area specificities. The distinction between Global North and Global South is at the core of this study.

The framework was applied to the case study of a metropolitan area in the Global South, Grand Tunis. When analysing the mobility variables calculated using clustering methods, the study shows that districts are divided into three groups, a group of districts with high urban structure, a group with low urban structure and high car usage, and a last group with low urban structure group and high public transport usage. These three groups are characterized by specific social disadvantages structure, showing a global mobility injustice that goes beyond district borders.

Keywords: Mobility poverty, Accessibility, Justice, Global South, Framework

1. Introduction

How can we increase the traffic? What infrastructure should we build? Fifty years ago, these questions were the core of mobility planning, known as the vehicle-oriented planning (Jones (2014)). Born of a rapid increase in the number of cars - that is reinforced by planning measures -, this mobility paradigm quickly showed its downsides for the environment and people. For example, 18% of CO2 emissions in Europe are due to road traffic[1] and it plays a role in climate change; High noise emissions from roads leads to sleep disturbance for 5 million people in Europe in 2017 [2].

With the increasing awareness of the risks of road traffic, the mobility planning system began its change in paridgm from car-designed transportation to person-based and sustainability-based mobility. This change is reinforced in Europe by the Sustainable Urban Mobility Plan (SUMP), a European guideline for this new concept of mobility planning (Wefering et al. (2013)). The core question of mobility becomes: who can move? Who has access to his basic needs? Are transportation modes sustainable?

Mobility justice is a theory and an approach to studying transportation in this new vision. The specificity of mobility justice is its high focus on different people's needs and on providing an equitable mobility system independent of individual capacities to move. This contemporary theory covers issues like migration, racial justice, and sustainable mobility, with a global reach (Sheller (2018)). Yet, in practice, studies on mobility justice - and broader mobility research - predominantly center on concerns prevalent in the Global North (Sheller (2018)). These studies often focus on contemporary urban lifestyles like cycling, walking, or autonomous vehicles, which may not align with the realities or priorities of cities in the Global South (Uteng and Lucas (2018)). While the concepts related to mobility justice and equity remain relevant to consider in a Global South context, the transfer of methods developed for the Global North faces limitations due to these disparities in mobility structure but also in data availability(Benevenuto and Caulfield (2019)). In this context, the current paper learns from a specific research conducted in Global North,

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[1] https://www.europarl.europa.eu/topics/en/article/20190313STO31218/co2-emissions-from-cars-facts-and-figures-infographics

[2] https://www.eea.europa.eu/en/analysis/indicators/health-impacts-of-exposure-to-1

the Mobility Injustice Atlas of Munich, to adapt it to study mobility justice in a city of Global South.

The remaining parts of the paper are structured as follows: After the introduction, the paper goes deeper into the theoretical background of mobility justice, comparing perspectives between the Global South and the Global North. It then introduces the mobility injustice atlas, a study previously designed for Munich in German. Section 3 develops a framework for designing mobility injustice atlas in different cities in the Global North and the Global South. This framework is then applied to the case study of Grand Tunis in the following section to design a mobility injustice atlas for this Global South city. The final section identifies the limits of this study.

2. Theoretical Background and Related Work

2.1. The Mobility Justice Theory

Mobility justice studies the inequalities present in the mobility and transportation systems across different scales and contexts. Sheller (2018) considers that mobility justice is not only an issue faced by cities, but it is also a global crisis, including immigration restrictions. Generally, mobility justice focuses on people's needs and mobility's impact on marginalized communities to provide an equitable environment. To understand what is equitable and what is inequitable, mobility justice relies on the justice judgment theory. This theory defines rules that regulate what is considered fairness (Leventhal (1980)). Researchers have defined different justice categories to classify these rules (Colquitt and Rodell (2015)). For example, distributive justice studies the equitable allocation of resources. While an important justice categories used in studying spatial and transportation equity, distributive justice is not sufficient to measure the fairness of our mobility system (Pereira et al. (2016)). Durand & al. (2022) suggest to use of environmental justice to include the externalities of transportation. Another aspect, though less commonly discussed, is temporal justice, which deals with the fair distribution of time (GOODIN (2010); Tyssedal (2021)).

In literature, the challenge in addressing mobility justice as defined by Sheller, lies in the multiplicity of closely related theories. This current study identifies three close concepts to mobility justice:

- **Transport poverty:** Researchers describe transport poverty as the area where social and transport disadvantages intersect (Lucas (2012)). This term can also include notions like accessibility poverty and exposure to transport externalities (Lucas et al. (2016)).
- **Spatial justice:** This theory is centered around the fair and equitable distribution of resources. When we examine the social and spatial disadvantages, geography emerges as a significant factor of injustice and inequity (Soja (2009)). In this context, mobility is regarded as a means to an end (Sheller (2018)).
- **Accessibility:** It is "a measure of the ease of an individual to pursue an activity of a desired type, at a desired location, by a desired mode, and at a desired time" (Bhat et al. (2000)). In practice, it predominantly focuses on the interactions between land use and transportation systems, regardless of individual characteristics.

In this study, we use the term 'mobility poverty' to summarise the theories previously described. Mobility poverty addresses the equitable integration of three types of disadvantages: social disadvantages, spatial disadvantages, and transport disadvantages. Figure 1 provides a conceptual map of the interconnections between the theories contributing to mobility poverty. What is the link between

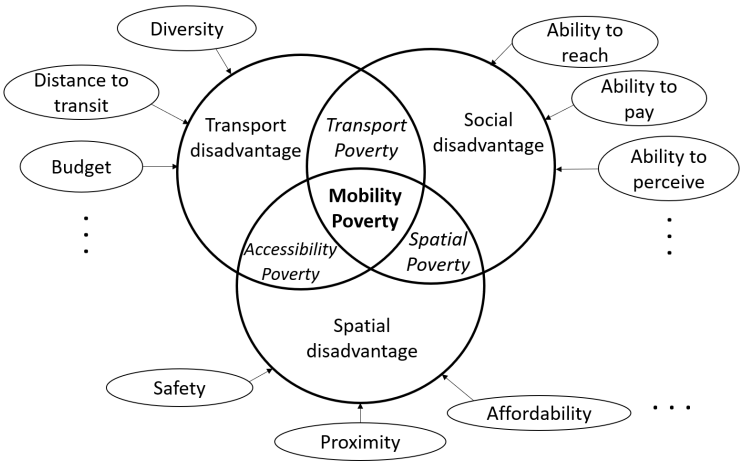

Figure 1: Diagram of concepts of mobility poverty - Inspired from Lucas (2012)

mobility justice and mobility poverty? Mobility poverty is a major part of the justice study, yet it should be completed by procedural justice, which refers to the fairness of the processes used to create mobility systems (Greenberg and Tyler (1987)). Including procedure justice provides a more strategic overview of the mobility justice by considering the decision-making process as a major component of the resulting equity or inequity. This study will primarily focus on mobility poverty. For simplification considerations, the terms 'mobility injustice' and 'mobility poverty,' are used interchangeably in the remaining parts of this study.

2.2. Mobility from the Global North to the Global South

Mobility Paradigm in the Global North is centered around sustainable post-automobility cities. This involves a shift towards sustainable modes like walking, biking and public transport or enhancing the efficiency of the automobile fleet through autonomic vehicles (Banister (2008); Sheller (2018)). From this remark, we can think that the Global South has taken a significant step in this vision with the prevalence of walking and cycling. However, reliance on these modes in many Global South cities is often a last option choice, due to a lack of comfort and a shortage

in urban infrastructure (Uteng and Lucas (2018)). Additionally, contrarily to the Global North, many Global South cities maintain a car-oriented mobility is their policies. With this increasing dependency on private vehicles and a diminished public transport service, car ownership may play a significant role in mobility opportunities in these areas (Venter et al. (2019)).

Non-scheduled transit or paratransit are modes of transportation that do not have fixed schedules. They can be either regulated or not and they are often associated with a poor quality of service. This mode comes usually as a solution to a lack of public transport options. While a Global North citizen would probably think about some specific (and still marginalized) cases of transportation on demand, a Global South citizen would think about a daily transportation mode like the 'Peseros' in Mexico city or the 'Matutus' in Nairoby (Cervero and Golub (2007); Behrens et al. (2021)).

We can conclude that existing mobility research on the Global North may face difficulties capturing the mobility challenges faced in the Global South. Does this imply that we should not consider these theories when studying the Global South mobility? This paper introduces a methodological framework for adapting a mobility injustice atlas, originally developed for Munich, to other cities, including perspectives from the Global South.

2.3. Related work: The Mobility Injustice Atlas of Munich

To study mobility injustice in Munich, the Chair of Urban Structure and Transportation Planning at TUM developed an online atlas [3] documented by a report. This mobility injustice atlas is a tool to guide decision-makers into identifying areas that require interventions to increase mobility equity. Indeed, the study identifies neighbourhoods facing mobility injustice, in other words, areas with a high proportion of disadvantaged groups live, and with fewer mobility resources or higher transport externalities or lower urban structure (Duran et al. (2022)).

2.3.1. Methodology

The distinct structure of this Atlas lies in its design aimed at aligning with the needs of involved stakeholders: a series of five workshops took place with various stakeholders to define together the major injustice aspects included in the atlas. These workshops, along with mobility justice theory and data analysis methods, conducted into the creation of the following variables and category of variables for the atlas. While these variables describe mobility poverty in Munich, the stakeholder participation is an approach to include procedure justice into the process of creation of the atlas.

- **Social disadvantages**: Six social vulnerable groups are defined: individuals aged over 65, children, non-German residents, unemployed people, single parents, and low income.
- **Transport and spatial disadvantages**: These variables are classified based on justice theory as follow:
  - **Environmental Justice**: exposure to road crashes, air pollution, and noise.
  - **Distributive Justice**: accessibility to amenities and availability of transport infrastructure.
  - **Procedural Justice**: fairness of decision making process and relies on the co-creation of the Atlas with stakeholders.

Based on these variables, a web-based tool is available, mapping vulnerable groups and mobility disadvantages distribution within the neighbourhoods of Munich(See Figure 2). The report complements the online atlas by including an integrated analysis of social and mobility disadvantages. This analysis goes deeper into the study of mobility injustice by identifying trends and patterns on injustice distribution. For example, the report includes a correlation matrix to identify pairs of social and mobility disadvantages that are correlated. Following this identification, the decision-maker can refer to a summary table of suggested interventions and to the web tool to target neighbourhoods facing the identified injustice. A second analysis assigns each neighbourhood with aa "Mobility Disadvantage Score". This score aggregates mobility variables to compare the overall mobility injustice situation between the neighbourhoods.

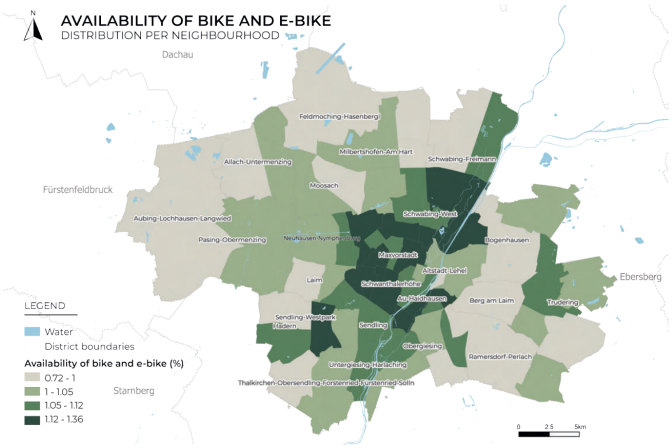

Figure 2: Example of variable display in the Mobility Injustice Atlas of Munich

2.3.2. Atlas Transfer

The Mobility (In)Justice Atlas is created in Munich as a "learning region" (Duran et al. (2022)). In fact, this project aims to be a first step towards studying mobility injustice in various cities worldwide. In theory, the transfer of the Atlas to another European metropolitan city appears plausible, given shared characteristics in the mobility paradigm. However, the potential for transfer may be reduced when studying cities in the Global South due to the distinct mobility behaviors there. Based on the methods employed in developing Munich's Atlas, the current

[3] `http://accessibility-atlas.de/`

study details a methodological framework for developing a mobility injustice atlas at a city level.

3. Framework for a Mobility (In)Justice Atlas

The mobility injustice atlas framework is a guideline for designing atlases applicable to cities in both the Global North and Global South. This methodology is structured into four main phases, as illustrated in Figure 3. This section develops each phase of the framework and highlights potential distinctions between the Global South and Global North contexts. The framework primarily focuses on mobility poverty and only covers the procedural justice by including stakeholders participation. Indeed, a deeper integration of this form of justice significantly depends on the relationship the atlas designer establishes with decision-makers and their capacity to provide their planning methodology.

3.1. Definition of Needs

Fairness is a subjective perception that depends on the cultural environment being studied. What is considered as a disadvantage in one city can be perceived differently in another. Therefore, the Mobility Injustice Atlas needs to be developed with local stakeholders inputs. This process can be conducted, for example, through individual interviews or workshops to identify the main variables contributing to mobility injustice. When researchers have limited knowledge of the study area or faces challenges in contacting stakeholders, they can conduct a literature review on the study area's mobility. In addition to these local inputs, the framework provides an initial list of sample variables and a structural guideline to classify variables based on the mobility justice rules, as illustrated in Figure 4. This guideline is organized into three levels of detail:

1. **First Level** defines the two main types of disadvantage in the atlas: social disadvantage and mobility disadvantage(which consists of transport and spatial disadvantages), aligning with the concept of mobility poverty.
2. **Second Level** defines the justice theory adopted by the atlas and the main categories to structure the atlas variables.
3. **Third Level** introduces examples of variables for each category based on Munich and Grand Tunis cases study - Tunis Atlas will be presented in the remaining part of this paper. For further variables, a literature review conducted by Hidayati et al. (2016) of 270 publications on mobility inequity can be a good resource to consider (Hidayati et al. (2016)).

The result of this first step is an understanding of the characteristics of the study area, and a list of potential variables that can be studied.

3.2. Data Collection

After defining the complete list of variable , a review of the available data should be conducted to define the variables that can be calculated as well as the scale of the study area (like neighbourhoods, districts). Regardless

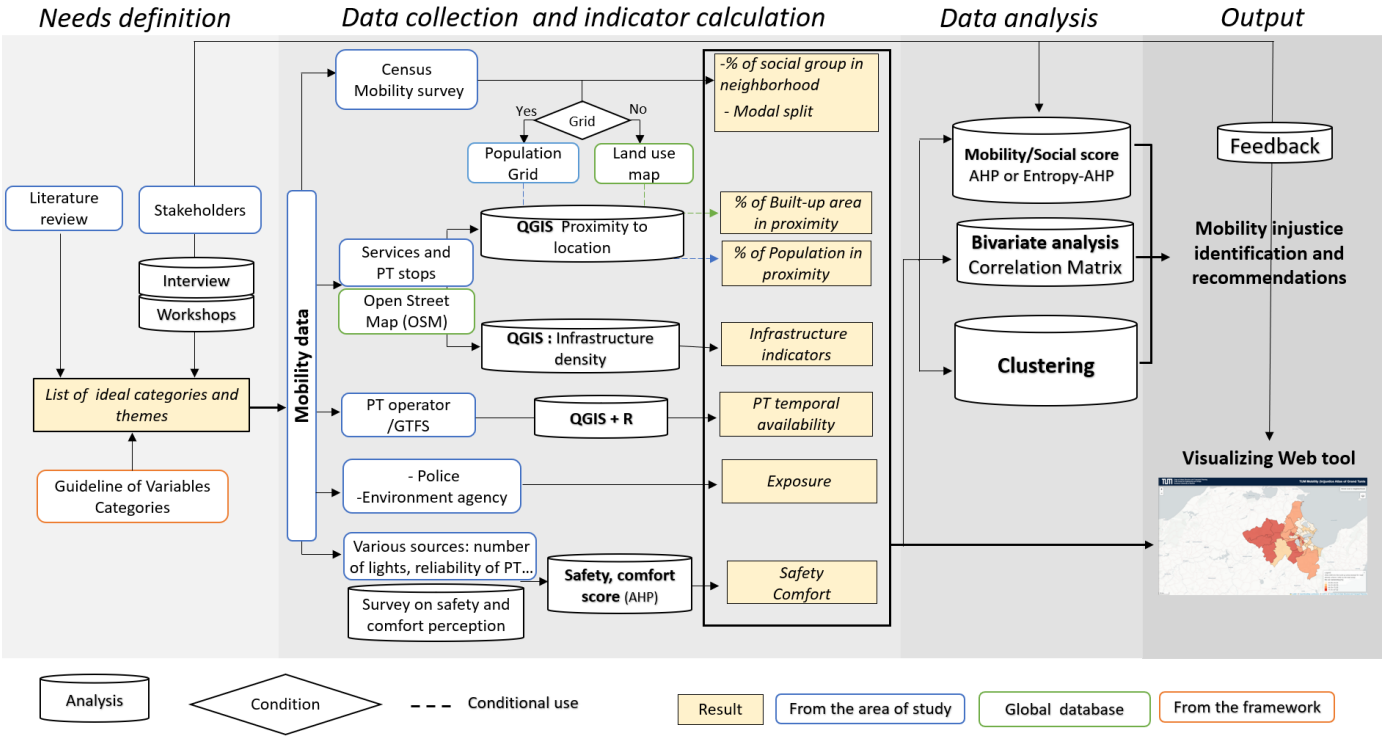

Figure 3: Framework of creating a Mobility Injustice Atlas

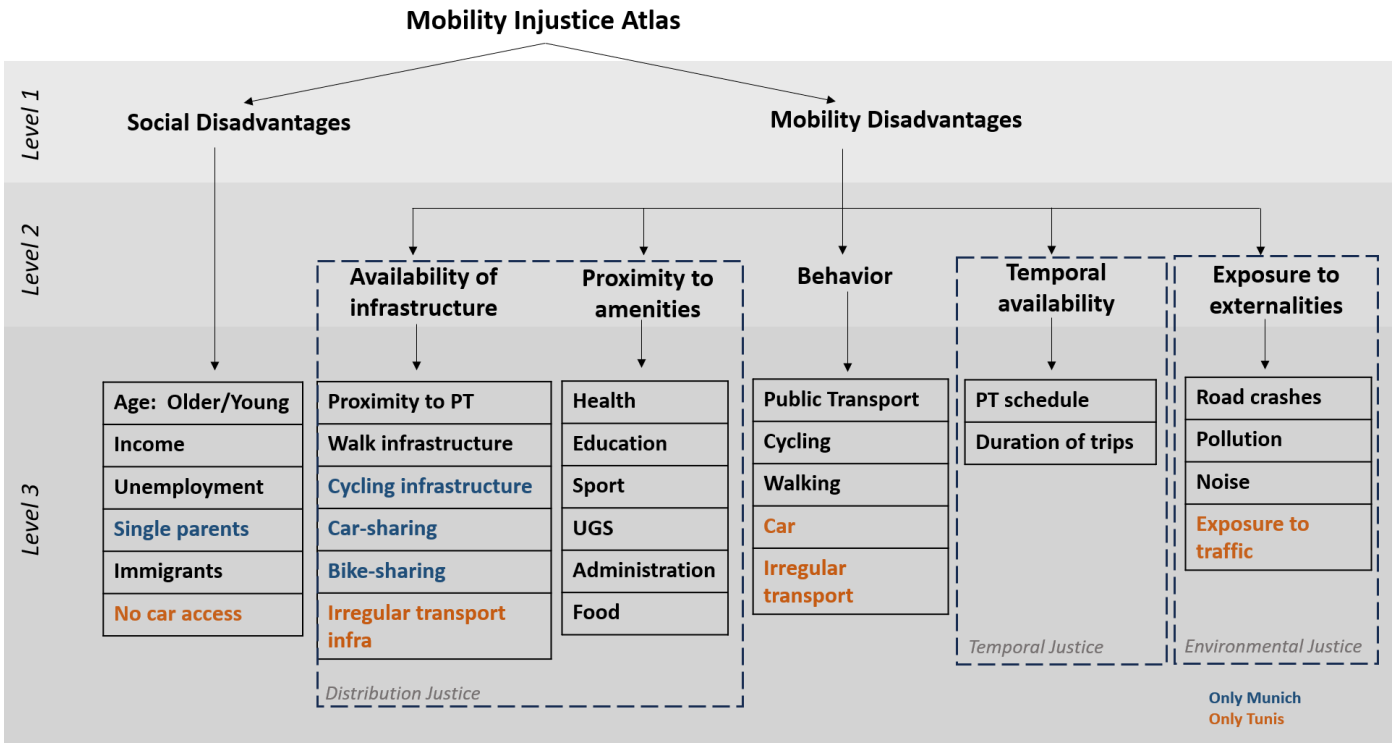

Figure 4: Guideline for variables categories based on Tunis and Munich Atlas

of the scale, the atlas should ideally incorporate person-based variables to approximate the real experience of citizens. Person-based data might be sourced from census or mobility surveys. This approach also shapes the types of variables that are calculated. For instance, in assessing public transport availability, the atlas focuses on proximity to public transport rather than the number of public transport stops. This proximity variable highlight the role of walkability to public transport in the overall user experience (Daniels and Mulley (2013)).

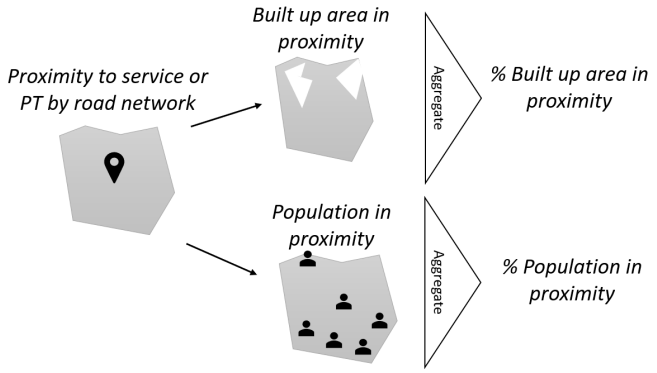

Figure 5: Spatial calculation of proximity to service

OpenStreetMap (OSM) is an important database that can be used in the atlas. It provides local positions of "Points of Interest" (POI), such as hospitals and schools. Even though OSM automatically provides the amenity data, its accuracy can vary depending on the study area. Consequently, in some cases, the use of this database should be limited to situations where no local data sources are available. In all cases, the accessibility to POI is estimated by calculating the area reachable from these points, for example within 7 minutes of walking using the road network. When a local population position grid is available, we can count the percentage of the population being in proximity to the considered amenity. In cases where this grid is unavailable —a scenario that might occur in cities in the Global South— the atlas can be adapted by approximating population location through the land-use type and analysing the percentage of built-up area in proximity to the considered amenity.

3.3. Data Analysis and Outputs

The first output of a mobility injustice atlas is a web tool that maps the social and mobility disadvantages on the study area at the selected scale. This visual representation of data can highlight disparities in mobility access and identify areas requiring intervention to increase equity. For further information, the atlas includes an analysis of the variables calculated using bivariate or multivariate analyses.

On the one hand, bivariate analysis focuses on exploring relationships between two variables in order to identify a risky situation, such as a strong correlation between children's share and low proximity to schools. The correlation matrix between social and mobility matrix is a

suggested analysis to conduct. On the other hand, multivariate analysis studies all the variables simultaneously. Therefore, this approach does not focus on one type of disadvantage, but it provides an overall understanding of mobility justice. Two methods are proposed as part of the atlas framework. First, we can cluster neighbourhoods based on shared social or mobility characteristics to go beyond the administrative boundaries and to understand the similarities in the structure of neighbourhoods. Several machine learning algorithms like the K-means algorithm can be computed for this purpose (Rokach and Maimon (2005)). Secondly, two composite variable, the mobility score or the social score, can be calculated as a weighted aggregation of the different disadvantages as suggested by Miller et al. (2013). When building the weighting factors, typically three approaches can be implemented (El Gibari et al. (2019)): equal weighting; data-driven methods, which determine weights based on characteristics inherent in the data as the Entropy (Zhu et al. (2020)) and participatory-based methods, involving the integration of subjective perspectives from stakeholders as the Analytic Hierarchy Process (AHP) (Darko et al. (2019)). Based on the data analysis, mobility injustices and recommendation can be provided for policy makers

In the following section, the framework is applied to the case study of a Global South city: Grand Tunis. As for Munich, the atlas focuses on mobility poverty and it incorporates procedure justice through stakeholder participation.

4. Application of The Atlas Framework on Grand Tunis

Tunisia is a developing country in North Africa and it is below the economic development stage. It is divided into 24 Gouvernorats, which are further subdivided into delegations. The "Grand Tunis" or "Greater Tunis" area is a metropolitan region in Tunisia, encircling the capital city, Tunis. This area is composed of four Gouvernorats (Tunis, Ariana, Ben Arous, and Manouba) and includes 48 delegations. With a population of approximately 2.65 million inhabitants (INS (2016a)), the region covers 2600 square kilometers and results in an average population density of 1020 individuals per square kilometer, which is 15 times higher than the national population density. The urban expansion of the Grand Tunis area is a consequence of unregulated urban sprawl, due to informal settlements around the capital city during the 1970s (Chabbi and Abid (2008)). The expansion of urban areas and the limited availability of public transport options increased the reliance on private cars, resulting in high congestion (BanqueMondiale (2019)). As a result of this increasing mobility demand and tax relief measures for low-powered vehicles, the percentage of households owning one car or more rose from 21% to 27.2% between 2004 and 2014 (INS (2016b); Chabbi and Abid (2008)).

The mobility injustice atlas framework is applied to Grand Tunis, as a Global South learning area. Indeed, this city not only belongs to in a developing country but it is also composed of both urban and rural areas within the same administrative borders and monitored by the same urban planning agency and public transport operator. In addition, the Urban Planning Agency of Greater Tunis (AUGT) is currently defining the local transport plan of the Metropolitan Area. Therefore, this Atlas could serve as input to include justice in this strategic planning process.

4.1. Definition of Needs

To understand which main elements should be analysed, a literature review of mobility in Tunis and interviews with local actors were conducted.

4.1.1. Case Study Literature

The Grand Tunis area is equipped with both buses and rail services, with buses offering a broader spatial coverage. The public operator Transtu (BanqueMondiale (2019)) manage the majority of this offer. Based on the literature, the public transport system in Grand Tunis is perceived by its users as lacking comfort, reliability, and safety, leading to its utilization primarily driven by budget constraints (Kilian-Yasin et al. (2016)). In this context, the cost of public transport subscriptions significantly influences the usage of this mode(Daldoul et al. (2015)). Notably, 36.7% of Transtu travelers benefit from a student or school subscription, which costs only 10% of the regular subscription price (Transtu (2019)).

Regarding active modes of transportation, the social report of the census indicates that the mode choice varies with education level (INS (2016b)), with an increased share of active modes or animal use as transport mode in economically disadvantaged areas. Statistics shows that 64.3% of students or pupils commute by walking. However, in car-dependent cities like Tunis, these modes face high challenges for their users, increased by congestion and the prevalent issue of illegal parking on sidewalks (BanqueMondiale (2019); Kilian-Yasin et al. (2016)).

It is important finally to note that in Tunisia taxis function as a daily mode, operating as an irregular public transport. Two main types of taxis are available in urban areas in Tunisia and they operate in different service options. **Shared Taxi** transports up to 9 passengers along fixed routes, starting their journey at variable schedules **Individual Taxi** functions as an on-demand service, which involves picking up passengers directly from the roadside and dropping them off at their specified destinations. It has fixed time-based pricing regulated by the ministry [4]. Estimating this last mode traffic and impact can be challenging due to drivers adapting their routes to each trip's destination.

[4] `http://www.transport.tn/fr/terrestre/tarifs-du-transport-non-regulier-des-personnes`

4.1.2. Interviews

In addition to the case study literature, three semi-structured interviews have been conducted with local stakeholders (academia[5], urban agency (AUGT) and national statistical institute (INS)). These interviews lead to defining common topics and identifying important topics for Tunis mobility justice after an analysis inspired from the methodology of the thematic analysis (See Figure 6)(Maguire and Delahunt (2017)). Reader should keep in mind that the interview analysis is not intended to represent a qualitative analysis method due to the limited sample size (Fugard and Potts (2015)) but it is rather an approach to identify relevant issues for Tunisia mobility.

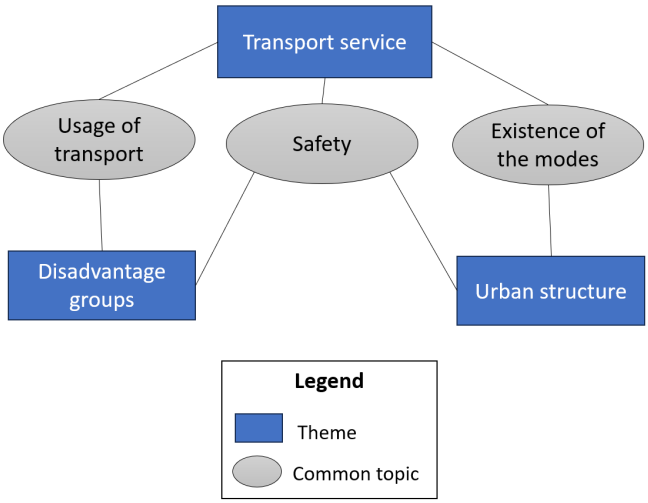

Figure 6: Thematic map from Tunisian stakeholders interviews

The interviewees highlight safety as a major issue for pedestrians and cyclists, particularly affecting the elderly and young. These concerns, coupled with the difficulties of quickly returning home due to congestion, drive some parents to choose schools near their workplaces rather than those closer to their homes. Additionally, the safety of public transportation is reported to vary with the neighbourhoods it serves. As pointed by the literature review of Tunis,in many areas, the reduced spacial cover of public transport led to the emergence of irregular transit. Indeed, the disparate urban growth and the economic difficulties encountered by public transport providers, leads to some areas being insufficiently covered by conventional public transit networks. In addition, interviewees raised concerns regarding the inclusivity of public transit for marginalized groups, with a special focus on individuals with disabilities. Finally, the growing dependency on cars is becoming increasingly problematic due to citizens' budget constraints and congestion, extending the travel time for both private vehicles and bus services.

[5]Due to time constraints and adapting to the interviewee, the academic interview was in an unstructured approach

4.2. Data Collection

Table 1 lists the selected mobility and social variables for the Mobility Injustice Atlas of Tunis. This selection is derived from the atlas methodology, and interviews with stakeholders, and is adapted to the data available. Due to restricted access of certain databases, the final set of variables in the atlas does not include irregular transport stops and congestion description. The perception of safety and comfort for different modes is also omitted. The absence of these factors poses significant limitations to the current study, as these variables are important in understanding mobility context in Grand Tunis.

The Statistics Institute (INS) provides results of the census of 2014 at the delegation scale. These available results were completed by the research group UAQAP-ISG to include the percentage of the population without car ownership and variables on mode share and duration of travel for commuters. Open Street Map (OSM) is the second major data source used after the census. Given the lack of precise population positioning, OSM-derived variables are calculated based on the built-up area as defined by the European Space Agency[7] and are further adjusted by removing roads width from the built-up surface. For our case study, focusing on built-up area is necessary to approximate population location, due to the high agricultural surface in some delegations.

Finally, the study estimates the temporal availability of public transport on the delegation level. The variable selected is the headway, in other words, the number of minutes between buses/trams of the same line. Initially, the headway of each line is evaluated based on the timetable provided by the public transport operator, as well as the share of hours of a day during which the service is available (named here the continuity rate). For each line, each stop is associated with the corresponding headway and continuity rate. To calculate an average headway per delegation, each stop is weighted by its 700m coverage area and the continuity rate. This approach ensures that central stops are given more significance compared to peripheral ones, reflecting their higher accessibility.

4.3. Data Analysis

After calculating the variables, the study analyses the relationships between them. By examining how different factors interact with each other, the study can uncover patterns and trends. This step is essential for understanding the structure of mobility poverty in Tunis. In the subsequent section, the variables "% of built-up area" are all normalized by the population size.

4.3.1. Bivariate Analysis for Grand Tunis

The study first analyses the correlation between social disadvantage and mobility disadvantage. To achieve this,

[6]National Observatory of road safety

[7]European Spacial Agency world cover classification `https://worldcover2020.esa.int/data/docs/WorldCover_PUM_V1.1.pdf`

Category		Variable	Description	Source	Remarks
Social		Older People (>60)	% of population	Census(2014)	
		Children (<9)			
		Teenagers (10-19)			
		Unemployed			
		Internal Migrant			
		No car ownership			
		Poverty rate		INS	
Mobility	**Availability**	PT Accessibility	% of built up area accessible to PT by 700m	Transtu	
		Streets intersection	Nb/ha built up	OSM	In a 300m buffer around the built up area
		Road density	Km/ha	OSM	
		Irregular transport	Unavailable data		
	Behavior	Mode choice	% of commuters per mode	Census	Car, PT, Walking or Irregular transport
	Exposure	Road crashes	Nb/ha build up	ONSR(2022)[6]	
		Air quality	Unavailable data		
		Congestion			
	Proximity	Health	% of population at 1km	Census	Hospital and dispensary
		Education			
		Sport centers			
		Food	% of built up area within 1km	OSM	
		Admin			Bank, town hall,post
		Green area		OSM and ESA	Park, lake and see
	Temporal	Duration of commuting	% of commuters	Census	15-30min, >30 min
		Headway of PT	Minutes	Transtu schedule	

Table 1: List of variables for Tunis Mobility Injustice Atlas

a correlation matrix is calculated using the Pearson correlation method as represented in Figure 7. The analysis of

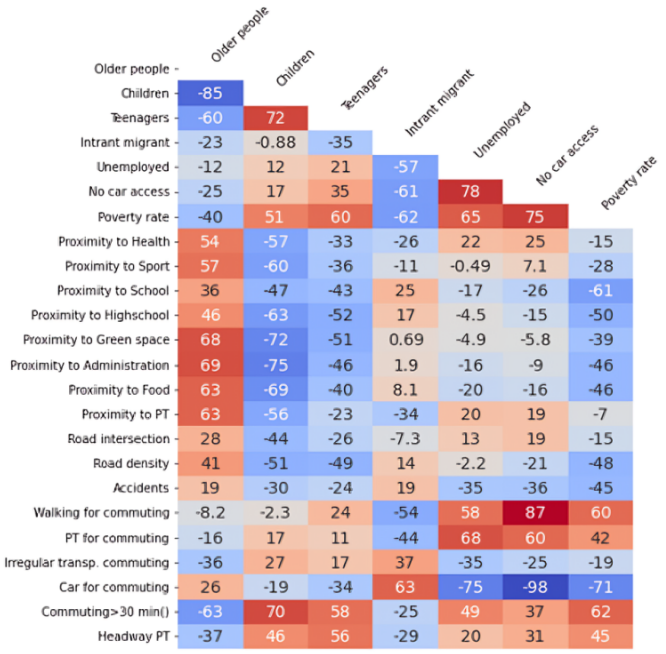

Figure 7: Correlation matrix of social and mobility variables

the correlation between social groups reveals that delegations are categorized into areas predominantly occupied by the elderly and areas primarily inhabited by families. This division may result from the recent urbanization dynamics in Grand Tunis. Considering poverty as a confounding variable can also be a second cause to explain this specific spatial distribution.

In a second part, correlation between social and mobility variables are calculated and presented at the bottom of the figure. This representation identifies which social groups are affected by which transportation disadvantages. This analysis shows that children, teenagers, and low income live far from all basic needs. With low revenue, people tend to use more public transport even though they live in areas where it is not frequent, resulting in high commuting time. They also face high accident risk. People who don't own a car are the main walkers and they tend to use public transport more than irregular transport for commuting. Finally, the elderly live in areas with high proximity to basic amenities, and high intersections. Therefore, this group does not seem to face major injustice at this stage of the analysis.

When calculating the mobility correlation matrix, high correlations are observed between the proximity to amenities. This observation is coherent with the differences in the construction of neighbourhoods in Grand Tunis, as some are pre-planned while others originate from illegal housing followed by urban adjustments.

4.3.2. Delegation Clustering

The current atlas provides data for each delegation independently. To go beyond this administrative boundary and to understand which delegations are facing a similar mobility poverty situation, the study clusters these zones based on the mobility variables. Due to the high degree of correlation among the attributes, Principal Component Analysis (PCA) is used on mobility variables to reduce both their number and correlation prior to the clustering (Jolliffe and Cadima (2016)). Five principal components are extracted from the PCA, capturing 80% of the data variance. Following this, the K-means clustering algorithm, a non-hierarchical clustering method (Likas et al. (2003)), is applied on these components. With this approach, we group the 48 delegations into three groups, with delegations within each group exhibit similar attribute values.

To understand how each group is defined, Figure 8 displays a radar plot of the standardised average values of variables for each cluster. For variables related to proximity and infrastructure availability, values close to 0 signify urban or transport disadvantages encountered by the cluster. On the contrary, for temporal or exposure variables, high values (approaching 1) indicate a situation of disadvantage. We note that, Cluster 1 stands out for its 'High urban structure'. Clusters 2 and 3, while exhibiting similar urban patterns, differ primarily in the transportation modes available and used. A first form of injustice is perceptible in this radar plot: Public transport is a predominant mode of transport in group 3, yet recording the greatest public transport headway.

Do these delegations with shared mobility disadvantages, have also specific social structure? To answer this question, we calculate for each cluster the average social disadvantage values. Cluster 2 is characterised by low poverty and unemployment and serves as the reference for comparing social disadvantages between the clusters. The Mann–Whitney U test (Mann and Whitney (1947)) is applied on the clusters to identify the ones having a social groups structure statistically different from the reference cluster. The results are detailed in Table 2. This analysis confirms the results of the correlation matrix and cluster 3 is considered as the group facing the highest social and mobility injustice. The Table shows also that the internal migrants are significantly higher in cluster 2, showing that this type of migration is headed to attractive neighbourhoods.

4.3.3. Mobility and Social Disadvantage Score

A last multivariable analysis for Grand Tunis atlas is to combine variables into a single score reflecting the overall mobility injustice situation. Two distinct scores are calculated: mobility and social disadvantage score. For each score, variables are standardized from 0 to 1, with 0 as the lowest and 1 as the highest value. For aggregation, we weight variables by -1 if a high value is associated with an advantage and +1 if a high value is associated with a disadvantage. Variables with unclear weight definition like

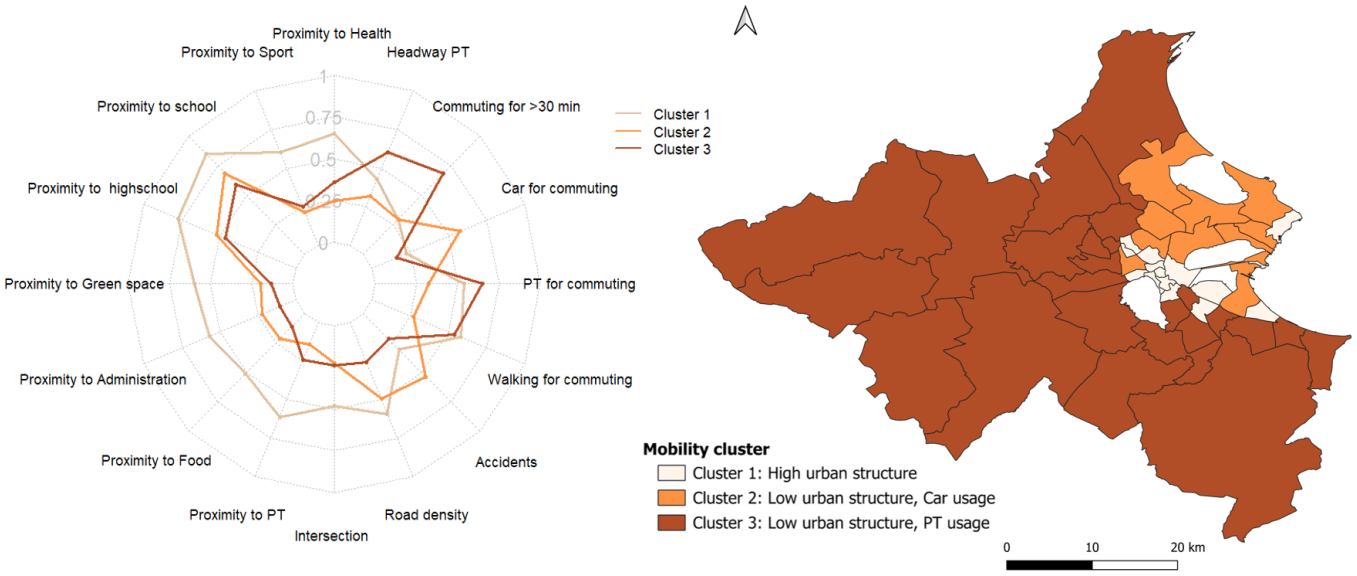

Figure 8: Grand Tunis delegations clustering based on mobility variables

	Mobility Cluster		
Social [%]	High urban (Cluster 1)	Low urban	
		Car usage (Cluster 2)	PT usage (Cluster 3)
Older people	**14.3***	12.3	10.3
Children	13.2	14.9	**16.7***
Teenagers	12.6	12.5	**13.9***
Unemployed	**14.3***	9.6	**15.7***
Intrant migrant	**9.2***	14.7	**9.2***
No car ownership	**67.2***	46.2	**71.2***
Poverty rate	4.4	2.7	**8.6***

'*' means that the social group is significantly different to the reference cluster 2.

Table 2: Comparison social groups distribution within Grand Tunis mobility clusters

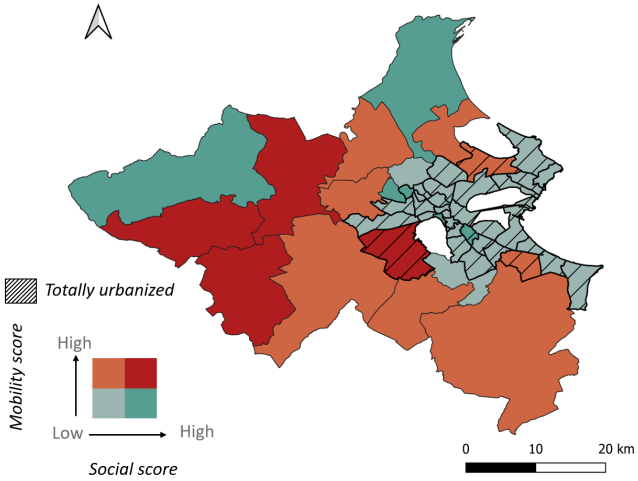

Figure 9: Aggregated social and mobility disadvantage score for Grand Tunis

the mode used for commuting are excluded. The scores are then normalized from 0 to 1. A score above 0.75 indicates a high social or mobility disadvantage. Figure 9 shows that the areas with low mobility injustice, defined as a low mobility score and and a low social score, are the ones in highly urbanized regions.

4.4. Outputs

4.4.1. Vizualization and Stakeholders Feedback

The Atlas designed for Grand Tunis describes the mobility poverty in the delegations, offering two outputs for citizens and decision-makers. First, the calculated variables are accessible through an online visualization tool: https://cyrkafrde.github.io/Altas_MJ_TN. This tool enables users to explore the distribution of social groups and transport disadvantages across delegations. It also highlights areas exposed to mobility justice, where high social disadvantage and transport disadvantage meet.

The website was presented to a previously interviewed stakeholder from AUGT to gather her feedback for future enhancements of the tool. Regarding the social groups, the stakeholder considers including women and various professional categories important as well as having an atlas with a more detailed spatial scale. Unfortunately, professional category and more disaggregated data are not available on open source. In addition, the stakeholder recommended having variables at a more disaggregated scale due to a high heterogeneity within some delegations. A

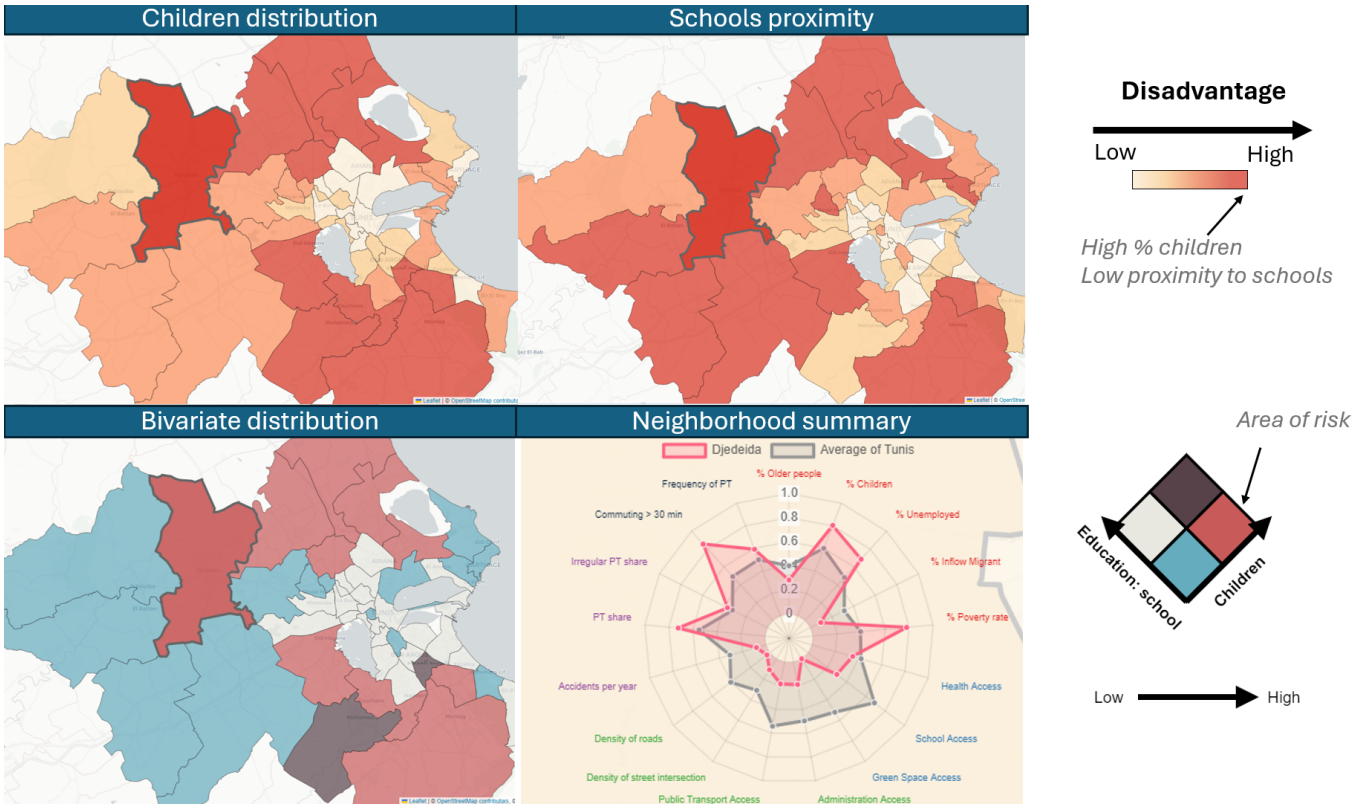

Figure 10: An example of how to use the web tool: children and proximity to school

sector-based scale was proposed as a more appropriate alternative to address this issue. However, data at this finer scale are not available in open source in the census.

In addition, the variable for public transport headway was considered confusing and not representative of user experiences. Indeed, if two bus stops are in the center of an area with a headway of 20 minutes for one and 1 hour for the second, the average headway in the area is 40 minutes. In reality, people might choose the high-frequency bus more often because of the destination it reaches. A suggested improvement by the stakeholders involves focusing on the minimum headway. Classifying public transport quality rather than providing an average headway can be a second option to improve this indicator[8].

4.4.2. Recommendations of Use for Decision-makers

The Mobility Injustice Atlas of Tunis highlights the situations of mobility injustice and their location to inform decision-making on areas where interventions are needed. How can the Atlas be used for decision-making? A first step consists on identifying from the correlation matrix a risky mobility injustice situation. After defining it, stakeholders have two primary approaches to identify areas facing search an injustice. They can use the online visualization tool to target specific delegations for intervention. Alternatively, and for a broader strategy, they can identify which delegation cluster faces this injustice. This cluster-based approach enables the development of an aggregated action plan.

Finally, the mobility and social scores indicate high disparities between fully urbanized delegations and mixed-use delegations within Grand Tunis. Although the study focuses on the built-up area, the delegations with rural zones have distinct mobility and social challenges. This remark underscores the need for targeted studies and measures on these areas to deepen into the conditions of the inhabitants.

5. Limits of The Study

5.1. Case Study Considerations

When designing the Mobility Injustice Atlas for Tunis, interviews were conducted to include specificities of the study area, such as the predominance of car usage and the existence of irregular transport. However, the limited number of interviews, affecting the depth of the stakeholder perspectives included. In addition, the absence of certain data excluded structuring variables such as irregular transport stops, exposure to congestion, safety and comfort. Finally, due to a lack of local population distribution data, some proximity variables are estimated based on the built-up area to approximate proximity of populations. The built-up area aims to approximate population

[8] https://www.are.admin.ch/dam/are/de/dokumente/verkehr/oev-gueteklassen-berechnungsmethodikare.pdf.download.pdf/oev-gueteklassen-berechnungsmethodikare.pdf

locations. However, the ESA's defines built-up area as any constructed area, including roads (though corrections are made), industrial zones, and settlements. This definition does not accurately reflect the proximity of populations to services.

The current method for calculating an aggregated mobility and social disadvantage score is simplistic: it treats all variables equally. A proposed method to improve the score significance is adopting an Analytical Hierarchy Process (AHP) to assign weights to variables based on stakeholders' perception of their importance (Darko et al. (2019)).

5.2. Framework Considerations

The methodological framework designed in this study offers a structured and scalable approach for creating a Mobility Injustice Atlas. It allows the integration of area-specific consideration by involving stakeholders in the atlas design. A guideline of variables structure and of examples of variables from Munich and Tunis case studies, provides a starting point for future adaptations. However, these cities cannot fully describe the different mobility and social structures across the world. Therefore, the guideline needs to be further improved to provide a more complete list of potential variables.

In the distributive justice theory applied in this study, a resource allocation is fair when it respects the three-justice rules: equity, equality, and need (Colquitt and Rodell (2015)). However the rules are generally not sufficient to understand individuals real needs and how they perceive the equity of a situation. This subjective perception of equity is named as the fairness approach (Cropanzano et al. (2015)). One suggested approach in the framework to understand citizens' perceptions is to measure safety and comfort through both data and surveys, yet it has not been tested in the cases study of Munich and Tunis.

Finally, while the framework provides a detailed methodology for analysing mobility poverty, it falls in exploring procedural justice in the study area. But procedural justice is an essential lever to achieve an improvement the equity. Indeed, when decision process integrates a variety of citizens perspectives, mobility plans have more chances to include citizens needs.

6. Conclusion

This study on mobility injustice transferred a tool from Global North perspective to Global South perspective, from Munich to Tunis. By including the specificities of the area, the atlas provides a first overview of injustice in Grand Tunis. Children being far from the schools, non-car-owners living where public transport is less frequent, people with low income living far from basic needs and in areas facing high accident risk. These critical situations should be included in Grand Tunis mobility and urban planning to provide equitable chances for these vulnerable groups.

Not only are there two Mobility Injustice Atlases, but this study also provides a framework to design atlases for cities over the world. The framework is generic and provides a list of potential variables based on Tunis and Munich atlases. Further research can be oriented to improve this framework by providing a complete list of variables and by implementing the methodology to calculate the safety and comfort index since it has not been applied yet in the atlases presented in this paper.

Mobility justice is about providing equitable transport and urban options for everyone no matter their capacities or the city they live in. But,is mobility justice limited by city borders? Further research can compare the main mobility injustices in Tunis and Munich to see whether these injustice are specific to a city or global.

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