Cartography M.Sc.

A Comprehensive Study on Bike Sharing Mobility in the City of Munich: Utilizing Community Detection Method

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2 Research Identification
3 Related Work
4 Workflow, Data & Methodology
5 Case Study & Results
6 Conclusions

1. Motivation

Background

- Bike Sharing Systems
  - Solution to **the first/last mile problem**.
  - Promotes **Sustainable** Urban Environments
  - Offers Cardiovascular Advantages
  - Reduces Travel Costs & Duration

- People use bicycles when they need mobility, without the expenses and responsibilities of owning a bike. Bike-sharing allows temporary access to bicycles, as an eco-friendly option for public transportation for its users and this temporary access to the system focuses on daily mobility, enabling individuals to conveniently benefit from public bikes.

MVG Rad Bike Station.

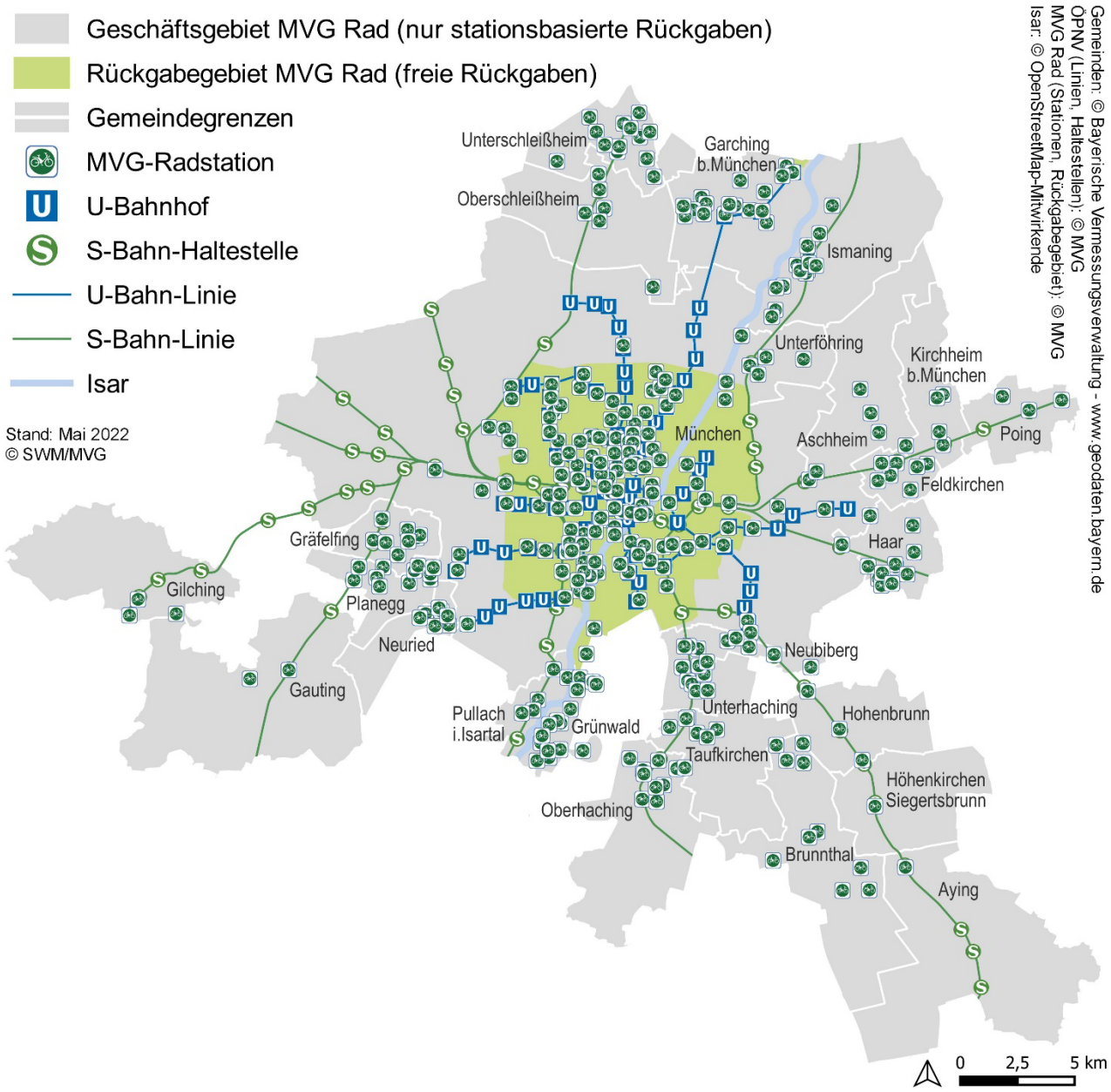
1. Motivation

Background

The spatial pattern of the human mobility is complex due to spatial and temporal heterogenety and needed to be detected.

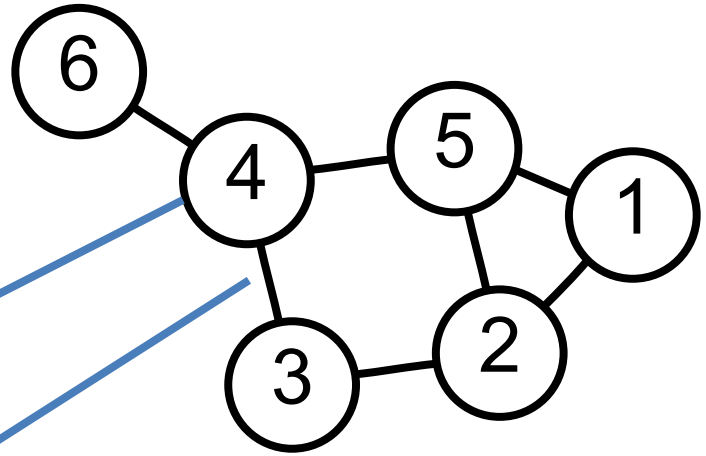
It can be far more extended from defined spatial units.

We can abstract bike sharing as a graph.

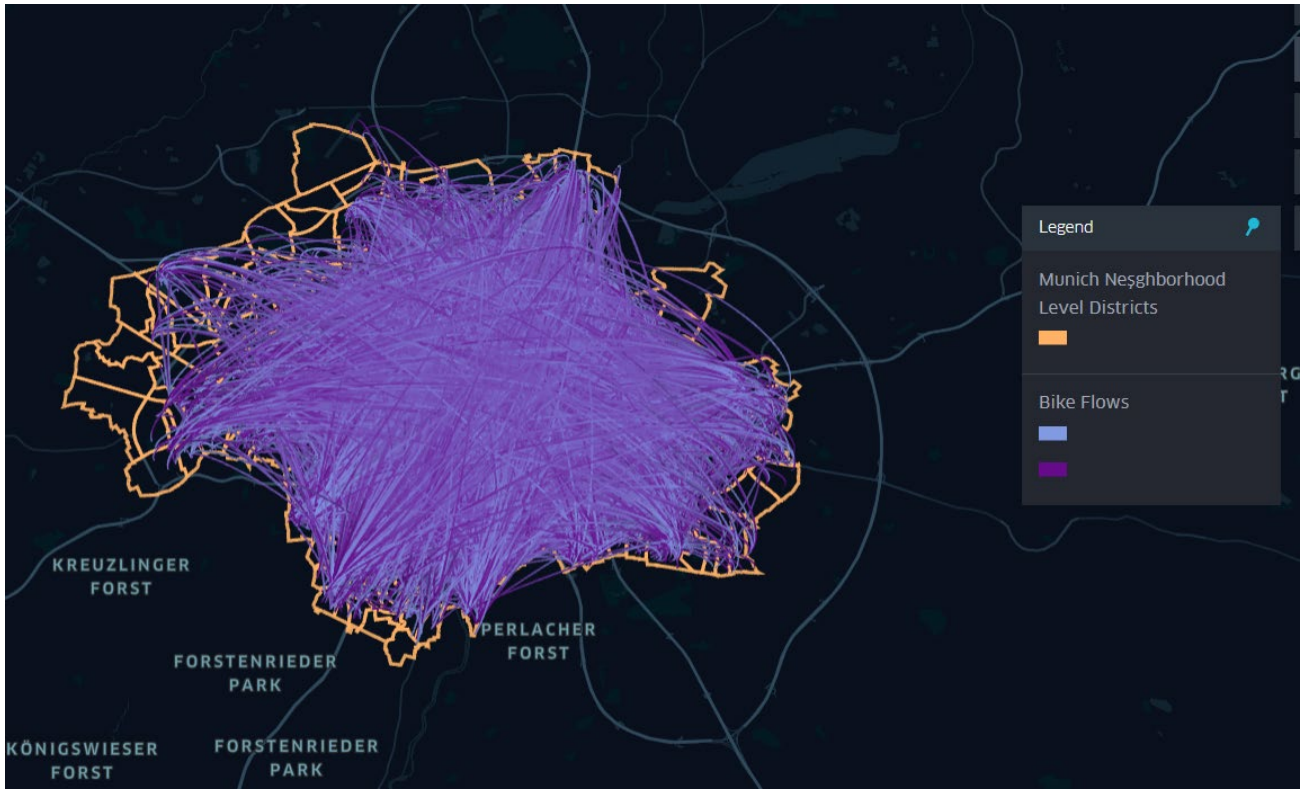


1. Motivation

Background



- Nodes
- Edges
- Problem in Graph Theory;
  - Finding clusters, modules or communities in a complex network
  - The community detection method determines clusters or modules that have more intra-region journeys than inter-region journeys within bike-sharing mobility data. The goal of such algorithms is to understand spatial patterns of bike share traffic from a network viewpoint and validate spatial pattern analysis methods (Song et al., 2021).



- Maps are planar graphs..
- Human mobility consist of the geospatial graph
- Nodes are spatial units
- Edges are traffic flow betweeen spatial units

1. Motivation

2. Research Identification

RO: Develop a spatiotemporal analysis workflow to model dynamic community structures of bike share usage.

RO 1.1: Evaluate existing spatiotemporal analysis methods that are used to extract bike share travel behavior.

- **RQ 1.1.1.** What are the current spatial pattern analysis methods of hybrid bike share system usage?

RO1.2: Adopt novel network analysis methods (dynamic community detection methods) to extract cluster/community structures.

- **RQ 1.2.1.** What would be the most suitable temporal time unit for the adopted method?
- **RQ 1.2.2.** What additional attributes or parameters could be used to extract meaningful information in a network?
- **RQ 1.2.3.** How would semantic information assign to communities?

RO1.3: Implement and evaluate the proposed workflow as an application of Urban Transport Planning and analyze travel patterns of hybrid bike share usage.

- **RQ 1.3.1.** Can community detection methods help to extract travel purposes?
- **RQ 1.3.2.** Is there any benefit of defining changing communities?

3. Related Work

Developing a spatiotemporal analysis workflow to model dynamic communities of bike-sharing systems is a complex objective to achieve. A collabration between various domains such as Urban Trasport Planning, Cartography & GI Science, and Graph Theories is necessary.

RQ 1.1.1. What are the current spatial pattern analysis methods of hybrid bike share system usage?

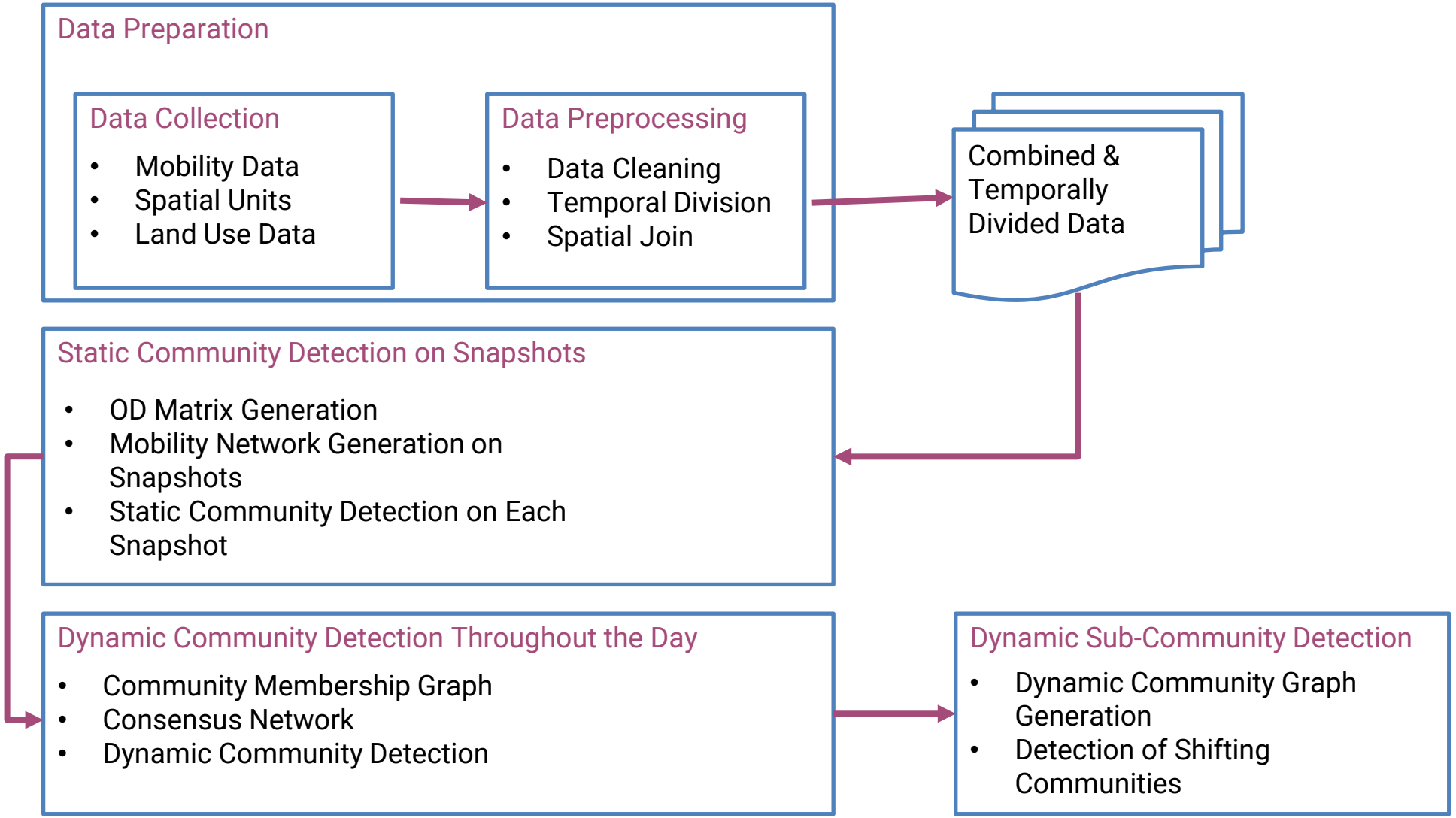
Study	Main Focus	Key Findings
Rixey (2013)	Factors Influencing Bike Sharing Ridership	Various factors including total population, job types, income levels, alternative commuting habits, education, parks, bikeways, etc., significantly influenced bike-sharing ridership. - Network effects played a crucial role in shaping ridership patterns across different cities' systems.
Reiss & Bogenberger (2015)	Insights from Munich's "Call a Bike" System	- Heavy users (20% of customers) accounted for 80% of all trips. - More than 50% of customers rode a bike less than 5 times a year. - Seasonal and temporal patterns observed in bike-sharing usage, with commuter peaks on weekdays and recreational use on weekends.
Zhou (2015)	Spatiotemporal Analysis of Chicago's Bike Share	- Bike flow patterns varied by time, weekdays/weekends, and user types. - Inbound trips dominated during morning peak hours, while outbound trends were observed during afternoon peak hours. - Different clusters of trips identified, indicating distinct travel patterns.
Y. Zhang et al. (2017)	Built Environment Factors' Impact on Bike Sharing	- Population density, bike lane length, secondary road length, mixed land-use types, and nearby stations positively affected trip demand and demand-to-supply ratio (D/S). - Range to the city center had a negative influence. - Spatial correlations of bike share usage between nearby stations were assessed using a spatial weighted matrix.
Albiński et al. (2018)	Performance of Munich's Bike-Sharing System	- Hexagonal partitioning used for analyzing censored demand. - Reservations mainly made for free-floating bikes. - Differences in system performance observed between highly-used and low-used districts. - Higher availability and fill rates in highly used districts and at bike stations.
McBain & Caulfield (2018)	Factors Affecting Trip Duration in Cork's System	- Influential factors in trip duration variation included station locations, temporal patterns (morning and evening peaks), one-way streets, station types, cycle-friendly routes, nearby amenities, public transport links, and user type.

3. Theoretical Background & Related Work

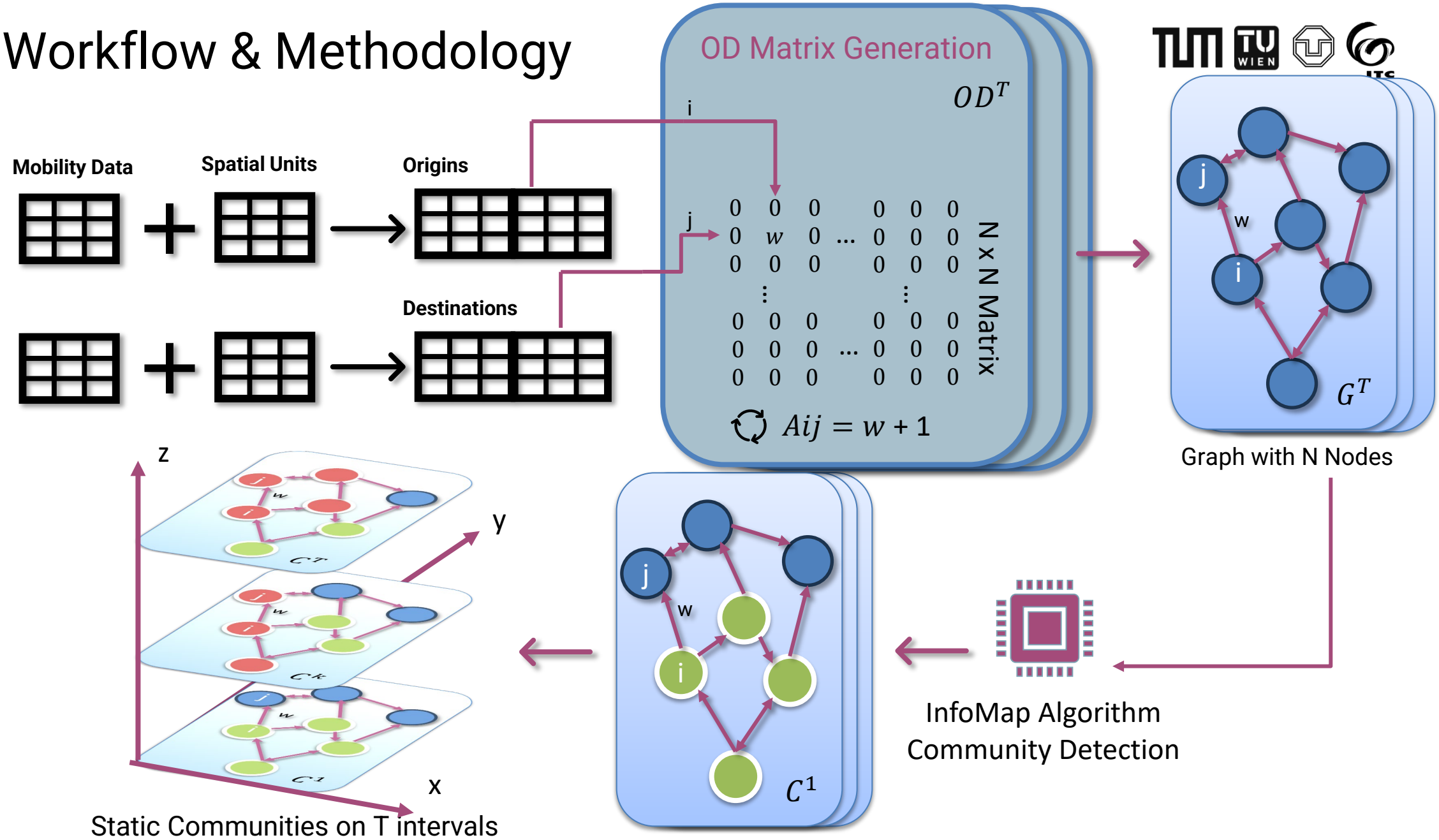
Bike Sharing Systems & Users' Travel Behaviour

Demographics	Travel Behavior	Built Environment
•Higher Income and Education Level •More likely to be male •Low cycling level --> Male •Strong cycling level --> Women •Young Adults (28 – 38 years) •Most likely to have a car •1.5 Times higher possibility to have driver licence	•Mostly preferred <30 Ĉ , no pericipitation, low wind •For shorter trips complementary, for longer trips bus substitudes bikes •Demand at night when public transport is not avilable •No big difference during weekdays and weekends, only time changes •Weekend ⍰ Parks, Weekdays ⍰ Commuting •Weekday usage peaks 7 am – 9 am, 4 pm. – 6 pm., Weekends middle of the day •Average duration 16-22 mins. •Convenience major motivation to use bs •Mostly between 200m to 400m	•More bicycle usage with high level of bicycle infrastructure •Seperated bicycle lanes from motor traffic, increases safety (convinience) •Mixed lanuse population density, employment areas positively correlated. •Proximity to green spaces, universities, museums, shopping centers, restaurants, bus/subway/ferry transit hubs has positive effect on the use of Bike share systems. •Higher density and more diverse land use regions prefer non-motorized travel modes. •Street lights, station connectivity positively correlated •First/Last mile solution

4. Workflow & Methodology



4. Workflow & Methodology



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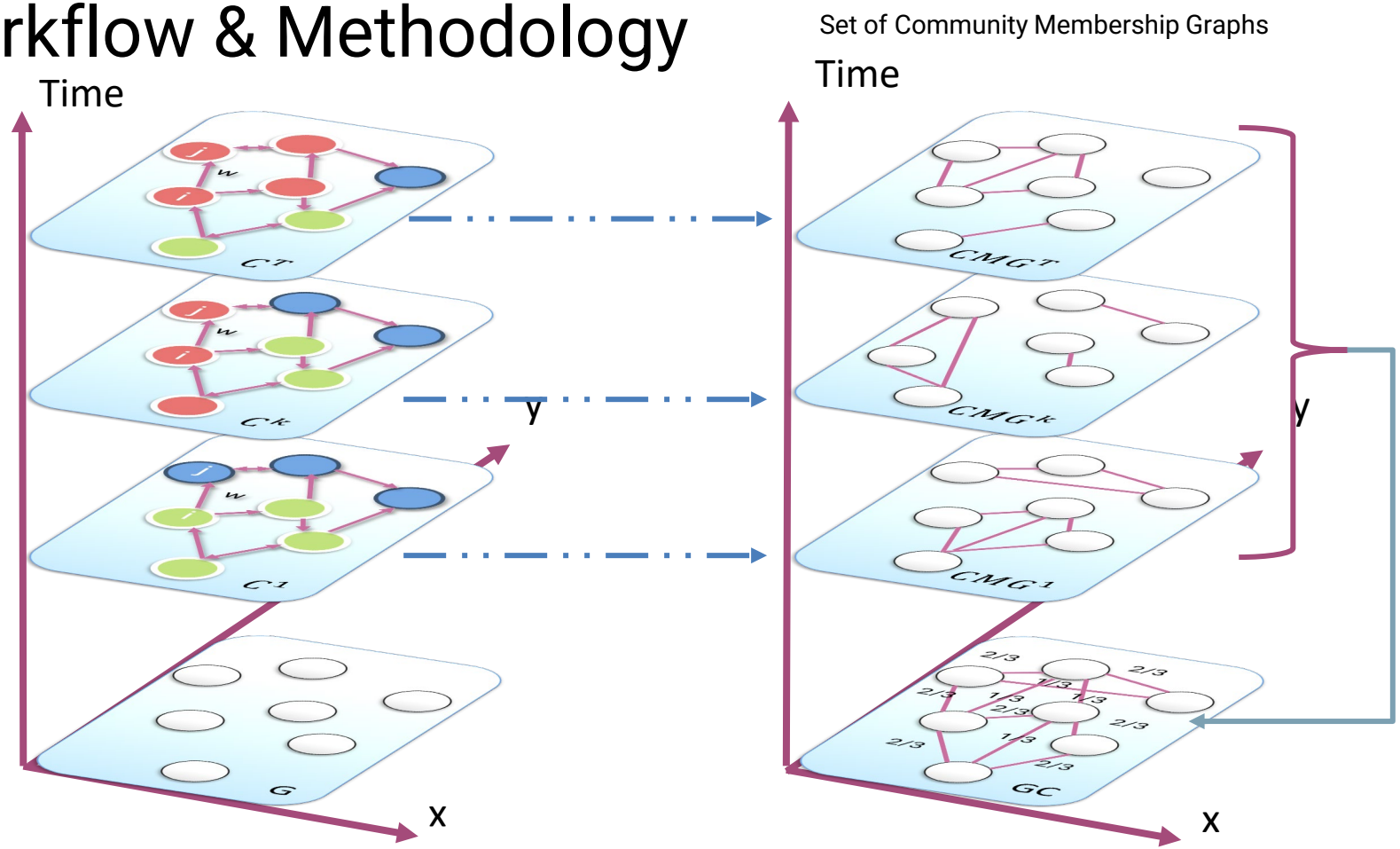
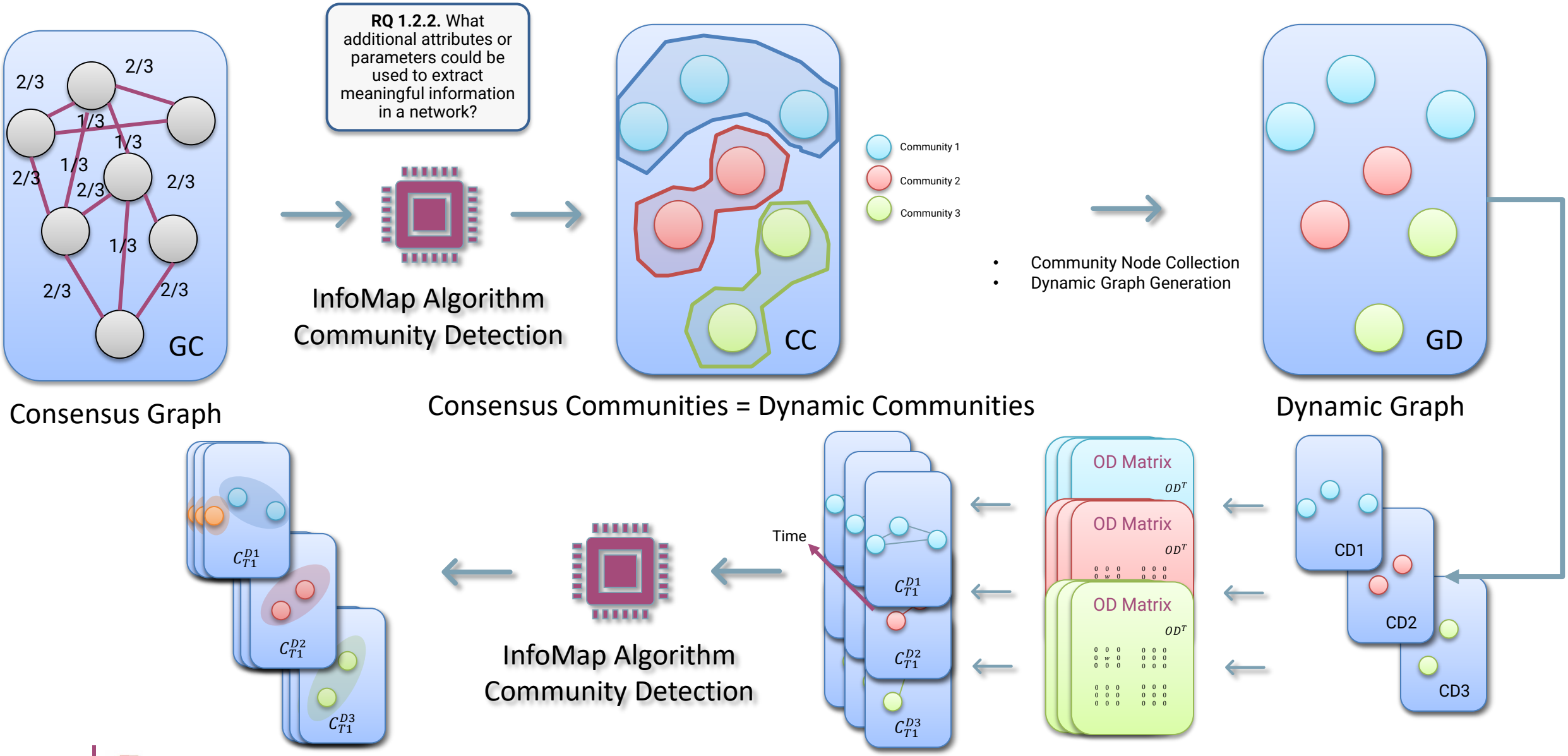


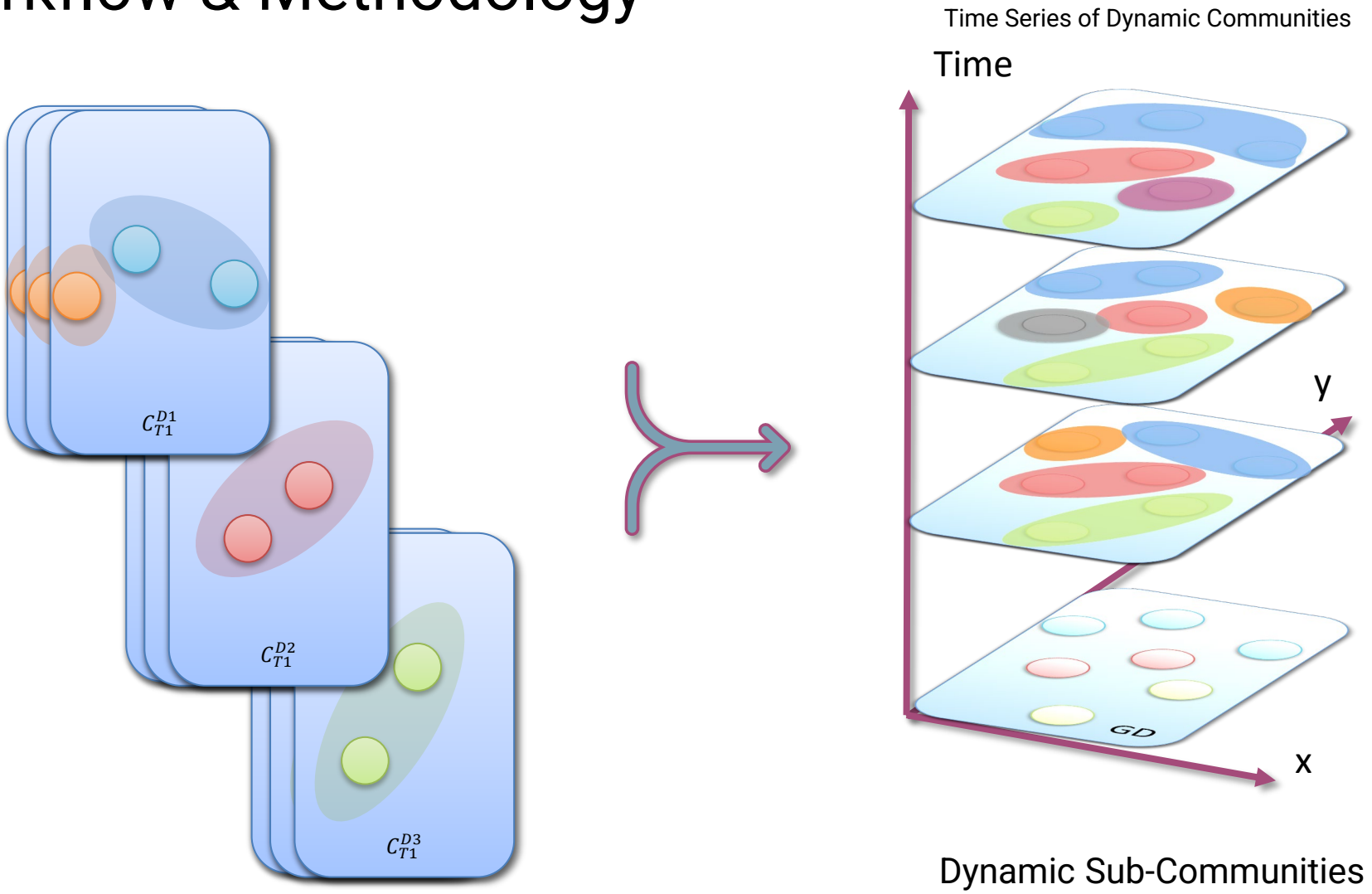
Time Series of Static Communities

Construction of Consensus Network

4. Workflow & Methodology



4. Workflow & Methodology

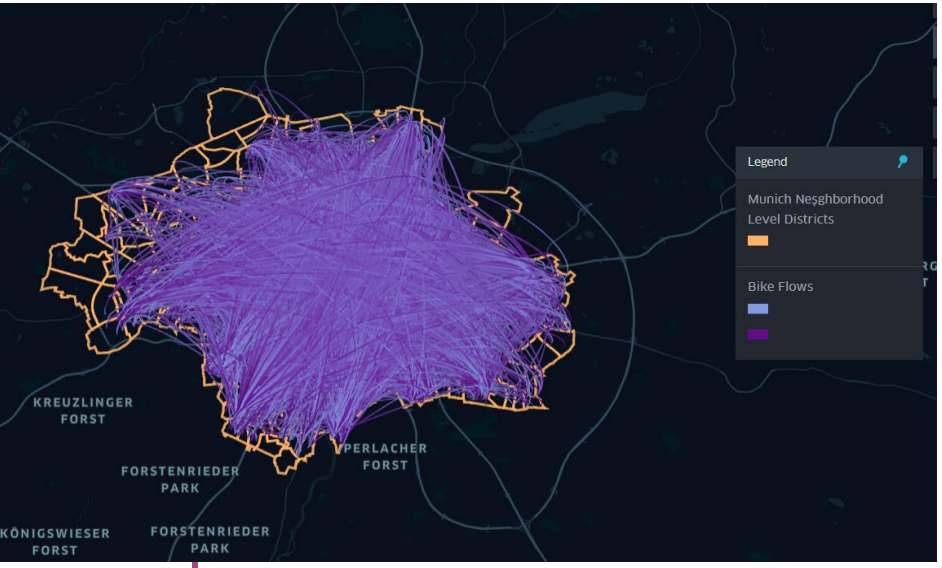


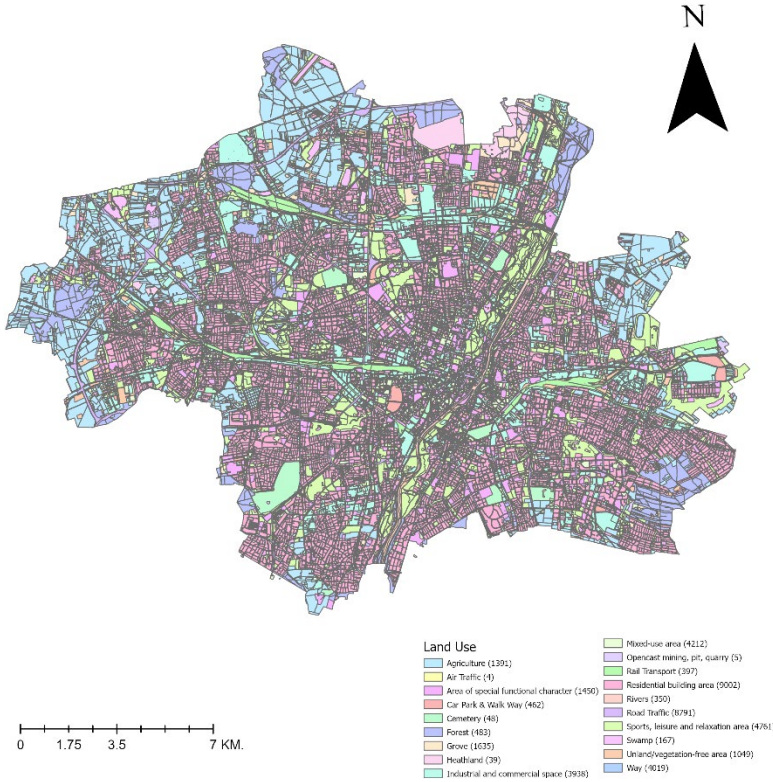
5. Case Study & Results

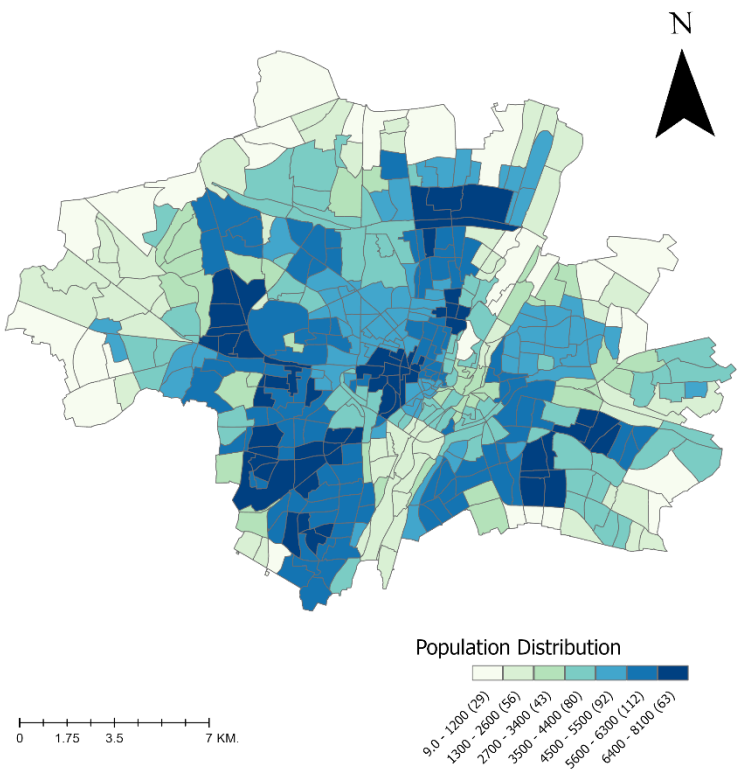
Test Data & Study Area

RQ 1.2.3. How would semantic information assign to communities?

OID_	Row	STARTTIME	ENDTIME	STARTLAT	STARTLON	ENDLAT	ENDLON	RENTAL_IS_	RENTAL_STA	RETURN_IS_	RETURN_STA
1	1	1/1/2022 0:00	1/1/2022 0:00	48.13658	11.59283	48.14159	11.59721	0		0	
2	2	1/1/2022 0:00	1/1/2022 0:00	48.13659	11.59282	48.14165	11.59701	0		0	
3	3	1/1/2022 0:00	1/1/2022 0:00	48.16849	11.55028	48.15526	11.54012	0		1	Albrechtstrasse
4	4	1/1/2022 0:00	1/1/2022 0:00	48.16852	11.5502	48.15526	11.54012	0		1	Albrechtstrasse
5	6	1/1/2022 0:00	1/1/2022 0:00	48.16862	11.55234	48.15288	11.56669	0		0	
6	7	1/1/2022 0:00	1/1/2022 0:00	48.14159	11.59721	48.14255	11.57747	0		0	
7	8	1/1/2022 0:00	1/1/2022 0:00	48.14165	11.59701	48.13715	11.57639	0		0	
8	9	1/1/2022 0:00	1/1/2022 0:00	48.14517	11.5934	48.14315	11.58409	0		0	
9	10	1/1/2022 0:00	1/1/2022 0:00	48.15791	11.52835	48.1544	11.53304	0		0	
10	11	1/1/2022 0:00	1/1/2022 0:00	48.10874	11.57478	48.11176	11.56994	1	Wettersteinplat	1	Candidplatz
11	12	1/1/2022 0:00	1/1/2022 0:00	48.15068	11.60936	48.16323	11.62491	1	Herkomerplatz	0	
12	13	1/1/2022 0:00	1/1/2022 0:00	48.1305	11.54688	48.13777	11.54201	0		0	
13	14	1/1/2022 0:00	1/1/2022 0:00	48.15068	11.60936	48.16344	11.62505	1	Herkomerplatz	0	
14	15	1/1/2022 0:00	1/1/2022 0:00	48.13203	11.57647	48.13648	11.58005	1	Gaertnerplatz	0	
15	16	1/1/2022 0:00	1/1/2022 0:00	48.15514	11.56676	48.15563	11.56707	1	Josephsplatz	0	
16	17	1/1/2022 0:00	1/1/2022 0:00	48.11781	11.54917	48.11759	11.54886	0		0	
17	18	1/1/2022 0:00	1/1/2022 0:00	48.1514	11.57927	48.1538	11.57324	1	Amalienstrasse,	0	
18	19	1/1/2022 0:00	1/1/2022 0:00	48.14984	11.5845	48.14848	11.56548	1	Koeniginstrasse	0	
19	20	1/1/2022 0:00	1/1/2022 0:00	48.16107	11.56782	48.12825	11.5694	1	Hohenzollernpla	0	
20	21	1/1/2022 0:00	1/1/2022 0:00	48.16685	11.56458	48.15406	11.55351	0		1	Hochschule Mue
21	22	1/1/2022 0:00	1/1/2022 0:00	48.12095	11.56997	48.13183	11.5797	0		0	
22	23	1/1/2022 0:00	1/1/2022 0:00	48.12972	11.58652	48.14044	11.56814	0		1	Lenbachplatz
23	24	1/1/2022 0:00	1/1/2022 0:00	48.1306	11.57758	48.12214	11.56265	0		0	
24	26	1/1/2022 0:00	1/1/2022 0:00	48.13648	11.58005	48.12572	11.5603	0		0	
25	27	1/1/2022 0:00	1/1/2022 0:00	48.18192	11.52992	48.18632	11.52607	1	Olympia-Einkau	0	
26	28	1/1/2022 0:00	1/1/2022 0:00	48.13363	11.54453	48.13778	11.54194	1	Schwanthalerho	0	
27	29	1/1/2022 0:00	1/1/2022 0:00	48.18067	11.59364	48.15514	11.56676	1	Marianne-Branc	1	Josephsplatz

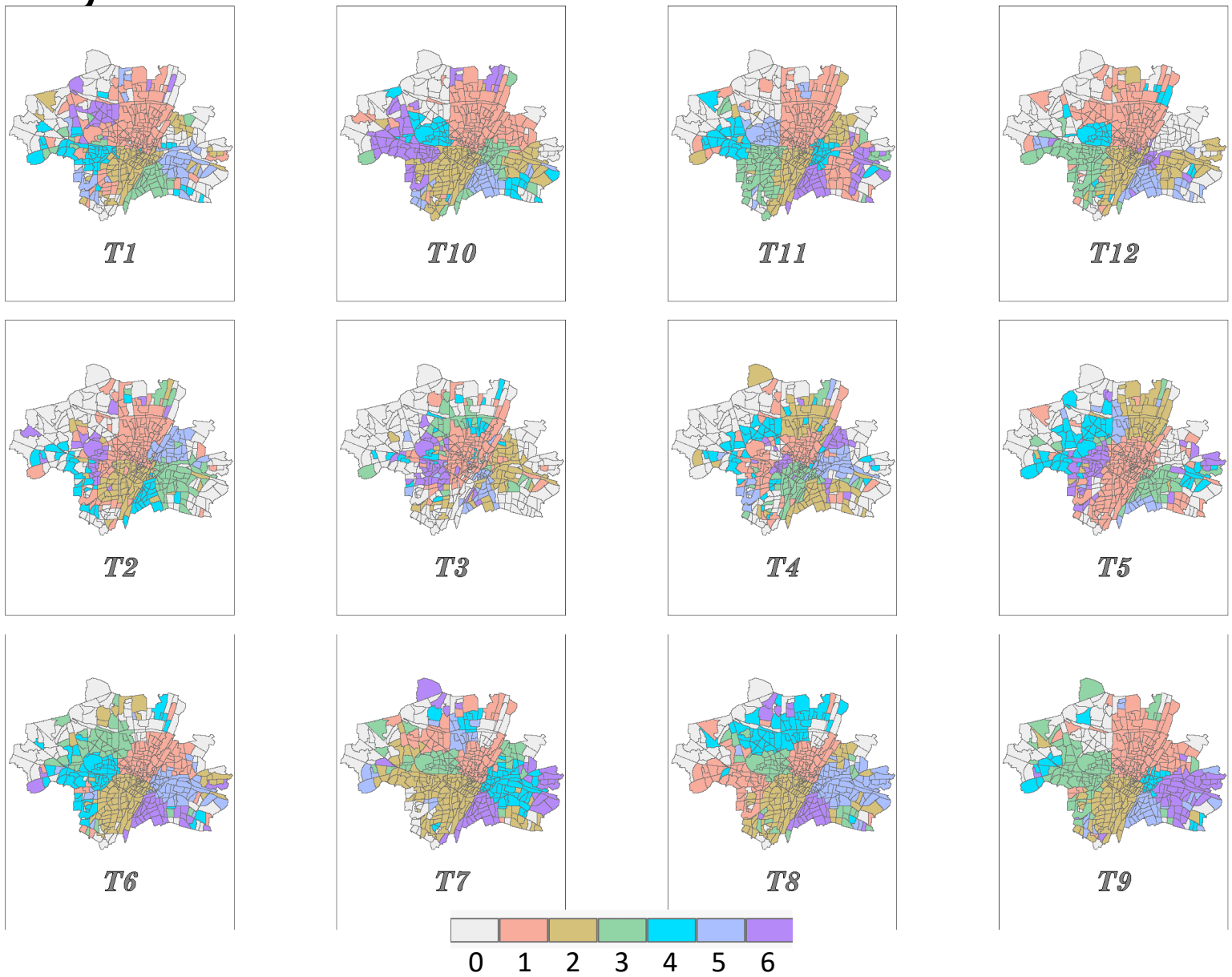






5. Case Study & Results *Static Communities*

RQ 1.2.1. What would be the most suitable temporal time unit for the adopted method?



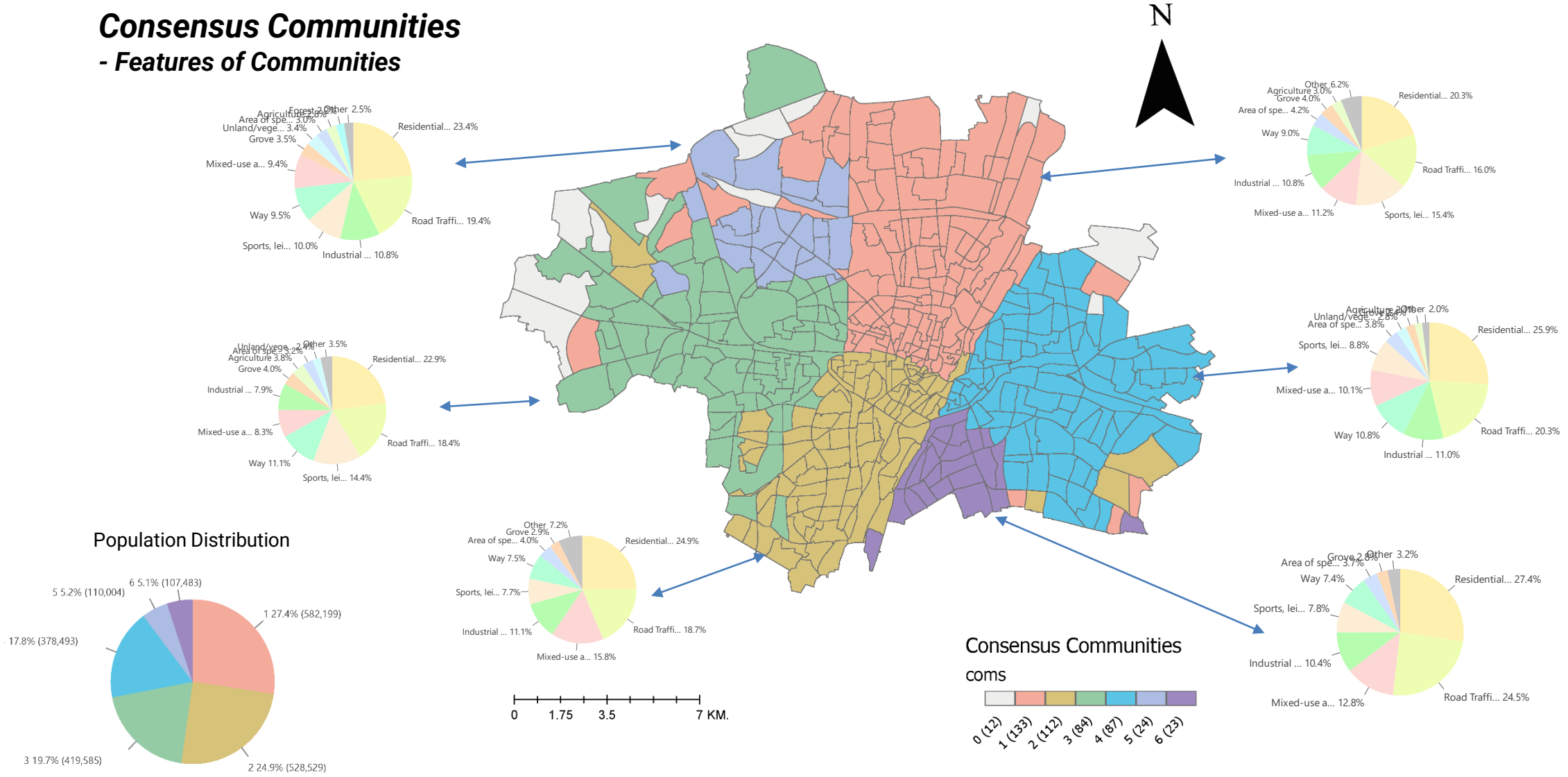
$$\Delta T = 2h$$

$$T1 = 00:00 - 02:00$$

5. Case Study & Results

Consensus Communities

- Features of Communities

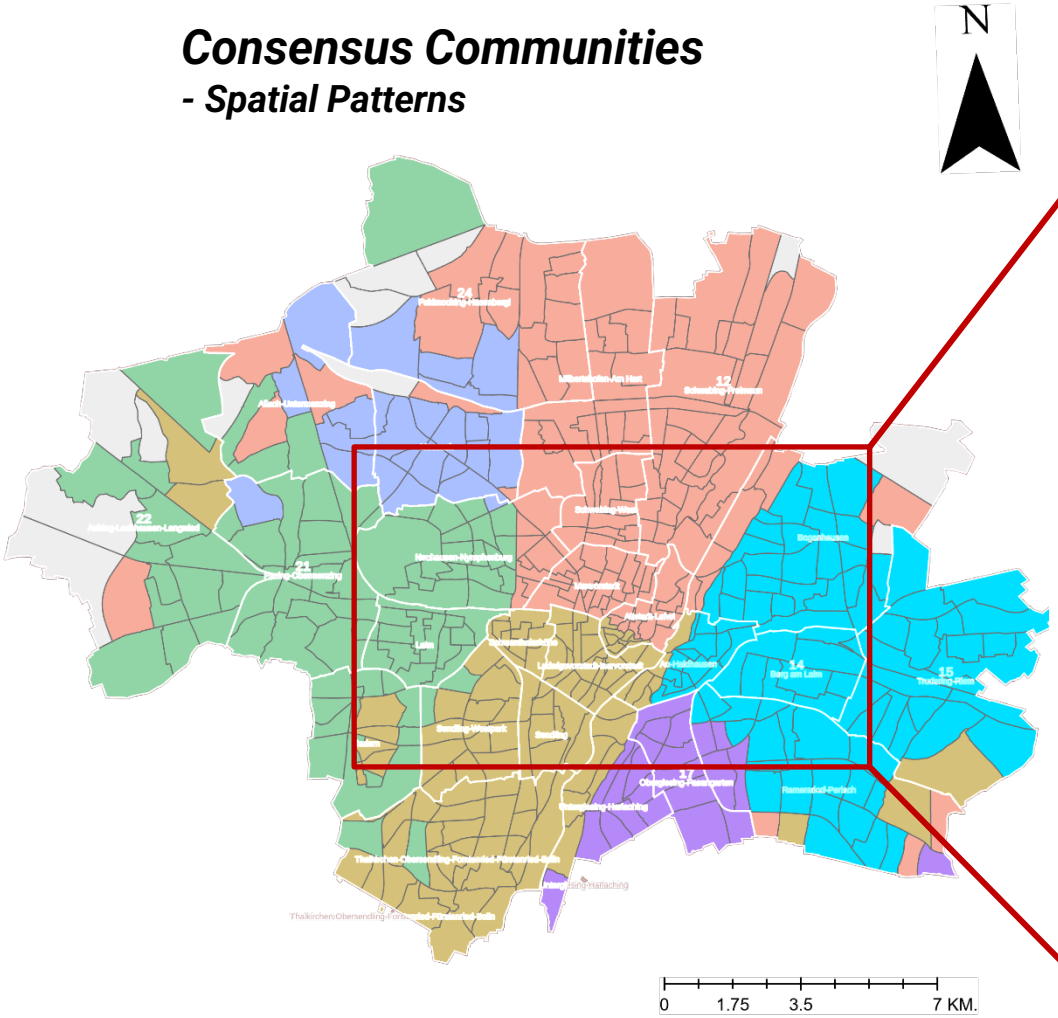


5. Case Study & Results

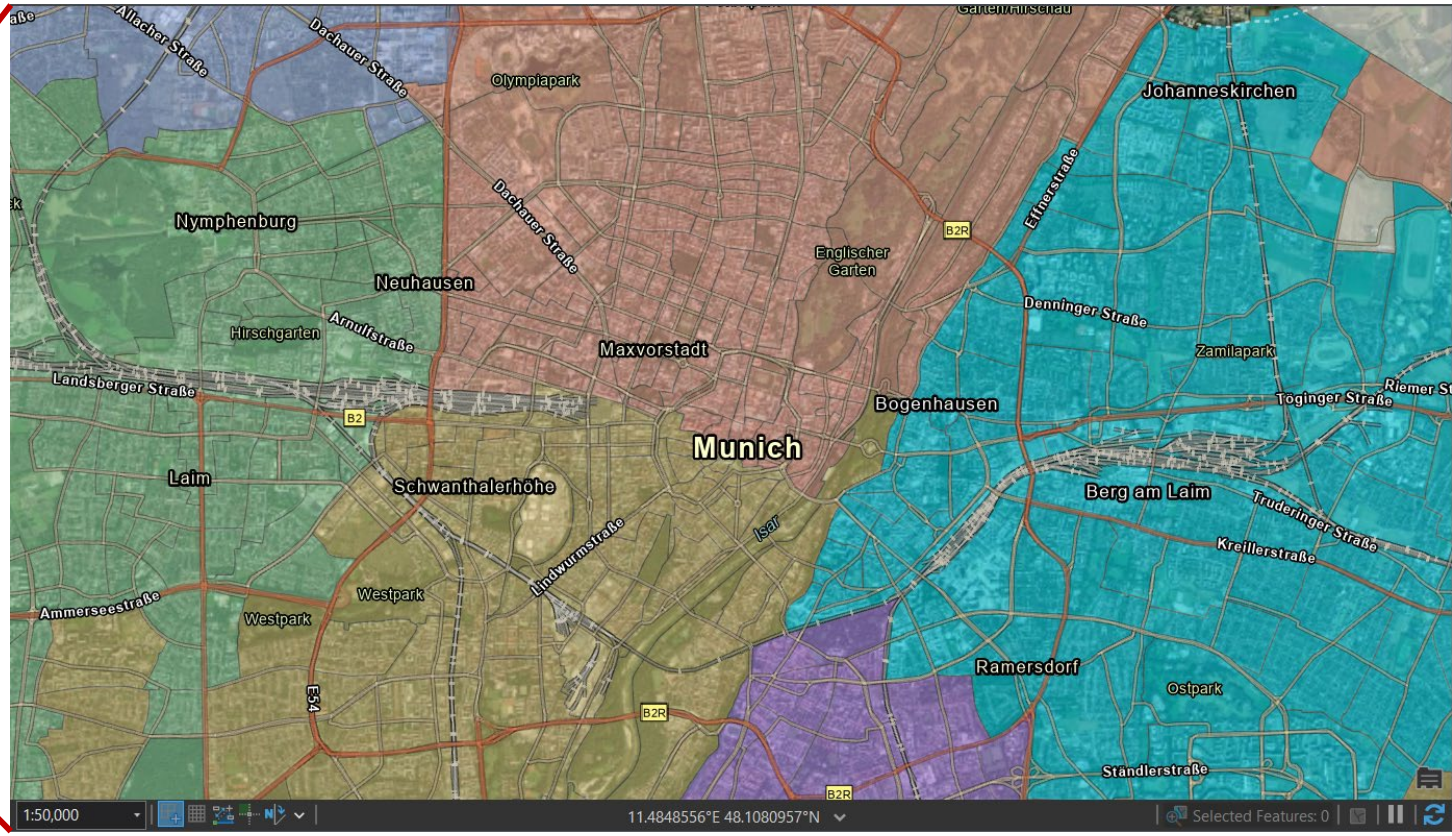
RQ 1.3.1. Can community detection methods help to extract travel purposes?

Consensus Communities

- Spatial Patterns



Comunity Boundaries



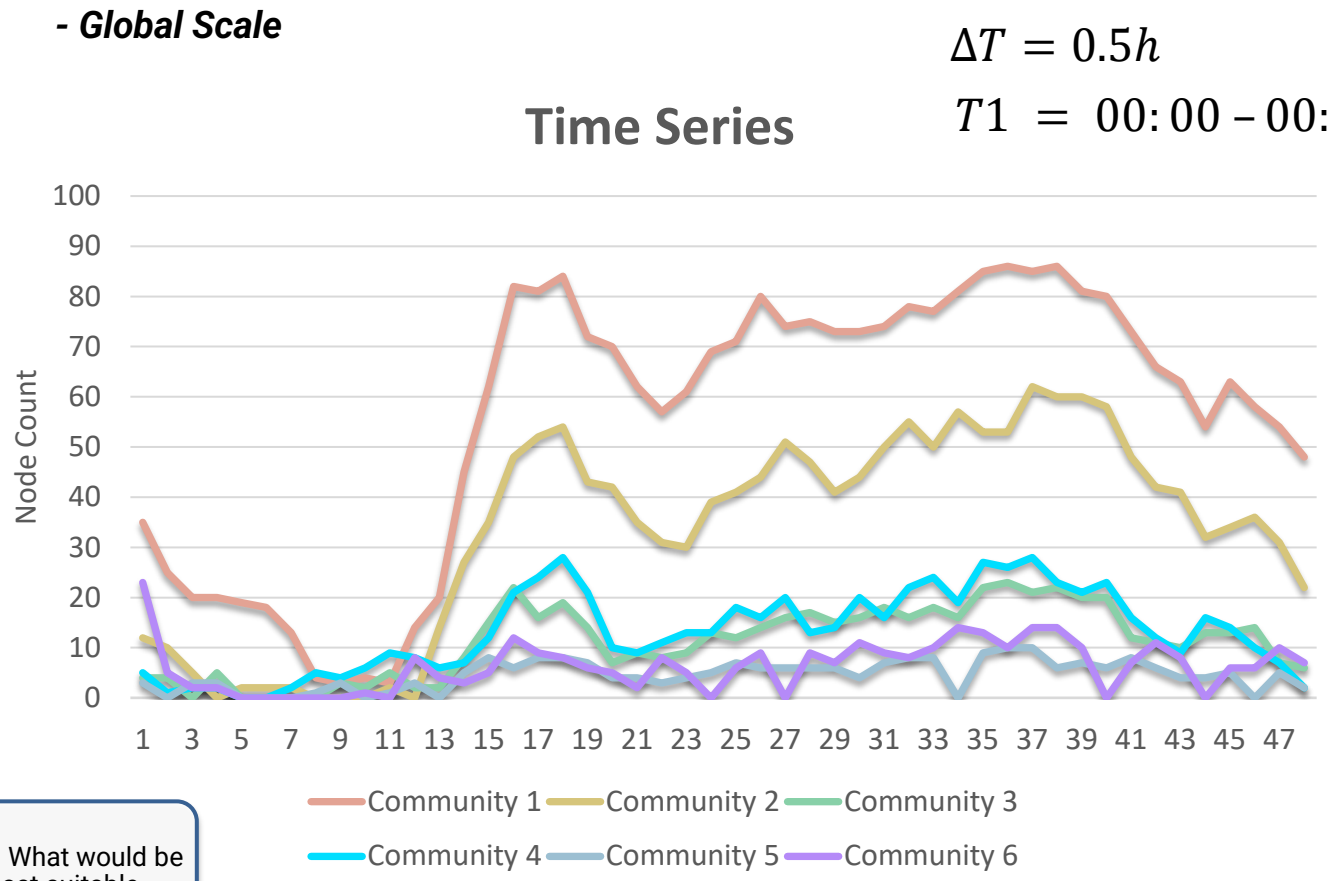
5. Case Study & Results

Dynamic Sub-Communities / Daily Rythm of Human Mobility

- Global Scale

$$\Delta T = 0.5h$$

$$T1 = 00:00 - 00:30$$



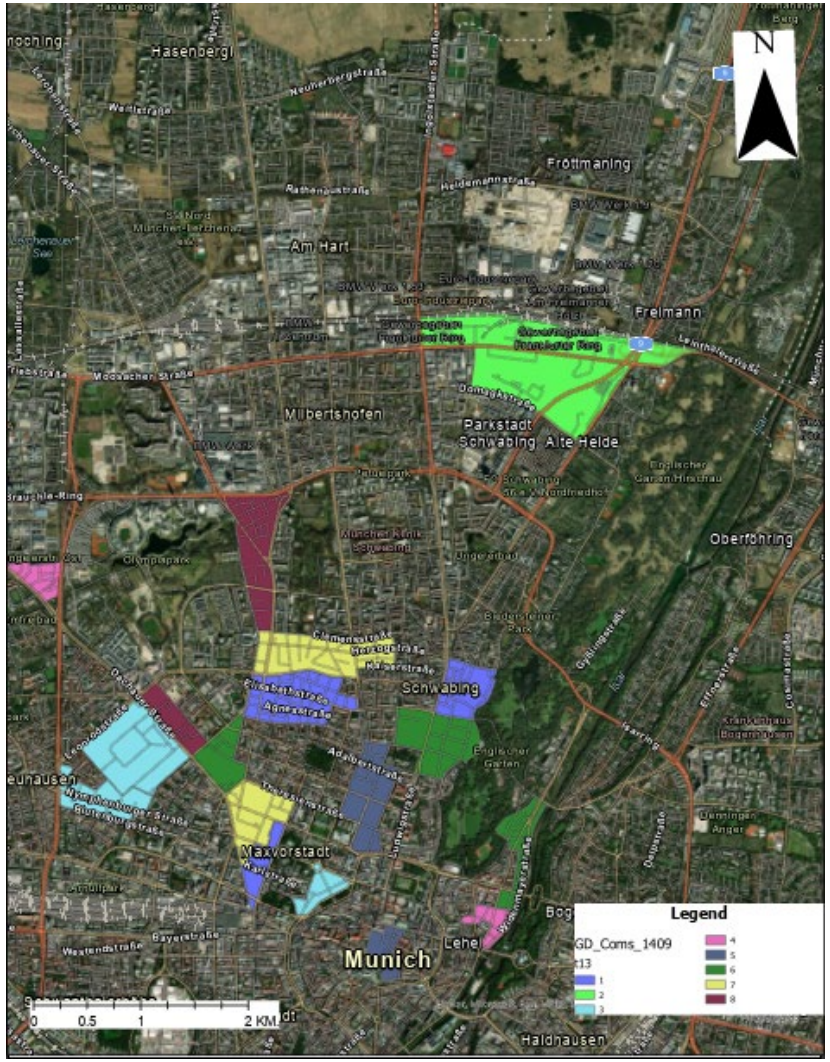
RQ 1.2.1. What would be the most suitable temporal time unit for the adopted method?

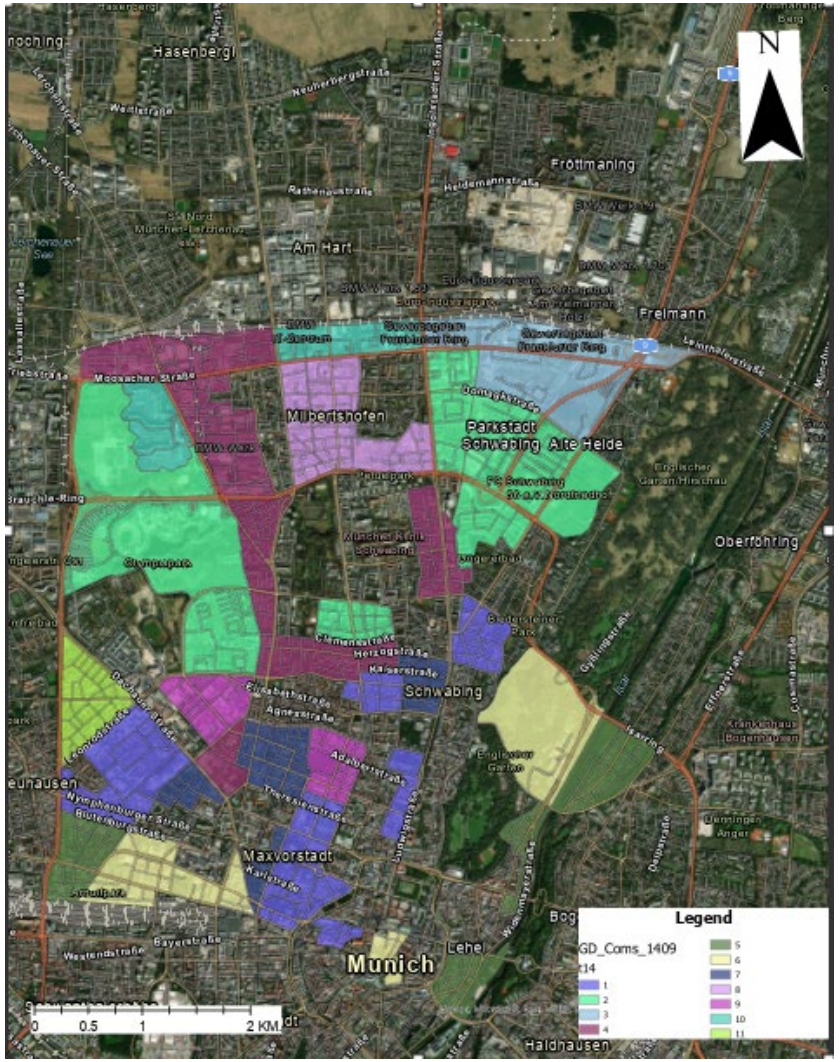
5. Case Study & Results

Dynamic Sub-Communities

- Local Scale

06:30 – 07:30





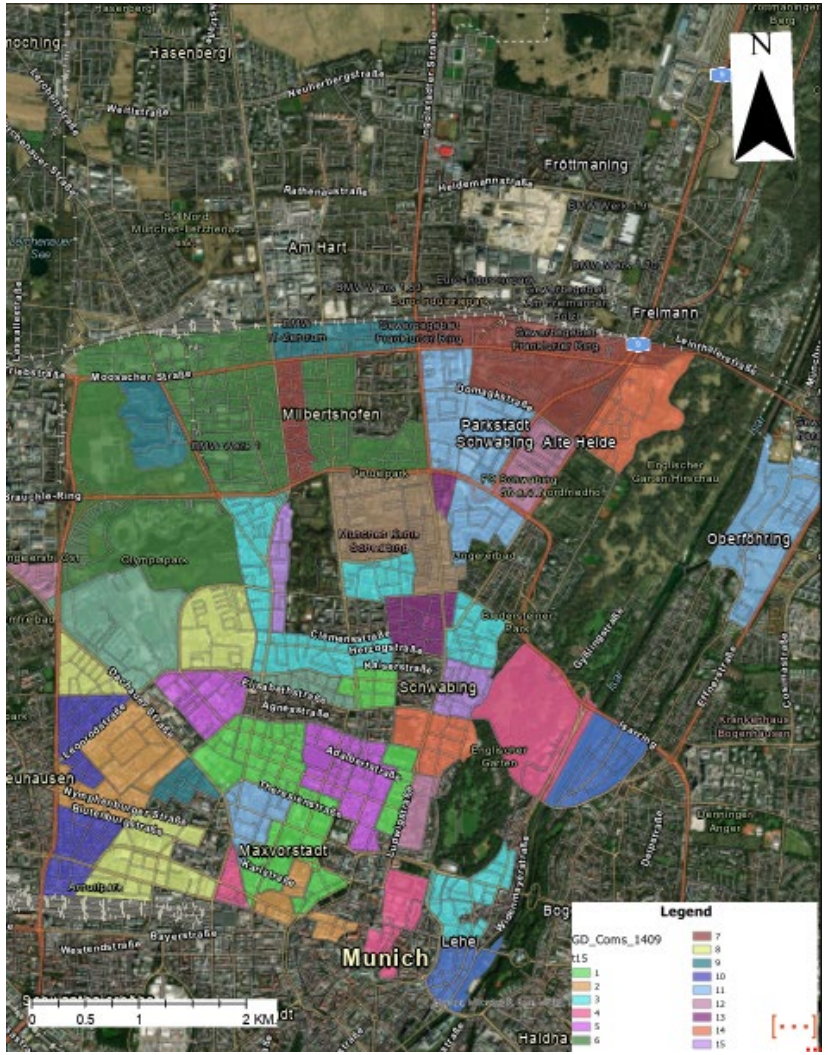
5. Case Study & Results

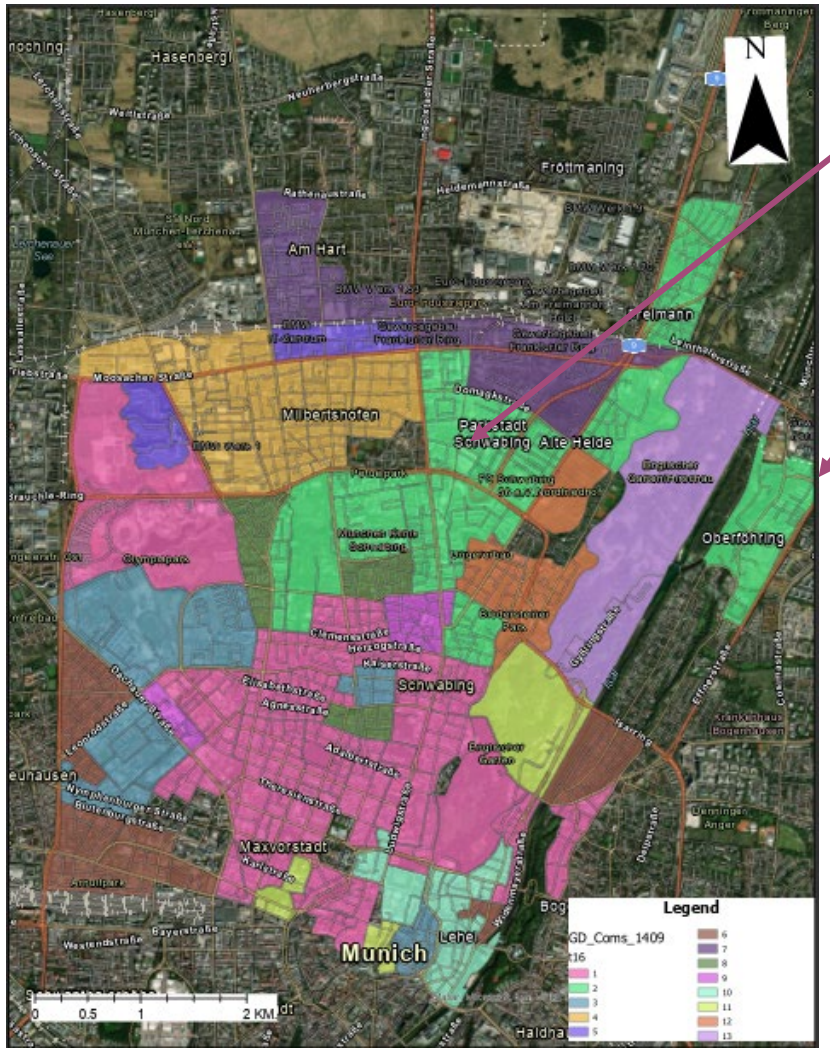
RQ 1.3.1. Can community detection methods help to extract travel purposes?

Dynamic Sub-Communities

- Local Scale

07:30 – 08:30





Schwabing (Residential) – Oberföhring(Grundschule)

RQ 1.3.2. Is there any benefit of defining changing communities?

5. Case Study & Results

Discussion

- ***Travel Behavior & Built Environment:***
  - Human mobility is highly affected by physical barriers within the city such as railways, highways, rivers, forests, private zones etc.
  - Number of connected spatial units sigficantly increases during rush hours (06:00 – 08:30, 17:00 – 19:30), and size of the communities remains consistent in between rush hours.
- ***Bike Sharing System:***
  - Operators can use defined communities for bike deployment to provide better service by meeting customer demand.
  - Operators can focus on the regions where communities are not strongly connected
  - Dividing operation area into communities can help operators to focus on specific regions on specific time intervals to reduce repositioning efforts. This can help to reduce CO2 emission and promote sustainable systems.

- Com1 → Olympiapark & Maxvorstadt
- Com2 → Ludvigsvorstadt & Untergiesing
- Com3 → Laim & Nymphenburg
- Com4 → Berg am Laim & Zamdorf
- Com5 → Moosach & Olympia – Einkaufzentrum
- Com6 → Stadelheim & Giesing

Temporally, consistently connected regions. They are either Subway, Tram, or Train Stations

RQ 1.3.1. Can community detection methods help to extract travel purposes?

RQ 1.3.2. Is there any benefit of defining changing communities?

5. Case Study & Results

Discussion

- ***GI Science:***
  - MAUP & Visualization Aspects
  - Community detection algorithms can be considered as Cartographic tool
  - One can further develop an interface to help people who wants to benefit the algorithm

- ***Urban Transport Planning:***
  - *Transport planners can benefit from the results by focusing on the regions that are belongs to a dynamic community but not strongly connected within the community. This way operators & planners can promote bicycle usage and sustainable transportation.*
  - *Urban planners can also benefit from results by adopting boundaries of communities with existing administrative borders and focus on the improving services within these areas.*

6. Conclusions

- RQ 1.1.1: By investigating the current spatial pattern analysis methods of hybrid bike share system usage, we have gained insights into the existing approaches for understanding how these systems are utilized. This evaluation has informed our subsequent analyses.

- RQ 1.2.1: Determining the most suitable temporal time unit for the adopted method was essential for capturing meaningful spatiotemporal patterns. This choice has been made to ensure the accuracy and relevance of our dynamic community detection.

- RQ 1.2.2: Identifying additional attributes or parameters such as modularity functions that could enhance our network analysis allowed us to extract more meaningful information. These enhancements have improved the depth of our community detection.

- RQ 1.2.3: Addressing how semantic information is assigned to communities enables a richer understanding of the structures identified. By assigning land use information to our communities, we have defined spatial characteristic. Thus, this semantic information aids in the interpretation of community behavior.

- RQ 1.3.1: The application of community detection methods has proven to be valuable in extracting travel purposes, shedding light on why and how hybrid bike share systems are used within urban areas. This contributes to urban transport planning.

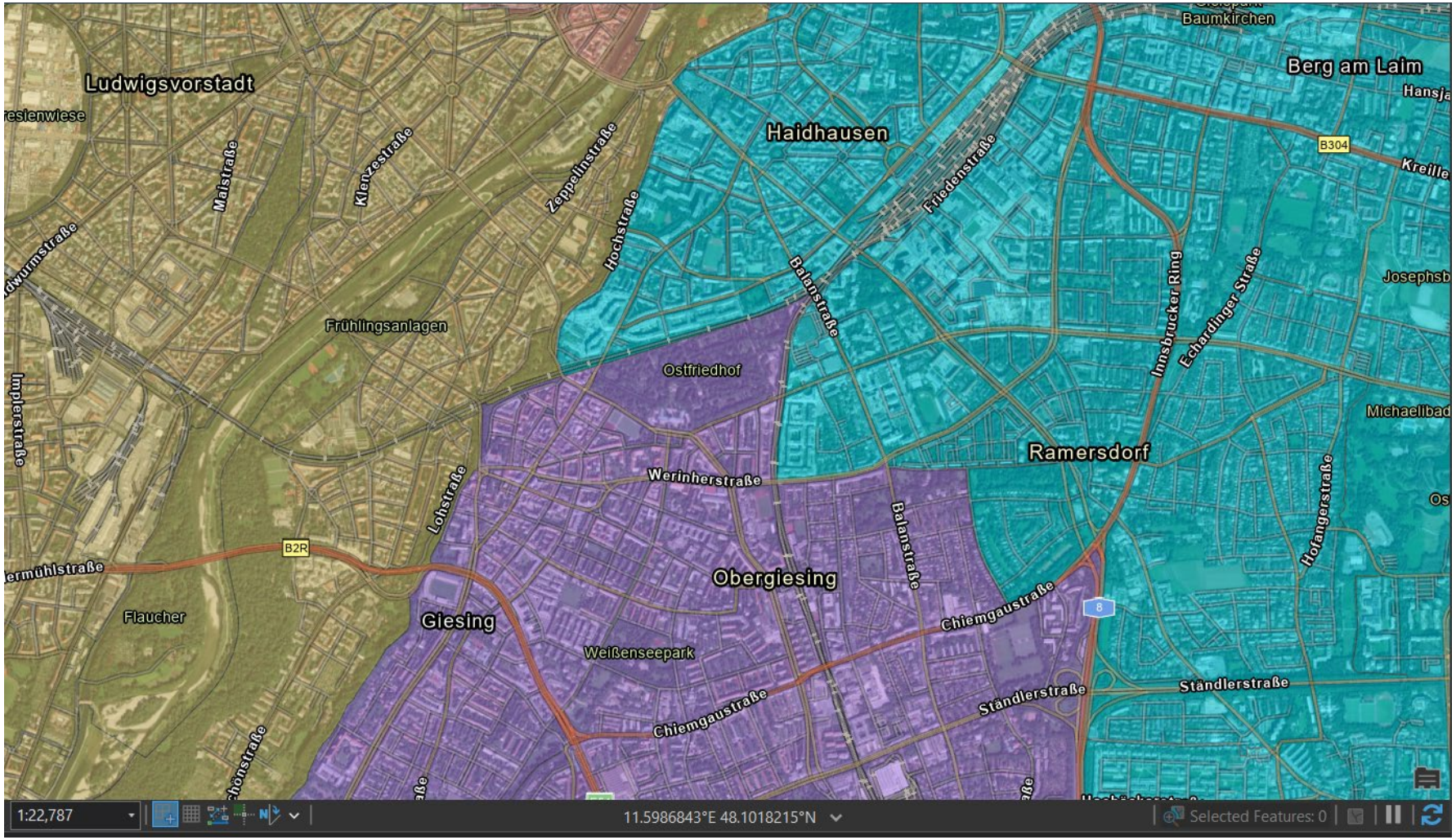
- RQ 1.3.2: Identifying dynamic communities offers insights into the both spatially and temporally connected clusters of bike share usage over time. This understanding is crucial for adapting urban transport planning strategies to meet planning needs.

6. Conclusions

- ***Limitations in Methodoloy***
  - Methodology has many sub steps for manipulating the big data which reduces the efficiency of computation.
  - Only spatial district indexes taken into account.

- ***Limitations in Spatial Units***
  - Pre-defined spatial units might omit some of the important results for example true boundaries of communities. One solution can be to work on grids as spatial units to define communities.

Supplementary



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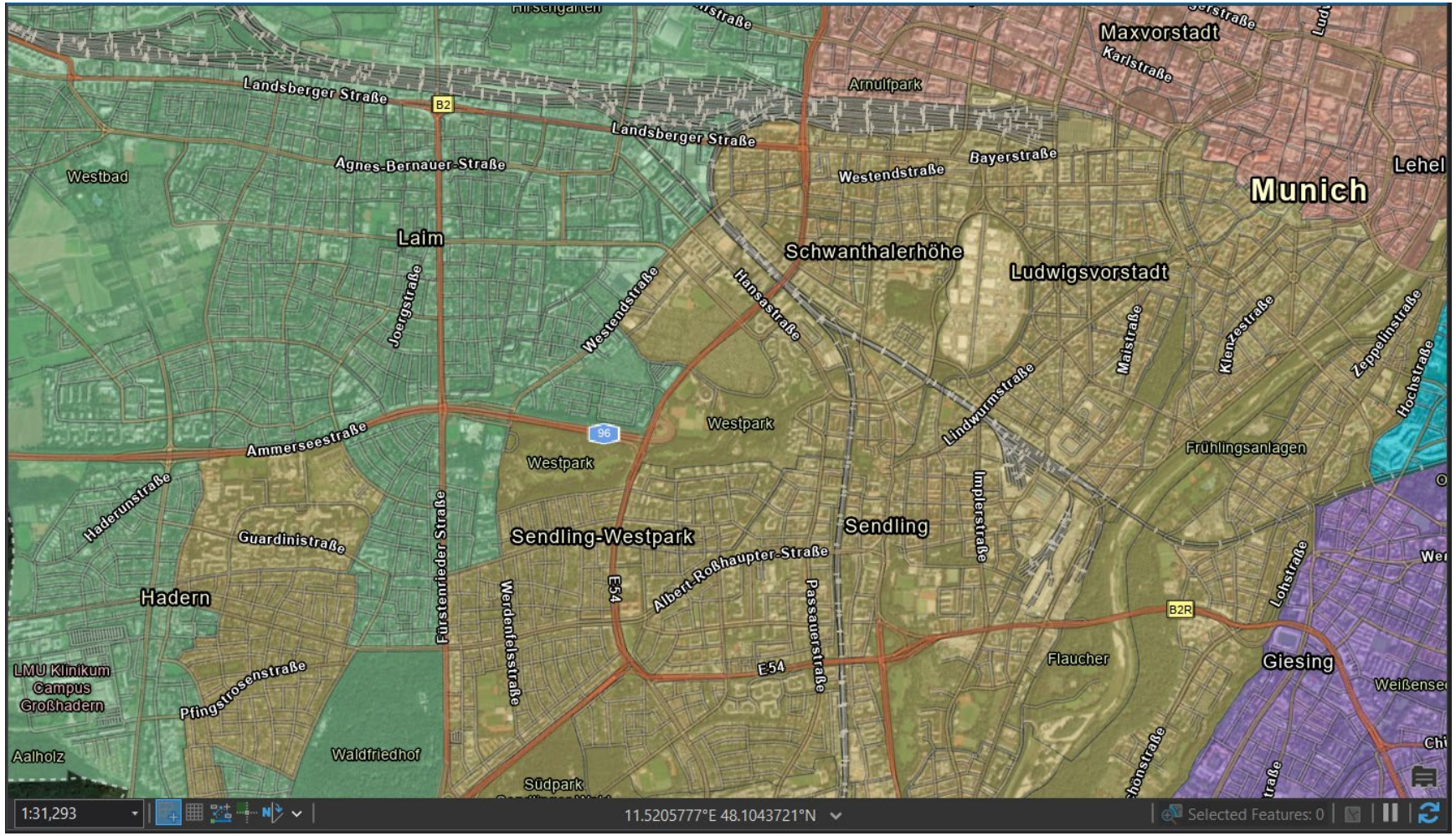

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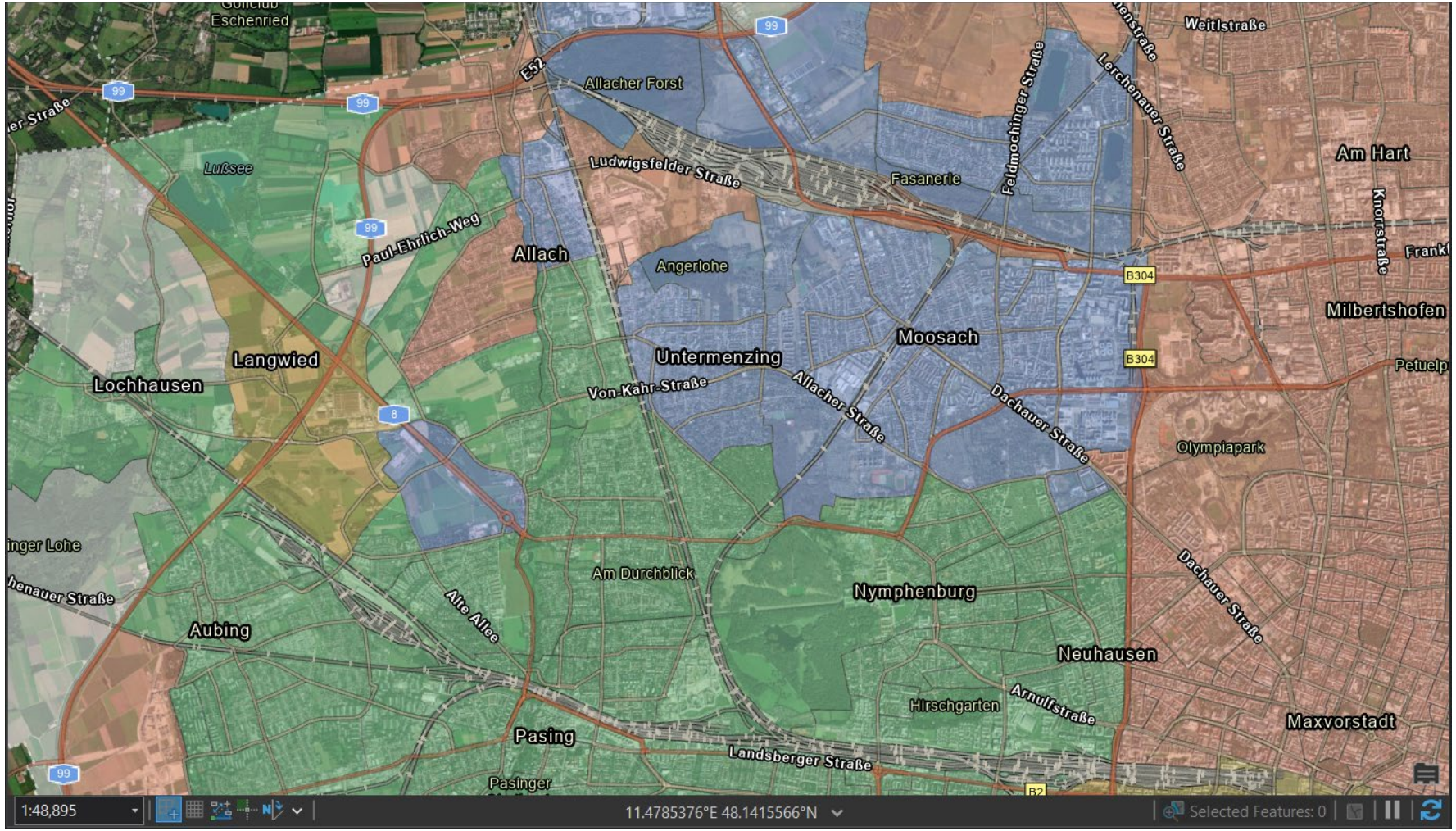

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UNIVERSITY OF TWENTE.

TECHNISCHE UNIVERSITÄT DRESDEN

Thank you ☺

Technical University of Munich

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology