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New Forms of Urban Data and their Potential for Municipal Decision Making

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1 ABSTRACT

In recent years, cities have been exposed to many disruptive influences. Among them is the digital revolution, which has also begun to transform urban space via the economy and society. The now ubiquitous and continuous connectivity has reached a large part of humanity, thanks to the mass distribution of smartphones, free Wi-Fi networks and the resulting access to information, social networks and audio-visual entertainment [1]. Digitalisation took on a particular importance in the context of pandemic-related impacts.

The need for digital connectivity increased, especially in the fight against COVID-19, as city governments around the globe used contact tracking (Bluetooth proximity data) from smartphones to detect infection contacts and reduce infection rates. The resulting form of urban data is new to municipal use and points to the hidden potential of other forms of data. Through the use of today's technologies, municipalities can collect their own data in many areas, generating a new understanding of complex urban dynamics aiding spatial decision-making with higher transparency [2].

Disruptive influences, uncertainty, crises and climate catastrophes require a more evidence-based and a bottom-up spatial planning process. In regard to solving more complex problems and increasing the speed and agility required by the city administrations, it is important to investigate how new data forms can affect spatial planning decisions. The German planning system referred to in the paper (section 2) is very hierarchically organised, as are its processes. Local, fast-moving and contextual data collection could counteract the inertia of the planning system.

In general, the use of data to understand urban systems is not a new phenomenon, but nevertheless necessary. The increasing complexity and constant change of cities now requires the use of more real-time and comprehensive data sets to complement censuses and surveys [3]. The temporal limitations of the latter seem only suitable for representing static or semi-static urban phenomena, as they do not take into account the subtleties of urban dynamics or the impact of real-time activities on various urban systems and the daily lives of citizens [4]. At the same time, improving the quality of life of the inhabitants is the ultimate goal of a city. While urban planning has an impact on the quality of life in cities, the citizens too have an important role in developing a city. It is thus essential to consider them in the decision making process.

But which data forms and sources are capable of meeting these challenges and what new information and opportunities do they offer? Specifically in regard to the German planning system which follows a bureaucratic approach of decision -making, it is important to find out the planning decisions which can be supplemented with new data forms at the municipal level. In this regard, the paper targets urban datasets that can add significant value to municipal decision-making processes and spatial development strategies (section 3).

The paper focusses on examining the emerging datasets and their application in spatial planning. For this purpose, an overview of the data landscape is shown (section 4), which highlights the new data forms (Figure 1). Qualitative literature analysis was used to investigate municipal decision-making and spatial planning decision-making processes in Germany. Drawing on the results, a SWOT-analysis will be used to display the potentials and limitations of new forms of urban data for spatial development (section 5). The conclusion (section 6) highlights this potential for municipal decision making.

Keywords: German Planning System, Urban Analytics, Urban Data Sources, Spatial-Planning Decisions Processes, New Data Forms

2 SPATIAL PLANNING IN GERMANY

The chosen framework for decision-making processes in spatial planning is the German planning system. The following paragraphs showcase the German context of spatial planning and the respective planning culture [5]. In order to understand the decision-making processes, first the German planning system is briefly explained and then the processes of decision-making in municipalities.

2.1 Planning system

In Germany, the planning system is a hierarchical system and has its administrative competences mainly at the local level [5]. These hierarchical, spatial levels are interconnected and interdependent due to the subsidiarity principle, the countercurrent principle and federalism [6]. Although the paper refers to the municipal level (cities and villages), it should be noted that due to the dependencies mentioned, a narrow consideration of this spatial level is only possible to a limited extent.

Legal foundations such as the Federal Spatial Planning Act and the Federal Building Code, but also EU directives, regulate the tasks, duties and competencies of the spatial planning levels and the instruments available for this purpose. In addition to the formally regulated instruments (e.g. binding land-use plan or preparatory land-use plan), there are also informal instruments for procesess of consensus-building such as masterplans and integrated development plans, which provide guidelines and strategic goals and thus influence the control of urban development [7]. Like the hierarchical system, spatial planning instruments are interrelated and need to be coordinated. Informal planning processes and tools, in addition to the lengthy, formal planning processes, can facilitate cooperation between stakeholders and lead to faster results and should be seen as complementary to formal tools [5].

The goal is to create a coordinated, strategic and integrated planning process that is guided by the goals, principles and other requirements of spatial planning [8] and that controls spatial developments in the medium to long term in the interest of the common good. In order to achieve this goal, all relevant stakeholders (e.g. public agencies) and specialist planning must be involved in the decision-making process [9], and a transparent data basis is required as a foundation for decision-making.

2.2 Municipal Decision Making Processes

Decisions made by a municipality must be politically legitimised. This also applies to planning and spatial decisions, e.g. on future urban development. The content-related and thematic processing of a problem or an issue naturally takes place via the responsible experts. Within their work, it is important to find the best possible alternative through analyses and scenarios, to provide the politicians with all the necessary information in this regard [10]. An example could be the question of maintaining a swimming pool. Closing the swimming pool can save costs of the municipality. At the same time, an important infrastructure in the leisure and sports sector is lost. Therefore, the effects are not only aimed at the municipal budget, but also at aspects of health and the climate for the municipality and its citizens (cooling in summer, fresh air corridor, sports training). The task of the spatial planner is enabling the politicians (e.g. city council) to decide in the interests of the general public by preparing decisions, despite the lack of their own processing [10]. The basis for all research and preparation is information and data, e.g. on socio-economic development and land use, as well as on effects of different scenarios.

As mentioned above, the decision itself must be made in the interest of the general public, i.e. the residents. The political legitimacy of the members of a city council is based on the representation of the citizens. In the interests of the residents and in accordance with applicable law, the best alternative must be found from among existing scenarios. This is done as part of a decision-making process in which various indicators or even entire scenarios are weighed against each other [11].

Since there are no universally valid indicators with fixed benchmarks for many questions and problems, a decision cannot simply be made logically. In addition, similar problems must also be individually classified and addressed by the prevailing local context. In this respect, urban data offer the opportunity to gain an objective, local and holistic understanding.

The planning decision-making process thus consists of an approximation of the best alternative, taking into account aspects such as economic viability, future viability and sustainability, as well as democracy (e.g. through participation). In the absence of a generally applicable scheme that fits all individual cases specific to a region, an individual solution must be found. In this process, actual, local information is crucial to provide adequate place-based development.

But which data sets should be considered? Which data sources are important? How should data be collected and how should data protection issues be dealt with?

3 URBAN DATA LANDSCAPE

Data protection is considered a fundamental right in Germany and is implemented through the European data protection regulation (DSGVO) and supplementary national laws [12]. As the process of digitisation is currently underway, data is being seen as an enabler of development. The Data Protection Laws in this regard set a boundary for the use of data without compromising the personal identity of a person directly, or indirectly. The section below discusses the types of data and their potential, keeping in view the overarching presence of Data Protection Laws.

3.1 Data Landscape

Today's cities are engines of a new data economy. The proliferation of technologies in the urban fabrics, such as sensors, wireless telecom networks and building management systems is generating vast troves of data to control energy and demand-based systems like traffic, transport, water supply and so on. Coupled with the growth of sensor and GPS technologies in hand-held devices such as smartphones and travel cards, the amount of data captured by a city- from volumes of energy used, movements of people, traffic, water and waste, social media interactions and multi-modal transport flows- is unprecedented. As such, cities are becoming knowledgeable and controlling in new dynamic ways, responsive to the data generated about them [13]. The Smart City Charter, Germany, first published in 2017 underlines the value of digital transformation to drive sustainable urban development and lays guidelines for cities, counties and municipalities for the application of new technologies for a long term, considered view. Novel analytical practices promise smoother decision-making as part of a more evidence-based and smarter urbanism [14]. While this continuous influx of data points towards the potential of knowing the city in real-time, it is also important to note that as their sources continue to increase in number, the produced data sets increase in diversity. The data from location-based sensor networks or geo-enabled social-media are temporally and spatially grained but they are not originally designed for their application in decision-making in the realm of spatial planning.

This current availability of data from multiple sources is both an opportunity and challenge for spatial planning and decision-making. Whereas there now exists a possibility of employing different data sources which could help overcome the bias of a single source (e.g. incompleteness, small sample coverage, lack of time tags etc.) and potentially provide richer descriptions of urban systems and human behaviour, significant problems of interoperability and integration are also raised [4]. Moreover, the urban data landscape for spatial planning is largely uncoordinated with respect to its producers, consumers and its operators making use of data restricted to limited areas in urban governance. The following section attempts to give a systematic overview of the available urban data sources that can be relevant for municipal spatial decision-making processes and increase an understanding of how data can be made actionable in a public-setting based on the German Planning System.

3.2 Types of Urban Data

The term urban data can be interpreted in many ways. According to the authors José António Tenedório et. al [15], urban data is a graphic and alphanumeric record referring to the urban, with highly accurate scales of analysis, providing information necessary for understanding, knowledge and decision-making in the fields of urbanism and urban planning. This definition emphasises the source of production of data, i.e.-urban as a basis for categorisation. Another definition, by authors Silke Cuno et. al places the importance on the specific effect of a dataset on urban space as a precursor for qualification as urban data. They define urban data as all types of data that are important in the urban context, regardless of the specific data origin, data management, the associated intellectual property rights and licensing requirements. Urban data may include data that extends beyond the direct local context, for example, when needed for a municipal process based on data of supra-regional or global relevance, or simply if it has general effects on the urban space/environment—for example, climate data or financial data [16]. Sidewalk Labs, an urban innovation unit within Google, defines urban data as the data collected in the "city's physical environment, including the public realm, publicly accessible spaces, and even some private buildings." It further consists of three subcategories: Type 1- data collected from public spaces like streets and parks, Type 2- data from publicly accessible private spaces like stores and building lobbies or courtyards and Type 3- data from private spaces not controlled by those who occupy them, such as office thermostats [17]. It clarifies urban data as produced by physical spaces, anchored by geography and differentiates it explicitly from 'Transaction Data' as information provided by people about themselves on websites, mobile phones and paper documents. On the other hand, the city of Bonn, Germany, considers urban data as a broad term that includes all data held, used or made available by urban actors (public administration, public institutions, municipal companies), private actors (e.g. companies, associations, citizens) or other actors, regardless of the context in which they were created and the type of survey [18]. According to that definition, urban data thus includes static and dynamic data (e.g. sensor-based real-time data, IoT) as well as citizen or user-generated data.

For the purpose of this paper, urban data is considered to encompass all data for cities that

- is georeferenced,
- is produced or consumed by public actors such as government administration and municipal companies; and private actors such as citizens or private companies.
- can be used to infer spatial conditions and improve understanding of spatial environment.

Based on their source, the types of urban data can be – A) Government Official Data, B) Company Generated Data, C) Machine Generated Data and D) User-Generated Data.

A) Government Official Data refers to the data primarily collected by the government for its administrative task and official record-keeping. These include official statistics, survey data, the data obtained from citizen registration offices and real estate cadastres. They are essentially characterised by their relatively high quality in terms of accuracy, completeness, validity, and general truthfulness of the content [4]. A part of this data is also available as Open Data that is freely available for anyone to access, use, modify, and share.

B) Company-generated Data refers to all the data that is generated by a company for its research and development purposes. It can be related to consumer behaviour, market trends, transactional research on company products and business insights. This data can contain trade secrets and personal data. However, the company generated data can be anonymised and be made available as Open Data depending upon the company policy and legal arrangements. An example of this kind of data would be transactional data in banks and health and fitness data in smartphone application operators.

C) Machine-generated Data encompass the data being collected by sensing devices, sensor networks and surveillance systems embedded in the urban environments. The examples of this category would be pedestrian counts, traffic and pollution levels, RFID Records, Infra-Red and CCTV surveillance data. These data sources are generally connected to machines in the Internet of Things category.

Type of Data	Urban Dataset	Source
A) Government official data	Census records Citizen registration data Real-estate records Land-uses	Federal and State Statistical Offices Statistic Department Housing Department Planning Department
B) Company-generated data	Data on consumer behaviour (Credit card usage data, market trends)	Consumer facing organisations
C) Machine-generated data	Sensor data (Pedestrian Counts, Traffic, Pollution levels) CCTV surveillance RFID records Infra-Red surveillance	Urban sensing devices Wi-Fi hotspot adaptors CCTV cameras RFID devices Infra-Red cameras
D) User-generated data	Crowdsourced data Social media content Surveys Bluetooth traces Wi-Fi traces GPS traces Other internal phone sensor data IP addresses Smartphone application data	Open Street Map, Blogging websites Twitter, Instagram, Facebook, Flickr Smartphone applications using Bluetooth Wi-Fi Adaptors GPS Trackers Smartphone company Network Provider Smartphone applications

Table 1: Types of urban data based on their source. Source: Own depiction

D) User-generated Data refers to all types of data that is generated by humans. This data can be sourced from social media websites, Local Based Sensor Networks, micro-blogging posts, pictures and videos. The growing penetration of smartphones, development of Social Web 2.0 and widespread internet connectivity has led to an increased amount of content generation actively, passively and even semi-actively. The actively generated data comprises of social media posts, crowdsourced data (e.g. OpenStreetMap) and online surveys.

The passively generated data on the other hand would the data produced by micro sensors in the smartphones such as Wi-Fi, GPS and Bluetooth traces, IP Addresses and other internal phone sensor data that is generally being produced in the background as the smartphone applications are running. The third category of semi-actively generated data refers to the smartphone application data for which the permission of data collection is given once and it keeps acquiring the required information over a span of time.

4 ANALYSING NEW FORMS OF DATA IN MUNICIPAL DECISION MAKING

As demonstrated earlier in this paper, municipal decisions in Germany are largely determined by complex and intertwined multi-level hierarchical processes. The structures and frameworks provide limited scope for flexibility. Especially for urgent problems, (such as during the pandemic) when quick decisions were needed, daily updated, user-generated data was key for situation-adapted reactions and decisions. The focus of this paper is therefore on the use of new forms of urban data, as a driver for more efficient and evidence-based decision making in spatial planning.

The previous section provided a classification for urban data based on their source which is a necessary step to set the context for identifying new forms of urban data. These data forms are fundamentally integrated datasets that can generate improved understanding of the complex urban systems by combining the strengths of traditional static/semi-static datasets with those of other dynamic sources of urban data. The overview provided is not exhaustive and can accommodate more data sources as the time proceeds. However, to eliminate silo-thinking in the decision-making processes, it is important to explore the combination of different datasets arising from various sources for their potential in evidence-based decision-making. In 2017, the KOSIS Association Urban Audit tested a new data source, OpenStreetMap (OSM), as an alternative for calculating the variable “length of the designated cycle network” [19]. It also confirmed some of the challenges with the current method of acquiring data directly from cities. While the city noted the heterogeneity between the datasets collected from OSM and the city, the advantage provided by a constantly updated dataset overweighed the disadvantages.

Building on these advantages, the city of Darmstadt used the mobile phone data from Telekom in 2019 to analyse commuter flow from the surrounding towns of the city. The city was provided with a dataset containing only origin and destination information of the commuters with a high spatial and temporal resolution while ensuring the anonymity of the individuals. It guaranteed that no conclusions could be drawn about individual mobility behaviour [19]. The resulting analysis could not just inform about the quarters attracting high influx and neighbouring towns with high commuter migration, but potentially point towards possible interventions for managing the high daily commute. Augmentation of public transport during peak hours, new transport infrastructure planning for high commute neighbouring towns, reduction in particulate matter through better traffic control and others were added on solutions resulting from the analysis [19].

The new forms of urban data have limitations of integration and challenges occurring from methodological, technological and political perspectives/ However, their potential for substantiating complex spatial analysis is unprecedented. Although, a few cities have already embarked on the journey of establishing data platforms, exploring such datasets and building digital twins, other municipalities are yet to turn their focus on data-driven decision making. A SWOT analysis from the context of the municipal decision-making processes is shown in the next paragraph.

5 SWOT ANALYSIS

Combining the knowledge of municipal decision process and data types as well as data landscape, the method of SWOT analysis is used to investigate the opportunities and risks of new forms of urban data for municipalities.

The SWOT analysis demonstrates that the strengths and identified opportunities of new forms of urban data can be capitalised for hyper-local spatial planning through a technically robust architecture for integration and analysis in the municipalities. In order to take advantages of the opportunities, the weakness identified needs to be mitigated through accessibility, interoperability and standardisation of urban datasets. While technological infrastructure is a means of using these data forms, an overarching supportive system of political will, regulatory framework and data-confidentiality is also required to mitigate the threats of unethical data usage.

Strengths	Weaknesses
Eliminate bias arising from a single data source The datasets are dynamic in nature, i.e., spatially and/or temporally grained Bottom-up planning process/perspective, in case of user-generated data	datasets are originally not designed to be used for spatial planning decision-making, can have differences arising from varying timelines, geospatial levels and missing APIs.
Opportunities	**Threats**
Optimisation of urban services Resilient decision-making Possibility of complex system analysis Hyper-local spatial planning Insights for demography, diversity, age and gender-sensitive spatial planning	Need supportive policies, regulatory framework and software architecture for data integration Dependent on the political will and thus susceptible to change Need for management of data confidentiality, security and citizen trust

Table 2: SWOT Analysis of new forms of urban data. Source: Own depiction

The Venn diagram in this section builds on the listed strengths and opportunities to bring out these new data forms and how they can be used by municipalities. It visualises the four urban data categories discussed in the previous section of the paper. The overlapping six sets denote the new forms of urban data and their use in municipal decision-making related to spatial planning. The diagram gives importance to the central dataset- Government official data as a precursor for any integration which is explained below.

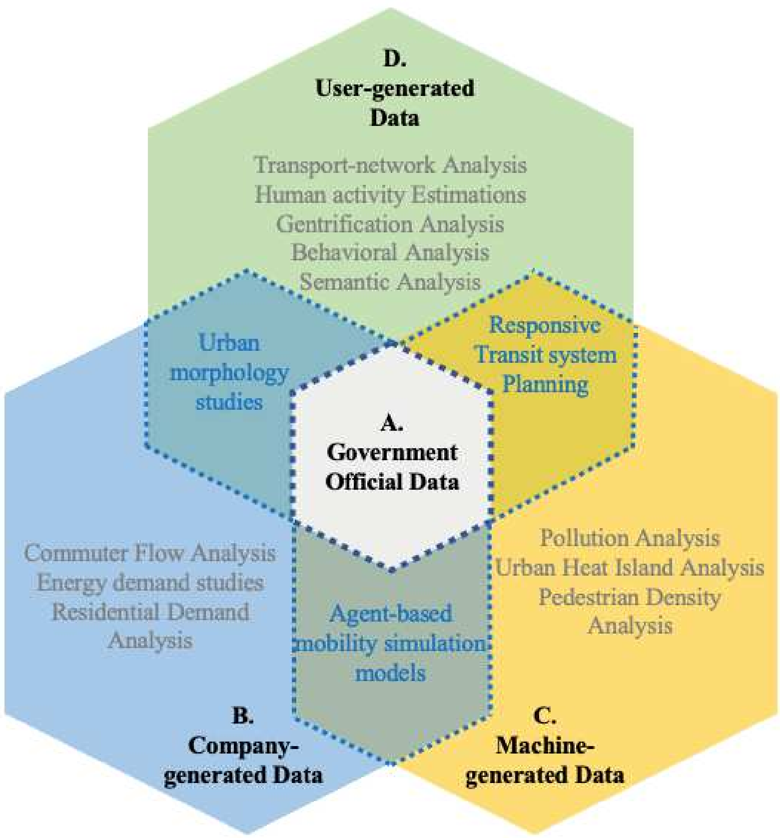

Figure 1: New forms of urban data. Source: Own depiction

The set of User-generated data denotes the data from the social-media websites that carries digital imprints of a user in terms of emotions, opinions and activity patterns. Combining city real estate plans (e.g. Points of Interests) with the geotagged social media such as geotagged photos and check-ins can be used for human-activity estimation in a city. This analysis can be used for transport and tourism planning. A semantic analysis through text-mining of the geotagged posts can help for crisis management during city events, as a further step of human-activity estimations. Geotagged posts over a period of time can also give an estimation of outsiders and residents of a neighbourhood and can help in identifying neighbourhood change which when augmented with Census data can yield gentrification analysis. A further integration of user-generated data with company-generated data such as mobile-phone records and supplemented by real estate and land-use data opens the possibility of urban morphological studies, as denoted in the overlapping subset of sets A, B and D (Figure 1). Identification of spatial structures, their usability and accessibility can help in planning cities that are sensitive to the needs of a certain gender and age-group.

Similarly, machine-generated data such as sensors monitoring pollutant counts and temperatures when integrated with real-estate data can yield pollutant analysis and heat-island effects in a city. When combined with points of interests of a city on a map, Wi-Fi-beacons log the IP- addresses of the connected devices could give an estimation of pedestrian density. These datasets can help a city in retrofitting pedestrian infrastructure in neighbourhoods and furthermore in planning commercial spaces which are proven to be thriving through pedestrian accessibility. A new form of data as denoted in the overlapping subset of sets A, C and D (Figure 1), Combining the pedestrian activity from sensor, along with the electronic travel card data (which can give origin and destination stamps) can help in removing redundancy in the public transit routing of a city and, in turn, making the transit system responsive to the demands.

Company generated data, in terms of mobile phone data can give a commuter flow analysis, as discussed earlier in the paper in the case of Darmstadt, Germany. This data, though with extreme potential, contains personal information and needs pre-processing to make it usable for urban analytics. Census data combined with the energy consumption data of households can give an insight into fuel-poverty in a city, demanding necessary policy actions. The fine-grained information characteristics of company-generated data combined with the high-coverage sensor data can help in agent-based modelling for various urban systems as denoted in the overlapping subset of sets A, B and C (Figure 1). This particular category holds potential for solving critical problems through detailed simulation of urban dynamics.

6 CONCLUSION

Considering ongoing trends such as digitalisation and existing research on urban analysis, combined with current challenges (for instance the pandemic, demographic change, the climate or the energy crisis) reveals the complexity under which municipalities have to operate. The need for information is increasing when taking current, adaptive, and strategic decisions. New forms of urban data can be used to meet this need.

New forms of urban data enable municipalities to make more robust, resilient planning decisions by taking into account larger and more recent datasets. This allows decision-making processes to be more informed and, ideally, increase not only the quality of the underlying information, but also the transparency and accountability of decision-making.

Through new forms of urban data, new hypotheses and use cases can be tested and reviewed. In addition, the long-term recording of activities (urban morphology studies) can provide strategic insights, for example, for people-centred and demand-driven development of urban infrastructures, mobility services or public open spaces.

However, it is important for municipalities to observe standards, data protection and data integration interfaces in order to be able to use new forms of urban data and harness their potential. Long term activity recording can yield strategic insights.

Based on the findings presented in this paper, further research requirements need to be reflected, which can be summarised in the following four points.

- Data collection in general needs to be further investigated. There is still uncertainty about how municipalities and governments collect data, what new sources can be tapped for this purpose, and which aspects in terms of technology and users respectively citizens need to be considered.
- Furthermore, municipalities should apply a monitoring and research component when collecting and using new forms of urban data, thus their findings can provide guidance for other municipalities. In particular, the implementation of the use of this data through political legitimation and specifications, as well as technical implementation (e.g., taking data protection into account) are of interest here.
- City labs, innovation hubs and pilot projects should be provided as laboratories for practical application and research under real-life conditions. In this way, standards, implementation methods

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and acceptance can be reviewed, potentials of usability can be unlocked, thus systems and applications can be further developed.

- Further research needs to be done on how to integrate datasets from various sources to provide an analytical base for decision-making. In the context of spatial planning decision-making, a decision support system could be the way forward.
- Finally, current societal challenges point to the fact that more flexible and agile decision-making processes are needed in municipal decision making. As speed cannot be the only decisive factor, it is necessary at the same time to maintain standards (in terms of data collection and accessibility) and to support the quality requirements and the responsibility of governmental actions.

To conclude, new forms of urban data offer the potential to secure the ability of municipalities to act in a future-oriented way which is adapted to fast changing societal requirements, yet more research is needed in this respect.

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